Australian Government
Department of Agriculture, Water and the Environment

Dairy Australia

IRRIGATION GUIDE

EFFICIENT WATER USE FOR DAIRY

ACKNOWLEDGMENTS

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CONTENTS

01

Planning – soils and water quality

This chapter outlines basic information about soils and water that underpin the planning, design and operation of an efficient irrigation system.

Soils are fundamental to irrigated pastures and fodder crops because they provide nutrients, water and a base to anchor the plant. Soils are the most significant factor in planning, selecting, designing and managing your irrigation system, so the first step is to identify the soil(s) in the area to be irrigated. The way to do this is with a soil survey, which will identify key parameters that underpin good irrigation performance.

Determining your soil type(s)

The two key things you need to know about your soil for irrigation are its texture and its structure. These two parameters affect how much water the soil holds and how easily the water can be taken in and extracted by the plant.

INFORMATION

Go to the **Dairy Soils and Fertiliser Manual** on the Fert$mart website for information about **Soil Properties, Soil Types** and **Managing Limiting Soil Factors**.

There are two key methods for conducting a soil survey–grid soil survey, the traditional method, and an electromagnetic (EM) soil survey.

For some irrigation regions, conducting a soil survey may be mandatory to access water. For example, the following standards are required for the Goulburn Broken irrigation and drainage management plan:

- soil information to the standard required by the University of Adelaide for accreditation of soil surveyors
- minimum pit depth of 1.5 m or soil core to 1.8 m
- grid spacing of 75 x 75 m.

The information to be obtained at each site is as follows:

- soil texture of each layer
- depth of each layer
- depth of potential crop root zone
- readily available water holding capacity (RAW)
- soil colour
- mottling
- soil salinity between 60 and 90 cm
- dispersion index
- coarse fragments.

The information to be obtained at representative sites is as follows:

- pH
- saturated and unsaturated infiltration rates for soils proposed to be flood or furrow irrigated.

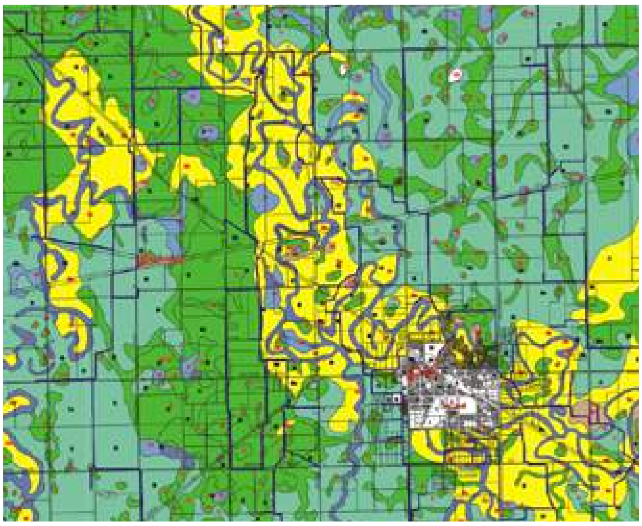
Grid soil survey

A grid soil survey involves digging holes with an auger or digging pits with a backhoe along several predetermined transects. The location of the holes or pits can be modified based on changes in things such as topography, surface colour, vegetation, crop type and irrigation system.

Because holes or pits are dug on spacings that are determined by the grid and they are usually widely spaced, a grid survey does not accurately define where the soils change. For this reason, it is only suitable to establish 'rough' groupings of the major soil types across the property and the range of pastures or fodder crops suitable for each soil type. While it is possible to reduce grid spacings as a way of improving accuracy and providing enough detail for use in irrigation system design, it adds significantly to the cost of the survey.

Grid surveys have historically been used for surveying most soils but newer, electromagnetic technology is more accurate and for this reason will be used in most situations for surveying soils for irrigation

Figure 1 An example of a grid survey from the Goulburn Valley



Source: Soils and Land Use in part of the Goulburn Valley Victoria
See source online **here**.

Electromagnetic soil survey

Electromagnetic (EM) instruments are being used more widely to map soil changes across a property. An EM instrument measures the electrical conductivity of the soil profile and, as different soil characteristics have varying electrical conductivity readings, key soil differences can be detected and mapped, e.g. clayey soils have a higher electrical conductivity than coarser textured soils.

The EM38, the instrument most commonly used, is usually pulled behind a four-wheel ATV equipped with a differential global positioning system (DGPS). The ATV is driven along transects, sometimes spaced as close as 15 m apart, producing hundreds of data points which are then mapped while it is moving to show the spatial variations in soil.

The EM38 works by measuring the strength of the magnetic field between transmitting and receiving coils. This strength depends on the volume and type of water, soil texture, cation exchange capacity (CEC), drainage, subsoil properties and salinity within the soil. Its responses to these soil characteristics vary, making simple interpretation unreliable so EM38 mapping should always be done with ground truthing through soil sampling. The on-board GPS, which locates each EM data point, also can be used to produce an elevation survey to determine topography.

For ground truthing, soil cores are taken or soil pits dug at locations identified from the EM soil survey. These cores are then assessed, usually in a laboratory, for a range of soil characteristics for each of the main zones of varying electrical conductivity. This identifies the texture classes for the area surveyed. Only a few soil cores or pits are needed, keeping the overall cost to a minimum.

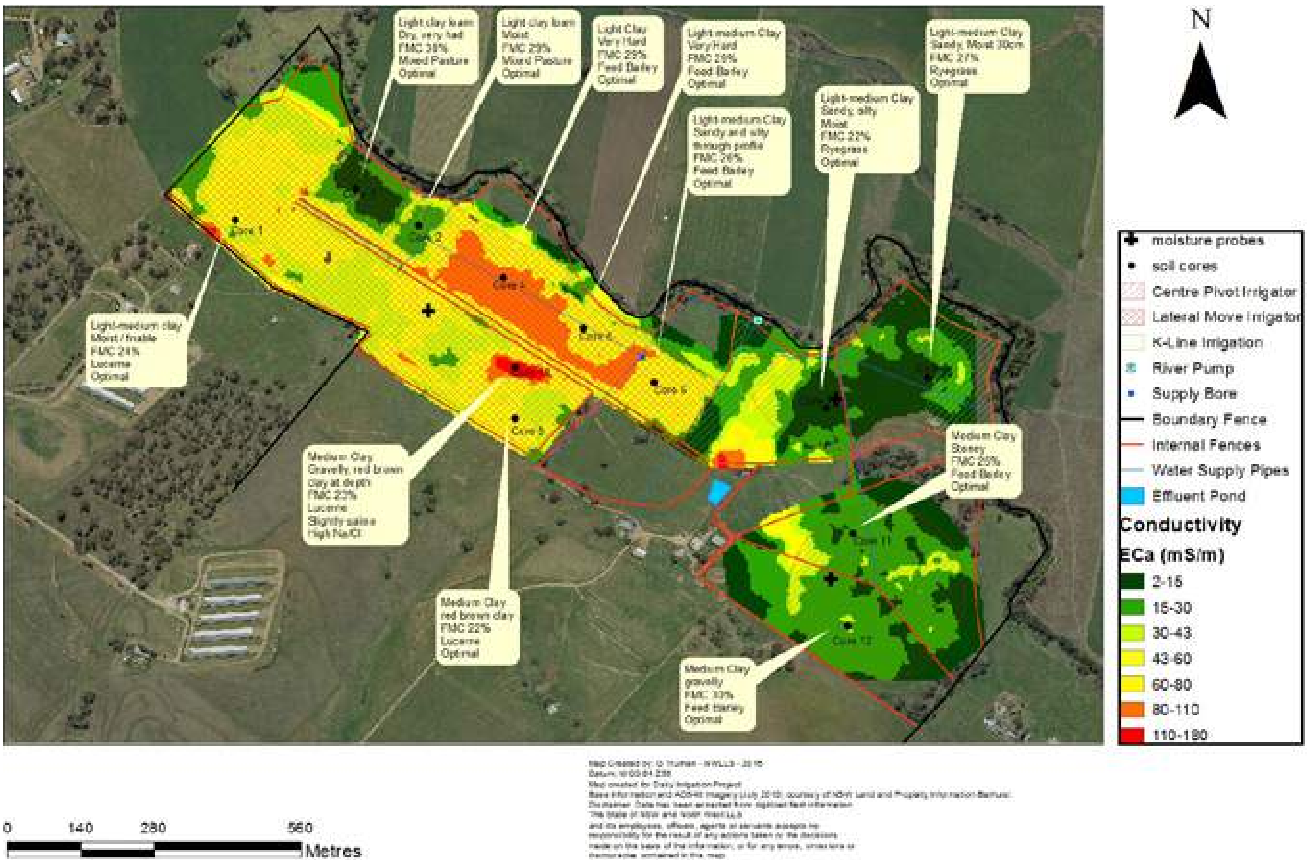
Figure 2 is an example of an EM38 soil survey. The colours show different zones of electrical conductivity, and the labels show the soil texture and a description of the soil and the pasture.

An important piece of information is the water holding capacity of the soil which is derived from the soil texture and, using the soil map, can be inferred for the irrigated area. For more on soil-water holding capacity, see the section on soils and water in Chapter 7, 'Scheduling.'

INFORMATION

For more information on EM38 and irrigation go to Variable Rate Irrigation and EM38 **click here**.

Figure 2 Example of an interpreted EM38 map



Source: National Smarter Irrigation for Profit Project, Tamworth Optimised Dairy Irrigation Farm New South Wales.

Infiltration rate

Another key piece of information you need to know about your soil(s) is the infiltration rate.

The soil infiltration rate is the speed at which applied water (rainfall or irrigation) can enter the soil. It is described as the millimetres depth of water infiltrated per hour (mm/hr).

Infiltration rates differ according to soil properties and are influenced by management practices. The key factors that influence soil infiltration are:

- **Texture.** Coarser textures (sands and gravels) allow water to enter the soil faster than finer ones (clays and silts)
- **Management practices.** Cultivation, stock and compaction as a result of vehicle movement can affect soil structural condition and can significantly reduce infiltration rates
- **Soil moisture.** Infiltration rates vary with soil moisture content, slowing as the soil becomes wetter.

Infiltration rate determines the maximum irrigation application rate, without run-off or ponding occurring. If water is applied faster than it can enter the soil, it will pond or run off or both. Ponding also often results in preferential flow, i.e. drainage through the macropores. Applying irrigation water at a rate higher than the soil's infiltration rate greatly reduces irrigation efficiency, wastes water and can cause crop damage.

Water that drains through the soil profile or runs off over the surface takes valuable nutrients and topsoil with it. This waste of water is then compounded by the waste of nutrients and fertility.

Infiltration over time

Infiltration rate reduces as the soil becomes wetter. As the soil gets wetter, the larger pores are filled first, leaving the finer pores to be filled.

This means infiltration rates reduce as irrigation duration (time) increases. This is shown in Table 1.

Table 1 Intake curve and soil class

Soil class	Approx. intake curve number
Tight clay	0.1
Clay/clay loam	0.1–0.2
Silt loam	0.2–0.3
Sandy, stony silt loam	0.3–0.5
Sandy loam and fine sand	0.5–1.0
Sand	1.0–1.5
Coarse sand	1.5

Management

Poor structure, resulting from cultivation practices or stock pugging and an impermeable layer forming below the surface as a result of cultivation methods, can reduce soil infiltration rates.Table 2 is a summary of infiltration rates for the different soil textures and the effect of soil structure.

Table 2 Typical values of infiltration and permeability based on texture and degree of structure (adapted from FAO)

Texture	Structure	Infiltration	Permeability (mm/hr)
Sand	None	Very rapid	>120
			>250
Sandy loam	Weak	Very rapid	>120
	None	Rapid	60–120
Loam	Moderate	Rapid	60–120
	Weak–none	Moderate – rapid	20–60
Clay loam	Moderate	Moderate – rapid	20–60
	Weak	Moderate	5–20
	None	Slow	2.5–5
Light clay	Well	Moderate	5–20
	Moderate	Slow	2.5–5
	Weak	Very slow	2.5
Medium to heavy clay	Well	Slow	2.5–20
	Moderate	Very slow	2.5
	Weak	Very slow	2.5

Slope also needs to be considered, as water moves more easily across the surface before soaking into the soil.

Table 3 is a guide to maximum infiltration rates on flat and sloping land for different soil types.

Bare, smooth soils with sparse groundcover allow more water to move across them more quickly. This enables water to move laterally before it has a chance to soak in. Increasing the amount of organic matter in the soil improves the infiltration rate, in part because it slows the rate that water can move across an area.

Table 3 Maximum Infiltration rates on flat and sloping land

Estimated maximum infiltration rates (mm/hr)		
Soil group	**Slope 0–8°**	**Slope 9–12.5°**
Sands and lightly sandy loams uniform in texture	31	25
Sandy loams overlaying a heavier subsoil	20	16
Medium loams to sandy clays over a heavier subsoil	16	13
Clay loams over a clay subsoil	13	10
Silt loams and silt clays	10	8
Clays	6	5
Peat	16	–

Measuring infiltration rate

A simple method for measuring the infiltration rate is with an infiltration ring.

The standard test uses a 300mm ring inside a 600mm ring. These can be made from PVC or poly pipe with a chamfer formed on the outside of the end that is to be put into the soil. Both are driven 150mm into the soil to create a seal and kept filled with water throughout the test. A single ring test will give an indication of the infiltration rate but not as accurately as a double ring test.

The outside ring saturates the soil at the same rate as the inside ring, and deals with outwards movement. The aim is for the inside ring to only have infiltration vertically down into the soil, as would occur in a rain or irrigation event.

The test continues until the speed at which water infiltrates into the soil from the inner ring is constant. This 'steady rate' is taken as the infiltration rate.

Soil infiltration rates are very variable; a crack or wormhole can make a big difference.

While the Food and Agricultural Organisation of the United Nations (FAO) state that at least two tests should be done at a site, it is better to do more. It does not take much longer to complete more tests if a number of sets of rings are available.

Water quality

Water quality is a key factor in planning and managing irrigation. The quality of water from all potential sources for irrigation should be tested before planning or installing irrigation infrastructure.

As a minimum, water analysis should include:

- salinity (EC)
- pH
- total dissolved solids (TDS)
- chloride
- sodium adsorption ratio (SAR)
- calcium carbonates.

If water is sourced from effluent streams or ponds, it should also be tested for:

- biological oxygen demand (BOD)
- nutrient values (nitrogen, sodium, potassium, magnesium, calcium).

Whether water quality will vary based on seasonal variation should also be assessed.

Water source

The source of your irrigation water will also influence water quality. Surface water usually has more physical quality issues e.g. sticks, leaves, seeds and algae. Groundwater quality issues might include:

INFORMATION

Click here for more information about water issues and potential remediation options. Refer to New South Wales DPI Primefact 1337, Farm water quality and treatment.

- high calcium (Ca) and bicarbonate (HCO3) concentrations that result in build-up of calcium carbonate scale (i.e. CaCO3) and block irrigation infrastructure components (e.g. drippers)
- biofouling as a result of iron and sulfate bacteria that cause clogging and reduce irrigation infrastructure performance (e.g. pumps and pipes)
- elevated salinity.

About biofouling

Biofouling is any process where material accumulates on a solid surface due to the presence of microorganisms, including bacteria. Iron and sulfate biofouling can be serious issues when using groundwater.

Iron biofouling is caused by iron bacteria and is usually observed as a sludgy and slimy orange-brown precipitate that clogs irrigation components, e.g. pumps, pipes and sprinklers.

Sulfate bacteria are a group of naturally occurring bacteria that interact with sulfate (SO4) in the environment and are also known to clog wells and irrigation infrastructure when water is pumped from anaerobic (oxygen-free) aquifers. High flow velocities near abstraction wells provide a larger food supply in the form of dissolved organic carbon and sulfate (SO4) for these microorganisms. Unlike iron bacteria, they are generally not able to remain attached to pipes, etc. under high flow velocities.

Figure 3a Soil infiltration testing

Source: University of Tasmania, Tasmanian Institute of Agriculture

Figure 3b Soil infiltration testing

Source: University of Tasmania, Tasmanian Institute of Agriculture

Physical features

For good irrigation planning and management, the physical features of the farm should be mapped and recorded, ideally on an irrigation drainage and management plan (IDMP). The excerpt below from IDMP Guidelines – how to prepare an irrigation and drainage management plan (New South Wales Agriculture 2002) details the information needed.

Infrastructure

Identify the roads and any rail services, rivers and creeks. Locate houses, sheds, fences, power and telephone lines, dams, effluent ponds, windmills, diversion or contour banks, stock troughs, water pipes, easements and access roads on the property.

Topography

Conduct a topographical survey, including elevation data and suitable contours. Sufficiently detailed topographical information can sometimes be obtained online. Show contours at an interval that suits the site and/or the irrigation development. For irrigation planning, closer contour intervals are usually required. If there is any, show the current irrigation infrastructure. Identify topographical features such as gullies, ridges and floodways.

Natural features

Detail areas and features that affect irrigation operations and productivity. Include areas of trees, native vegetation, wetlands, watercourses, natural springs and sites of cultural significance. Note any environmentally sensitive areas such as river corridors, important habitats, salt-affected zones, acid sulfate soils, waterlogging, flood zones and erosion zones.

REFERENCES

1 Dairy Australia, Sustainability Framework NRM Survey 2015.

2 Irrigation New Zealand Irrigation Essentials. For their website, click **here**

3 CSIRO Land and Water and the Lower Murray Irrigation Action Group (1999), The SWAMP Trainers Manual.

4 New South Wales Agriculture (2002), IDMP Guidelines – how to prepare an irrigation and drainage management plan

SUMMARY

Get a complete picture of your soils

A detailed understanding of the soils on your property is critical to all stages of irrigation, from planning and selecting the system to effective operation and management. Good soil management is also fundamental to optimum production as soil health determines nutrient availability and plant growth.

Soils should be surveyed to determine what soil types exist on the property and the extent and location of each one. The survey should also identify the key physical, chemical and biological characteristics of each soil type. In some areas, a soil survey is mandatory before water for irrigation can be accessed Soils can be surveyed using a grid method or an EM38 survey. A grid survey involves digging holes or pits at regular intervals (a grid) across a field. This gives a general picture of soils but not where they change.

An electromagnetic (EM) survey, e.g. with an EM38, is more accurate than a grid survey. The EM38 is usually pulled behind a four-wheel ATV equipped with a differential global positioning system (DGPS) along transects, which are mapped to show the spatial variations in soil. It can map features such as texture, subsoil properties and salinity and can be used to produce an elevation survey to determine topography. The most accurate survey is a combination of EM38 survey backed up by ground truthing from physical soil sampling. For ground truthing, soil cores are taken at locations identified from the EM soil survey. These cores are then assessed for a range of soil characteristics for each of the main zones of varying electrical conductivity. This identifies the texture classes for the area surveyed.

The information that can be collected at each site includes: texture and depth of each layer, depth of potential crop root zone, readily available water holding capacity, soil colour, soil salinity, pH and saturated and unsaturated infiltration rates, particularly for soils to be surface irrigated.

Infiltration rate

When planning an irrigation system, it is important to understand the infiltration rate of the soils being irrigated because it determines maximum irrigation application rates. Infiltration rate is affected by soil texture and management practices. It reduces as soils become wetter, so typically decreases over the duration of an irrigation event. Slope, ground cover and grazing practices, as well as soil texture can all influence infiltration.

Water quality

The quality of water to be used for irrigation influences the design and selection of the irrigation system to be used. As a minimum, water analysis should include salinity, pH, total dissolved solids, chloride, sodium adsorption ratio and calcium carbonates. If water is sourced from effluent streams or ponds, it should also be tested for BOD (biological oxygen demand) and nutrient values (nitrogen, sodium, potassium, magnesium, calcium).

Check whether water quality will vary based on seasonal variation should also be assessed.

Water quality varies with the water source. Surface water usually has more physical contaminants while groundwater quality issues might include high calcium (Ca) and bicarbonate (HCO3) concentrations and iron and sulfate bacteria. High concentrations can cause clogging in irrigation infrastructure. High salinity can also be an issue in some water sources. Effluent water sources should be carefully analysed before being used for irrigation.

02

Selecting an irrigation system

Selecting an irrigation system involves determining which type of system is most suitable for your situation. In most cases, there is no single best solution rather each system type has its advantages and disadvantages.

A number of factors should be considered when deciding which irrigation system to use, including enterprise goals, area of land to be irrigated, topography, soils, water supply, climate, crops, finances, regulatory requirements and management style.

It can be helpful to visit other farms to investigate systems that are working well in situations like yours.

Agriculture Victoria has developed a web-based, easy-to-use resource, Irrigation System Selection and Design Guidelines, to help dairy farmers choose an irrigation system.

Types of irrigation systems

This website focuses on border check, centre pivot and subsurface drip systems and describes the following five key steps as a guide for deciding on the system most suited to your situation.

Step 1: What do I want to achieve?

Step 2: What are my farm's features and constraints?

Step 3: What irrigation options should I consider? (This section includes a table comparing the features of a range of irrigation systems.)

Step 4: What needs to be considered in my design and management, and what will it cost? (This section includes information on costs of the systems.)

Step 5: What option best meets my goals?

INFORMATION

For more information about features of irrigation systems and choosing a system, go to the Agriculture Victoria website **here**.

Irrigation systems can be categorised into two broad groups:

- Surface irrigation systems, where water is applied to the root zone by flow over the soil surface by gravity, e.g. furrow, border check and contour bay. Border check is almost exclusively the surface system used for pastures.
- Pressurised irrigation systems, where water is applied through a pressurised pipe system and discharged through emitters or sprinklers, e.g. spray line, centre pivot, lateral move, travelling irrigator and drip.

No system type is inherently better than another, rather an irrigation system should be selected and designed depending on the factors specific to each site.

Border check

Border check irrigation consists of a sloping strip of land, level across the strip, bordered by low check banks. Laser-levelled fields are essential for even water distribution. Slopes range from 1:100 to 1:1200, and bays are usually between 300 and 600 m long and between 30 and 100 m wide. Bay inlets are usually gates or siphons, and the lower ends of the bays generally drain directly into a shallow tailwater channel. Border check is widely used by dairy farmers in northern Victoria and south-western New South Wales and in the Macalister Irrigation Area in Gippsland.

Figure 4 Border check irrigation system in South Australia

Source: Monique White

Figure 5 Border check irrigation system in Northern Victoria

Source: Dairy Australia

Pressurised irrigation systems

Spray lines – fixed

With fixed spray lines, water is delivered through a permanent, buried mainline. The irrigation area is usually divided into a number of blocks with a submain for each block running off the mainline. Submains are usually permanent (buried) but may be portable (laid on the surface). Water reaches the pasture or crop through a grid of surface laterals fitted with sprinklers, which are generally of the 'knocker' type and provide from 5 to 20 mm per hour of water and operate at between 200 and 450 kPa.

Figure 6 Fixed overhead irrigation system

Source: Dairy Australia

Spray lines – movable

Hand shift spray lines consist of lengths of aluminium irrigation pipe with quick connect and release couplings at both ends and a sprinkler at one end. These are moved and fitted together by hand and usually supplied from a riser attached to a buried submain. The sprinklers can also be mounted on risers to get above a crop. Pressures range from 150 to 450 kPa. This system is suitable for regular- or irregular-shaped fields.

Side-roll

Side-roll systems are similar to hand shift except each length of pipe is mounted through the centre of a large wheel about 2 m in diameter. The entire length of pipe can then be shifted to the next position in a few minutes by rolling it sideways. A small motor and drive mechanism is usually fitted at the centre of the length of pipes to eliminate all manual effort.

The sprinklers are mounted on a swivel, so they remain upright. The system must be moved when it is empty of water, so the couplings have spring-loaded valves that open when the pressurehas dropped, allowing the water to drain out. This system is best suited to rectangular fields with gentle topography.

End-tow spray lines

End-tow systems, e.g. bike shift and K-Line, are like hand shift systems except they are moved using a vehicle such as an ATV or quad bike.

With bike shift systems, each coupling is fitted with a skid or pair of small wheels. This allows the entire length of connected pipes to be towed by the end from one position to the next, reducing the labour requirement. The couplings need to be more robust than for hand shift spray lines.

Bike shift systems must be moved when they have no water in them, so the couplings have spring-loaded valves that open when the pressure has dropped, allowing the water to drain out. If they are fitted with skids, you can only tow them in line with the pipes, meaning they can be moved only directly to an adjacent paddock. If wheels are fitted, they can be moved straight ahead to another paddock or at an angle of 45º to the next position in the same paddock in a zigzag pattern, towed alternatively from opposite ends. This system is best suited to rectangular paddocks with gentle topography.

The K-Line is a modular system that comprises small transportable pods, each fitted with an impact sprinkler. The pods are connected to a flexible, low density pipe and can be towed and positioned to water different areas. The low centre of gravity of the pods stops them from being tipped over when they are moved.

Unlike bike shift systems, they don't have to be drained before they are moved, and they can be moved while they are still irrigating.

Travelling guns and booms

These irrigators come in two forms: one with a soft hose and a cable drum, and one with a hard hose drum. They can be fitted with a single 'gun' sprinkler or with a boom that has emitters along it. The booms use sprinklers that are commonly fitted to other sprinkler systems such as centre pivots or spray lines.

Travelling guns require high pressure to operate properly, so they use a lot of energy and are expensive to operate. Rotary boom irrigators are similar except that the gun sprinkler is replaced by a boom fitted with medium to low pressure sprinklers set at an angle off vertical. The boom is rotated by the discharge from the sprinkler nozzles, and the rotation provides the energy to operate the drive mechanism and cable winch. Various sprinkler combinations (gun, rotating and low pressure) can be used.

Working pressures for travelling guns and booms range from 70 to 500 kPa. These systems are commonly used to irrigate pastures and lucerne. Machines with elevated wheels can be used on taller crops.

Figure 7 Travelling gun irrigator

Source: P Smith

Figure 8 Rotary boom irrigator

Source: Rod Jackson, NSW DPI.

Centre pivot and lateral move (CPLM) systems are both a mobile pipeline and a platform for water application devices. The towers position the pipeline high above the ground. The fixed centre tower contains the water supply point and the power source for the towers. A major advantage of centre pivots is that they cover large areas at low operating pressures, thus minimising labour and pumping costs. These systems can operate over undulating country as long as pressure regulators are fitted to each sprinkler.

Lateral move machines are similar to centre pivots except they do not have a central fixed supply point. Instead, the water supply point is located either in the middle (centre-feed) or at one end (end-feed) of the machine. Longer machines are usually supplied by a channel and have a cart-tower assembly which contains a mobile power plant and the pump. Shorter machines are usually supplied with a flexible hose connected to hydrants from a buried mainline and have a smaller cart-tower assembly which contains a mobile power plant to enable the machine to move.

They range from 100 to 1000 m wide with run lengths up to a kilometre or more. Lateral moves require level, rectangular blocks.

CPLM machines can be fitted with end guns to increase the irrigable area for a small extra cost, but careful design is required to ensure acceptable distribution uniformity. End gun systems typically require on-board booster pumps to provide enough nozzle pressure, which increases energy use.

The direction and speed of CPLM systems is governed by the end towers. With electric machines, the drive points on the intermediate tower(s) start when they get slightly behind and stop when they get slightly ahead of the end tower(s). With hydraulic units, the towers are in constant motion but at varying speeds according to oil flow and pressure. The intermediate towers have mechanisms to control the oil flow or pressure, speeding them up when slightly behind and slowing them down when slightly ahead.

The direction and speed of CPLM systems is governed by the end towers. With electric machines, the drive points on the intermediate tower(s) start when they get slightly behind and stop when they get slightly ahead of the end tower(s). With hydraulic units, the towers are in constant motion but at varying speeds according to oil flow and pressure. The intermediate towers have mechanisms to control the oil flow or pressure, speeding them up when slightly behind and slowing them down when slightly ahead.

Figure 9 Lateral move irrigation system

Source: Dairy Australia

Drip irrigation

Drip irrigation systems are so named because they use low-flow-rate emitters. Above ground drip systems are commonly used in permanent horticulture but subsurface drip is needed for pasture or broadacre crops. Because drip systems apply water at precise rates near or at the root zone, losses through evaporation run-off or deep drainage are almost nil, and irrigation efficiency can be very high.

Drip systems are usually installed permanently, which means they can be easily automated.

Water must be filtered to remove contaminants and stop emitters clogging. Equipment required depends on water quality and may be up to a third of the total cost of the system.

Water is usually delivered to the field through PVC or poly main supply lines and submains. The small-diameter plastic lines (laterals) placed in the pasture or crop are laid parallel to each other and are connected to the submains. The plastic emitters or drippers are usually built into the laterals during manufacture, though they can be installed afterwards. For sloping or undulating terrain, pressure compensating emitters are usually required to ensure even application.

Figure 10 Dairy subsurface drip irrigation site, 12 years after installation

Source: C. Phelps

INFORMATION

Click **here** to see an animation explaining the steps in subsurface drip irrigation.

Commissioning

A vital part of buying an irrigation system is proper commissioning. This stage is often neglected and results in many problems and disputes.Commissioning is a process where everyone agrees that the installed system meets the design performance specifications. It verifies that the system is complete to the required workmanship standards, is safe to operate and is ready to perform to the designer's and operator's expectations.

As part of the commissioning process, all key components should be checked, including pumps and meters, and a full evaluation of the irrigation system should be completed. This verifies that the entire system is performing to specification and provides the benchmarks for future checks to be measured against.

Before buying a system or signing a contract for an irrigation development, confirm what commissioning checks and services are supplied as part of the purchase agreement. These should include:

- key contact details e.g. sales manager, commissioning manager
- system key performance indicators (KPIs)
- components to be tested, i.e.:
  - power supply – safety, compliance, failsafe
  - motor performance – compliance with KPIs (power and amp ratings, speed)
  - suction performance – functional, no vortexing, screen or filter fitted according to specification
  - pump performance – compliance with KPIs (pressure, flow)
  - mainline and distribution network – compliance with design, leaks
  - valves – compliance with design, operational ability
  - filters – compliance with design, operational ability
  - control systems – operability
  - water meters – compliance with specifications, verification
  - telemetry – accuracy, operability
- relevant pre-commissioning documents
- a list of measured KPIs and actions achieved during the commissioning
- any as-built drawings and information identifying departure from construction drawings or specifications as approved (or not) during the installation process
- comprehensive explanation of how to operate and maintain the system
- manufacturers' operations manuals for all items of equipment
- maintenance schedule for all items of equipment.

Figure 11 Drip commissioning

Source: Dairy Australia

INFORMATION

For more information about commissioning a system, download the Best Practice Guide to Commissioning a Piped Irrigation System from the Irrigation NZ website, **here**.

REFERENCE

1 Cotton Info WATERpak provides a guide for Selecting an irrigation system. Click **here** to download.

SUMMARY

No system type is inherently better than another; rather an irrigation system should be selected and designed depending on the factors specific to each site.

Irrigation systems can be categorised into two broad groups:

- surface irrigation systems, such as border check, where water is applied to the root zone by flow over the soil surface by gravity
- pressurised irrigation systems, such as spray lines, centre pivot, lateral move and drip, where water is applied through a pressurised pipe system and discharged through emitters or sprinklers.

Factors to consider when deciding which irrigation system to use include enterprise goals, area of land to be irrigated, topography, soils, water supply, climate, crops, finances, regulatory requirements and management style.

Agriculture Victoria has developed irrigation system selection and design guidelines to help dairy farmers choose an irrigation system. They describe five key steps for deciding on the system most suited to your situation. They are:

Step 1: What do I want to achieve?

Step 2: What are my farm's features and constraints?

Step 3: What irrigation options should I consider?

Step 4: What needs to be considered in my design and management, and what will it cost?

Step 5: What option best meets my goals?

Don't forget commissioning the system

Once an irrigation system has been selected and installed all systems should be commissioned before final delivery is accepted. Commissioning should detail the checks and services supplied as part of the purchase agreement. These should include:

- key contact details e.g. sales manager, commissioning manager
- system key performance indicators (KPIs)
- components to be tested, e.g. power supply, pump performance, valves, filters, control systems and telemetry
- relevant pre-commissioning documents
- a list of measured KPIs and actions achieved during the commissioning
- any as-built drawings and information identifying departure from construction drawings or specifications as approved (or not) during the installation process
- comprehensive explanation of how to operate and maintain the system
- manufacturers' operations manuals for all items of equipment
- maintenance schedule for all items of equipment.

03

Irrigation system design

Irrigation systems are unique items of farm infrastructure that should be designed to suit each situation. This means that buying an irrigation system is not the same as buying a tractor or a plough from a supplier. To obtain the best performance over its full service life, a system should be designed by a skilled designer, and no changes made without consulting a designer.

The process of designing an irrigation system requires information on soil types, topography, water supply, climate, pasture or crop types, water demand and the owner's preferences. Done properly, the outcome is a system that is productive, water efficient, labour efficient, uses minimum energy and is environmentally sustainable over its full service life.

There is wisdom in the saying that you will pay for your design – one way or the other. Irrigation Australia Ltd operates a program for certified irrigation designers (CIDs). CIDs are experts with recognised technical skills and experience and up-to-date understanding of the latest water management practices. It is recommended that you engage a CID if you are intending to install or undertake major alterations to an irrigation system.

Finding a certified irrigation designer

Go to Irrigation Australia (IAL) website **irrigationaustralia.com.au** to locate a designer and to see the list of all IAL certified professionals.

Factors to consider for irrigation design

When designing an irrigation system, there are key considerations that need to be addressed for each of the three main systems used on dairy farms.

These are:

Centre pivot

- What is the right system capacity to meet plant water requirements?
- What sprinklers do I need?
- Is the irrigation application uniform?
- What pressure does the system need?
- Is the soil infiltration rate adequate (centre pivots have a very high average application rate at the outer end)?
- How do I minimise wheel rutting?
- Do I need a drainage system?
- Should I choose a hydraulic or electric drive system?
- Centre pivot or lateral move?
- What energy source do I choose – diesel or electric operation?

Border check

Designing border check irrigation bays for optimum efficiency and productivity is a complex process, involving a number of interrelated factors:

- the likely soil moisture deficit
- the soil infiltration rate (which is partly dependant on the soil moisture deficit)
- the slope of the bay
- the length and width and hence the area of the bay
- the hydraulic resistance of the pasture
- the flow rate applied
- the time the flow is applied for, or the time of cut-off.

Subsurface drip

- What should be the emitter flow rate, spacing and depth?
- How large an area can I develop?
- Do I need system automation?
- How much energy is required?

Plant water requirements and system capacity

Pasture or crop water requirements are met through rainfall and irrigation. For crops with periods critical for production such as flowering and seed fill, the irrigation system must be able to supply water at a rate to satisfy the plant at these times, otherwise substantial yield penalties will result.

For seed crops, if water is not fully supplied at peak times, the penalty could be a major seasonal failure. For pasture or fodder crops, if water is not fully supplied at peak times, the penalty is less dry matter produced. This loss of feed can still be substantial and shows up in reduced milk production. Ideally, the irrigation system should be capable of supplying water at the rate that the crop or pasture requires during the peak water use period. In other words, the system capacity should be at least equal to the peak water use of the pasture or crop.

Determining peak water use for pastures and crops

Finding out the peak water use for pastures is simple. Most grass pastures consume water at the same rate as reference crop evapotranspiration, denoted as ETo, in mm per day. You can find your nearest Bureau of Meteorology (BoM) weather station, which monitors ETo for sites all around Australia, on the BoM website **bom.gov.au**. For summer pasture, it is usually enough to use the average ETo for the hottest month of the year. For cooler growing period pastures, use the average ETo of the hottest month during the growing period.

For crops or non-grass pastures, peak water use requires another step: the use of a 'crop coefficient,' denoted as 'Kc.' The correct Kc that coincides with the hottest month is usually needed, and this commonly ranges from 1.0 for healthy grass pasture to 1.05 for lucerne to 1.35 for maize. The ETo amount is then multiplied by the Kc to give the pasture water use.

Table 4 A soil moisture trace showing a green drought

For Tatura, Victoria, BoM ETo figures are:

Pump efficiency (Eff.Pump)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average daily evapotranspiration (ETo) (mm)	8.7	7.9	5.8	3.7	2.0	1.3	1.4	2.1	3.0	4.8	7.0	7.7

The highest average daily evaporation is in January at 8.7 mm/day.

For summer grass pastures, the system capacity should be at least 8.7 mm/day.

For lucerne, the system capacity should be 8.7 mm/day x 1.05 (Kc) = 9.1 mm/day.

For maize, the system capacity should be 8.7 mm/day x 1.35 (Kc) = 11.7 mm/day Research undertaken at the Tasmanian Institute of Agriculture shows how significant the loss of pasture production can be if the pasture water demand is not met.

Case study: the cost of not meeting pasture water demand

For every day that irrigation is delayed, there is a potential loss of up to 105 kg DM/ha. A delay in irrigation of 7 to 10 days can reduce pasture production by up to 50 per cent over the next 40 days, regardless of the amount of catch-up irrigation applied.

Assuming that 1 kg DM of irrigated pasture has 11 MJME, 100 kg DM/ha consumed will produce 7.5 kg MS (100 ÷ 13 = kg MS).

The opportunity cost of not meeting pasture water demand is calculated as follows:

For a milk price of $4.50 kg MS and 100 ha field averaging 70 kg DM/ha/day

Lost pasture production	= 70 kg DM ha/day x 50 per cent
	= 35 kg DM ha/day
	= 3500 kg DM/day
Opportunity cost	= 3500 ÷ 13 x $4.50
	= $1212 per day

Over 40 days, the **total potential loss is $48,460**.

System capacity

System capacity is an important design parameter for all types of irrigation systems, especially for centre pivot and lateral move (CPLM) systems. The design and management issues associated with system capacity are often not well understood by producers who use CPLM systems and this is often the reason for many of the perceived failures of these systems.

SYSTEM CAPACITY DEFINED

System capacity is the average daily flow rate of water pumped divided by the area of that irrigated pasture or crop.

System capacity is expressed in millimetres per day, so that it can be directly compared with the peak pasture evapotranspiration rate. It is the maximum possible rate at which a system can apply water to the chosen area of irrigated field.

$$\text{System capacity (mm/day)} = \frac{\text{Average daily pump flow rate (L/day)}}{\text{Area irrigated (m2)}}$$

or

$$\text{System capacity (mm/day)} = \frac{\text{Average daily pump flow rate (ML/day)}}{\text{Area irrigated (ha) x 100}}$$

EXAMPLE

A centre pivot is 233 m long (four × 48 m spans with 16 m overhang and an end gun throwing 25 m) with a pump flow rate of 25 L/sec.

Volume applied (L/day)

= 25 L/sec × 60 s/min × 60 min/hour × 24 hours

=2160 000 L/day

Area irrigated(m2) = π × radius2 (π = 3.14 approx.)

= 3.14 × 233 m × 233 m

= 170 467.5 m2 or 17 ha

(as 10 000 m2 = 1 ha)

System capacity (mm/day)

= volume applied (L/day) ÷ area irrigated (m2)

= 2 160 000 L/day ÷ 170 467.5 m2

= 12.7 L/m2

For CPLM systems, it is important to recognise that system capacity is not the amount of water that is applied per irrigation pass, rather it is the amount that can be applied per day.

A simple water application rate calculator can be found here **https://www.irrigationbox.com.au/irrigation-system-required-total-flow-rate**

Dairy farmers in Queensland can also access a web-based calculator for the Queensland Murray-Darling Basin only at **https://kmsi.usq.edu.au/cplm/**

Design system capacity

The system capacity calculation on the prior page is referred to as system capacity or **design system capacity,** as dealers and manufacturers of CPLM systems use this for their design calculations. It assumes that the pump is running for 24 hours a day, seven days a week, providing 168 hours a week of system operating time, and that all of the pumped water is used by the plants.

Managed system capacity

Design system capacity of a CPLM is much less in the real world because of practical management issues and the efficiency of water application. Management issues to allow for include field operations, pumping time limits, stock movements, repairs and maintenance. If they are not taken into account, the system will not be able to keep up, and the pasture or crops will be stressed through much of the hotter growing period.

Management issues reduce the available number of hours that the pump can be turned on during any given irrigation cycle. The amount of time the pump is actually running during any irrigation cycle is called the pumping utilisation ratio (PUR). The PUR can be calculated from the average number of pumping hours per day or a longer period such as a week or a 10-day period.

Design system capacity is further reduced by water losses that always occur when irrigating. The proportion of water that actually makes it into the crop root zone compared to the total amount of pumped water is called the application efficiency (Ea). For well-maintained CPLM systems, this should be between 90 and 95 per cent (0.90 to 0.95).

This reduced system capacity is called **managed system capacity** and is determined from the following calculation.

EXAMPLE

For the centre pivot system in the previous example, a producer can run his pump for 10 hours a day for five days a week and 24 hours a day for the weekends during the period of peak pasture water use, using a well-maintained CPLM system.

PUR

$$= \frac{[(10 \text{ hours} \times 5 \text{ days}) + (24 \text{ hours} \times 2 \text{ days})]}{(7 \text{ days} \times 24 \text{ hours})}$$

= [50 hours + 48 hours] ÷ 168 hours

= 98 hours ÷ 168 hours

= 0.59 (59%)

Managed system capacity

= Design system capacity (mm/day) x Ea x PUR

= 12.7 mm/day x 0.90 x 0.59

= 6.7 mm/day

Managed system capacity (mm/day) = Design system capacity x Ea x PUR.

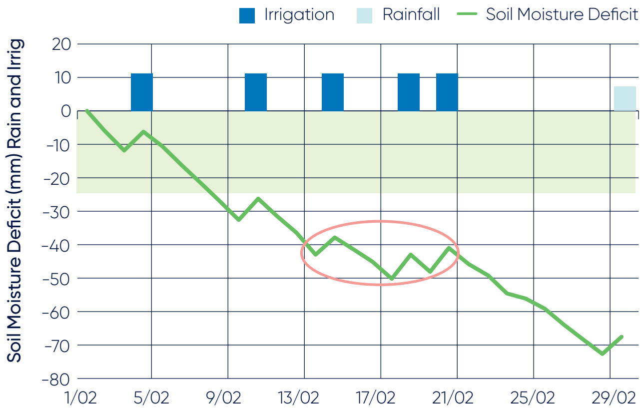
It is important that the managed system capacity be at least equal to the peak pasture or crop water use. It is better if it is higher than peak water use as this allows you to catch up if there is an unforeseen delay in irrigation, for example, a breakdown of the centre pivot or pump or if you apply your first irrigation for the season later than desired.

With pastures in particular, if irrigation is started after a delay, it is possible to have a 'green drought' effect. This is where the plants respond to irrigation by appearing greener but, because the soil moisture levels are too low, put on little real growth. If managed system capacity is higher than plant water use, soil moisture levels can be replenished, usually over several irrigation events, overcoming the green drought.

In figure 12, the circled section of the soil moisture trace is fairly level or flat, indicating that irrigation is keeping up with pasture water demand. However, the amount of water in the soil is too low for the plants to grow properly – it should be up in the green shaded zone. This is the green drought.

If the managed system capacity was higher, irrigation in excess of the plant water demand could be applied, and this would steadily increase the amount of water in the soil and move the soil moisture trace back up into the shaded zone where the pasture production would be much greater. (See Chapter 8 for more detail on green drought.)

Figure 12 A soil moisture trace showing a green drought.



Source: Dr J Hills, University of Tasmania, Tasmanian Institute of Agriculture

REFERENCE

1 WaterPak 5.5, **https://www.cottoninfo.com.au/sites/default/files/documents/WATERpak.pdf**

SUMMARY

Irrigation systems should be designed by qualified professionals so that they suit the purposes and parameters of the farm where the system is going to operate.

Since every situation is slightly different it is important the system is tailored to the site and enterprise where it will operate. There is no such thing as buying a system 'off the shelf'.

Whichever system is selected it should be designed to meet peak plant water demand. In other words, system capacity should be at least equal to the peak water use of the pasture or crop. Being unable to meet plant water demand has a high cost and greatly reduces production and profitability.

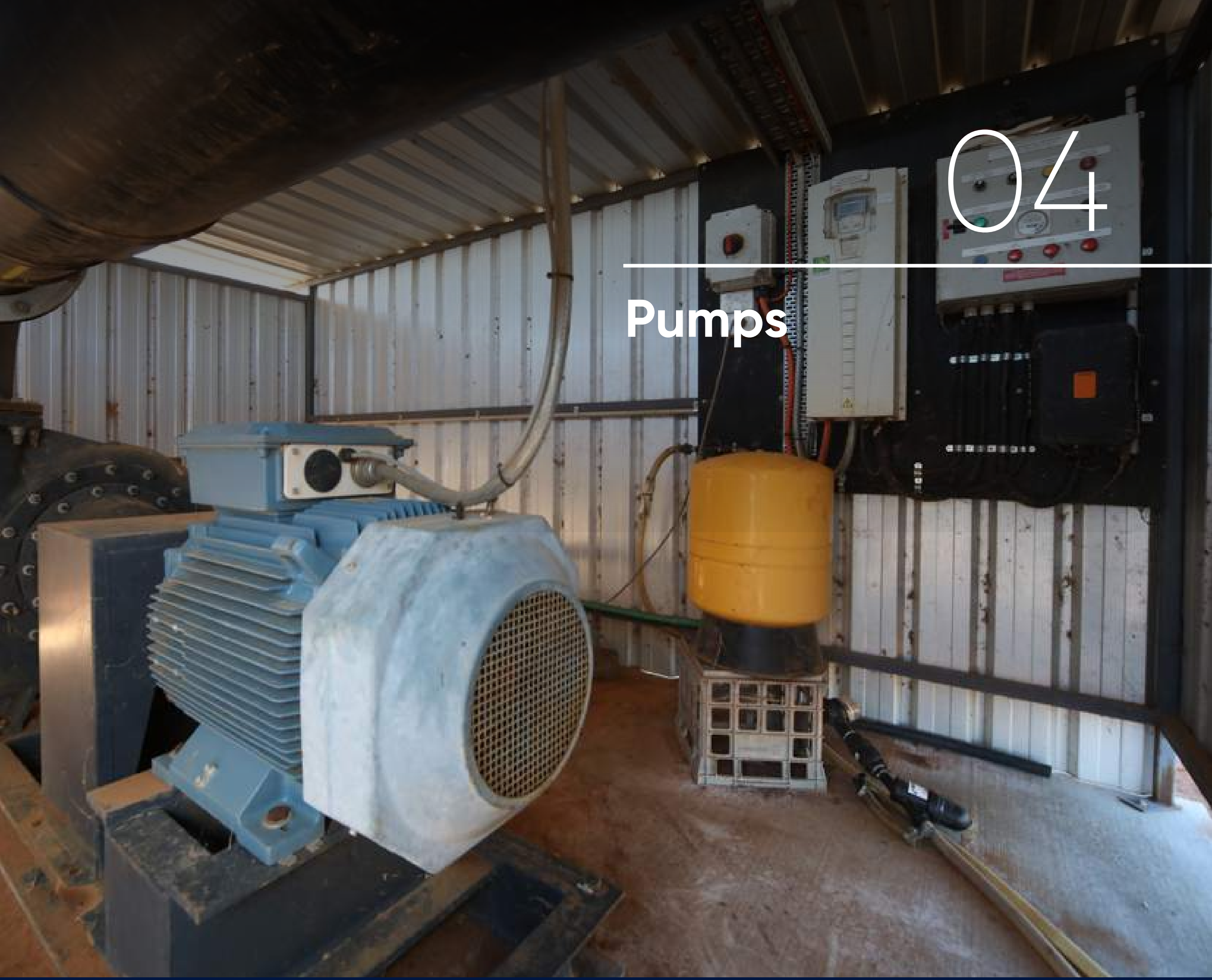
System capacity is defined as the average daily flow rate of water pumped divided by the area of that irrigated pasture or crop. It is assumed that the pump runs 24 hours a day for seven days each week. For CPLM system the system capacity is not the amount of water applied per irrigation pass, it is the amount that can be applied per day.

The design system capacity will be much less in the real world to allow for those times when the system is not operating, e.g. during stock movements, repairs and maintenance. This is taken into consideration by estimating the pump utilisation ratio (PUR).

The designer also takes into consideration the application efficiency (Ea) of the unit, which should be at least 90 per cent. These considerations enable the designer to calculate the managed system capacity from the equation:

managed system capacity (mm/day) = design system capacity X Ea X PUR

The designer should ensure that managed system capacity is at least equal to peak plant water demand. Ideally, managed system capacity will be higher than peak plant water demand so that water deficits due to extreme weather or breakdowns can be made up.



04

Pumps

A poorly performing pump can affect the entire irrigation system, reducing irrigation efficiency and productivity. For example, if a centre pivot 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 being applied, uneven distribution, reduced yield and increased variation across the paddock (see case study).

Case study: Smarter Irrigation for Profit Project – Tamworth Optimised Dairy Irrigation Farm, 2017

The flow rate measurements of a 3-span centre pivot showed that it was being supplied with 26 per cent less water than specified. The flow rate from the sprinklers was an average of 9 per cent lower than specified and the DU was low at 79 per cent causing under-watering of the pasture. The main reason was that the pump was not well suited to the duty.

As well as reducing irrigation performance, it was operating at only 12 per cent efficiency, costing the enterprise much more than it should. By buying a new pump and improving efficiency to 75 per cent, the savings in energy costs for using 50 ML of water at $0.29 c/kWh were $6564.00 a year. This easily paid for the new pump in one year.

Figure 13 Centre Pivot, Rex Tout's property

Source: North West Local Land Services, NSW

Figure 14 Rex Tout explaining energy costs

Source: Marguerite White

Common types of irrigation pumps

The main types of pump used for irrigation are:

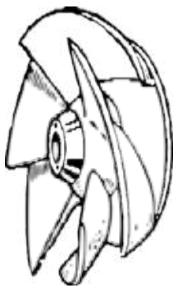
- radial flow (centrifugal)
- mixed flow
- turbine.

Radial flow pumps

Radial flow pumps are commonly referred to as centrifugal pumps. They are often used with pressurised irrigation systems and are suited to situations of high head and low flow.

With a radial flow pump, water 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.

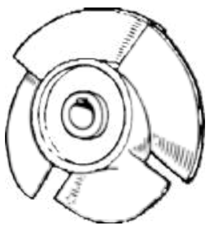


Mixed flow volute pumps

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

Mixed flow impellers are suited to situations of medium head and medium flow.

Liquid enters the impeller axially and is discharged at an angle between axial and radial. The head developed is the result of a combination of the centrifugal force on the liquid and the lift produced by the vanes on the impeller.



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 borehole diameter limits the impeller size, the pressure that 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 multistage pumps.

Pump duty

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

- flow rate
- head, or pressure.

Flow rate

The flow rate is the quantity of water your pump is required to deliver over a specific period. It is expressed in several ways:

- litres per second (L/s) or 1 litre per second
- kilolitres per hour (kL/hr) or 1000 litres per hour
- megalitres per hour (ML/hr) or 1 000 000 litres per hour
- megalitres per day (ML/d)
- cumecs (m3/second) or 1 cubic metre per second (1 m3 = 1000 litres).

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 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 or a change in the number or size of outlets.

Note: Some overseas manufacturers use gallons per minute (gpm), especially for centre pivot and lateral move systems. Be careful imperial (UK) gallons and United States (US) 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 needs to be supplied for a specific pumping task. It is often expressed in metres, meaning the pressure at the top of an equivalent vertical column of water at sea level.

1 m head = 10 kPa = 1.45 psi

1 psi = 6.89 kPa = 0.689 m head

It is better termed total head (H or TH) or total dynamic head (TDH) because it is made up of four components added together: static head (SH) + friction head (FH) + pressure head (PH) + velocity head (vh)

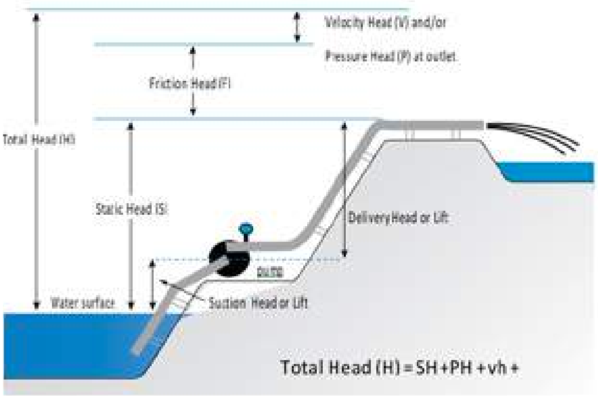
Static head

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.

Figure 15 Components of total head.



Friction head

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, longer pipes and rougher materials.

Smaller diameter pipes may cost less to buy but they create additional head through increased friction. For instance:

- A 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 m 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.
- Distributing 400 L/s (35 ML/d) through a 450 mm concrete pipe will result in a friction head loss of 1.1 m in every 100 m of pipe length. The same flow through a larger 600 mm pipe results in only 0.25 m of head in every 100 m of pipe.

Pressure head

Pressure head is the pressure required to make an emitter (e.g. sprinkler or dripper) work. 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. They become inaccurate after a few years or, if attached to a pump, after a few months.

Velocity head

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 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 m or 5 kPa which may be only between 1 and 2 per cent of a pressurised system.

When large volumes of water are pumped against a low head, e.g. stormwater 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 m. This is around 11 per cent of the total head. Any irrigation system design should account for this and compare the costs of larger pipe sizes with 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 pressure head.

Choosing a pump

Do not choose a pump simply on cost. The pump on sale at the local supplier or the secondhand one for sale next door is unlikely to meet the demands of your system and pasture. What you save on the purchase price will most likely be greatly outweighed by increased operating costs.

The best way to choose a pump is to check its performance by using a pump performance curve. A pump curve is a graphical representation of the performance characteristics of a pump, such as efficiency and suction lift.

The following outlines the steps in choosing a pump using a performance curve.

Step 1. Select the duty point

The first step in selecting a pump is to establish the duty point. This will help you choose a pump that is matched to the requirements of the irrigation system, not vice versa.

The duty point is the intersection of the flow rate (Q) and the total head (H). For a new irrigation system, the flow rate and total head should be specified in the irrigation design.

Once you know the duty point, locate it on the H-Q curve for a pump. The flow rate is along the bottom axis of the pump performance chart and the head is along the vertical axis on the left side. If you cannot locate the duty point on a curve, that pump will not suit your task.

EXAMPLE

A farmer wants to choose a pump for a centre pivot. The pivot requires water at a flow rate of 120 L/sec, and the pressure gauge reading, or total head, is 250 kPa (25 m).

Referring to Figure 16, locate 120 L/sec on the bottom axis and 25 m on the lefthand axis and identify the intersection, marked with a blue dot.

At this point the impeller size is 325 mm (shown on the H-Q curve second from the top) and the speed is 1470 rpm.

Step 2. Check pump efficiency

When the duty point is located on the H-Q curve, find the corresponding efficiency on the efficiency curve. The operating efficiency of the pump at each duty point is marked on the pump curves, often indicated with percentages. The aim is to have the efficiency as high as possible. If it is below 65 per cent, try another pump curve. For most irrigation systems, you will find a number of pumps over 65 per cent. Select the highest efficiency unit that has a competitive price. In the example below, the efficiency is 78 per cent.

Step 3. Check the suction lift

This depends on the net positive suction head required (NPSHR). The theoretical maximum vertical height any pump can lift water is about 10 m at sea level, and less than this at higher altitudes. The NPSHR is how much of this 10 m is 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 (form vapour bubbles in the water that can lead to damage) or simply not pump water.

Suction lift can be measured directly at the pump site or read from the irrigation design plan. The suction lift varies with factors such as river height, storage level and bore depth, so the highest likely figure should be used for pump selection.

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

Referring to Figure 17, locate 120 L/sec on the bottom axis and 25 m on the lefthand axis and identify the intersection, marked with a blue dot. At this point the impeller size is 325 mm (shown on the H-Q curve second from the top) and the speed is 1470 rpm.

Figure 16 Locating the duty point.

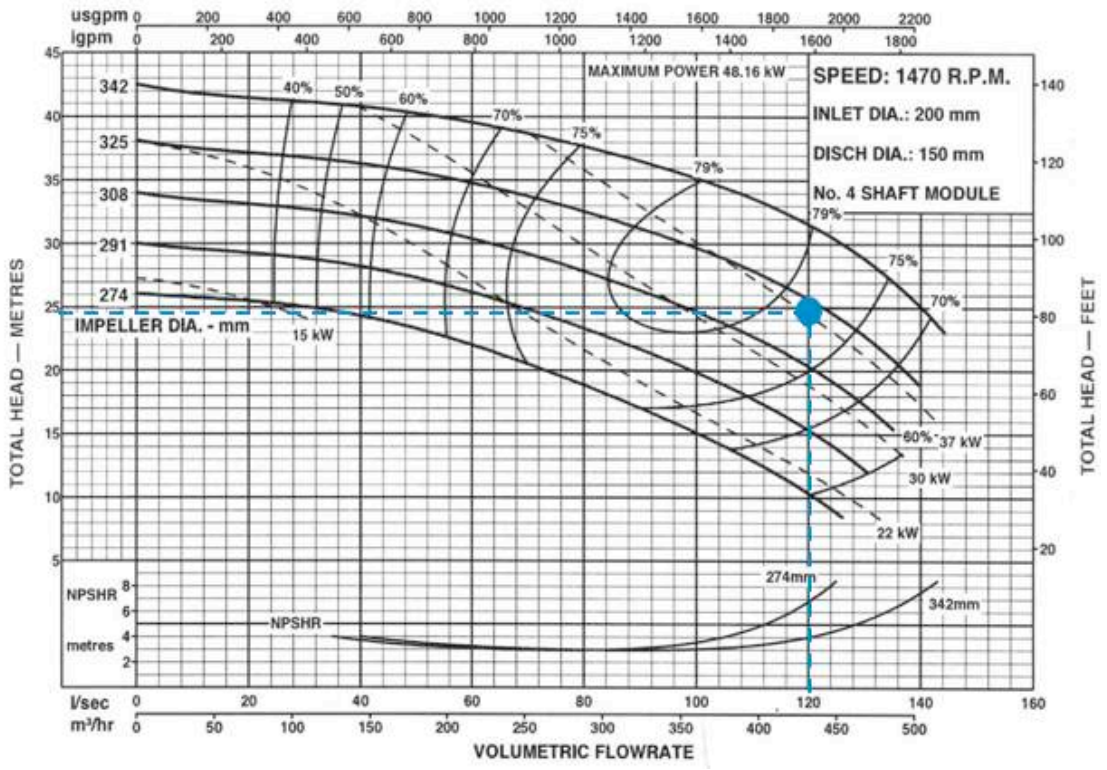
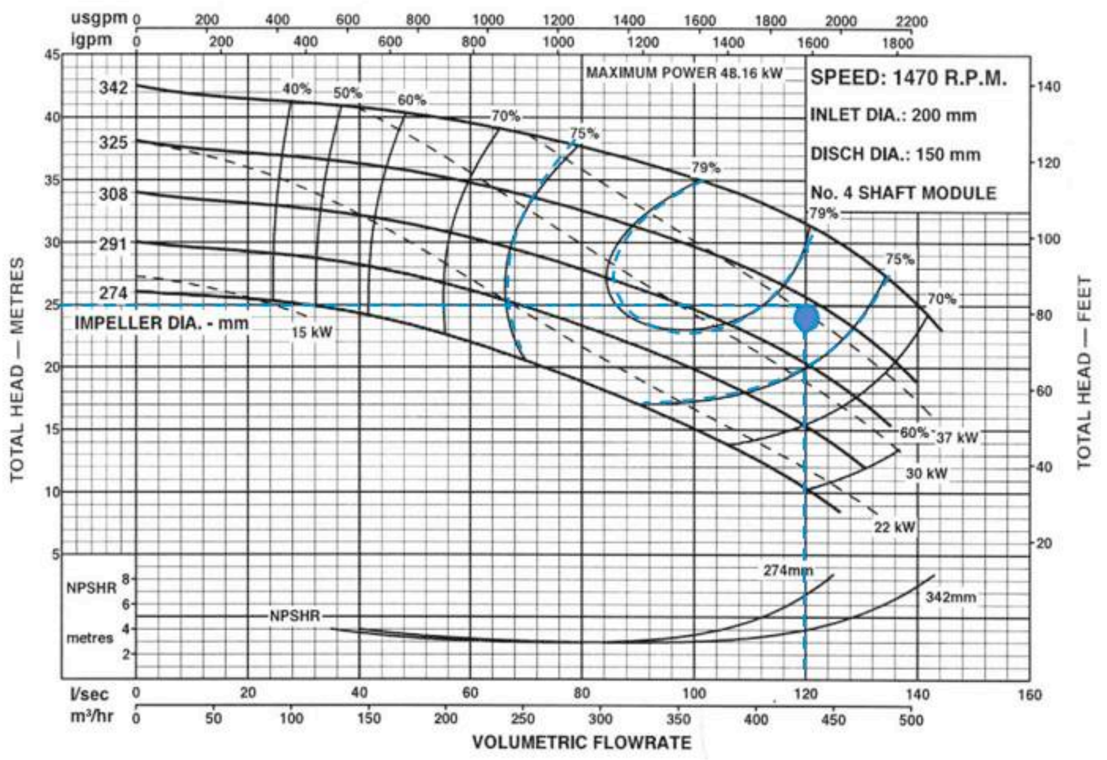


Figure 17 Check pump efficiency.



The formula for calculating suction lift is:

Suction lift = Atmospheric pressure – NPSHR – suction pipe friction = 10 – NPSHR – suction pipe friction

Read the NPSHR from the curve (Figure 18), subtract it plus the friction head of the suction pipe from the average atmospheric pressure (10 m at sea level), and check that it is less than suction lift. If not, try another curve. Pressure variation due to altitude is shown in Table 5.

Table 5 Variation in atmospheric pressure relative to altitude.

Altitude (m)	Atmospheric pressure (m)
Sea level	10
500	9.5
1000	9
5486	5

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

Suction lift = 10 – NPSHR – suction pipe friction

= 10 – 5 m – 1 m (estimated)

= 4 m

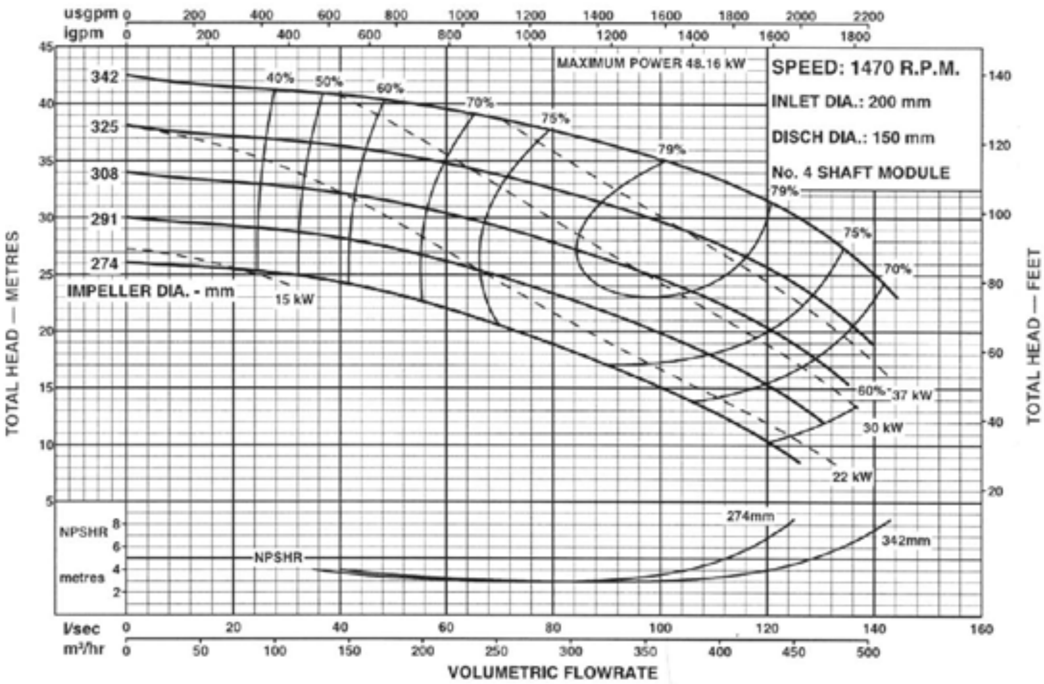
Generally, if the suction lift is less than 4 m the pump should perform properly.

Step 4. Determine the power required

The amount of power required to drive the pump (at the pump shaft) is also shown on a pump curve. Sometimes the power curves are placed across the other curves (as in Figure 19) and sometimes separately. 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.

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

Figure 18 Check the suction lift.



Step 5. Determine the drive unit size

Double check the power required at the pump by using this calculation:

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

EXAMPLE

Power = 120 L/s × 25 m ÷ 0.78 ÷ 100

= 3000 ÷ 0.78 ÷ 100

= 38.5 kW

Several factors cause both diesel and electric motors to run at less than maximum efficiency and allowing for these is termed 'derating'. The type of drive is a factor affecting all motors. For electric motors, the other main factor is whether it is part of a submersible pump.

For diesel engines, altitude and ambient temperature are the other main factors. Derating should be undertaken with your designer to ensure the motor can provide enough power to the pump all the time.

As well as derating, it is advisable to choose a motor or engine that has extra power in reserve. This means the power unit will not be struggling to do its task as it and the pump age or if there are unexpected changes to operating conditions, e.g. temporary voltage drops and extreme heat. As a guide, for electric motors add 20 per cent to the derated figure, and 40 per cent for internal combustion engines:

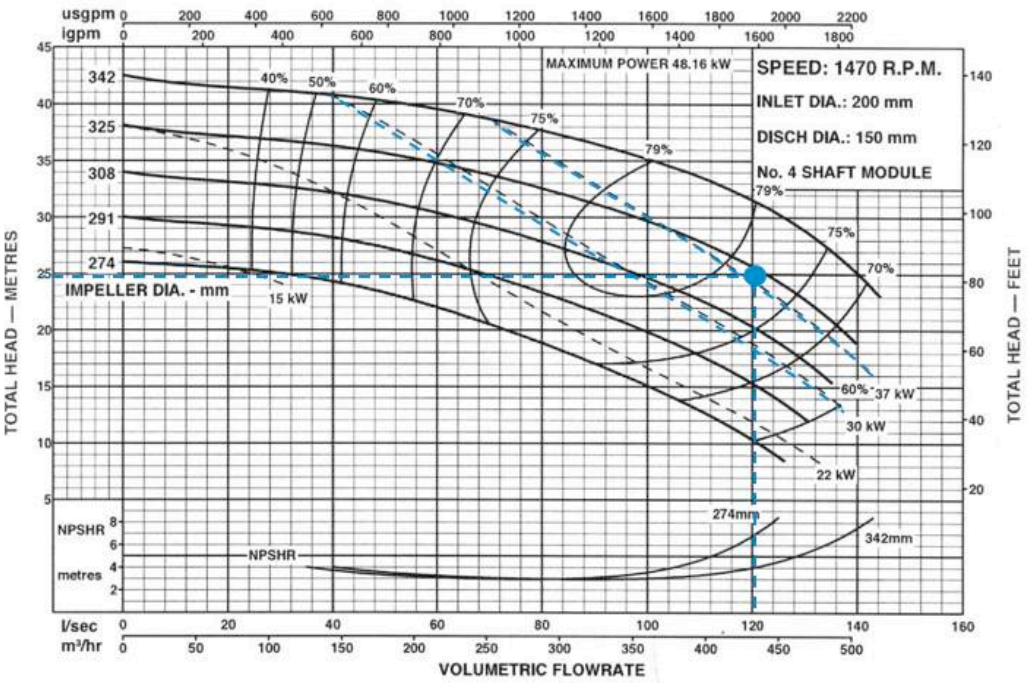
Size of electric motor to purchase =

pump power + derating factors + 20%

Size of diesel engine to purchase =

pump power + derating factors + 40%.

Figure 19 Determine the pump power required.



Pump installation checklist.

Table 6 Pump installation checklist.

System on checks (system running)

Check
☑ 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 does not move during operation
☑ Ensure pump and motor connection is aligned
☑ Provide ventilation for the motor or engine
☑ Do not install suction pipes so that air can build up in them

Source: Adapted from Managing Water in Plant Nurseries (2000), C Rolfe, W Yiasoumi and E Keskula, NSW Agriculture, p.196

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. You should check your pump and fittings before each irrigation season.

Table 7 Operation and maintenance checklist.

System on checks (system running)

Check
☑ Keep pump and motor connection aligned
☑ Make sure suction and delivery pipes are not straining the pump casing
☑ Check that all pipe connections are tight and suction lines are airtight
☑ Make sure pump is primed before starting
☑ Work the pump within its limits
☑ Keep the strainer clean
☑ Service the pump regularly
☑ Do not operate pump if it is vibrating excessively
☑ Do not operate pump if strainer is blocked
☑ Do not operate pump if it is vibrating excessively

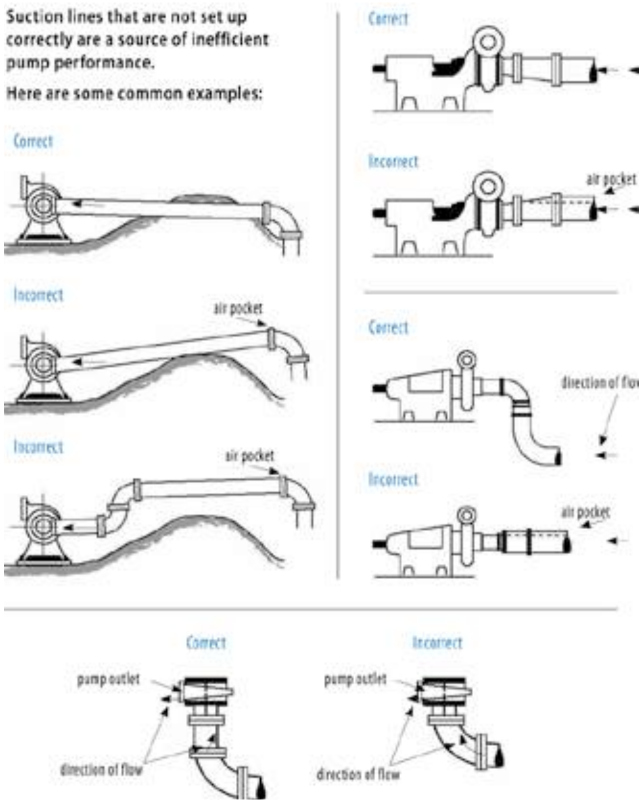
Source: Adapted from Managing Water in Plant Nurseries (2000), C Rolfe, W Yiasoumi and E Keskula, NSW Agriculture, p.196.

Suction

A major cause of poor pump performance is problems in the suction line. Things to watch for when designing and installing the suction side of the pump are:

- Suction lift too high. About 4.5 m 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 could damage the pump
- Air pockets. Installing suction pipes and fittings incorrectly may cause pockets of trapped air (see Figure 20). 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 the foot valve causes a severe drop in pump performance and damage to the pump itself. Ensure all joints are tight with correctly fitted gaskets
- Foot valve. Ensure that the foot valve is far enough below water level – at least 0.5 m – to prevent a vortex of air being drawn into the suction. Also ensure it is not too close to the bottom of the water source to avoid sucking in foreign matter or clogging the system or both.

Figure 20 Pump suction line set-up – dos and dont's.



Bearings

A screwdriver (preferably one with metal through the handle) held against the pump near the bearings and against the ear will help check for bearing wear. A smooth hum will indicate the bearings are sound. A grinding, rattling 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 indicates 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, rather than a packing gland, any leakage indicates the mechanical seal is worn and needs to be replaced.

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 between 0.13 to 0.25 mm, although this should be confirmed with the pump manufacturer. A clearance outside of the pump manufacturer's range indicates new wear rings or a new impeller are needed.

Pump shaft

Check the pump shaft 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 run-out should not exceed 0.05 mm.

Pump bowl

The pump bowl and the impeller should be cleared of any build-up of rust or corrosion. If there is wear or damage to the metal and it is not severe, it can often be repaired with water resistant epoxy, otherwise the bowl or the impeller or both should be replaced.

Seal and O-ring

Check the condition of the seal at the drive end of the shaft and the O-ring on the back cover for wear and replace them if necessary.

Cavitation

Cavitation occurs because the pressure on the water in the suction line is 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. If a pump is cavitating it usually sounds like it is pumping gravel.

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

Cavitation may also occur if the flow rate has increased, e.g. through worn sprinkler nozzles and 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.

REFERENCE

1 This chapter was adapted from WaterPak 1.8, **http://cottoninfo.com.au/publications/waterpak**

SUMMARY

The efficient operation of the whole irrigation system depends on the correct selection, operation of the pump that delivers water.

The main types of pumps used are radial flow, mixed flow and turbine pumps. Radial flow pumps are used for pressurised systems and are suited to high head and low flow systems. Mixed flow volute pumps pump large volumes of water at low head. Mixed flow impeller pumps discharge medium volumes of water at medium heads. Turbine pumps, which can be mixed flow or axial flow, are commonly used in boreholes. Depending on design, turbine pumps can deliver high volumes at low head but in some configurations higher head and lower flows.

Incorrect pump sizing is a major cause of irrigation inefficiency so all irrigators should take the time to understand the basic principles of pump operation. This includes understanding duty points, static and dynamic head, friction losses and power requirements. It is also important to know how to read a pump curve as this details the information required to select a pump for a specific irrigation system.

The steps in selecting the right pump are:

Step 1. Select the duty point

The first step is to establish the duty point. This the flow rate (Q) and total head (H) necessary to efficiently operate the irrigation system. The duty point is detailed on the pump curve and is the intersection of the flow rate (Q) curve and the total head (H) curve.

Step 2. Check pump efficiency

Pump curves also show efficiency curves, which detail the efficiency of the pump at different flows and heads, and different duty points. The efficiency of a pump should be at least 65 per cent and preferably higher.

Step 3. Check the suction lift

Pump curves also detail the net positive suction head required (NPSHR). This information is needed to see whether the pump can lift water under the suction line conditions prevailing at the site. Suction lift varies with atmospheric pressure so height above sea level and temperature both affect pump performance and suction lift.

Step 4. Determine the power requirements

The amount of power required to drive the pump (at the pump shaft) is also shown on a pump curve. Often the power curves are placed across the other curves (head, flow and efficiency) and sometimes separately. The power curve is usually marked in kW. You can work out the power at any point by estimating the figure from the closest power curve.

Step 5. Determine the drive unit size

The drive unit should provide sufficient power to operate the system efficiently. Motors are not 100 per cent efficient so their efficiency, detailed by the manufacturer, should be taken into account. Other factors also effect the operation of the unit so it should be derated and units with additional power selected to ensure the unit can work in all operating conditions. As a guide 20 per cent is added to the power requirements of an electric motor and 40 per cent for internal combustion engines.

Even after selecting the right pump it is important to maintain the pump throughout the life of the system. Problems commonly arise in the suction line and the performance of all pumps degrades over time due to wear. A regular maintenance schedule is vital.

05

Water metering

There are two main reasons for accurately metering water use:

Measurement for use. Metering is used by authorities to monitor individual customer use against entitlement, to find out how much water is being extracted from the catchment and to bill customers for water used.

Measurement for farm management. Irrigators are increasingly metering irrigation water to make more informed management decisions. Metering helps in calculating system efficiency as well as helping to identify water losses such as leaks, seepage and evaporation and to make better planning decisions.

While a wide range of meters is available, irrespective of which meter is used, three things are essential. It must be:

- installed correctly
- well maintained
- read accurately.

In recent years, state governments have developed legislative requirements about metering. It is recommended that you refer to the conditions and terms of your licence or approval to familiarise yourself with specific requirements.

Where required for regulatory purposes, meters that were installed before 1 July 2010 must meet standards developed under the National Water Initiative. After that date, new water meters, where required, must be 'pattern approved' (by the meter manufacturer or supplier) in accordance with requirements of the National Measurement Institute. They must also be installed and operated in accordance with ATS 4747 of Standards Australia.

Factors affecting water metering

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 to low head (from high to low pressure).

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

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.

Almost all flow meters use this equation (see box) 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).

CALCULATING FLOW

The equation for measuring and calculating flow is:

$Q = A \times V$

Where: Q is the flow rate or discharge rate (m3/s)

A is the cross-sectional area (m2)

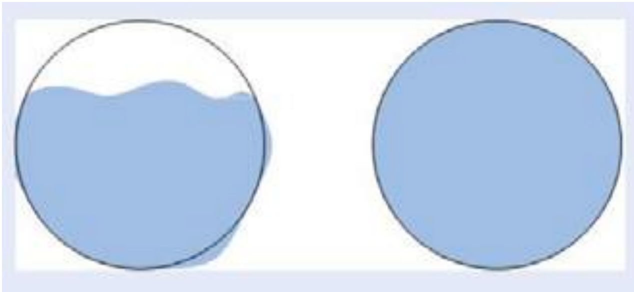
V is the average velocity of the water (m/s)

Note: The flow rate in m3/s can be converted to other units as follows:

1 m3/s = 86.4 ML/day

1 m3/s = 1000 L/s

Figure 21 The partially full pipe on the left is classified as open channel flow. The full pipe on the right is referred to as closed conduit flow.



Source: Panametrics

How water flows

Open channel flow. Water in an open channel will only flow if the water surface slopes downwards. The greater the fall, or head, the faster the water will flow.

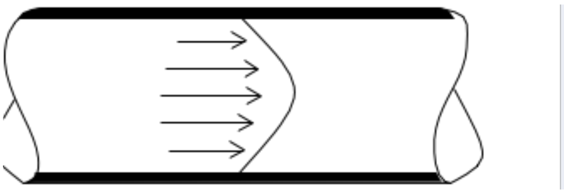
Closed conduit flow. This is commonly known as full pipe flow, but applies to any closed conduit, not just circular pipes. Regardless of the structure, the conduit must be completely full – if water does not completely fill the pipe then the water movement is classified as open channel flow, irrespective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

Turbulent flow. This occurs when the water swirls in the pipe or channel. It can be caused by obstructions in the flow stream, including the presence of the water meter itself. Other obstructions can include weeds, incorrectly placed gaskets protruding into the flow, shells, chemical build-up, valves, bends and other fittings.

Most manufacturers recommend a length equivalent to 10 pipe diameters before the meter to restore established flow conditions. There should also be straight pipe after the meter to ensure that any subsequent turbulence does not affect flow conditions near the meter.

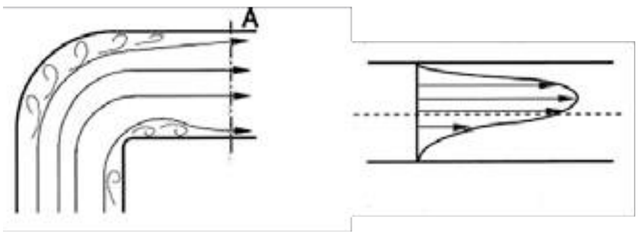
Laminar flow. This term is often used to describe the conditions under which metering must occur. However, in practice, few of the flows that occur in irrigation are laminar rather they are more accurately described as 'smooth turbulent'. What is needed are established flow conditions so that the velocity profile is regular and predictable.

Figure 22 Velocity profile in horizontal pipe for established flow.



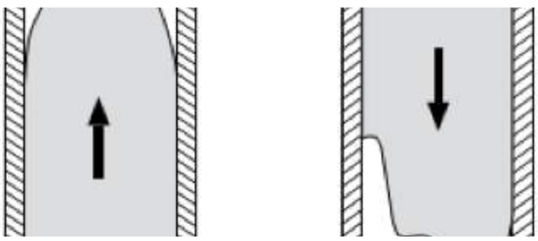
Source: Panametrics

Figure 23 Streamlines in an elbow and the corresponding velocity profile at 'A'.



Source: Guide to Flow Measurements, Bailey Fischer & Porter.

Figure 24 Difference in profiles in a vertical pipe for upwards flow and downwards flow.



Source: Panametrics

Water velocity

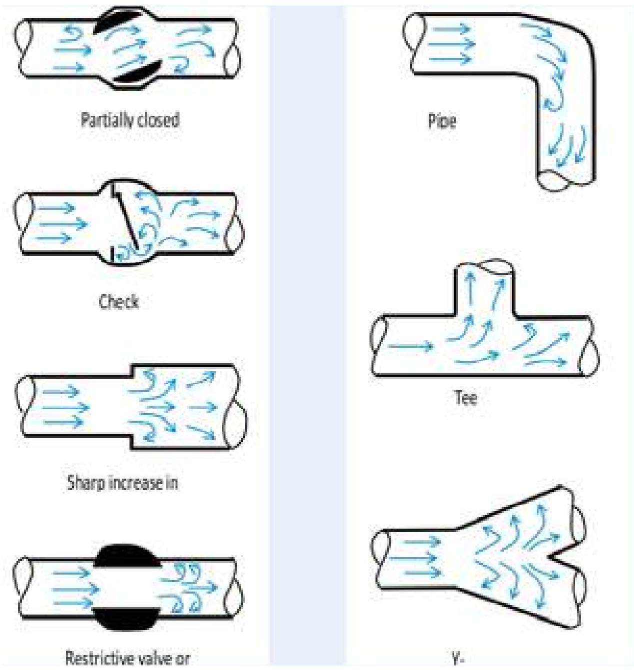
It is important to understand how water velocity varies across a pipe or channel.

As indicated in Figure 22, the velocity of water moving in 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.

When the flow is not established, the velocity profile changes, as indicated in Figure 23. In this case, the velocity profile after an elbow is skewed and varies in shape and cannot be correctly interpreted by a flow meter, affecting measurement accuracy.

Velocity profiles can be allowed for in metering calculations if they are consistent. This is achieved when the pipe orientation is between horizontal and vertical. However, downward flows in pipes have a more uneven profile due to gravity (see Figure 24). For this reason, do not measure flow in a vertical pipe with water flowing down the pipe. As well, avoid measuring flow in other situations where turbulence is created such as in Figure 25. In these situations, the meter should be located away from the turbulence according to the manufacturer's specifications.

Figure 25 Ways that turbulence can develop due to bends, valves and obstructions.



Source: Trimec

Principles of water measurement

Key considerations when it comes to measuring water are accuracy and error and repeatability.

Accuracy and error

Accuracy of measurement relates to the quality of the result. For water meters, this is the degree to which a meter conforms to a standard or true value. Accuracy is reported in percentages of error, for example, a manufacturer will claim that a meter will be accurate to ± 2 per cent, that is, it can have up to 2 per cent error. This meter is deemed accurate if it reads anywhere between 2 per cent below or 2 per cent above the correct reading.

Field conditions influence the accuracy of a meter. It is important that meters are installed correctly so they have an acceptable level of accuracy. The acceptable level of accuracy 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 per cent. In the field, the meters are operating in an imperfect environment so an acceptable accuracy is ± 5 per cent.

Repeatability

Repeatability relates to the quality or precision 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 shown in Figure 26. In this case, 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 26 From left to right, repeatability without accuracy, accuracy with a moderate degree of repeatability and accuracy with high degree of repeatability.

Types of flowmeters

Flow rate is related to the velocity of the water and the cross-sectional area of the conduit. Velocity of the water is related to the pressure or head in the system at the point of measurement. Some meters measure the velocity of the flow while others measure the head or pressure from which flow is then calculated. Mechanical, electromagnetic and ultrasonic meters measure velocity of the water. Venturi and orifice meters measure pressure or head.

Dethridge meter

Sometimes referred to as a Dethridge wheel, this type of meter has been installed in Australian irrigation systems for over 100 years. In most areas they are being phased out and replaced by more accurate types.

Propeller meter – open flow

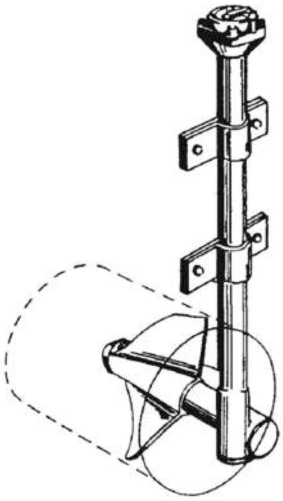
This type of meter consists of a propeller and extended spindle shaft. It is mounted on the downstream end of a pipe culvert with the propeller projecting inside the pipe and its axis located at the centre of, and parallel to, the flow.

For the propeller meter to measure accurately, the culvert pipe must always flow full of water and 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

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

Figure 27 Open flow meter.



Source: ABB Metering.

Instead of a propeller mounted in the flow of the water, these meters have a paddlewheel impeller that is rotated by the water passing through the bore. Unlike propeller meters, which record velocity in the middle (fastest) portion of the flow, paddlewheel meters record velocity nearer to the pipe edge.

These meters are available in various sizes and must be full of water when measuring flow.

In pumped systems the meter can be installed in the suction or the discharge pipework. Because of the large free passage through the meter they are well suited to water with a lot of physical debris. Some impeller designs are prone to catching some debris, however, drastically reducing accuracy or even stopping the meter from turning. Paddlewheel type meters are also prone to wear and damage as they have moving parts.

Figure 28 A paddlewheel meter installed in the field.

Source: Monique White

Figure 29 A paddlewheel meter installed in the field.

Source: Monique White

Ultrasonic meter

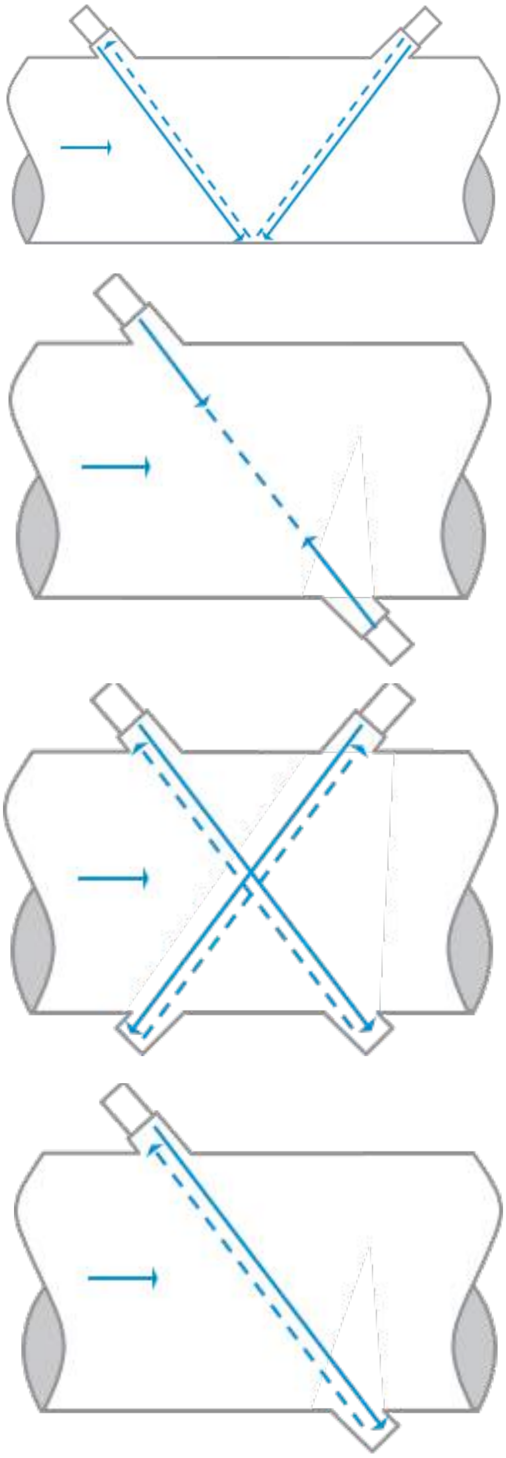
Ultrasonic meters operate by producing ultrasonic (sound) waves which travel through the water and are either sped up or slowed down by its velocity. Some meters combine both velocity and depth measurements, which means they can be used in open channel and partially full pipe situations. Ultrasonic meters use transducers or sensors to measure water velocity in full pipe applications and convert this to flow rate for a particular conduit cross-section. Meters that 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 models use multiple transducers to measure velocity in more than one plane to improve accuracy.

Two methods are used to calculate the velocity with ultrasonic meters; transit time and doppler.

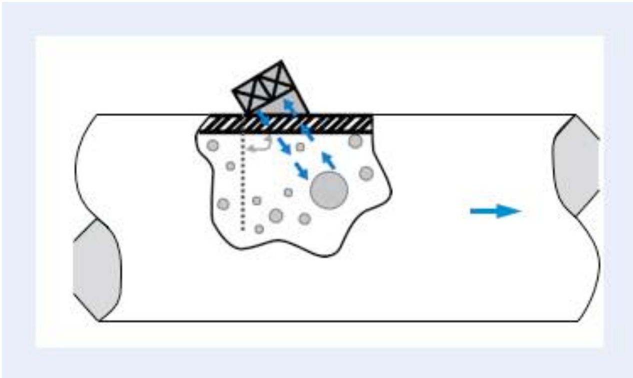
Transit time measures the small variations in time for an ultrasonic sound wave to travel upstream and downstream between fixed points. The velocity of the two sound pulses is compared to determine average velocity and therefore flow rate.

Figure 30 Examples of the various ways that transit time sensors can be set up.



Doppler calculates velocity by bouncing sound pulses out into the water mass and reading the pulses that are returned after reflecting from small moving particles, such as air bubbles in the water mass. Doppler meters generally consist of a sensor installed in an existing pipe or structure. Ultrasonic doppler meters can have an additional sensor installed to measure the depth of flow. This makes them capable of measuring flow in partial pipes, pumped or gravity fed pipes as well as full pipes. Doppler flowmeter performance is highly dependent on physical properties such as the liquid's sonic conductivity, particle density and flow profile, so accuracy is more sensitive to velocity profile variations and to distribution of acoustic reflectors.

Figure 31 Schematic of a doppler meter showing the reflected path from a non-wetted transducer.



Source: 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 a pipe, a small electrical voltage proportional to the fluid velocity is created. The electrodes detect the voltages generated by the flowing water which is then converted to velocity from which the flow rate is derived.

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

Figure 32 Electromagnetic meter.

Source: G.Roth

Flumes and weirs

These are used to measure flow in open channels. A weir is a small holding wall. It measures flow by recording the height of the water as it flows over the wall or through a smaller cut-out, e.g. a v-shaped notch, which is easier to measure.

A flume is a narrowing of a channel. Water height is read with measuring sticks or ultrasonic meters. Ultrasonic meters allow flow to be automatically logged and recorded. While any weir or flume structure can be used to measure flow, the greatest challenge is ensuring that height and flow are correctly calibrated.

Storage meter

Another approach to metering is to measure the change in volume of water in an on-farm storage. Recent developments of accurate, cheap, automated storage volume meters have made it much easier to measure and continuously record storage volumes and then to estimate the volume of water that has been moved to other parts of the farm.

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.

Figure 33 Diagram of water meter installation.

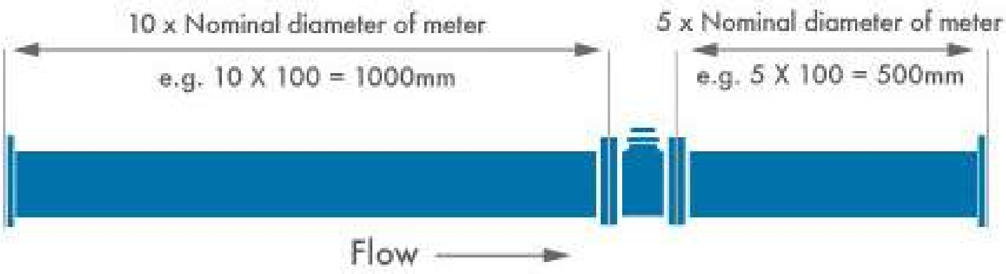
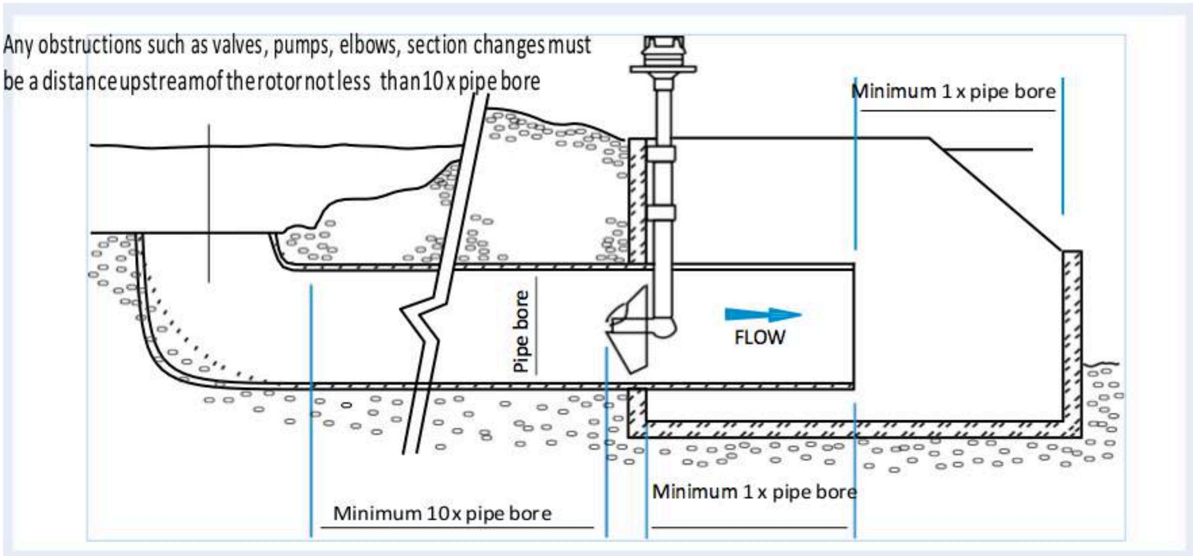


Figure 34 Example of minimum requirements for straight pipe before and after an open flowmeter installation.



Source: ABB Metering

☑ Flow conditions

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

Nearly all meters require established flow conditions to operate accurately. This means that the installation location must be straight enough and there must be no obstructions to ensure the flow is not turbulent. While manufacturers will specify the length of conduit required to ensure appropriate flow conditions, the norm is 5 to 10 diameters upstream and 3 to 5 diameters downstream.

☑ Water source

The source could be a river, surface water, groundwater, open channel or pressurised pipe. Surface water and river water carry trash and other foreign material while some groundwater can cause iron oxide and iron bacteria build-up on the internal surface of meters and pipes. Select a meter that suits your water source and water quality.

☑ 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 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 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 while others may have a variety of power source requirements. Many meters that require power can be supplied by battery/solar systems while others 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 data accuracy of 2 per cent then it would not be useful to choose a meter that only reads with an accuracy of 5 per cent. The reverse may also be true, particularly if a more accurate meter costs more to buy.

A manufacturer's claims for meter accuracy are usually 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 manufacturer's requirements of flow profile, temperature, humidity, flow range, radiation, vibration, etc.

☑ Reliability

A meter needs to be reliably accurate over its service life 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, while others need external data logging capabilities, at additional expense. Some systems can 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 while others could be left alone for years without needing to be seen. Some meters can 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. Ongoing maintenance requirements should also be considered. Some operating conditions, e.g. water quality, may vary the recommended operating life.

☑ 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. Do not forget to include the value of the data collected when determining how much you should spend.

Maintenance

Mechanical meters

Mechanical meters, like all things driven mechanically, require maintenance. These meters should be maintained in good condition without wear and correctly adjusted. They should be 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 can be removed and the meter thoroughly cleaned.

If it is too worn, replace the meter. In aggressive water, e.g. chemically corrosive and where sand content is high, it may need to be replaced often or to be made of special material.

Meter failure can be detected by the vigilance of the meter reader or by monitoring 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 failure for mechanical meters:

- Mechanical failure, which 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 flow rates that are too high, poor quality parts, tampering, metal fatigue and vibration.
- Environmental failure, which occurs when the meter is fouled or damaged by foreign matter or objects in the water supply system. This type of failure is usually caused by gravel or sand, weeds, algae, iron oxide, fish or eels and rubbish, e.g. sticks and shellfish.

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 next to the meter
- large air bubbles in the flow
- full-pipe situations not running full due to air entering the system
- mechanical meters being jammed or slowed by weeds, twigs, fibre, iron oxide, iron bacteria or shells in the propeller/rotor/paddle or the internal surface of the meter
- operating the meter outside its minimum and maximum flow range.

Ultrasonic meters

Ultrasonic meters require little maintenance once installed. Batteries will last between 5 and 10 years depending on how often they are completely discharged. 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. 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 need little maintenance. The straight-through section of pipe has no obstruction to restrict flow, and there are no moving parts to wear or break. As with ultrasonic meters, the power source will need to be checked.

REFERENCE

1 This chapter was adapted from WaterPak 1.7, **http://cottoninfo.com.au/publications/waterpak**

SUMMARY

Metering is used for compliance, measuring water allocations and extractions, and for management. Metering can be a vital tool in helping manage irrigation systems as it provides critical information on whether the system, as a whole, and parts of the system are operating correctly. In particular, pump performance cannot be assessed without flow measurement.

All water meters, regardless of type, must be correctly installed and maintained and read accurately. Meters used for measuring irrigation water extraction must comply with the conditions laid in the Australian Standard, ATS 4747. All new meters installed after 1 July 2010 must have been pattern approved, that is tested for accuracy and performance.

Measuring flow

Flow measurement is based on the equation:

Flow (Q) = Area (A) X Velocity (V)

All meters measure velocity in a given pipe or conduit dimension, which allows flow to be calculated. Accurate measurement relies on there being 'established flow' in the conduit or pipe where the water is being measured. Any fitting or device near the spot where the meter is installed can have a significant effect on flow velocity and lead to inaccurate measurements. This is why the standard defines the installation conditions as having a certain number of pipe diameters of clear upstream and downstream from the meter.

Irrigation meters

The main meter types used in irrigation are:

Dethridge wheels which comprise a circular drum with vanes set in a concrete structure of fixed dimensions. It is commonly used in gravity fed irrigation schemes.

Propeller meters can be used in both open flow and closed pipe conditions. This type of 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.

In 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.

- Ultrasonic meters operate by producing ultrasonic (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 means they can be used in open channel and partially full pipe situations.
- Electromagnetic meters consist of a section of pipe with a magnetic field across it and electrodes to detect electrical voltage changes. When a conductive fluid, e.g. water, passes along a pipe, a small electrical voltage proportional to the fluid velocity is created in the fluid.
- Flumes and weirs are used to measure flow in open channels. A weir is a small holding wall. It measures flow by recording the height of the water as it flows over a wall, or through at a smaller cut-out, e.g. a v-shaped notch. A flume is a narrowing of a channel. Water height is read with measuring sticks or ultrasonic meters.
- Storage meters can be used to measure the change in volume of water in storage. Recent developments of accurate, cheap, automated storage volume meters have made it much easier to measure and continuously record storage volumes.

Choosing a meter

Meter selection is a complex task that should be done by a certified professional. There are a number of important parameters, such as flow range and flow velocity, which must be considered.

To maintain accuracy the meter should be regularly maintained and protected from mechanical or environmental failure.

06

Irrigation performance

Your irrigation system is a vital and expensive piece of your farming equipment. Just as you would undertake pre-season checks for farm equipment such as tractors and balers, you should do the same for your irrigation system to ensure you are getting the best performance out of it and to ensure a long service life for your investment.

Starting your system without checking it could mean that it might be applying water inefficiently or unevenly or both, limiting your productivity and wasting water and energy. At worst, it could result in a catastrophic failure that will have you out of action for months.

Pre-season system checks

It is important to check your system each year both before and after the irrigation season as well as more extensively every few years. The following pages detail the minimum checks to make before each irrigation season begins. Photocopy the sheet(s) relevant to your system(s) and take them with you when doing checks.

Checks include structural and mechanical inspections of the hardware and performance assessments of water flow, nozzle delivery and pressure. It can be helpful if two people work together to get these done.

SAFETY

Remember to be safety conscious around your irrigation system – electrical, height and mechanical hazards are present.

Begin the checks with the system turned off.

- Ensure electrical isolator or motor switches are tagged or locked to prevent accidental starting.
- Examine equipment and components, looking for damage or wear and tear.
- Tighten, adjust, maintain or replace components as required.

Make checks with the system running.

- Consider which aspects require a qualified expert (e.g. an electrician).
- Ensure the pumping system is safe before starting the irrigator.
- Check operation of the pump system, pipework, hydrants/off-takes, laterals and nozzles.
- For moving systems ensure the irrigator travel path is clear before starting the machine then test its operation, drive system and nozzles.

Check system calibration.

- Ensure depth and uniformity of application are as expected.

While many things can be fixed on farm, others require specialist skills or equipment. Tick the check boxes in your checklist (over page) as each item is found OK and make notes against items requiring follow up attention.

Every system should be supplied with a system operation manual. Read it and follow the instructions. The manual may include extra checks not listed here. It will give more detail than these checklists, including information specific to your system.

Pre-season checklist – spraylines

Checks completed by:

Signature: Sign here Date:

Table 8 System off checks (system not running)

Component		Check
Safety	☑	Pump switch is tagged and locked
Water supply	☑	Checks completed
Filtration	☑	Rings/screens clean with no holes
	☑	Pressure gauges in good condition
Control valves	☑	Wiring and hydraulic lines secure
Off-takes	☑	Hydrants secure
	☑	Manual valves correctly set
Flushing points	☑	Flushing points accessible
	☑	Caps in place
Laterals	☑	Laterals undamaged
	☑	Tapping saddles/connections secure
	☑	Risers for wear or damage
Sprinklers	☑	Every sprinkler against nozzle chart
	☑	Every sprinkler for wear and damage
	☑	Alignment correct
Control unit	☑	Electronic controls and battery charge
Prepare to start	☑	Before starting: pump system secure

Table 9 System on checks (system running)

Component		Check
Headworks	☑	For leaks
	☑	Flow rate of each block
System pressure	☑	Pump pressure for each block
	☑	Pressure before and after filters
	☑	All off-take pressures correct
	☑	Lateral inlet pressures*
	☑	Lateral end pressures**
Pipe network	☑	For leaks along mains
	☑	For leaks along submains
	☑	For leaks along laterals
	☑	Laterals flush clear
Off-takes	☑	Hydrants not leaking
Sprinklers	☑	Application pattern
	☑	Moving sprinkler parts free
Calibration	☑	Calibration checks completed
Other	☑	

** Can measure at first sprinkler*

*** Can measure at last sprinkler*

Pre-season checklist – travellers

Checks completed by:

Signature: Sign here Date:

Table 10 System off checks (system not running)

Component	Check
Safety	☑ Electrical isolator and motor switches tagged/locked
Water supply	☑ Checks completed
Filtration	☑ Rings/screens clean with no holes
	☑ Pressure gauges in good condition
Hose reel and cable reel	☑ Structure condition, corrosion or damage
	☑ Gearboxes, drive shafts – lubricate as required
	☑ Cable winch action and ratchets
	☑ Tighten all bolts, check pins
	☑ Lubrication, grease (see manual)
	☑ Seals and flanges
Gun cart	☑ Structure condition, corrosion or damage
	☑ Wheel bolts, tyre condition and pressure
	☑ Tighten all bolts, check pins
	☑ Condition of other connections
	☑ Lubrication, grease (see manual)
	☑ Seals and flanges
	☑ Rotating boom turntable not worn, allows free turning
Drag Hose	☑ Hose condition for wear, kinks or other damage
	☑ Boots – tighten bands if necessary
Sprinklers	☑ Nozzle orifice condition – replace if wear detectable
	☑ Ensure rotating nozzles are free turning and cages not damaged
	☑ Splash plate, angle, alignment
	☑ Components for looseness, freedom of movement
	☑ Outlet nozzle orifice condition – replace if wear detectable
Prepare to start	☑ Ensure nothing is parked in front of the irrigator

Checks completed by:

Signature: Sign here Date:

Table 11 System on checks (system running)

Component	Check
Hose reel and cable reel	☑ Reel(s) turning smoothly
	☑ Hose or cable winding in correctly
	☑ Inlet pressure gauge – replace if necessary
	☑ Inlet pressure– preferably at furthest hydrant
Drag hose	☑ Turbine functioning
	☑ No leaks
	☑ Not misshapen
Gun cart	☑ Cart moving correctly
	☑ Inlet pressure– replace gauge if necessary
	☑ No leaks
Sprinklers	☑ Each sprinkler is turning correctly and cage not damaged
	☑ No leaks, repair or replace as necessary
	☑ Pressure above last sprinkler, above pressure regulator if fitted
Gun	☑ Operation
	☑ Gun angles are correct, switches direction at right locations
Control unit	☑ Correct functioning
Other	☑

Pre-season checklist – drip irrigation

Checks completed by:

Signature: Sign here Date:

Table 12 System off checks (system not running)

Component	Check
Safety	☑ Pump switch is tagged/locked
Water supply	☑ Checks completed
Filtration	☑ Condition of filter media
	☑ Rings/screens clean with no holes
	☑ Pressure gauges in good condition
Fertigation/ Chemigation	☑ No signs of corrosion
	☑ System clean, no blockages
	☑ No leaks
	☑ Wiring and hydraulic lines secure
Control valves	☑ Valves, wiring and hydraulic lines secure
Off-takes	☑ Manual taps correctly set
Flushing points	☑ Flushing points accessible
	☑ Caps in place
Pipe network	☑ Submains/headers
	☑ Laterals undamaged
Control unit	☑ Electronic controls and battery charge
Prepare to	☑ Pump system secure

Table 13 System on checks (system running)

Component	Check
Pipe network	☑ For leaks along mains and submains
	☑ For leaks along laterals
	☑ Laterals flush clear
Fertigation/ Chemigation	☑ No wet patches
	☑ No low growth patches
Headworks	☑ For leaks
	☑ Flow rate of each block
System pressure	☑ Pump pressure for each block
	☑ Pressure before and after filters
	☑ All off-take pressures correct
	☑ End pressure - tested at ends of far laterals
Calibration	☑ Calibration checks completed
Other	☑

Checklist – centre pivot & lateral move

Checks completed by:

Signature: Sign here Date:

Table 14 System off checks (system not running)

Component	Check
Safety	☑ Electrical isolator switch is tagged/locked
Water supply	☑ Checks completed
Filtration	☑ Rings/screens clean with no holes
	☑ Pressure gauges in good condition
Pivot point	☑ Lubrication, grease
Drag hose (LMs)	☑ Condition of other connections
	☑ Hose condition and fittings secure
Towers	☑ U joints for wear, replace if necessary
	☑ Cable and rod connections
	☑ Wheel bolts, tyre condition and pressure
	☑ Gearboxes, drive shafts lubricate as required
Risers and spans	☑ Boots – tighten bands if necessary
	☑ Flanges
End gun corners	☑ Connections
	☑ Wiring and hydraulic lines
Sprinklers	☑ Every sprinkler against nozzle chart, for damage and correct size
	☑ Droppers for wear or damage, replace as necessary
Control unit	☑ Electronic controls and battery charge
Prepare to start	☑ Ensure nothing is parked

Table 15 System on checks (system running)

Component	Check
Pivot point	☑ For leaks, movement
Riser and spans	☑ For leaks along spans and at towers
	☑ Flanges – call service company if flanges leaking
Towers	☑ Motors, gear box and drive shaft operation for noise or vibration
Sand trap	☑ Empty and flush
Sprinklers	☑ Each sprinkler is turning correctly and cage not damaged
End gun corners	☑ Droppers for leaks, repair or replace as necessary
	☑ Connections
	☑ Operation
	☑ Gun angles are correct, turns on and off at right locations
	☑ Corner arm sprinklers turn on and off correctly
System pressure	☑ Inlet pressure gauge with alternative - replace if necessary
	☑ Inlet pressure is correct
	☑ End pressure - above pressure regulator at last dropper

System evaluation

Your irrigation system is one of the most important components on your property. To supply water to all your pastures in the right amounts at the right times means you have a vital interest in how well your irrigation system performs.

There are two key reasons for knowing the performance of your irrigation system:

- Profitability. Effective irrigation maximises production. A well set up system makes money.
- Sustainability. Efficient irrigation minimises water use and leaching. A well set up system saves money.

The first step to ensuring peak performance is to properly maintain your system – lack of maintenance results in poor performance. There is little point evaluating a system that has not been maintained as it almost certainly will not be performing well.

How to evaluate your system

Each type of irrigation system functions differently and is affected by different factors, so they must be evaluated differently. Fortunately, many performance indicators are common, so although each system may need measuring in a different way, their performance is easily comparable.

Irrigation NZ and Page Bloomer consultants have developed IRRIG8Quick, a series of do-it-yourself, in-field irrigation system checks. Using the guidelines and worksheets relevant to your system, you can complete each check in a couple of hours. It is recommended that you evaluate your system every two years. The free guidelines and field sheets are available at **pagebloomer.co.nz/resources/irrigation-calibration/irrig8quick/**

If you suspect problems with your irrigation system or it has been many years since the system was fully checked, a full evaluation should be undertaken by a specialist irrigation auditor.

Depth of application

It is important to ensure that the depth of water applied is the same as the irrigation manager expects it to be. If not, every time the pasture or crop is irrigated the field will receive less or more water than expected. If less water than expected is applied, plants will be under-watered. This accumulates with each irrigation event so that by the end of the season they will be under-watered and suffering severe stress, with the result being lost production.

If more water than expected is applied, plants will be over-watered. This is a waste of water because excess water goes past the root zone. If overwatering is significant it will waterlog the soil, reducing productivity and perhaps affecting plant health.

Irrigation evaluations (sometimes called irrigation audits) focus on a set of key checks:

- Is the system applying the expected depth of water? It is essential to know how much water is being applied as it is an important input for irrigation budgeting and scheduling. It is especially important if nutrients are being applied with the irrigation, either as effluent or fertigation.
- Is it applying the water at a rate that the soil can accept? If the water can't get into the soil and runs off, the plants don't get to use it.
- Is it applying the water uniformly? Uniformity of irrigation determines whether all plants are receiving the same amount of water. As uniformity decreases, some plants will receive too much water while others will not receive enough.
- Is energy use reasonable? With rising energy costs, it is important that the system uses only what is required for it to operate well. Excess system pressure and poor pump performance are the usual culprits if energy use is too high.
- What is causing it not to perform? If a system is not performing, it is important to identify the issue or issues so that they can be fixed.

For pressurised irrigation systems (e.g. sprinkler or drip), irrigation system evaluation involves arranging a set of catch cans to measure the volume of water applied to specific locations within the field. For fixed systems, the cans are normally arranged in a grid pattern, while for moving systems they may be arranged either perpendicular or parallel to the direction of travel. This catch can data is then used to evaluate application depth, rate and uniformity.

Depth of application is a common problem with centre pivots where the depth indicated on the control panel is often different from the depth applied, even for new systems.

Figure 35 Catch can testing.

Source: AgVic

Rate of application

Irrigation water should be applied at a rate no higher than the infiltration rate of the soil, which varies a lot depending on the soil type. If the application rate (mm per hour) is higher than the infiltration rate, water will move from higher to lower spots, and perhaps off the irrigated field. This movement reduces application uniformity and, if there is run-off, reduces the average depth applied.

At the outer end of centre pivot systems, where application rates can range from 60 to 150 mm/hr and higher, it is almost impossible to achieve an application rate less than the soil infiltration rate. Fortunately, only a relatively small amount of water is applied at each pass, minimising the potential for water movement. Good groundcover helps to retain water. Best practice is to use sprinkler arrangements that will keep the application rate as low as possible, i.e. sprinklers with a large diameter of throw and spreader bars.

Uniformity of application

Distribution uniformity (DU) is a measure of the evenness of application. It is measured in decimal units up to 1 or expressed as a percentage. A value of 1.0 or 100 per cent would mean the irrigation system is applying water perfectly evenly across the entire irrigated area.

Irrigation application is never completely even, e.g. a well-maintained and well-operated spray line will have a uniformity value between 0.75 (75 per cent) and 0.85 (85 per cent).

A catch can test, where cans are placed at regular intervals across an irrigated area, is used to check uniformity. Water is applied over the whole irrigated area and the average of the lowest quarter of the volumes collected is compared with the average of the water collected in all catch cans. This can then be applied to scheduling calculations to determine how much extra water is required so that all plants get enough water. This is termed the 'scheduling coefficient'. The scheduling coefficient (SC) is the reciprocal of the DU, i.e. SC = 1 ÷ DU

EXAMPLE

If an irrigation system has a DU of 0.75, the scheduling co-efficient is 1 ÷ 0.75 = 1.33.

If the irrigation application required is 15 mm, the average depth that should be applied is 15 x 1.33 = 19.95 mm. This will ensure that 7/8ths of the plants get at least 15 mm of irrigation. Some will get more and a few a little less.

Because centre pivots are designed to apply more water progressively along the pivot starting at the centre, another measure of uniformity is often used for these systems, called Christiansen's Coefficient of Uniformity – Heerman and Hein (CUH).

It uses the same catch can data, but instead of comparing the lowest quarter of the catches with the average of all of the catches, this measure compares each catch with the average of all the catches. The reason for using CUH for centre pivots especially is because it is a simpler method of allowing for the increasing applications. It is expressed the same way as DU, i.e. in decimal units up to 1, or as a percentage, with a value of 1.0 or 100 per cent indicating the application is perfectly even. The figures for CUH are usually a little higher than for DU with the benchmark being 0.9 or 90 per cent.

In general, shallow narrow-rooted plants need more uniform application than deeper, wide-root system plants, which can compensate for lower uniformity with a larger root mass and area covered.

Border check system evaluation

Border check is a non-pressurised method of irrigation, so while the previous information is relevant, several key factors influence surface irrigation performance in the field. While some of these are fixed, some can be adjusted through design or management. These provide a basis for field testing procedures.

Inflow

Inflow is an important variable in the surface irrigation process, second only to soil infiltration. It affects advance but has little impact on the rate of recession (surface drainage). Provided all other factors are held constant, increasing the rate of inflow yields more rapid advance.

Inflow is expressed as litres per second per metre width (L/sec/m), which is a common unit enabling different fields to be compared. It is found by dividing the rate of flow through the bay inlet by the bay width, as follows:

Inflow = flow rate (L/sec) ÷ bay width (m)

SLOPE EXAMPLE

Two bays 22.5 m wide and 30 m wide, both have a flow rate of 100 L/sec

Inflow bay 1 = 100 ÷ 22.5 = 4.4 L/sec/m

Inflow bay 2 = 100 ÷ 30.0 = 3.3 L/sec/m

Inflow of around 2 L/sec/m is common, although up to 7 L/sec/m has been recorded at case study sites.

Figure 36 Measuring the inflow advance.

Source: C. Phelps

The slope down the field influences both advance and recession, and greater slope increases the rates of both. A higher slope (around 0.2 per cent or 20 cm per 100 m or 1:500) is desirable for lighter, more permeable soils.

While laser levelling helps to achieve a more accurate and even surface, a topographic survey on completion is worthwhile to ensure that the final product is as designed. This is very important when the field surface is relatively flat, as shallow gradients are more sensitive to surface variations and therefore more prone to uneven irrigation and drainage. Higher slopes and uniformity are harder to achieve with longer fields.

Significant changes in slope (such as in Figure 37) can have a detrimental effect on irrigation performance and pasture health. These conditions usually promote slow advance and poor drainage, causing excessive application depth and restricting plant growth through prolonged periods of soil saturation.

TIP

When measuring irrigation advance, position markers at changes in slope to capture any effect this variable may have on performance.

Infiltration opportunity time

Infiltration occurs when water is on the soil surface. Infiltration opportunity time (IOT) is a product of irrigation advance and recession (surface drainage). To apply the desired depth of water evenly across the field, advance and recession curves should be separated by the required opportunity time and be parallel.

Depth of irrigation increases with greater IOT and the appropriate length of time for any given irrigation event is determined by the soil infiltration characteristic and soil moisture deficit. It is typical for soils with high infiltration rates or low water holding capacity to require short irrigation times, while soils with low infiltration rates or high water holding capacity need longer irrigation times.

Advance and recession, along with methods used to measure and assess both, are described below.

Figure 37 Field slope of a border check system.

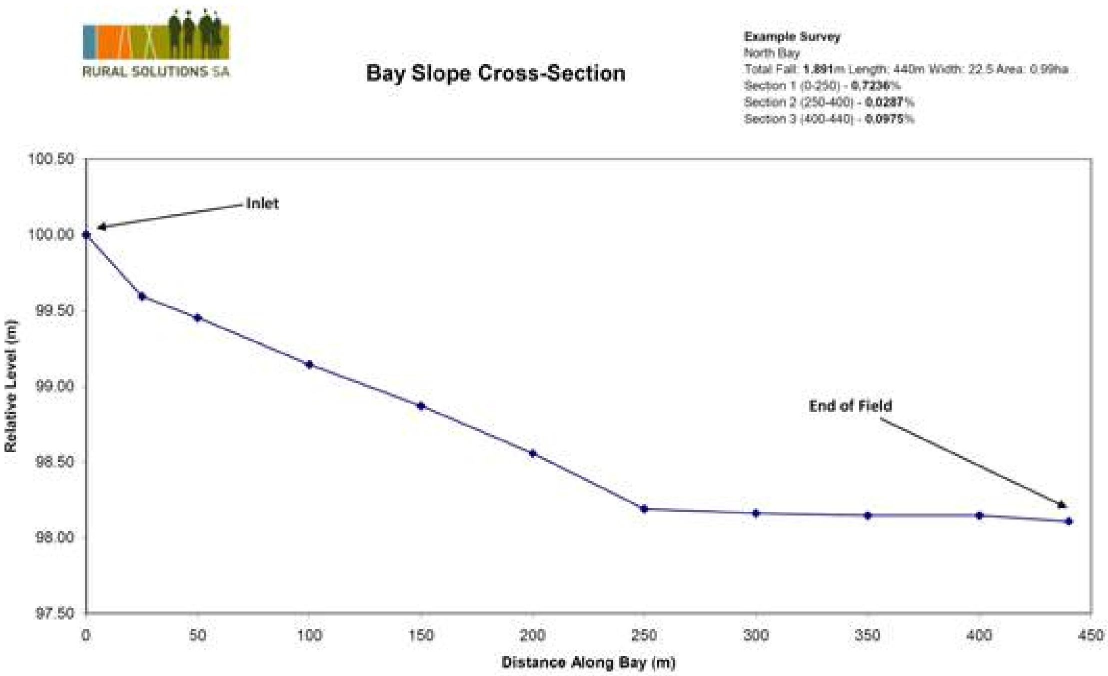


Figure 38 Advance and recession curves for a poorly performing trial site, 2007.

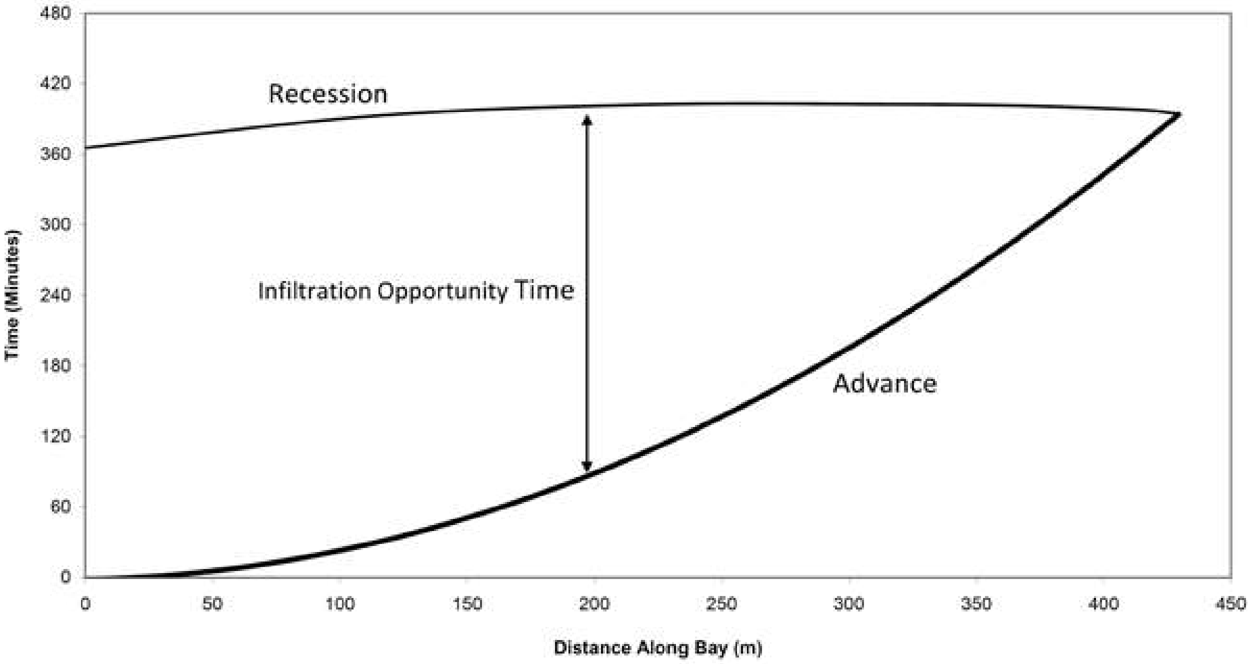
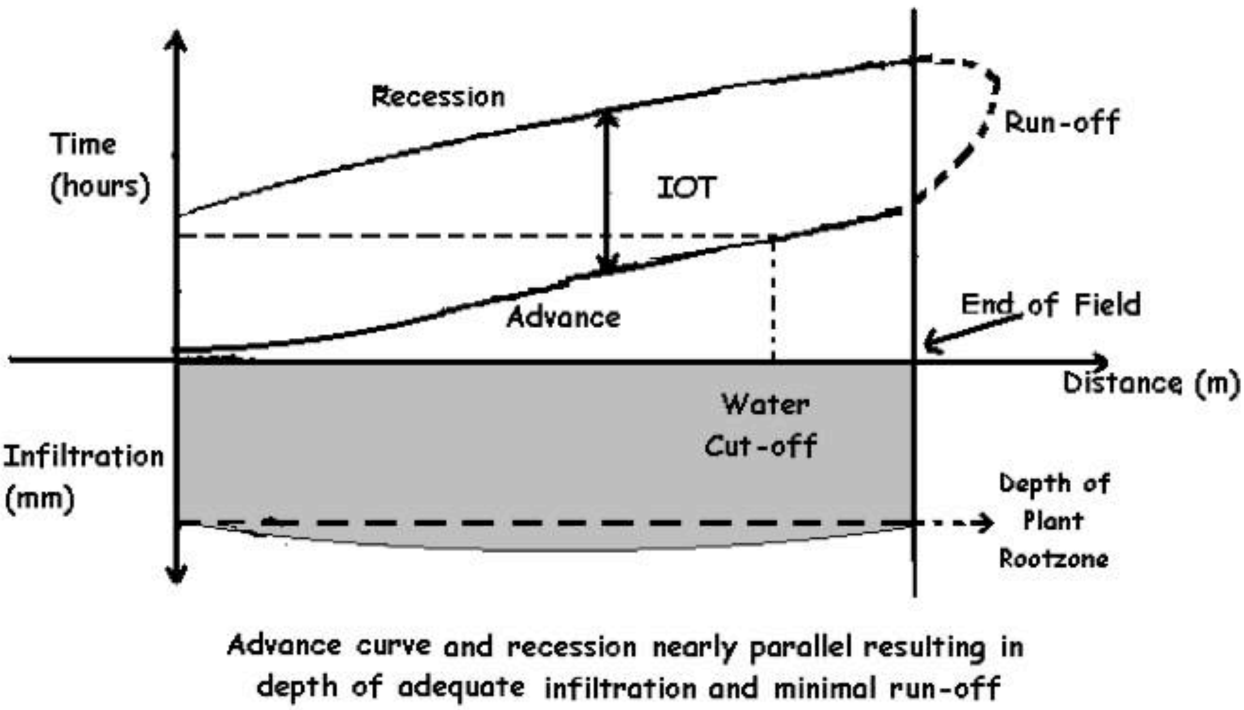


Figure 39 Idealised advance and recession curves for a properly performing system.



Depth of irrigation increases with greater IOT and the appropriate length of time for any given irrigation event is determined by the soil infiltration characteristic and soil moisture deficit. It is typical for soils with high infiltration rates or low water holding capacity to require short irrigation times, while soils with low infiltration rates or high water holding capacity need longer irrigation times.

Advance and recession, along with methods used to measure and assess both, are described below.

Irrigation advance

When irrigation is applied to the field, water advances across the surface until it covers the entire area. Under border check irrigation, water will directly wet the entire surface as the whole bay area is designed as the flow path.

The rate of irrigation advance is expected to slow during an irrigation event because the area of the bay with water on it and where infiltration is occurring increases as the irrigation event progresses. As a result, a smaller proportion of inflow contributes to advance over time. The soil infiltration characteristic and inflow are important as they are the main determinants for the rate of change. Irrigation advance also varies between bare fields and those with pasture or crop, and with the height and density of the plants.

It is best to measure the advance with the field in with a representative plant height and density.

Advance can be measured simply, as follows:

- Record the time when the bay inlet is opened.
- Return to the bay at regular intervals, say, hourly and place a marker at the leading edge of the wetted front. Alternatively, you can place markers at known distances before irrigation and note the times at which the wetted front passes each point.
- Mark the final position before closing the inlet and record the time when the inlet is closed.
- When irrigation is complete, measure the distance between each marker position.
- Draw a graph with distance (m) along the x-axis and time (h) along the y-axis. Plot the numbers recorded in the field to see the 'shape' of irrigation advance.

Use the advance curve to judge how appropriate inflow is for the bay length. A curve that becomes near-vertical indicates the inflow has become very slow and is inadequate for the bay length.

Recession (surface drainage)

The volume of water on the soil begins to decline when the irrigation is cut off. It either runs off the field or infiltrates into the soil so drainage is considered in both vertical and horizontal phases.

- **Depletion (vertical drainage).** The depletion phase is when depth of water at the upstream end falls to zero.
- **Recession (horizontal drainage).** The recession phase begins at the point of depletion and continues until the surface is drained.

The receding edge of the water is not always apparent due to factors such as slope and crop density. Recession is often a notional phase, but at the latest it is when the field surface has drained.

Depth applied

Average depth applied is calculated as:

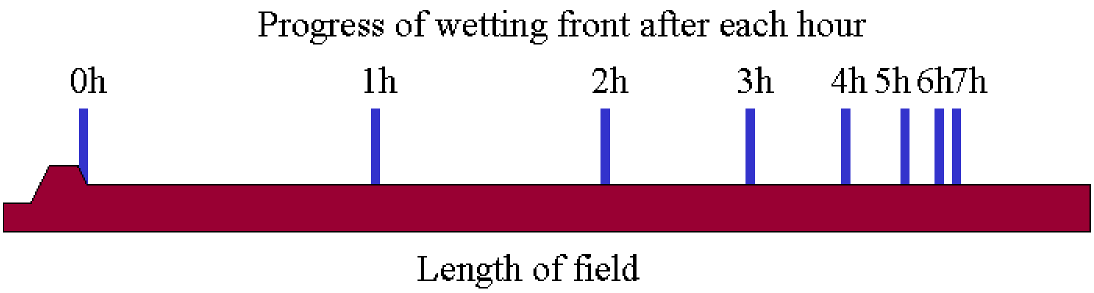
Depth applied (mm) =

$$\frac{[\text{flow rate (KL/h)} \times \text{time (h)}] - \text{run-off (KL)}}{\text{area of field (ha)} \times 10}$$

Run-off can be estimated if it cannot be measured, but all other parameters should be measured. This calculation is the average depth applied and therefore does not account for distribution uniformity.

To assess application efficiency, depth applied is compared to the estimated soil water deficit (or target application). If it is far higher than the deficit (or water holding capacity of the rootzone), soil saturation and losses to deep drainage are more likely.

Figure 40 Hourly wetting front progress



EXAMPLE 1

Irrigation is applied to a 425 x 25 m bay for 6 hours at 430 kL/hr. Run-off is estimated at 200 kL.

Bay area (ha)	= (425 x 25) ÷ 10 000
	= 1.06 ha
Depth applied	= [(430 x 6) – 200] ÷ (1.06 x 10)
	= [2,580 – 200] ÷ 10.6
	= 2,380 ÷ 10.6
	= 225 mm

If the waterholding capacity of the rootzone was 190 mm, then the field application efficiency (Ea) for this irrigation event was 190 ÷ 225 = 84% because only 190 mm was available for the plants to use and the other 35 mm was wasted.

EXAMPLE 2

Irrigation is applied to two 1.3 ha bays for 12 hours at 385 kL/h. No run-off is observed.

Depth applied	= [(385 x 12) – 0] ÷ [(2 x 1.3) x 10]
	= [4,620 – 0] ÷ [2.6 x 10]
	= 4,620 ÷ 26
	= 178 mm

If the waterholding capacity of the rootzone was 190 mm, then the field application efficiency (Ea) for this irrigation event was 178 ÷ 178 = 100% because all the 178 mm was available for the plants to use. However, if the intention was to fill the rootzone, if the time until the next irrigation is not reduced, the plants will be under-watered and suffer stress.

For more on field application efficiency, go to page 13.

Energy use and efficiency testing

Pumping water for irrigation uses a lot of energy as water is a heavy liquid. Every litre of water has a mass of one kilogram. A cubic metre (m3) or 1000 L of water has a mass of 1000 kg, or one tonne. A megalitre (ML) has a mass of 1,000,000 kg or 1,000 t.

When we pump water, we use energy to work against Earth's gravity and to apply pressure to make sprinklers work. Energy is measured in Joules (J), kiloJoules (kJ) or MegaJoules (MJ). Diesel and electrical energy are the most common energy sources used for pumping water on Australian farms

1 L of diesel contains 38.4 MJ of energy

1 kWh of electricity contains 3.6 MJ of energy

In a perfect world with no energy losses in pumps and motors and no other energy losses due to friction, pipe bends, valves and fittings, 9.81 J of energy would be required to lift 1 L of water 1 m high, or 9.81 MJ of energy to lift 1 ML of water 1 m high (or 1 m of head).

This means:

1 ML pumped against 1 m of head uses 9.81 MJ ÷ 38.4 MJ = 0.255 L of diesel

or

1 ML pumped against 1 m of head uses 9.81 MJ ÷ 3.6 MJ = 2.725 kWh of electricity.

Pumps and motors are not 100 per cent efficient, so energy consumption will be much higher than the values given above. If pump efficiency was 70 per cent or 0.70, drive train efficiency was 95 per cent or 0.95, diesel motor efficiency was 35 per cent or 0.35 and electric motor efficiency was 90 per cent or 0.90, energy consumption would be:

1 ML pumped against 1 m of head would use 0.255 ÷ 0.70 ÷ 0.95 ÷ 0.35 = 1.10 L of diesel

1 ML pumped against 1 m of head would use 2.725 ÷ 0.70 ÷ 0.95 ÷ 0.90 = 4.55 kWh of electricity

If diesel cost $1.00/L and electricity cost $0.25/kWh, the pumping costs would be:

1 ML pumped against 1 m of head using diesel would cost $1.00 x 1.10 = $1.10

1 ML pumped against 1 m of head using electricity would cost $0.25 x 4.55 = $1.14

The 'head' used in the discussion so far is properly call the total dynamic head or TDH of the pump (see Chapter 4).

This consists of three components:

- the vertical height difference between the water source and where the water is being pumped to
- losses due to pipe friction
- minor friction head losses in valves, bends and fittings in the pipes.

Equations for calculating actual energy use are:

Diesel (L) to pump 1 ML = (0.255 × TDH) ÷ (Eff.Pump × Eff.Drive × Eff.Motor)

Electricity (kWh) to pump 1 ML = (2.725 × TDH) ÷ (Eff.Pump × Eff.Drive × Eff.Motor)

'Eff' = Efficiency written using decimals

Table 16 Typical efficiencies for pumping units.

Pump efficiency (Eff.Pump)	70% or 0.7 (range 50% or 0.5 to 90% or 0.9)
Drive efficiency (Eff.Drive)	Direct coupled: 100% or 1.0 Belts: 90% or 0.9 to 97% or 0.97 Gearbox: 95% or 0.95
Motor efficiency (Eff.Motor)	Large diesels, old or worn: 25% or 0.25 Large diesels, modern: 40% or 0.4 Electric motors: 90% or 0.9

Energy use and your pump

Pumping costs vary greatly between systems, and irrigating with an inefficient or damaged pump can cost significant dollars in extra energy.

If you think that your pump is operating inefficiently and costing you money, the next step is to find out why.

High pumping costs can be caused by several things, including a worn or damaged pump or using an inappropriate pump for the task. If a pump is damaged or worn, it could, for example, add an extra $10/ML to pumping costs. This means that if a replacement pump costs around $2000, pumping 200 ML equates to the cost of a new pump (200 ML is enough to irrigate about 35 ha at 6 ML/ha for the season).

The upshot is that irrigating with an inefficient or damaged pump can cost a lot in extra energy.

To test how well your electric pump is working you can time the electricity meters and relate power consumption to water flow. Benchmarks for a good result for your pump are between 150 and 300 kWh/ML pumped, between $30 and $70/ML (costs in 2018) pumped, or 4 to 8 kWh/ML/meter head

Table 8 shows pump performance for five centre pivot irrigation sites. The first three sites fit within the benchmark ranges while the fourth site is just on the limit. The pump on the fifth site is not meeting the benchmarks and therefore needed closer scrutiny.

This pump was designed for a high pressure travelling irrigator and did not suit the lower pressure of the centre pivot system. Replacing it with a new, appropriately sized pump and motor resulted in a reduction from 787 to 206 kWh/ML and a cost savings of $25,000 over one irrigation season.

Table 17 Pump performance figures for five centre pivot sites.

Pivot site	Flow (m3/hr)	Pump size	Motor size (kW)	Energy used (kWh/ML)	Energy cost ($ per kWh)	Energy cost ($/ML)
1	232	150 x 125-315	30	113	0.23	$26.08
2	225	150 x 125-315	37	157	0.23	$36.16
3	316	150 x 125-250	75	220	0.23	$50.65
4	163	100 x 75-315	45	304	0.23	$70.00
5	92	100 x 65-315	75	787	0.23	$181.05

Comparative costs over a full irrigation season (September 2015 to March 2016) are shown in Table 9 for two centre pivot sites under dairy pasture in Tasmania.

Table 18 Pump performance figures for two centre pivot sites.

	Energy used (kWh)	Energy cost ($ per kWh)	Water pumped (ML)	Energy cost ($ perML)
Site 1 (Cressy)	167 460	0.194	723	$45.00
Site 2 (Montana)	38 985	0.194	221	$34.00

Irrigation benchmarking

Several terms are used when discussing irrigation benchmarking and measuring performance. The most common are explained below.

Water use efficiency

Water use efficiency (WUE) is a concept that causes much confusion. A reason for this is that it is not a clearly defined term, rather it covers a range of irrigation performance indicators and can be used to mean any one of them. So, if you use this term be sure you know which indicator you are referring to.

The performance indicators that WUE includes are in three main categories:

- water use index (WUI), relating production to water use e.g. bales /ML, t/ML, litres of milk/ML, $/ML)
- irrigation system efficiency, relating water inputs to water outputs at different locations in the system
- distribution uniformity (DU), a measure of how even an irrigation application is.

Each of these is explained further on.

Effective rainfall

Effective rainfall is another concept that adds to the confusion. Rainfall is considered effective if it contributes to the water requirement of the crop. It includes:

- water intercepted by vegetation
- evaporation from soil
- transpiration by plants
- extra contribution for leaching of salts ('leaching requirement').

Ineffective rainfall includes uncaptured surface run-off, deep drainage and any remaining soil moisture that is not used for subsequent crops. It is estimated from:

Effective rainfall = total rainfall – run-off – deep drainage

For simplicity, effective rainfall is often assumed to be 75 per cent of the seasonal rainfall, although some prefer 50 per cent if the rain comes as frequent storms and little soaking rain.

All the indicators are only as accurate as the information that is used to calculate them, so it is important to install and maintain accurate meters and rain gauges and to measure yields as accurately as possible.

Irrigation water use index

Irrigation water use index (IWUI) relates the total amount of production to the amount of irrigation water applied. It is useful for on-farm analysis as it only accounts for irrigation water and helps identify differences in on-farm irrigation management. It is less useful as a comparison between different farms or regions as it takes no account of differences in rainfall.

IWUI can be applied to either an individual field or to the whole farm.

Field scale:
IWUI (applied) = total yield (tonnes, bales, L milk, etc.) ÷ irrigation water applied to field (ML)

Farm scale:
IWUI (farm) = total yield (tonnes, bales, L milk, etc.) ÷ irrigation water supplied to farm (ML)

EXAMPLE

A pasture field has a yield of 1088 t of baled hay and 422 ML of irrigation water was applied during a season.

IWUI (applied) = (1088 ÷ 422) = 2.58 t/ML

Across the whole farm, 3222 t of baled hay were produced using 1520 ML of irrigation water.

IWUI (farm) = 3222 ÷ 1520 = 2.1 t/ML

Gross production water use index

Gross production water use index (GPWUI) is the amount of yield produced compared to the total water input. The total water input includes irrigation and rainfall and can include moisture used from the soil or from a storage.

GPWUI is helpful for comparing irrigation performance across different regions and seasons because it allows for rainfall differences that result in different irrigation requirements.

Calculating GPWUI is simpler if total rainfall is used, but a better result is obtained by using effective rainfall. For example, you might want to compare two fields that both received 350 mm of rain throughout the season. If one field received all that rain in one event, much more irrigation water would be required for the rest of the season than on another field that may have received the rain in regular, smaller events.

Field scale:
GPWUI (applied) = total yield (tonnes, bales, L milk, etc.) ÷ total water applied to field (ML)

Farm scale:
GPWUI (farm) = total yield (tonnes, bales, L milk, etc.) ÷ total water used on farm (ML)

Figure 41 Harvesting maize.

Source: Western Dairy

EXAMPLE

From the previous example, a pasture field has a yield of 1088 t of baled hay which used 422 ML of irrigation water. If 373 ML was contributed from effective rainfall and used soil moisture, the total water use is 795 ML.

GPWUI (effective) (applied) = (1088 ÷ 795) = 1.37 t/ML

Across the whole farm, if 3222 t were produced using 2500 ML of total water (irrigation, effective rainfall and used soil moisture):

GPWUI (effective) (farm) = (3222 ÷ 2500) = 1.29 t/ML

Crop water use index

Crop water use index (CWUI) is an indicator that describes plant-water interactions at the pasture or crop scale and is represented as the yield produced per millimetre of water used by plants (evapotranspiration or ET) during the growing season.

Daily evapotranspiration data is available from the Bureau of Meteorology. This data can be converted into daily crop water use using a crop coefficient (Kc). For most grass pastures, the Kc is 1.0 so no conversion is needed.

CWUI represents the ability of the plant to produce yield for the water used. It is influenced by many factors such as variety, nutrition, pests, disease and climate as well as by irrigation management. Because of the wide range of factors that influence this index, it provides a broad measure of pasture or crop performance rather than a specific measure of irrigation performance.

CWUI = yield (tonnes or bales/ha) ÷ seasonal evapotranspiration (mm)

EXAMPLE

A pasture field producing 16 t/ha or 16,000 kg/ha of hay and 1050 mm of seasonal evapotranspiration:

CWUI = 16 000 ÷ 1050 = 15.2 kg/ha/mm = 1.52 t/ML

Irrigation system efficiency

Irrigation system efficiency is different to water use indices. This is because it compares the water output to the water input at certain points of the farm or irrigation system. Efficiencies do not have units, they are expressed as a percentage.

Although it is possible to determine the efficiency of any component of the irrigation system, two main efficiency terms are applicable to dairy farming systems:

- Application efficiency (Ea)
- Field canal/conduit efficiency (Eb) (using the terms 'canal' and 'conduit' indicates that this efficiency term is applicable to both channels and pipes).

Application efficiency

Application efficiency relates the amount of water supplied to the field to the amount of water available to the pasture or crop. Calculating application efficiency is useful as it indicates the potential for water savings within the field. It may be hard, however, to determine the amount of water available to the crop, as run-off and deep drainage losses need to be considered.

Ea = irrigation water directly available to the crop for use ÷ water received at field inlet

For surface irrigation systems, the amount of water received at the field can be measured with flow meters at the field inlet or water source, e.g. the pump. For drip and overhead irrigation systems, water applied to the field can be measured with flow meters attached to the system or obtained from a calibrated control panel.

This calculation does not account for losses due to wind or evaporation. For centre pivot or lateral move systems, these losses are usually less than 5 per cent and are very hard to measure. For surface irrigation systems, evaporation from bays can be significant if there is an open, ponded surface for a long period, and this can also be hard to measure.

EXAMPLE

Border check irrigation

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 0 mm

Water delivered to rootzone = 70 – 0 = 70 mm

Total water applied = 1.2 ML/ha = 120 mm

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

Centre pivot irrigation

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 30 mm

Water delivered to rootzone = 70 – 30 = 40 mm

Total water applied = 40 mm

Application efficiency = 40 ÷ 40 = 100%

Figure 42 Tail water return.

Source: C.Phelps

Where tailwater is recycled, field application efficiency is increased by reusing this irrigation water. However, not all tailwater is available for reuse as there are losses in the tailwater return system, so this must be allowed for.

Note that the amount of tailwater available for reuse is not equal to the amount of tailwater leaving the field. In this case, 0.3 ML/ha of water left the field as tailwater, but due to losses in the tailwater and reuse channel system, only 0.25 ML/ha (83%) was available.

EXAMPLE

Border check irrigation with tailwater recycling

Soil moisture deficit before irrigation = 70 mm

Soil moisture deficit after irrigation = 0 mm

Total water applied = 1.2 ML/ha = 120 mm

Tailwater available for reuse = 25 mm

Net water applied = 120 – 25 = 95 mm

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

Field canal/conduit efficiency

Field canal/conduit efficiency covers the on-farm distribution system. On-farm distribution systems may be channels or enclosed pipes and includes storages. Field canal/conduit efficiency relates the water received at the field inlet to the water received at the farm gate.

Eb = water received at field inlet ÷ water received at the inlet to a farm.

Smaller dairy farms often have only piped water or only a few earthen channels. If the pipes do not leak and the channels are properly constructed from appropriate clay material, losses in the distribution system are usually low and can be ignored. However, if there is an extensive system of channels on larger farms, particularly with lighter soil types, measuring the Eb may be worthwhile.

Water use efficiency benchmarks for dairy

The main determinant of WUE is the yield of different pasture species, rather than their water use. Species with the highest annual yield have the highest WUE and those that are lower yielding have lower WUE.

WUE has two components: the supply and use of the water to grow the feed, and the management and use of the feed grown.

Significant irrigation responses of up to 2.71 t DM/ML irrigation water applied have been shown by not over-irrigating, improved scheduling and using appropriate start-up times, while maintaining adequate available soil moisture.

The dairy industry is the second highest user of irrigation water in Australia, (ABARES 2015-16). Almost 60 per cent of Australian dairy farms have irrigated pastures or fodder crops. This ranges from fully irrigated dairy farms mainly in the Murray dairy region in Victoria, NSW and South Australia and the Macalister and Harvey districts, to all other dairy districts where irrigation is mainly used to supplement seasonal rainfall.

Top operators in the dairy industry achieve IWUI of 2000 L/ML of milk compared to the industry average of 1200L/ML. Analysis of reported benefits and costs of irrigation by MDBC (2006) show that IWUI for irrigated dairy farms ranges from 600 to 2000 L/ML milk.

Australian studies show that GPWUI, when measured as milk solids per ML of water (MS/ML), has two components:

- the supply and use of the water to grow the feed
- the management and use of the feed grown.

Both components can vary considerably (see Table 10), and suboptimal grazing management can nullify any improvement in GPWUI. A 2004 case study indicated that there was no simple, direct association between WUE and profitability.

Investing in improving WUE is often complex and is likely to impact on a number of areas of the farm business. For example, increasing WUE by increasing pasture utilisation may require an increase in stocking rate and herd size.

An increase in herd size may make it necessary to replace some of the existing infrastructure, such as the dairy or employ more labour. Options that result in simultaneous increases in WUE, profitability and labour efficiency appear more likely to be adopted than options that focus solely on increasing water use efficiency.

Table 19 Water use efficiency from published Australian data (Armstrong 2001; Linehan et al. 2004).

Region	Irrigation system	GPWUI* (kg milk solids/ML)	Pasture consumption (t DM/ha)
Victoria: Goulburn Irrigation System	Border check	62 – 68 (average) 30 – 124 (range)	8.9 – 9.5 (average) 2.4 – 17.7 (range)
NSW: Murray Irrigation System	Border check	57 – 64 (average) 22 – 112 (range)	9.1 – 9.9 (average) 1.6 – 19.4 (range)
Northern Victoria and New South Wales	Sprinkler or flood irrigation	25-115	

** kg milk fat plus protein produced from pasture per ML of water (irrigation plus effective rainfall)*

The main determinant of WUE is the yield of different species, rather than water use. Species with the highest annual yields (perennial ryegrass, tall fescue, kikuyu and prairie grass), apart from paspalum (a C4 grass), have the highest WUE (CWUI – total yield ÷ evapotranspiration) and those that are lower yielding, e.g. white clover, have lower WUE.

The C4 species such as kikuyu and paspalum gain a productivity advantage over C3 species once the temperature rises above 25oC. Under optimal irrigation, kikuyu has the highest (27.3 kg/ha/mm) WUE and birdsfoot trefoil the lowest (14.8 kg/ha/mm).

To maximise WUE for any forage, it is necessary to maximise yield by removing the other limitations to yield such as low fertility and poor management. Improved irrigation management can grow more grass, but the extra grass requires management to use it to its optimum for increased milk production.

Extra growth that is not managed can lead to lodging, dead grass in the base of a pasture and stalky growth with seed heads that have low energy content. A farmer may need to speed up the rotation, close more paddocks for silage, do some pasture topping or milk more cows.

Reseach by Armstrong in 2000 found that, compared with low WUE farms, high WUE farms had the same milk production and had a similar number of cows but used less water (387 ML compared to 572 ML) and less land (42 ha compared to 83 ha). High WUE farms also had higher estimated pasture consumption per ha (11.5 t DM/ha compard 5.5 t DM/ha), higher milk production per cow (396 kg MS compared to 277 kg MS), higher stocking rates (3.2 cows/ha compared to 1.8 cows/ha), higher N fertiliser use (59 kg/ha compared to 18 kg/ha) and directed a higher proportion of the estimated energy consumed by cows into milk production (53% compared to 46%).

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Table 20 Irrigation systems, average pasture utilisation, water application amounts and IWUI on six Tasmanian dairy farms (Rawnsley et al. 2007).

Location	Mersey Lea	East Ridgley	Elliott	Riana	Ringarooma	Mella
Irrigation system	Centre pivot	K-Line	Fixed	Travelling gun	Centre pivot	K-Line
Irrigated pasture utilisation	7.23	6.90	5.29	4.50	7.52	6.20
Dryland pasture utilisation	2.48	1.30*	1.29	1.30*	3.02	2.63
Amount of water applied	1.75	2.63	2.70	2.31	3.29	2.65
IWUI (t DM/ML)	2.71	2.13	1.48	1.39	1.37	1.35

SUMMARY

There are two key reasons for knowing the performance of your irrigation system:

- **Profitability.** Effective irrigation maximises production. A well set up system makes money.
- **Sustainability.** Efficient irrigation minimises water use and leaching. A well set up system saves money.

Irrigation evaluations focus on a set of key checks:

- Is the system applying the expected depth of water?
- Is it applying the water at a rate that the soil can accept?
- Is it applying the water uniformly?
- Is energy use reasonable?
- What is causing it not to perform?

All these checks can be carried out on all types of irrigation system, although the way the checks are done varies according to the system type.

While there are resources to help farmers do their own checks, if the system is large it may be more cost effective to use a professional, especially if the system has not been checked for some years.

Indexes of performance

Measures or indexes of irrigation performance enable comparisons between seasons and with industry benchmarks. The most used indexes are:

- Irrigation water use index (IWUI), which relates the total amount of production to the amount of irrigation water applied.
- Gross production water use index (GPWUI), the amount of yield produced compared to the total water input, which includes irrigation and rainfall and can include moisture used from the soil or from a storage.
- Crop water use index (CWUI), an indicator of plant water use and is represented as the yield produced per millimetre of water used by plants (evapotranspiration or ET).

The efficiency of the system can be measured by comparing water output to water input at certain points of the system. Efficiencies do not have units, they are expressed as a percentage. Two main efficiency terms are applicable to dairy farming systems:

- Application efficiency (Ea), which measures irrigation water directly available to the crop for use ÷ water received at field inlet.
- Field canal/conduit efficiency (Eb), which measures water received at field inlet ÷ water received at the inlet to a farm.

Top operators in the dairy industry achieve IWUI of 2000 L/ML of milk compared to the industry average of 1200L/ML.

Australian studies show that GPWUI, when measured as milk solids per ML of water (MS/ML), has two components:

- The supply and use of the water to grow the feed
- The management and use of the feed grown.

Both components can vary considerably and suboptimal grazing management can nullify any improvement in GPWUI. There is no simple, direct association between WUE and profitability. Investing in improving WUE is often complex and is likely to affect the farm business in several ways.

07

Irrigation scheduling

Irrigation scheduling is deciding when and how much water to apply to an irrigated pasture or crop to maximise production. While it is the basis of irrigation management, our variable and unpredictable climate, summer storms and changes to prevailing air temperatures can make scheduling a challenge.

It is worth the effort, however, as correct irrigation scheduling improves water use efficiency, reduces waterlogging, maximises pasture development, quantifies the effectiveness of rain and allows better management of soil structure issues.

Developing an irrigation schedule

Developing an irrigation schedule requires an understanding of the rate that the pasture or crop uses water and an estimate of how much water in the soil is readily available to the plants.

There are two main ways to schedule irrigation events:

- weather-based scheduling
- soil-based scheduling.

Weather-based scheduling

Weather-based scheduling uses weather data to work out the water demand of the pasture or crop and then calculates the pasture or crop water use by using a crop coefficient.

The weather data used is solar radiation, temperature, humidity and wind speed. This data is used to calculate the evapotranspiration (ET) of a reference crop, which is a well-watered, healthy grass. This is known as 'reference crop evapotranspiration' and is denoted as ETo. Daily ETo can be obtained from most BoM weather stations. A prediction of ETo for the next seven days can be found from other sources mentioned later in this chapter.

Different pastures and crops have different crop coefficients, or Kc values, which also change over the growing season as plants develop. Estimates of Kc for some irrigated pastures and crops are shown in Table 21.

Soil-based scheduling

With soil-based scheduling, soil moisture sensors are monitored to observe when the soil water is getting low and should be refilled and when to stop irrigating to avoid waterlogging.

Measuring soil moisture allows us to infer the likely stress that a plant may be undergoing.

Irrigators have a range of choices about the type of moisture sensor they use, how data is transmitted and displayed and the overall cost.

Figure 43 Process for calculating pasture or crop water use based on weather.

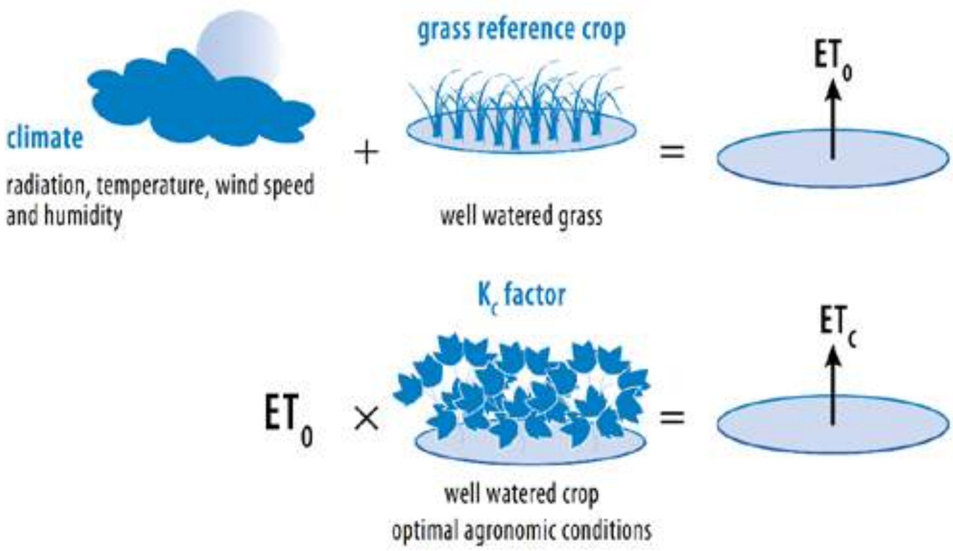


Table 21 Crop coefficients (Kc) for a range of crops and pastures.

Crop	Kc initial	Kc midseason	Kc end of season
Barley	0.30	1.15	0.25
Chickpea	0.40	1.00	0.35
Maize	0.30	1.20	0.35
Sorghum	0.30	1.00-1.10	0.55
Wheat	0.30	1.15	0.25
Lucerne hay – averaged cutting effects	0.40	0.95	0.90
Lucerne – single growth cycle	1.20	1.20	1.15
Clover hay – averaged cutting effects	0.40	0.90	0.90
Clover hay – single growth cycle	0.40	1.15	1.10
Grazing pasture – rotated grazing	0.40	0.85-1.05	0.85
Grazing pasture – extensive grazing	0.40	0.75	0.75
Rye grass hay – averaged cutting effects	0.95	1.05	1.00

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

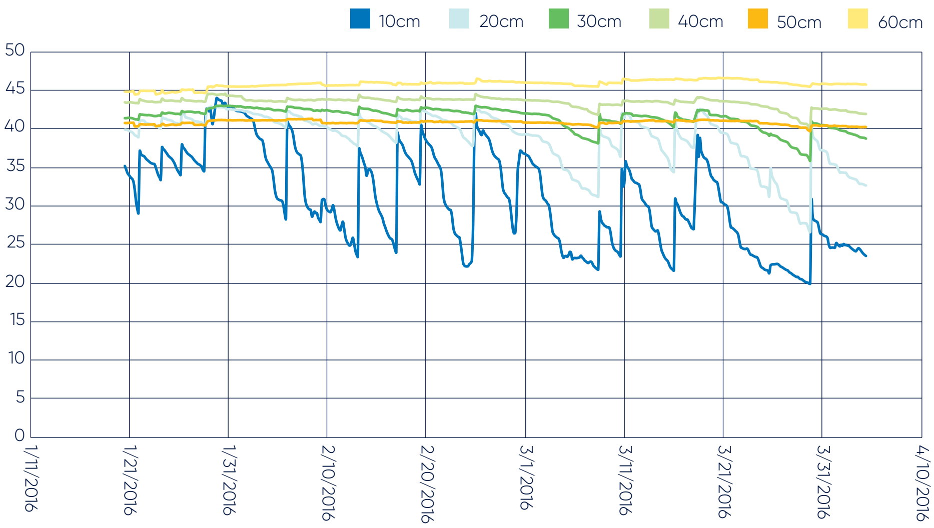
There are two main types of commercially available soil moisture sensors:

- Suction based sensors, which measure how tightly water is held in the soil, or the soil water 'tension.' This measurement is usually shown in kilopascals (kPa) as a negative figure because it measures suction and relates directly to how hard the plant has to work to extract water from the soil. It is directly comparable across different soil types. Gypsum blocks and tensiometers are two commonly used suction based tools.
- Volumetric based sensors, which use a measurement of the soil 'dielectric' which reflects the capacity of a material to transmit electromagnetic waves or pulses. The dielectric of dry soil is much lower than that of water, so small changes in free soil moisture will have a large effect on the dielectric properties of the soil. Capacitance probes and total domain reflectometry (TDR) capacitance spikes are examples of commonly used volumetric monitoring tools.

Figure 44 Installing a soil moisture probe.

Source: Western Dairy

Figure 45 A stacked soil moisture probe graph from a dairy at Cressy, Tasmania.



Source: Dr James Hills, University of Tasmania, Tasmanian Institute of Agriculture

Soil moisture monitors

Soil moisture probes usually have sensors placed at different depths in the soil profile, and the data is presented as a graph of moisture content over time (see Figure 45). The graph can either represent a sum of all soil moisture readings in the profile (called a 'summed' graph) or show the lines for each sensor at different depths (called a 'stacked' graph).

The stacked graph is useful for determining refill points and examining extraction patterns. Figure 45 is from a lucerne and mixed pasture field. It shows a stacked soil moisture graph in the top part and a summed graph at the bottom. (In this case, the scale for the summed graph is upside down so the line moves in the inverse direction to the stacked graph traces.)

For irrigation scheduling, soil moisture data is used as a proxy for plant stress. As plants usually extract water from closer to the surface first, the sensors closer to the surface will show more response to plant daily water use and applied irrigation or rain. The varying extraction rates from different depths can be seen in Figure 46 where the coloured lines represent different depths below the surface. A decline at the shallow depth does not mean the pasture is under stress if the plants are still accessing enough water from deeper in the profile. If the extraction rate has slowed at all depths, the plant is suffering stress.

Pastures and crops start to stress when they reach the 'refill point' and will die when they reach 'permanent wilting point'.

The full point of a soil, termed 'field capacity', occurs when the profile has drained fully. This point usually can be easily identified from continuous soil moisture data.

The refill point is where yield is reduced if the soil moisture is depleted any further. It can be hard to determine the refill point because it changes during the season, different plants suffer stress at different soil moisture levels, and the change is often not easy to observe from the soil moisture trace. The main indicator is the slope of the soil moisture trace – a steep slope indicates rapid water use, which means the plant is growing strongly, while a flatter slope indicates slower water use, which indicates waterlogging or stress.

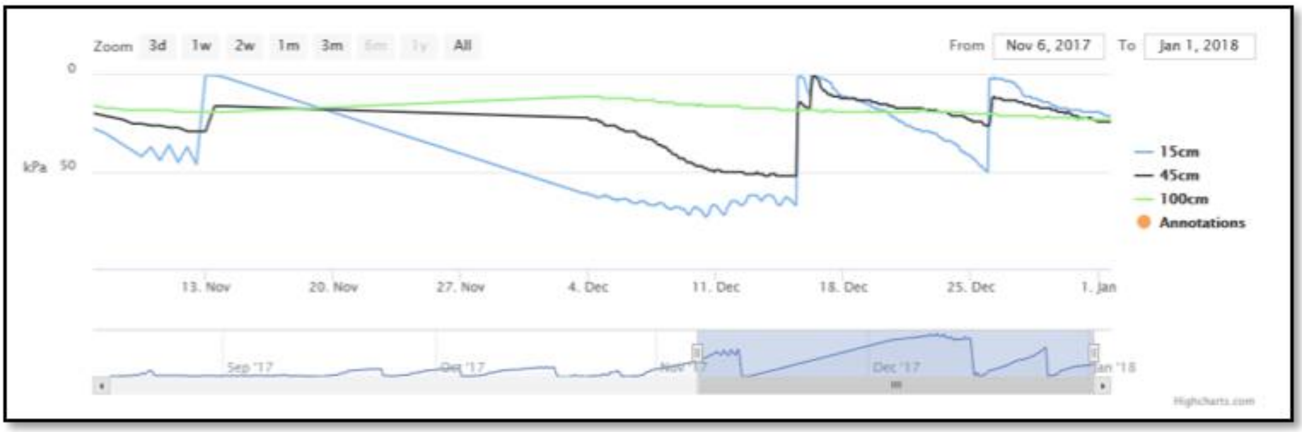
Young plants have small roots that only access a limited part of the soil profile. As the plants grow, the roots can access more of the profile and therefore tolerate a larger soil moisture deficit before reaching refill point. Most pastures and fodder crops grown on dairy farms are hardy.

Determining the refill point involves examining the daily water use figures of the pasture. When the daily water use starts dropping, indicating the plants are suffering stress, refill point has been reached or passed.

For example, in Figure 46, the flat pattern of two of the traces in the centre of the graph indicates that the refill point was reached and maintained at these soil depths. The shallow 15 cm sensor (blue line) indicates that it reached about –70 kPa around 8 December and maintained this until irrigation was applied on the 14 and 16 December.

The 45 cm sensor (black line) shows a similar pattern to the 15 cm trace with the slope becoming flat at –50 kPa from 10 December, a couple of days later than the 15 cm trace. For irrigation events after this one, the producer knows that when the 15 cm trace is getting near to –70 kPa or the 45 cm trace is getting near to –50 kPa, they should be preparing to irrigate and refill the soil profile.

Figure 46 Soil moisture probe traces on a dairy farm at Aberdeen, NSW (image from Smarter Irrigation for Profit Project – Hunter Optimised Dairy Irrigation Farm NSW).



Water budget

A water budget should be prepared at the beginning of each season to determine what area of pasture or crop should be sown.

Some things to take into account are:

- the seasonal water requirements for your crop (ML/ha)
- available water supply (e.g. flow rate, on-farm capture, total storage capacity, trading)
- median rainfall
- probability of above or below median rainfall for the coming season
- economics (is it better economically to fully irrigate a smaller area, or partially irrigate a larger area?).

INFORMATION

Dairy NZ has similar information available at **dairynz.co.nz/environment/water-use/irrigation/irrigation-scheduling/**

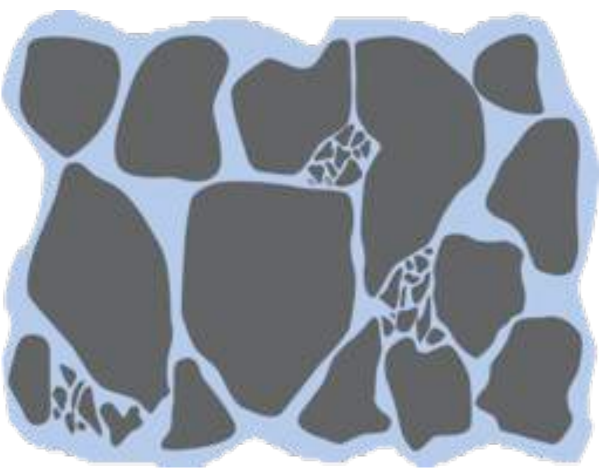
Soils and water

An understanding of how soil holds water is important for managing irrigation. The terms below describe the soil water status of a soil.

Saturation

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

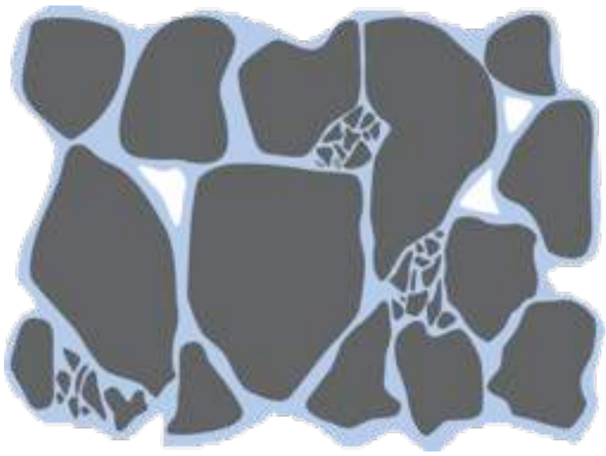
water | soil particles



Field capacity or full point

Field capacity occurs after the large soil pores have drained due to gravity. Depending on the type of soil, it may take from a few hours to several days for the pores to drain. When the large pores have drained, the soil is still wet but not saturated. Field capacity in most soils is at a soil water tension of about −8 kPa.

capillary water | soil particles | air space



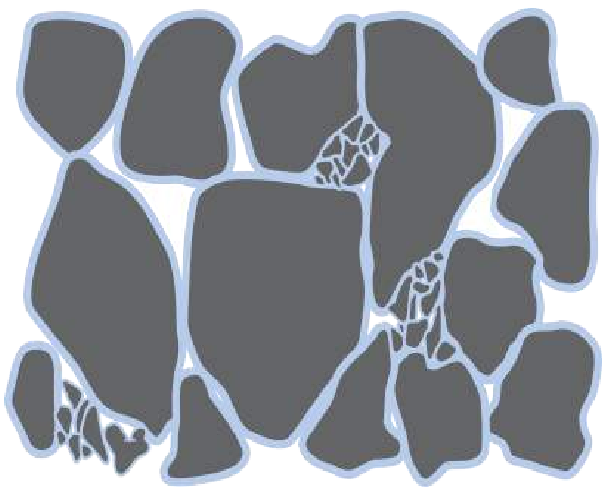
Refill point

This is where a pasture or crop finds it hard to extract water from the soil. Plants begin to stress, slowing crop growth. For most pastures and grain crops, this usually occurs when the soil water potential is between −60 and−100 kPa.

Permanent wilting point

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

absorbed water | soil particles | air space



Most soils have a similar total water holding capacity, generally between 400 and 500 mm per metre depth of soil, as illustrated in Figure 47. How much of this water is available for use by the plant varies greatly for different soil textures.

The dark 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.

Readily available water

The amount of water held in the soil between field capacity and the permanent wilting point is the plant available water capacity (PAWC) or total available water (TAW). Irrigation scheduling should aim to maintain the soil moisture between field capacity and the refill point, which is known as the readily available water (RAW). This can be visualised as a fuel gauge (see Figure 48).

Figure 47 Water holding capacities of soil texture classes.

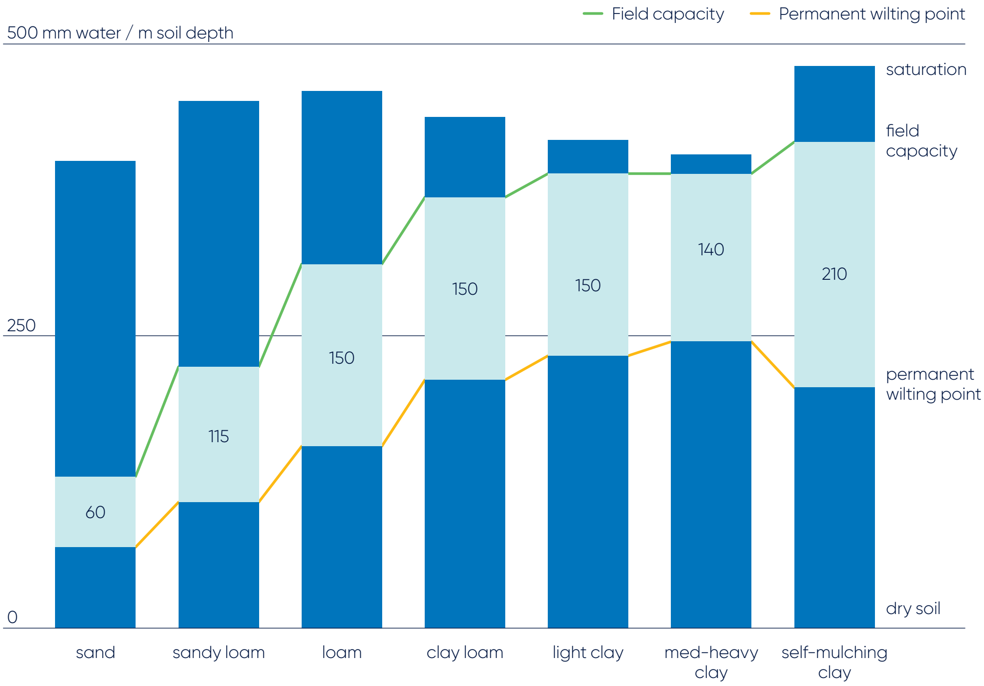
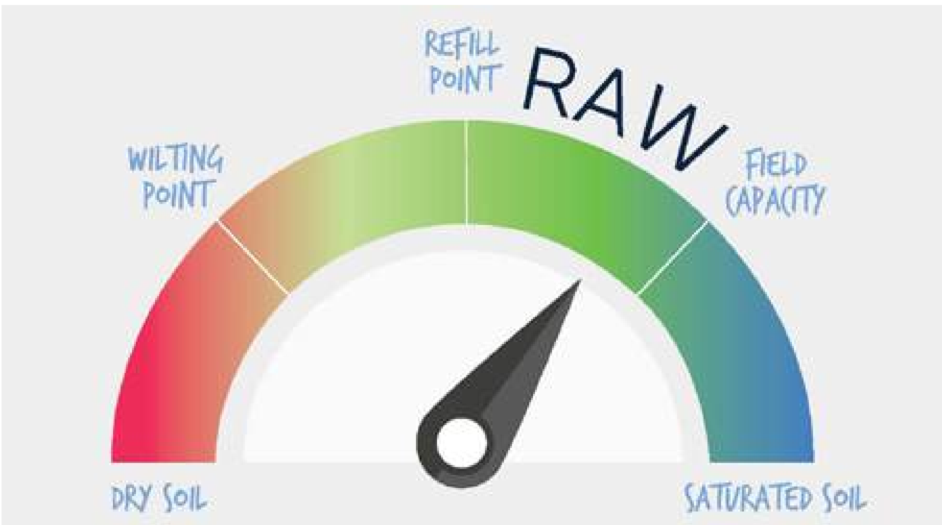


Figure 48 Soil moisture 'fuel guage'.



RAW is determined from the water holding capacity of the soil, how much suction a plant can apply to extract water and the depth of the plant roots. Tables 22 and 23 show the RAW of groups of plants with varying abilities to extract water in different types of soil.

'Water suction' is the vacuum that a plant can apply to the soil to extract water. The figures in the first row of each of the tables below are negative kPa and indicate the threshold suction level where the particular plants begin to suffer water stress. Different plant types have widely different extraction abilities.

Table 22 shows the RAW in mm if the roots were 1 m deep (mm/m) and Table 23 shows RAW if the roots were 300 mm deep (which is the usual depth of ryegrass roots). Where the roots reach other depths, or the soil type changes below the surface, the figures need to be altered to suit, as shown in the example in Figure 49.

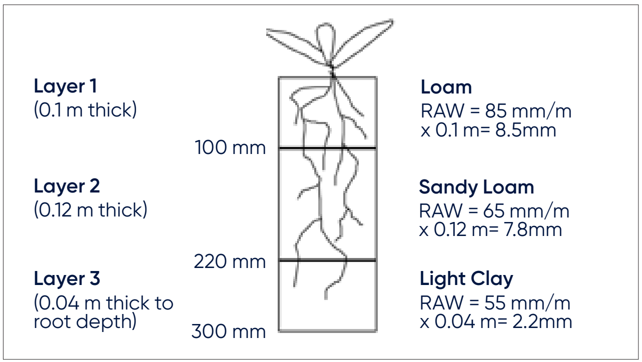
Table 22 RAW (mm) if roots are at 1 m depth.

Water suction:	**To –20 kPa**	**To –40 kPa**	**To –60 kPa**	**To –100 kPa**	**To –1500 kPa**
	Water-sensitive crops (e.g. vegetables)	Most fruit crops, table grapes	Lucerne, most pasture, maize, soybeans, grapes	Annual pastures, cotton, sorghum, winter crops	Total available water (TAW)
Soil texture	**Readily available water (RAW) (mm/m)**				**TAW(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

Table 23 RAW (mm) if roots are at 300 mm depth.

Water suction:	**To –20 kPa**	**To –40 kPa**	**To –60 kPa**	**To –100 kPa**	**To –1500 kPa**
	Water-sensitive crops (e.g. vegetables)	Most fruit crops, table grapes	Lucerne, most pasture, maize, soybeans, grapes	Annual pastures, cotton, sorghum, winter crops	Total available water (TAW)
Soil texture	**Readily available water (RAW) (mm/m)**				**TAW (mm to 300 mm depth)**
Sand	10.5	10.5	10.5	12	18
Sandy loam	13.5	18	19.5	21	34.5
Loam	15	21	25.5	27	45
Clay loam	9	16.5	19.5	24	45
Light Clay	7.5	13.5	16.5	21	45
Medium to heavy clay	7.5	13.5	16.5	19.5	42
Self-mulching clay	11.4	20.4	24.9	29.4	63

Figure 49 A pasture is growing in 100 mm of loam over 120 mm of sandy loam over 80 mm of light clay. The pasture root depth is 260 mm. Scheduling VRI irrigation systems



Scheduling VRI irrigation systems

If you are using variable rate irrigation (VRI), scheduling is basically the same but with a few extra complications.

Preparing the variable speed setting or the variable zone prescription map requires information from an EM soil map, which provides a key input for scheduling. Soil moisture sensors are often installed into each major zone to monitor real-time soil moisture status. This information is then used to optimise variable rate irrigation scheduling.

For pivots, it is best to concentrate on the outer 30 to 50 per cent of the pivot circle, as this accounts for 50 to 75 per cent of the total area. The base application depth can be adjusted higher or lower without changing the variable rate settings or the prescription map.

During the growing season, as crop water demands change, irrigation scheduling may call for different zone control maps. For best results, these should be prepared and uploaded in consultation with your agronomist.

Scheduling tools

IrriPasture – simple water budgeting tool for farmers

One water budget tool that can be used by farmers is the newly updated IrriPasture. IrriPasture is a simple, user friendly water budgeting tool developed to minimise the farmer inputs required, but with meaningful irrigation scheduling outputs via a dashboard. IrriPasture can be used on phone, computer or tablet and is freely available via the IrriPasture.com **link**.

The broad aim of this tool is to create improved irrigation scheduling decisions leading to improved production and water use efficiency of irrigated pastures and other crops grown by dairy farmers.

IrriPasture has a simple interface with minimal farmer inputs required after the farm account and paddocks have been set up. Automatic ingestion of the nearest Bureau of Meteorology (BOM) weather data includes the rainfall and reference crop evapotranspiration. Soil moisture inputs can be ingested (if available). Irrigation events need to be entered by the farmer. There is also the ability to overwrite the automatically ingested BOM rainfall data if needed.

IrriPasture will work for numerous crops grown on dairy farms. These include ryegrass, kikuyu and annual ryegrass systems, millet, lucerne, maize, fescue and mixed pastures.

A dashboard provides recommended irrigation scheduling using the information that has been ingested and entered into IrriPasture. The recommendation will suggest how much irrigation water (based on the readily available water) is required and when.

Find the web based IrriPasture tool at **Irripasture.com**.

Figure 50 An example of the IrriPasture dashboard providing an irrigation recommendation.

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3 WaterPak, Section 2.1, **cottoninfo.com.au/publications/waterpak**

SUMMARY

Scheduling irrigation can make a big difference to pasture and crop production and thus to the profitability of the farm. Scheduling is making the decision on when to apply water by irrigation and for how long. There are two methods for making these decisions, weather-based scheduling and soil-based scheduling.

Weather-based scheduling uses the fact that prevailing weather conditions determine how much water plants will use or transpire. The Bureau of Meteorology (BoM) publishes daily evapotranspiration data for hundreds of sites across Australia. This information on reference evapotranspiration (ETo) can be used to estimate plant water use on the farm. Different plants transpire different amounts of water throughout the growing season and throughout their growing cycle. Water use by plants on a farm can be estimated by multiplying ETo by a crop factor, Kc. The crop factor depends on the plant being grown and its stage of growth. For example, if the BoM ETo figure was 5 mm per day and the farm was growing rye grass pastures with a Kc of .95 then estimated crop water use would be 5 x .95 = 4.75 mm for that day.

Soil-based scheduling relies on taking measurements of soil moisture and timing irrigation to refill the soil profile and to ensure healthy plant growth at all times. Soil moisture status can be estimated by manual methods and a wide range of sensors is available. Sensors either measure suction, a measure of how tightly water is held to soil particles, or estimate the volume of water in the soil profile. Many sensors can be installed which send or transmit the data to a central point, either an irrigation controller or a computer which displays the information. The scheduling decision can then either be made automatically by the controller or by the manager.

The aim of scheduling is to keep the soil water status between field capacity, when the soil is full of water, and the refill point. If water use continues past the refill point it may reach the permanent wilting point, when the plant is no longer able to extract water from the soil. The amount of water held in the soil between field capacity and the permanent wilting point is known as the total available water (TAW).

The amount of water held in the soil between field capacity and the refill point is known as the readily available water (RAW). Both TAW and RAW depend on the texture of the soil. The plants being watered will also help to determine RAW as plants differ in their ability to extract water from the soil. A deep-rooted perennial crop like lucerne can extract more water from the soil profile than a shallow rooted annual crop like vegetables.

A water budget should be prepared at the beginning of each season to determine what area of pasture or crop should be sown. Some things to take into account are:

- the seasonal water requirements for your crop (ML/ha)
- available water supply
- median rainfall
- probability of above or below median rainfall for the coming season
- economics.

Successful irrigation scheduling requires the manager to understand their soil, so they know the water that can be held in the soil profile. They must understand and watch the weather to know how fast water is being used by the plant and they must know the water use of the plants being grown. With this information the manager can time irrigation to refill the soil before it dries out completely and knows how long to run the irrigation system to refill the soil profile of the root zone.

08

Managing pasture irrigation

Along with a properly designed and performing irrigation system, irrigation scheduling (see Chapter 7) is the basis of irrigation management. Where there is ample water, no soil problems and no plant issues such as disease or lack of nutrients, scheduling is straightforward. Where there are issues, however, scheduling needs to be varied to suit growing conditions. This chapter covers some of the issues encountered and how to manage for them.

Growth responses to water stress

Avoiding the green drought

A delay in irrigating at any time during the season can also result in pasture growth at below maximum potential rates. This phenomenon has become known as 'the green drought'. Pastures look green and are growing, but at reduced rates. Once this period of deficit starts, applying irrigation at rates to satisfy evapotranspiration demand does not result in maximum potential growth rates. There is an accumulating soil water deficit (see Figure 52) so that irrigation does not refill the soil enough to replenish the readily available water zone (RAW; the green zone on Figure 52).

Irrigation should commence at a time that allows the irrigation rotation to be completed before soil moisture status falls below the refill point (i.e. before RAW is completely used). The optimum scheduling interval will vary with both soil type and seasonal rainfall and evapotranspiration.

Managing irrigated pasture agronomy

Managing irrigated pastures for optimal yields, especially fertiliser application, requires expert agronomic knowledge.

For perennial ryegrass and two forage brassicas (Hunter and PG545), a study in south-western Victoria showed they all responded to irrigation, with the degree of response depending on volume of water applied. The DM yield of fully irrigated ryegrass was double that of dryland ryegrass, while DM yield increases for both brassica species were between 40 and 80 per cent higher than for dryland. DM yields for the same pastures irrigated to 50 per cent of requirements on a weekly basis were higher than for dryland. Applying nitrogen (N) at a high rate also gave higher DM yields. While these results are positive, more work is needed to define the optimal irrigation strategies to maximise DM yield and WUE (water use efficiency).

In the southern Murray-Darling Basin, white clover and perennial ryegrass pastures generally have a competitive advantage in irrigated areas compared to annual pastures because of their potential for year-round feed production. To illustrate this, perennial pastures produce between 14 and 20 t DM/ha/year under full irrigation, pure swards of white clover may produce up to 14 t DM/ha/year under frequent irrigation and lucerne swards can produce up to 23 t DM/ha/year. Pure swards of red clover may produce a similar amount as white clover but it usually lasts for less than two years.

Starting smarter

When to start irrigating pastures is a key decision for dairy farmers to make, and it is one that is often made too late. Not getting this timing right for ryegrass/white clover based pastures is a major reason for poor subsequent pasture yields.

As an example, a seven-day delay in starting up irrigation can result in a 50 per cent reduction in pasture growth for a period of 30 or more days.

TOP TIP:

The optimum irrigation start-up time can be easily determined with soil moisture monitoring or by calculating a water budget (evapotranspiration and rainfall).

At the end of winter, soils begin to dry out as evapotranspiration exceeds rainfall. Plants will suffer moisture stress once the readily available water (RAW) has been used. This means that at the start of the irrigation season the first paddock to be irrigated must be irrigated at a moisture content that will allow the last paddock to be irrigated before the RAW has been used, i.e. the first paddock might still have a lot of moisture in it when irrigation starts. This means that less than the full amount the irrigation system can supply will be applied to the first paddocks to be irrigated.

Farmers often use visual changes in pasture, such as reduced growth rates or seed head production, to determine when to start irrigating. In perennial plants such as perennial ryegrass and white clover the processes of dormancy will have started before any visual effect is noted. This means that, even once water is applied, a period of recovery is needed before maximum potential growth rates are re-established.

Once ryegrass and clover pasture growth slows due to moisture stress it can take some time to recover even if the soil is irrigated to field capacity. It can take 30 or more days for the pasture to recover, to the yield levels of continuously watered pasture, and production during the 30 days after full watering may be only 50 to 60 per cent of continually watered pasture. (See Figure 31, where the period of low yield is circled in red.)

In Tasmania, for every one day delay in irrigation start-up there is a potential reduction in pasture production of about 105 kg DM/ha. A five-day delay over an irrigated area of 50 ha can result in a reduction of about 26 t DM utilisation across the irrigated area.

Figure 51 Average ryegrass/clover pasture growth rates under a 117 ha centre pivot irrigator in northern Tasmania for 2016–17 irrigation season.

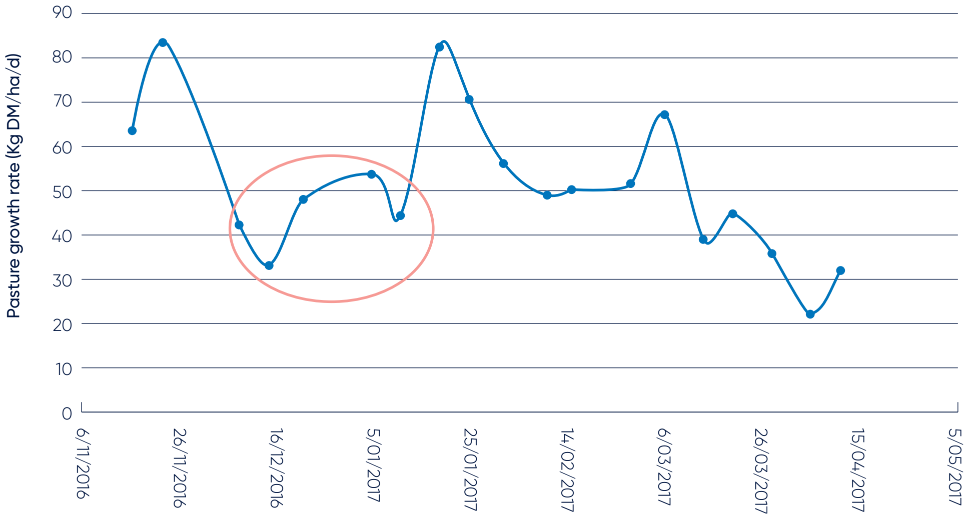
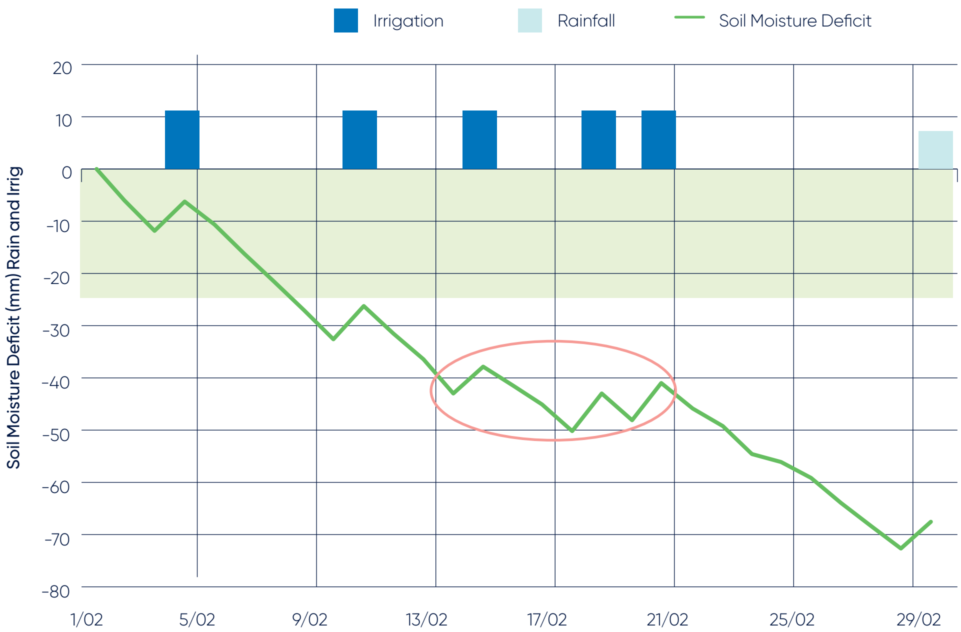


Figure 52 A soil moisture trace showing a green drought.



Source: Dr J Hills, University of Tasmania, Tasmanian Insitute of Agriculture

Managing irrigation with limited water

Deficit irrigation is the deliberate and systematic under-irrigation of pastures or crops. This is usually done by either irrigating at the same frequency but applying less water at each irrigation event or maintaining the amount of water per irrigation but increasing the interval between irrigation events.

Climate has a strong effect on pasture responses to deficit irrigation. Regions with low summer rainfall and high potential evapotranspiration have reduced WUE from deficit irrigation compared to regions that have high summer rainfall and can increase WUE by reducing losses from drainage or runoff, or both.

This means that when summer rainfall is unlikely it is better to fully irrigate a smaller area than to partially irrigate a larger area.

Irrigated summer forage crops produce more feed per ML of water than established irrigated perennial pasture. They are also more tolerant of missed irrigations and can respond favourably and profitably to once-off irrigations in the mid to latter phases of their growth period.

Contrasting results for WUE under deficit irrigation have been reported from different dairy regions due to differences in rainfall and evapotranspiration. These differences result in more efficient rainfall use and a decrease in the amount of water lost to through drainage or runoff. For example, in south-western Victoria, applying only 70 per cent of water requirements reduced the WUE of the pasture by 21 per cent and increasing the irrigation interval by 3 to 4 days reduced the WUE by 45 per cent. In New South Wales, deficit irrigation led to a significant decline in annual WUE for all species except lucerne. Kikuyu was the most water-use-efficient forage under an extreme deficit irrigation treatment, with mean WUE declining by 15 per cent, while white clover had the largest decline of 44 per cent and the lowest WUE.

The decline in WUE suggests that pasture forages are unable to use water as efficiently under deficit irrigation, compared to optimum irrigation. Plants under moisture stress increase the root-to-shoot ratio, as root growth is stimulated to increase water uptake at the expense of shoot growth. For these pastures, low rainfall and high daily evaporation rates will rapidly deplete plant-available water from the root zone, reducing the effectiveness of a deficit irrigation approach. Therefore, for any forage, strategies that maximise yield potential, including non-limiting nitrogen fertiliser and optimum grazing interval, have more potential to increase WUE, rather than strategies that try to reduce water use.

A common response to reduced irrigation water supplies is to continue to irrigate the same area of perennial pasture but apply less water per hectare.

Trials clearly indicate that it is far more efficient to fully irrigate a smaller area of pasture with its full requirement of water than to under-irrigate a larger area of pasture. One of the biggest limitations of irrigating perennial pasture is that it is particularly sensitive to missed irrigations.

When scheduled irrigations are delayed or missed, the plants go into partial water stress and growth rates decline. As a result, total pasture yields decline and the WUE of the applied irrigation water is reduced. If the stressed pasture is then fully irrigated, there is a lag period before pasture growth rates are back to normal.

In north-west Tasmania, a deficit irrigation approach maintains pasture in a responsive state and can make more efficient use of any summer rainfall events. In seasons where summer rainfall occurs, WUE can increase by 11 per cent when half of the soil water deficit is replaced at the same irrigation interval and up to 45 per cent when only 10 per cent of the water deficit is replaced. In seasons where minimal summer rainfall occurs, however, it is more efficient to fully irrigate a smaller area of pasture.

Forage crops

The WUE of irrigated summer forage crops, such as rape or turnip, can be higher than that of an established irrigated perennial pasture. While this might be the case, unless the pasture is degraded and in need of renovation, it is usually not economical to plough up a pasture and sow a forage crop. Other factors, such as the period of feed availability, the herbage quality and the method of feeding the crop, also need to be taken into account before moving water from pasture to forage crops.

Summer forage crops appear to be more tolerant of missed irrigations than pasture, and they can respond favourably and profitably to once-off irrigations in the middle to end phases of their growth period. The most additional feed grown per ML of irrigation water on forage crops is where the crop is partially irrigated. A possible strategy therefore could be to irrigate a core area of perennial pasture with the irrigation water supply that is reasonably secure and apply additional, less secure water to summer forage crops in an opportunistic manner.

The choice of forage cannot be based on WUE alone. Research has shown the forage options that maximised profitability in Victoria were predominantly a mix of perennial ryegrass and prairie grass, mainly due to their high yield and high nutritive value. This highlights the complexity of choosing forages, as there are important tradeoffs in WUE, yield and nutritive value that need to be considered. A limitation on using kikuyu is its relatively low nutritive value, which limits potential milk production compared to perennial ryegrass.

Impact of waterlogging

Waterlogging occurs when roots cannot respire because there is too much water in the soil profile. Importantly, water does not have to appear on the surface for waterlogging to be a potential problem.

In wetter climates, waterlogging can be a significant problem that needs to be addressed. Waterlogged soils are notorious for mud, farmer discomfort (grumpy farmers), pugged soil and pasture damage, slow grass growth, late start to seasonal growth and late crop sowing, slow stock movement, restricted machinery access (bogged), low pasture utilisation rate, poor shed hygiene (mastitis, high cell counts), bogged laneways and crop disease.

Waterlogged soils release increased amounts of nitrous oxide (N2O), a particularly damaging greenhouse gas.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space (i.e. the soil is anaerobic) for plant roots to be able to adequately respire.

THE IMPORTANCE OF DRAINAGE

Draining is crucial to decreasing the effects of waterlogging. Improving drainage from an inundated paddock can shorten the time plant roots are subjected to anaerobic conditions. It also makes soils easier to manage, increases plant growth by improving aeration and soil temperature and helps to control plant and animal diseases.

Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants. Plants differ in their demand for oxygen and their demand for oxygen in the root zone will vary with growth stage. Many farmers only realise that a site is waterlogged when water appears on the soil surface. However, by this stage, plant roots may already be damaged and yield potential severely affected.

The effect of waterlogging on a pasture will depend on the species present, the proportion of each and their tolerance to waterlogging. Research has shown ryegrass growth was reduced by 25 per cent after long-term waterlogging and subterranean clover growth by 26 per cent when flooded for 21 days. Many pastures in the Murray Valley are dominated by paspalum, largely as a consequence of waterlogging.

The wetter a soil becomes, the weaker its 'strength' and the less its ability to withstand compaction and pugging. This varies with soil type. The severity of pugging depends on factors such as the physical properties of soil, rainfall, soil moisture content, the number and size of cows on the damaged area, the length of time they are left there and the pasture cover.

Pugging damage can range from light, requiring little or no repair work, to very severe, necessitating a full re-sowing program. Pugging can reduce pasture growth by between 20 and 80 per cent and pasture utilisation by between 20 and 40 per cent, depending on pugging severity. There may also be an increase in weeds and poor grass species following a period of pugging.

A major consequence of shallow watertables in some areas of irrigated land is increased salinisation of soil in the root zone because of the capillary rise of salt from the subsoil or groundwater. Disposing of saline groundwater by extractive pumping is problematic and rules out this approach on a widespread basis.

Since irrigation is the primary cause of land salinisation and shallow watertable development in some areas, through excessive percolation of drainage water beyond the root zone of crop plants, adopting improved techniques of irrigation management should be the first strategy for reducing accessions to groundwater.

Where drainage is necessary, diagnosing your waterlogging problem is the key to success. You need to know the source of the water and where it is moving in the soil.

This will ensure correct selection of drain type to install and the appropriate depth at which to place drains. In winter it is easier to identify the limits of wet areas, particularly seepage areas, and to identify soil horizons on which a perched watertable occurs.

Benefits of improved drainage

Reducing the length of time soils remain waterlogged by installing appropriate drainage systems makes it easier to manage soils, increases plant growth by improving aeration and soil temperature and helps control plant and animal diseases. Other benefits are as follows:

- Improving drainage results in the soil becoming friable rather than plastic, and it is less likely to be compacted or pugged. A more aerated soil encourages organisms which metabolise organic matter and stabilise soil aggregates.
- Improved drainage increases the depth of aerated soil, allowing plant roots to explore a greater soil volume. This increases the pool of nutrients available, and with a greater volume of soil to draw on for water, plants are able to continue growing for longer during dry summer periods. Pasture growth and crop yields are increased as a consequence. Increased pasture growth during summer is often one of the unexpected benefits of improved drainage which has its most obvious benefits during wet winter and spring periods.
- Installing underground drains has resulted in a 65 to 100 per cent improvement in crop yield on poorly drained soils in Tasmania.

- Animal health problems are often reduced by improved drainage. These include mastitis, cracked teats, liver fluke and intestinal worms.
- Poor soil drainage may be limiting plant growth to the extent that no responses are gained from increased fertiliser use.
- Drainage is also an important way of improving the working conditions by removing the unpleasantness of muddy, wet conditions.

Types of drainage

Drainage is carried out either on the surface or underground, depending on the problem. Surface drainage can take the form of open arterial ditches, grassed waterways, reverse bank interceptor drains or hump and hollow drainage. Most surface drains are a minimal investment, last a long time provided stock are excluded, and can always be deepened. Underground drainage can take the form of pipe drains, mole drains, or deep ripping.

Different soil types require different solutions to drainage problems. It is important to remember to investigate and plan your drainage in the winter, and install drains in the summer. For more information on drainage, watch the following videos.

Mole drainage installation **click here**

Mole drainage case study **click here**

Water logging costs production **click here**

Designing drainage **click here**

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SUMMARY

Managing pasture irrigation brings together the efficient operation of the irrigation system and knowledge of pasture agronomy. It has been shown that paying attention to irrigated pasture management is well worth the effort, e.g. fully irrigating pastures such as ryegrass can double DM yields compared to dryland ryegrass.

When to start irrigating

A key issue with pasture management is when to start applying irrigation water, with many dairy farmers waiting for visual signs of water stress. Often this is too late. The result is that pastures will need a period of recovery after water is applied, which can mean pasture growth (and DM production) will be at below maximum potential rates. This is known as a 'green drought' and can take some time to correct.

Deficit irrigation

One strategy where irrigation water is limited is deficit irrigation, i.e. the deliberate and systematic under-irrigation of a crop or pasture. Contrasting results for pasture water use efficiency under deficit irrigation have been reported from different dairy regions due to differences in rainfall and evapotranspiration.

The general message, however, is that in all areas it is more efficient to fully irrigate a smaller area of pasture than to under-irrigate a larger one.

The situation is different with summer forage crops such as rape and turnip, which appear to be more tolerant of missed irrigations than pasture. Where both perennial pastures and fodder crops are being irrigated, a possible strategy is to fully irrigate a core area of pasture and opportunistically apply extra, less secure water to forage crops.

Waterlogging and drainage

Waterlogging is an important issue with irrigated pasture and must be managed. Not only does it affect DM production, it can result in pugging, farmer discomfort, pasture damage, slow grass growth, slow stock movement, restricted machinery access, poor shed hygiene and crop disease.

The key to managing waterlogging is to identify the cause of the problem, i.e. the source of the water and where it is moving in the soil. When you have done this you are ready to choose the correct drain type to install and the right depth to install them at.

Depending on the cause and the situation, drainage can be installed either on the surface, e.g. open arterial ditches, grassed waterways, banks or hump and hollow drainage, or under the ground, e.g. mole drains or deep ripping.

09

Automation of irrigation

Many dairy farmers have taken advantage of the benefits of automating their irrigation systems to reduce the time needed to operate them or at least to shift the timing to be more people-friendly. Recently, automation has also shown exciting potential to improve irrigation management and performance.

There are varying levels of automation, from simple alarms to indicate when water has reached a certain point in the field and should be shut off, to mechanisms that will do the shutting off, to programmable irrigators that will vary the amount of water applied to different sections of the field. Current research is developing automatic sensing of plant stress in different parts of the field as a way of controlling real-time irrigation of those plants. While irrigation will continue to become more automated in the future, it is important to keep in mind that there will be a cost, so adoption of new technology must be financially viable, i.e. it must increase productivity and profitability.

This chapter provides information on automation technology that is already commercially available and on technology being developed, as well as changes to management that will be needed to get the best from it.

Automation of surface irrigation systems

Automation of irrigation channel supply systems using irrigation control gates that communicate and automatically control flow rates is now common across irrigation districts in Australia.

Figure 53 Researchers with an autonomous irrigation system.

Source: University of Tasmania, Tasmanian Institute of Agriculture

Some of this technology is available at a farm level so that with remote control technology farmers can open and shut gates remotely or, according to an automated schedule, across many surface irrigation bays. This equipment, which is produced in Australia, is reliable and accurate.

Irrigating fields in surface systems can be automated cost-effectively where irrigation of a large area is controlled through one water source, e.g. an outlet into a border check bay or several outlets into small pipe-through-the-bank furrow irrigation systems that operate as a single unit.

This automation requires remotely controlled opening and closing mechanisms such as flume gates and irrigation control valves. It also requires a suitable telemetry communication system to be installed on the farm.

Figure 54 An automated outlet for a border check bay.

Source: AgVic

Figure 55 An automated control gate.

Source: S. Birchall

Advantages of automated surface

There are many advantages with automating surface irrigation systems, including the following:

- less labour is needed to complete the same tasks
- improved lifestyle as it is not necessary to constantly check the progress of water down the bays being irrigated
- more timely irrigation, because automating surface systems results in operators being more inclined to irrigate when plants need water
- helps with managing higher flow rates, which reduces the time and number of staff required to irrigate a bay
- more accurate cut-off than manual checking
- reduced run-off of water and nutrients, therefore retaining more fertiliser on the bay
- reduced use and costs of vehicles as irrigation does not need to be constantly checked.

Disadvantages of automatic irrigation

There are also some disadvantages with automating surface irrigation systems, including the following:

- The cost of buying, installing and maintaining automatic equipment.
- Reliability. Sometimes equipment failures occur. How quickly can it be repaired and proper operation be resumed? A re-use system is good insurance against failures.
- Increased channel maintenance as channels and equipment need to be well maintained to ensure the system works correctly. Channels should be fenced to protect the automatic units from stock damage.

> **INFORMATION:**
>
> For more information on automatic irrigation for border check systems **click here**

In the pipeline

Automation technology being developed includes using a range of plant, soil and weather sensors with crop and soil infiltration models to control the timing and flowrate of surface irrigations so that each individual irrigation event can be optimised.

Automation in permanent sprinkler systems

Permanent systems are relatively simple to automate, as all of the infrastructure remains in the same place and the irrigation blocks or units are always the same. This means irrigation can be automatically controlled with a central control box, remotely controlled valves and flow sensors. Such units have been commercially available for many years and are an established technology.

The use of soil moisture or other sensors to control when irrigation starts and stops is also simple for permanent sprinkler systems.

Remote control of pumps, especially if they are electrically driven, is also common.

Automation in centre pivot and lateral move systems

For centre pivot and lateral move (CPLM) systems, a level of automation is usually already built into technology to move and control the machine across the field, e.g. programming varying speeds to apply different depths for different sections of the field as the machine moves. Automatic switching from forward to reverse can also be programmed in to most existing control panels. Technology exists for automating start and stop according to real-time data from external sensors such as soil moisture probes.

Variable rate irrigation (VRI) for CPLM systems is an additional level of automation that is commercially available from all major suppliers as part of a new system or it can be retro-fitted to old systems.

Recent research in Australia has shown that on commercial fields, automated generation of VRI prescription maps for centre pivots along with automated remote installation of these into the centre pivot control panel is possible.

Visual sensors mounted on the CPLM structure for detecting plant water status for automatic, real-time watering is in advanced stages of development.

Figure 56 An autonomous irrigation set up centre pivot.

Source: University of Tasmania, Tasmanian Institute of Agriculture

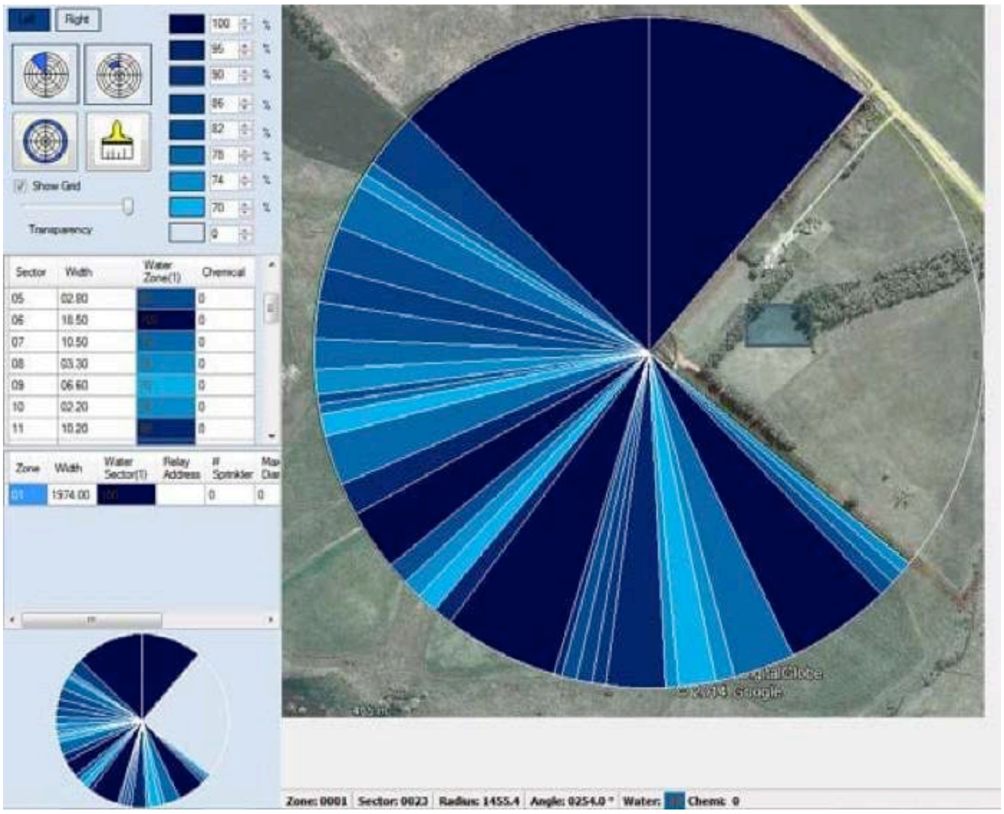
Variable rate irrigation systems

VRI technology allows farmers to apply varying rates of irrigation water to individual management zones under a CPLM irrigator. Water application is controlled by a prescription map uploaded to a suitable control panel using a sector or a zone control VRI system. A sector-control system varies the speed of a centre pivot in each sector or pie-like wedge, and each wedge can be accurately proportioned down to one tenth of a degree (3600 increments around the circle).

For linear moves, each sector is a rectangular slice, down to as little as 30 cm increments.

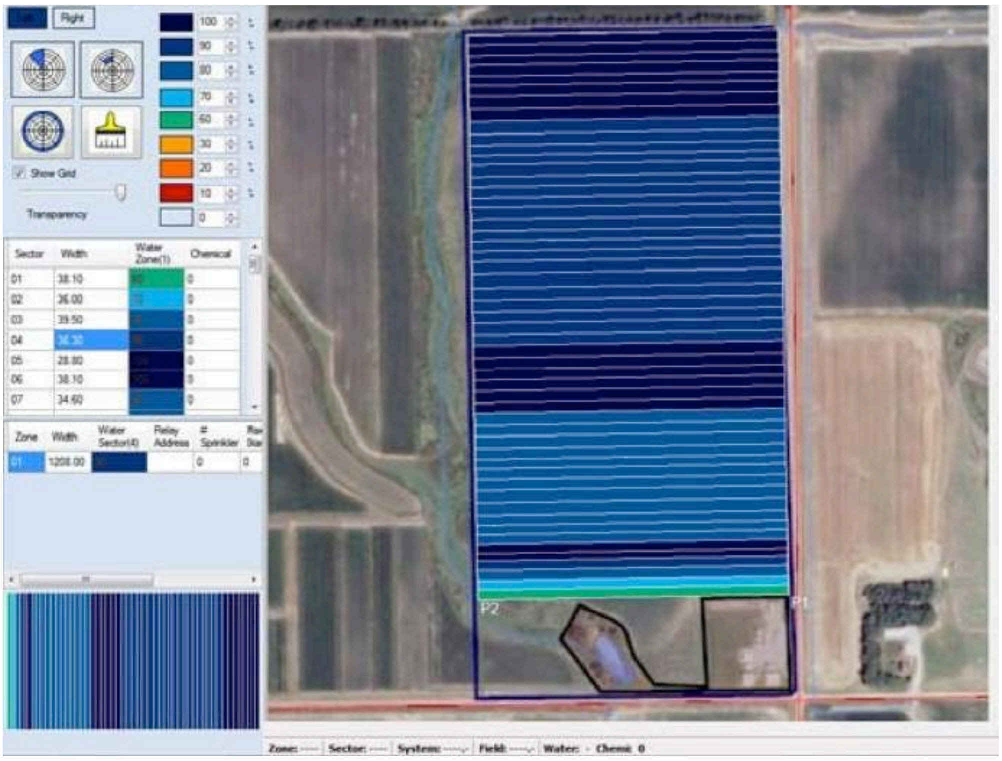
For both CP and LM, faster speeds reduce and slower speeds increase the amount applied.

Figure 57 VRI sectors for a centre pivot.



Source: Image courtesy Reinke Manufacturing Company Inc

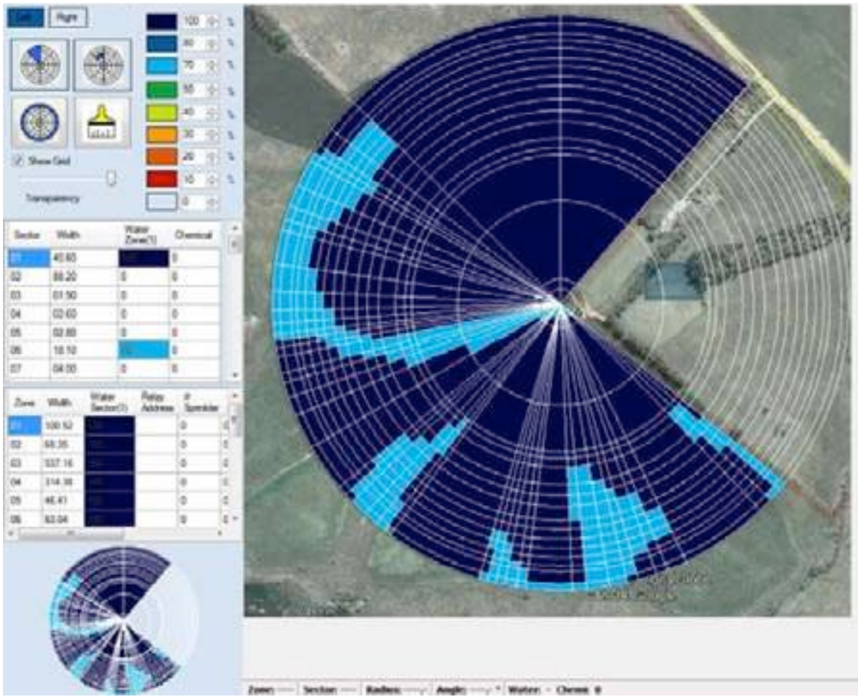
Figure 58 VRI sectors for a linear move.



Source: Image courtesy Reinke Manufacturing Company Inc

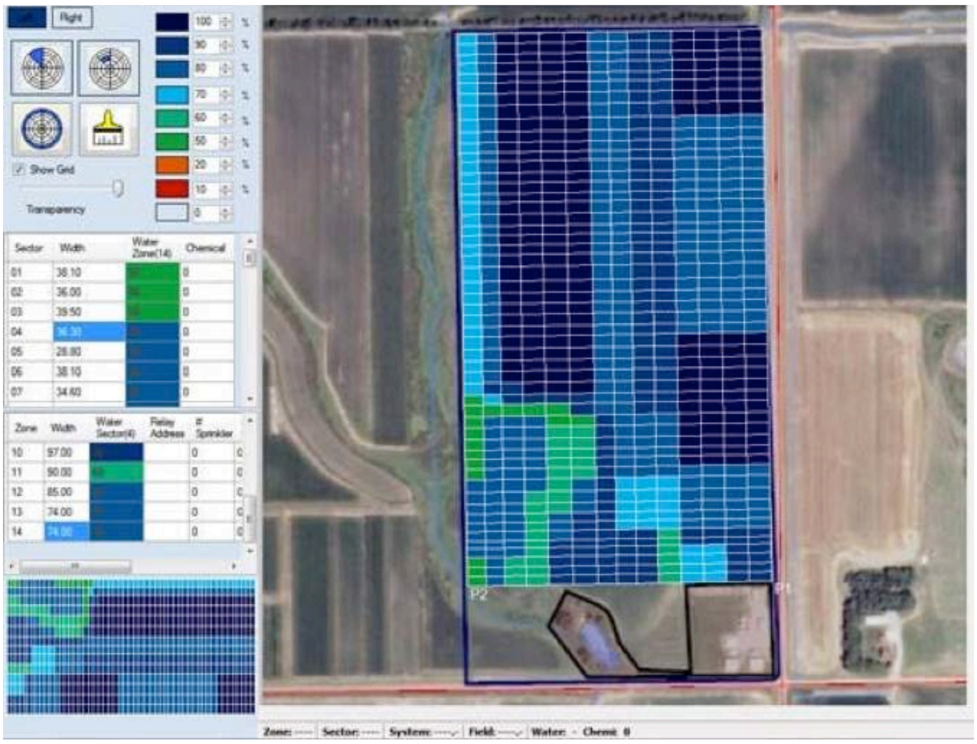
In a zone-control system, water is variably applied through separate electro- or hydro-mechanically controlled individual or groups of sprinklers. The on-off pulse rate varies to achieve the desired application depth within each management zone. Thus, water application amounts can be matched with spatial variation in soil properties or pasture type for each management zone. The base application depth can be adjusted higher or lower as usual without needing to change the variable rate settings.

Figure 59 VRI sectors and zones for a centre pivot..



Source: Image courtesy Reinke Manufacturing Company Inc

Figure 60 VRI sectors and zones for a linear move irrigator.



Source: Image courtesy Reinke Manufacturing Company Inc

The first step in using VRI is to have a professional undertake an EM soil survey under each VRI irrigator. The EM sensor measures soil apparent electrical conductivity (ECa), and the on-board GPS is used to produce an elevation survey to determine topography. The ECa data are processed through software to produce visual layers (see Figure 61A).

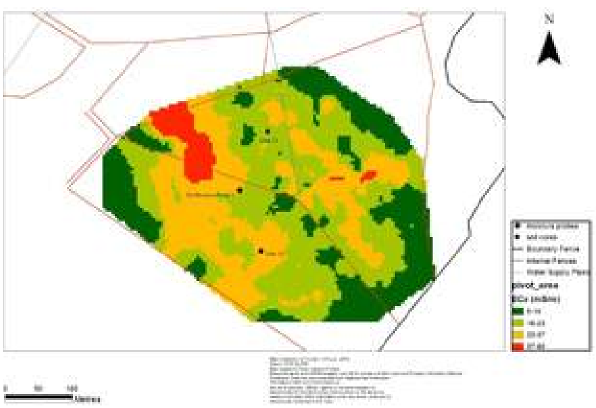
When the soil ECa maps are ground-truthed, this information, together with easily identified zones such as laneways and drains, is used to define irrigation management zones under the pivot or linear move (see Figure 61B). The management zones' definition, termed a 'prescription', is then uploaded into the irrigation control panel. Irrigation application amounts and ranges are then varied automatically according to the prescription.

Soil moisture sensors are often installed into each zone to monitor real-time soil moisture status. This information can be used to optimise variable rate irrigation scheduling.

Figure 61 Electromagnetic survey results (A)) and irrigation management zones (B) under a centre pivot irrigator.

A

B



Source: supplied by North West Local Landcare services

VRI can be used to:

- exclude irrigation from drains, gateways, laneways, water troughs, streams and other infrastructure under your centre pivot or lateral move
- vary irrigation according to pasture differences under irrigation
- delay start up and reduce irrigation on wetter, low-lying areas that get boggy
- apply varying amounts of irrigation to soil zones according to their plant available water storage
- exclude irrigating paddocks where pasture is being renovated or hay or silage is being made
- exclude irrigating dairy paddocks the day before they are grazed.

Water is saved through matching irrigation to land and soil characteristics and avoiding watering unproductive land. These farm management strategies result in more efficient use of irrigation water, and the water saved can often be redistributed to other parts of the farm.

There are likely to be many benefits from installing a VRI on a pivot irrigator. Research in Tasmania by Dr James Hills has found the following:

- improved crop quality and yield by up to 20 per cent
- savings on water volume of up to 27 per cent on dairy and field crops
- reduced pumping (energy) costs
- reduced soil saturation and improved grass growth, as well as less pugging damage in wet areas
- reduced muddiness on laneways and easier movement of cows across paddocks.

VRI investment payback

Return on investment (ROI) for a VRI can range from less than two years up to nine years or longer depending on the amount of water saved and its value and the gains in grass growth. The key question is whether you have enough variability to gain enough benefit for the investment to be worthwhile.

EXAMPLE:

A VRI system installed on a 55 ha pivot cost $47 225 and resulted in a saving of 1.4 ML/ha of water. If this water had a value of $100/ML, the ROI is 9 years.

The same VRI gave an increase of 1 t DM/ha consumed. If this feed is valued at $250 t/DM, the ROI is 3 years. The overall result is an ROI of less than 2 years.

Potential issues

Potential issues with VRI are as follows:

- During the growing season, as crop water demands alter, irrigation scheduling may call for different zone control maps. This requires having a control panel that can store several prescriptions, and these need to be uploaded and the appropriate one chosen as the growing season progresses.
- Improved irrigation management can grow you more grass, but this extra pasture needs to be managed to its optimum for increased milk production. Extra growth may result in lodging, dead grass in the base of your pasture, and stalky growth with seed heads that have low energy content. You may need to speed up your grazing rotation, close up more paddocks for silage, do some pasture topping or milk more cows.
- Variable frequency drive (VFD) pumps are likely to be required to minimise pressure fluctuations from the changing rate of system flow resulting from frequently turning sprinklers on and off.

Suppliers and cost

VRI technology works with centre pivot and linear move irrigators from all major suppliers and manufacturers. Precision VRI technology for pivots has an installed cost (2018) of between $600 and $900/ha which includes hardware, GPS software and remote access. The cost of a VFD pump is additional. Contact your local irrigation hardware supplier.

Autonomous irrigation

Autonomous irrigation systems are operated and controlled without human intervention, once a proposed irrigation event on a field has been remotely authorised by the irrigation manager.

Automated systems, which provide farmers control over their irrigation systems and pumping plant using web-connected devices and software, are not the same as autonomous ones, which determine the timing, depth and location of the precision irrigation automatically and then 'request' permission to complete the irrigation process from the farmer. These systems operate the motors, pumps, valves, and gates to deliver the requested irrigation. The irrigation could be site-specific and therefore variable across the field, or it could be uniform across the entire field.

Autonomous irrigation systems require:

- automatic precision control of the irrigation equipment and infrastructure
- reliable methods of automatically determining when to commence irrigation
- reliable methods for automatically determining how much water to apply and therefore when to cease irrigation
- the ability to automatically sense areas of the field that need different amounts or no irrigation
- built-in comprehensive fail-safe functionalities such as loss-of-prime on pumps, flow range limitations and automatic shut-down of pump stations
- Fully autonomous systems are not yet available from irrigation equipment suppliers but have been demonstrated to work at a commercial scale.

REFERENCE

1 Automatic irrigation, website **http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/lwm_farmwater_irrigation_technologies**

Figure 62 VRI on centre pivot.

Source: University of Tasmania, Tasmanian Institute of Agriculture

SUMMARY

Most types of irrigation systems can be automated. The automation can range from simple starts and stops of systems through to completely automated systems using real-time inputs from sensors to control the entire irrigation operation.

Technology is becoming more widespread and cheaper, but the management question of what return will be obtained through the investment remains. Careful analysis is necessary to determine what automation, if any, will be appropriate and financially viable for each farm situation.

Automatic bay gates have been working in border check irrigation for many years. Studies have found advantages include; reduced labour, improved lifestyle, more timely irrigation, better management of higher flow rates, more accurate cut-off, reduced run-off of water and nutrients and reduced vehicle running costs. The biggest disadvantages include the additional cost, the reliability and the increased channel maintenance.

Automated control of fixed pressurised systems has been commercial for many years. Controllers can be set up to schedule individual irrigation events and sequences of events over several weeks. A variety of sensors can be involved in the automation including flow and pressure sensors as well soil and weather sensors for controlling duration and timing of irrigation events.

CPLM irrigators can now be programmed for variable rate irrigation (VRI). In VRI different amounts of water are applied to different sections of the irrigated area, enabling closer matching of irrigation application to soil type and to plant water demand.

These sophisticated systems have many potential benefits but must be installed and operated correctly. It is also important that there is sufficient variability in the conditions under the pivot or lateral move to justify the expense of the VRI control system. Professional assistance in mapping soils and conditions under the irrigator is usually important.

It is important to note that all improvements in irrigation management by automation must fit into the whole farming program. There is no point growing more grass or fodder if it cannot be grazed effectively and used by cows.

Autonomous irrigation may become more common in the future. Autonomous irrigation involves the complete operation and management of the irrigation system by the control system. It includes all the control features to enable continuous operation without human intervention. This is different from automatic irrigation in which the manager still controls most system operations but has the ability to do so remotely because of various communication technologies.

10

Land application of dairy effluent

If distributing effluent were only a matter of pumping green-coloured water through an irrigation system, there would not be any need for a specialist chapter on the topic.

However, the reality is that distributing effluent poses a number of additional challenges over conventional irrigation as a result of its nutrient (N,P,K) and salt content and the likelihood of it containing solids that can cause problems with pumps, pipes and nozzles.

This chapter explains how the design and management of effluent irrigation systems differ from those running clean water.

Note: this chapter does not address effluent management regulations. Other industry guidelines and local authorities should be consulted to check for specific requirements, e,g. storage requirements, appropriate buffer distances from effluent reuse to waterways and requirements for any nutrient/irrigation management plan.

Irrigation or distribution?

The minimum area of land over which effluent is to be applied must be based on either:

- a nutrient budget e.g. Fert$mart plan or guidelines
- a hydraulic balance (annual deficit, Readily Available Water – see Chapter 7 Scheduling).

The most stringent of these (i.e. the one requiring the largest area) must be used as the minimum size for the application area. Because this is usually nutrient content (and in particular for pond effluent, potassium), effluent distribution is usually limited to no more than two to three applications per year, each typically ranging from 8 to 20 mm deep.

TOP TIP:

A typical second-pond effluent has been tested to contain the following nutrient concentrations:

Test Results:

Nitrogen (N) (kg/ML)	240
Phosphorus (P) (kg/ML)	80
Potassium (K) (kg/ML)	420

From the Fert$mart program's Dairy Soils and Fertiliser Manual, a typical nutrient budget for a grazed pasture would limit the application of effluent to no more than 60 kg/ha of potassium in any one application, and no more than 120 kg/ha annually. The effluent in this example should be applied at a rate of no more than 0.14 ML/ha (or 14 mm depth). At a maximum of two applications to the same area (observing the limit of 120 kg/ha of K a year) over the year, annual application is 0.28 ML/ha (or 28 mm), which is much less than even the lower end of the typical range of seasonal crop evapotranspiration of 3 to 11 ML/ha, or 6 to 9 ML/ha for perennial pasture.

Clearly, while effluent reuse is by irrigation equipment, effluent does not involve enough water or rates of application that would support irrigation. It is more accurate to call it an effluent distribution system, however, the terms are often used interchangeably.

Underlying principles for application of dairy effluent

The following excerpt from the Fert$mart Dairy Soils and Fertiliser Manual, section 13.5, outlines principles that need to be followed to effectively use and safely return effluent onto the farm. They include:

- Allow enough land area to apply effluent at an agronomically sensible rate to meet the crop or pasture's nutrient requirements.
- The main nutrients in effluent are not 'balanced' and each must be considered individually. The nutrient that requires the largest reuse area sets the application rate.
- To avoid metabolic disorders, no more than 60 kg potassium/ha should be applied in one application, and no more than 120 kg potassium/ha per year to grazed pastures.
- Total nitrogen per application should be no more than 80 kg/ha.
- Heavier applications increase the risk of problems such as nitrate poisoning, mineral imbalances and make less efficient use of the applied N as well as increase the risk of losses to the environment.
- Treat effluent as a nutrient source rather than just something that needs disposing of and credit the nutrients applied to reduce commercial fertiliser applications.
- A lighter rate over a larger area is preferable to overloading a small area. If no chemical analysis is available, effluent should be spread at a rate of 1 ML per 12 ha. This is based on the upper range of typical nutrient concentrations found in surveys of farm treatment systems.
- Apply effluent to paddocks when there is no likelihood of run-off from the property.
- Conduct regular soil testing of the areas where effluent is being applied to monitor nutrient levels and soil health.
- Isolate the paddock and restrict cattle grazing for at least 21 days after effluent is applied to pasture or crops. This withholding period will overcome any palatability or fouling issues, reduce the risk of any pathogens and allow plants time to respond to nutrients.

Choice of reuse area and distribution system

Where a dairy farm has an operational irrigation system and enough irrigated area to accommodate the nutrients contained in the effluent, using that system is a logical choice. The challenge is to ensure the effluent can be run through the existing irrigation system without residual solids causing blockages, which might require some changes to the effluent management system. Further information on system design can be found in the Effluent and Manure Management Database.

Dairy farmers with dryland farms will need to develop an irrigation system (or some other means) for applying the effluent over a reuse area chosen for its ability to use the nutrients contained in the effluent. As noted above, while this may generally be called an irrigation system, its main purpose is nutrient distribution as the volumes involved are much less than would be required to meet typical irrigation demand. Table 24 lists some selection criteria for choosing an area of land to be developed for effluent application.

INFORMATION:

Refer to nutrient management guidelines such as the **Dairy Soils and Fertiliser Manual** or the **Effluent and Manure Management Database** for determining the appropriate size for an effluent reuse area. A rule-of-thumb allowance of 5 ha per 100 cows is a good starting point. (Note: that this rule-of-thumb only applies to grazing-based dairies that do not use a feedpad.)

Table 24 Selection criteria for land to be used for effluent application.

Criteria	Comment
Existing soil fertility status	Target the development of irrigation on those areas where the nutrient is required - avoid night paddocks and historical effluent paddocks if nutrient status is already elevated.
Buffer distances to waterways	Refer to local requirements/guidelines, see following section for explanation.
Location of neighbours and prevailing wind direction	Typical separation distance from a neighbouring house to the effluent reuse area is 100 m for intermittent use. Note that the direction of very low wind conditions is important. Such conditions are more likely to create conditions that favour stable odour plumes.
Ease of access	Minimise distance from storage after satisfying the above criteria. Avoid mainline alignments requiring river or creek crossings if possible, otherwise address the risk of pollution if the main leaks.

After you choose the land for effluent reuse, you are ready to select the system for applying the effluent. While the factors discussed in Chapter 2 are relevant, the application system must also be compatible with the nature of the effluent management system and the effluent to be handled (see Table 25). In particular, choose components that can handle the expected solids content resulting from the effluent management approach without causing pumps, pipelines, hydraulic mechanisms or nozzles to block.

The effluent distribution system should be selected to spread material uniformly at a target depth that maximises the beneficial use of the nutrients contained while minimising the risk of contamination of ground or surface waters. To do this, effluent should be applied:

- when there is a soil moisture deficit equal to or greater than the application depth
- at a rate less than infiltration rate
- to a depth less than readily available water (RAW) to keep effluent in the root zone.

Further information on meeting these requirements is in section 'Hydraulic Design for Effluent' on page 138, **Effluent and Manure Management Database for the Australian Dairy Industry**

Buffers to waterways

The separation distance between the reuse area and any neighbours or sensitive environments must be considered. Buffer distances are stipulated in some states to protect local amenity and ground or surface water quality as well as the long-term future of the reuse scheme.

Buffer distances will vary with the impacts to be controlled (i.e. runoff versus odour) and the nature of the environment to be protected (a larger buffer will be required for a river that provides a town water supply compared to an ephemeral drainage line).

Buffers may also vary with the method of irrigation that is intended, e.g. a high pressure irrigator may produce more aerosols compared to a low pressure irrigator. Refer to your state-based guidelines or contact relevant authorities for information about buffers.

Selecting irrigation components to handle solids

Pump types

Many types of pumps are available for pumping dairy effluent, however, not all effluent pumps will be suitable for all types of effluent.

The type of pump you select will depend on the solids content of the effluent to be pumped.

Special emphasis must be given to selecting pumps that are able to handle the solids content of the particular effluent in question without blocking or wearing excessively.

Table 25 Factors in the selection of an effluent distribution system (modified from Dairy NZ, 2015a).

	Pros	Cons
Traveller – application depth 8 mm+	• Low capital outlay • Can distribute large quantities of effluent in one application cycle • Do not require fine solids removal • In case of breakdown, easy to interchange with alternate traveller • Easy to service and maintain	• Unsuited to topography steeper than 7o and high rainfall or high drainage areas • High application rates and depths • Risk of poor performance due to lack of maintenance • Not well suited to small or irregular paddocks • High application depth when travelling at slow speeds
Low rate sprinkler systems – application depth 1 to 10 mm	• Low application rates • More irrigation days available throughout the year, and less storage required • Suited to small or irregular shaped paddocks • Less moving parts – easy to maintain • Less chance of spray drift over boundaries, etc • Can distribute large quantities of effluent in one application cycle at low depths if multiple sprinkler units are used over a large area • Easier to shift and run in rolling topography • Suits high rainfall, high risk soils, rolling or artificially drained land	• Harder to apply evenly throughout the paddock, particularly if different people shifting each time • More shifts involved to get same volume of effluent as traveller (depending on soil moisture deficit) • Easily blocked (solids need to be separated or filtered) • Specific planning and design needed to get correct pressures and volumes to all sprinklers
Pivot – application depth 1 mm+	• Excellent low application depths • More irrigation days available throughout the year, and less storage required • Can get rid of large volumes of effluent quickly • Little time spent setting up and moving • Covers large area easily with valuable nutrients	• May have to wash effluent out of lines afterwards • Must have back-flow preventer (valve) • Pivots have been known to get stuck when operating during the winter • Requires VRI if irrigating effluent over paddocks with water courses and drains • Some 'add on' effluent sprinklers to pivots i.e. large bore end-guns have very poor distribution uniformity • Need excellent solids removal or nozzles will block • Can have different application at each bay

Figure 63 Pump selection guide; solids content limits for various pump types (modified from Tyson 1995).

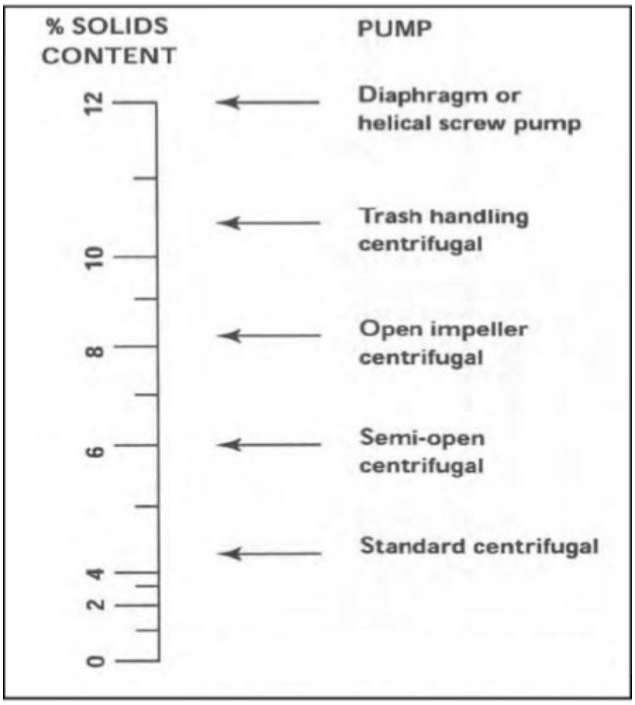
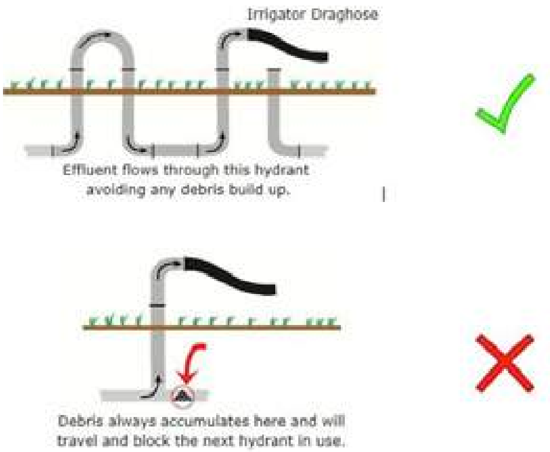


Figure 64 Hydrants for effluent containing solids (modified from source: ecostream.co.nz).



Choose the pump type with the highest level of efficiency for the expected solids content, subject to meeting pump duty requirements. While selecting an open-impeller centrifugal pump to pump effluent from a second pond (in a two-pond system where few solids remain if the primary pond is well maintained) might initially be regarded as a suitably cautious choice, the downside in reduced efficiency and much higher cost over the life of the pump must be considered. Pumps should be selected so that they operate at near their maximum efficiency points as much as is reasonably possible (see Chapter 4 for more on pumps and efficiency).

Hydrants

Hydrants provide a connection point between land application systems and a buried mainline. Traditional irrigation hydrants that 'T' into the mainline may not be adequate for systems incorporating solids as those solids may settle in the dead section of the mainline and cause blockages (see Figure 63).

Where solids are present, consider using hydrants that break into the mainline so that the entire flow of effluent is directed to the irrigator and the mainline from that point on is no longer 'charged' (full of stationary liquid).

Appropriate provisions such as valves must be included to prevent or control emptying of pipelines during changeover between hydrants.

Hydraulic design for distributing effluent using irrigation systems

The hydraulic design of effluent application systems must consider its physical and chemical properties, which differ from clean water. The hydraulic design standards in this section apply broadly to all components of the effluent system, including drains, pipes, pumps, storage and land applicators.

Application rate

The land application system must be selected so that its average application rate (AAR) does not exceed the expected infiltration rate of the soil based on the best available information. For sloping land (>7o or other areas identified as high risk, the instantaneous application rate of the land application system may need to be considered.

EXAMPLE

A travelling rotating boom irrigator with a circular wetted diameter of 30 m and a flow rate of 5.5 L/s is operating on level well drained land. The average application rate is calculated by the following equation:

AAR (mm/hr) = 3600 × Flow rate (L/s) ÷ Wetted area (m2)

The wetted diameter of the irrigator is 30 m so the wetted radius (r) is 15 m. The area of a circle is found from the formula π × r2.

AAR = (3600 × 5.5) ÷ (π × 152) = 28 mm/hr

This irrigator must only be used if the soil's infiltration rate is 28 mm/hr or more.See Chapter 1 for information on typical infiltration rates.

Solids in effluent can reduce a soil's infiltration rate by physically blocking the surface pores. The higher the percentage of total solids in the effluent, the lower the resultant infiltration rate will be. This effect is most severe (i.e. the largest proportional reduction in infiltration rate) when applying effluent to coarse grained soils, because the naturally large pores, which normally have a high infiltration rate, become blocked with finer material. Table 26 provides adjustment coefficients to account for this reduction.

EXAMPLE

For a silt loam subjected to a 30-minute watering time, an infiltration rate of about 14 mm/hr may be expected (from Chapter 1).

If irrigating with clean water (no solids), the irrigation system must be designed for an average application intensity of ≤14 mm/hr.

If applying effluent with 5% solids content, the design application intensity will need to be adjusted by the coefficient from Table 26: 14 mm/hr * 0.81 = 11 mm/hr

Therefore, the irrigation system must be designed to achieve an average application intensity of ≤11 mm/hr.

Pipe friction loss

Friction losses must be accounted for when designing any irrigation system. Choose pipe sizes for mainline and lateral pipes that do not result in a flow velocity exceeding 2 m/s or a friction loss of more than 2.0 m per 100 m of pipe.

Table 26 Coefficients for infiltration rate reduction with solids (Table 11-3, USDA 1997).

Soil texture	Total solids(%)						
	0.5	1.0	2.0	3.0	5.0	7.0	10.0
Sand	0.88	0.55	0.31	0.22	0.13	0.10	0.07
Loamy sand	0.70	0.54	0.37	0.28	0.19	0.14	0.10
Sandy loam	0.87	0.77	0.63	0.53	0.40	0.32	0.25
Loam	0.97	0.93	0.88	0.83	0.74	0.67	0.59
Silt loam	0.98	0.95	0.91	0.87	0.81	0.75	0.68
Sandy clay loam	0.99	0.97	0.95	0.92	0.87	0.83	0.78
Clay loam	0.99	0.99	0.98	0.97	0.94	0.92	0.89
Silt clay loam	1.00	1.00	0.99	0.99	0.98	0.97	0.96
Sandy clay	1.00	1.00	1.00	1.00	0.99	0.99	0.99
Silty clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Clay	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Typical pipe friction calculations to establish system resistance curves (see Chapter 4) are based on clean water and therefore may need to be corrected to account for the solids content of effluent. Refer to Table 27 to modify friction loss if pumping effluent with a solids content greater than 4 per cent. If the solids content is less than or equal to 4 per cent, hydraulic properties for clean water can be used.

Table 27 Pipe friction loss adjustment coefficient (Table 11-1, USDA 1997)

Velocity (m/s)	Total solids(%)					
	4	5	6	7	8	10
0.3	1.1	1.5	2.1	2.9	4.0	5.3
0.46	1.0	1.2	1.5	2.1	2.5	4.0
0.61	1.0	1.0	1.0	1.6	1.9	3.3
0.76	1.0	1.0	1.0	1.3	1.6	2.9
0.91	1.0	1.0	1.0	1.2	1.5	2.7
1.1	1.0	1.0	1.0	1.1	1.3	2.5
1.2	1.0	1.0	1.0	1.0	1.0	2.4
1.4	1.0	1.0	1.0	1.0	1.0	2.3
1.5	1.0	1.0	1.0	1.0	1.0	2.2
1.7	1.0	1.0	1.0	1.0	1.0	2.1
1.8	1.0	1.0	1.0	1.0	1.0	2.0
2.0	1.0	1.0	1.0	1.0	1.0	2.0
2.1	1.0	1.0	1.0	1.0	1.0	2.0

EXAMPLE

Consider that for a design pumping rate (Qp) of 7.5 L/s, the pipe manufacturer's data suggests a 100 mm (inside diameter) pipe (d) will theoretically result in an acceptable level of friction loss of 1.0 m per 100 m.

However, because the effluent on this property contains 7% solids, the expected friction loss should be adjusted according to Table 27.

First, the velocity through the pipe must be known, and can be calculated as:

Velocity = 4 × Qp ÷ πd2

Velocity = 4 × (0.0075 m3/s) ÷ (π × 0.1 × 0.1 m) = 0.95 m/s

Based on this velocity, the appropriate adjustment coefficient (from Table 27) is approximately 1.2. The expected friction loss may be calculated as:

Actual friction loss = clean water friction loss × adjustment coefficient

Actual friction loss = (1.0 m per 100 m) × 1.2
= 1.2 m/100 m

A friction loss of 1.2 m per 100 m should therefore be considered in the design.

Minimum water velocity

While it is necessary to limit maximum water velocity to no more than 2 m/s to keep pipe friction below a reasonable level, a minimum velocity is also required to ensure that solids do not settle and cause blockages. The minimum velocity in all pipes and open channels should not be less than 0.8 m/s to avoid deposition of solids. Consult a designer to ensure that the water velocity at any part of your effluent reuse system is within these limits.

Uniformity

As the nutrient content is almost always the limiting factor for planning effluent applications, it is especially important that it be applied very evenly to maximise the benefit to pasture/crops and avoid potentially adverse effects on water quality. See Chapter 6 for more information on uniformity.

Other considerations

Material selection

All components and structures must be made from corrosion resistant materials, as they may spend long periods of time submerged in potentially corrosive material.

Flushing

Consider providing the facility to allow the effluent conveyance system to be flushed with clean water after use. This will avoid the build-up of any solids in the distribution system as well as reduce the potential for corrosion.

Flow control

All flow through the system must stop when the system is shut down for any reason. For systems with mainline running downhill from the effluent storage pond, measures must be put in place to prevent the unintended siphoning from the effluent storage and drainage of the main pipeline.

Backflow prevention

Because of the potential for contamination, an effluent system must include backflow prevention if it is to be connected to a fresh water source. Regardless of whether such connections may be on the suction side or the delivery side, the system must be designed to ensure that effluent cannot inadvertently enter any fresh water source via system connections. You may need to consult local water authorities to determine if they have any specific requirements.

Automatic cut-offs

Fail-safe devices should be used to protect the system and the environment. These can include:

- Auto shutdown in case of high pressure (e.g. pipe blockage).
- Auto shutdown that avoids continuous pumping in case of low pressure (e.g. burst pipe, empty storage).
- For systems with travelling irrigators, it is also useful to have an auto shutdown that turns the system off if the irrigator has not moved for more than, say, 5 minutes (e.g. if the traveller is bogged, has snagged its drag hose or is at the end of its run).
- Fit any fixed sprinklers with a timer that limits the depth of application to the targeted amount.

Alarms

Consider installing an alarm or signal that can alert the system manager to:

- the level in storage if it is not easily seen from the manager's usual daily routes
- an effluent level in storage that shows when the pond is full or almost full.

Monitoring

As the manager of an effluent reuse system needs to know how much nutrient was applied across the reuse area, it is very useful to have a flow meter on the distribution side if possible (volume x concentration gives the amount of nutrient applied).

Consider the nature of the effluent to be pumped, especially the solids content, as some meters will not be suited to the task.

Installing a pressure gauge or test point at the pump outlet and at the applicator also supports regular checks on performance and better awareness of the depth of effluent applied. It is recommended that you install protection (an air-bell or similar) to stop the gauge rusting or blocking, and that you consider the need for an isolating valve to prevent damage when the system is not in use.

Serviceability and OHS

All pumps require regular servicing so access is an important consideration given effluent ponds introduce additional risks over clean water sources such as:

- crusting and weed growth on water surface, which makes identifying the edge difficult
- deep sumps, which may constitute a confined space and support dangerous conditions (build-up of hazardous or asphyxiating gases)
- effluent, which may contain pathogenic organisms.

All staff should be trained and provided with safe working instructions before working on or around the effluent system.

Safety and ease of maintenance are important considerations. Locate pumps where they can be accessed easily and safely. Avoid mounting pumps on pontoons unless necessary as they require special safety considerations such as design and devices to prevent them turning over or getting trapped in any hinged joints.

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SUMMARY

While it is possible to use the farm's irrigation system to distribute effluent where there is enough land to accommodate the nutrients it contains, there are a number of factors to consider before turning the switch to 'on'.

Effluent has some extra challenges because of its high nutrient and salt content and because it will probably contain solids that can block equipment such as pumps, pipes and nozzles.

As well as the physical and chemical challenges of dealing with effluent, there are regulatory ones, so you should consult your local and state authorities and check for specific requirements.

Where you can apply effluent

The minimum area of land over which you can apply effluent must be based on either:

- a nutrient budget, e.g. Fert$mart plan or guidelines
- a hydraulic balance.

The most stringent of these – the one requiring most land – must be used as the minimum size for the application area.

Other criteria used to select the area of land for effluent application include soil fertility status, buffer distances to waterways, location of neighbours and prevailing wind direction and ease of access.

Irrigation system requirements

Once you have established where you will distribute dairy effluent, you can decide on the system to use. It is important to choose components in the system that can handle the expected solids content without causing pumps, pipelines, hydraulic mechanisms or nozzles to block.

Different irrigation systems, e.g. travellers, low rate sprinkler systems and centre pivots, will differ in their requirements and have advantages and disadvantages. The important thing is that the system is able to spread material evenly at a target depth that maximises the beneficial use of nutrients contained while minimising the risk of contamination of surface or ground waters.

Pay careful attention to the type of pump you use. As a guide it should have the highest level of efficiency for the expected solids content, while also meeting pump duty requirements, and it should be able to operate at near its maximum efficiency point.

Hydrants also need to be installed so they do not allow solids to settle in the mainline and cause blockages.

Hydraulics

The hydraulic design of the system should also take account of the irrigation water's physical and chemical properties. Some factors to consider include slope of the land, application rate, pipe friction losses, minimum water velocity and uniformity of application.

Note that dairy farmers who have dryland systems will need to develop an irrigation system or some other way of applying effluent, and the same conditions will apply.

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