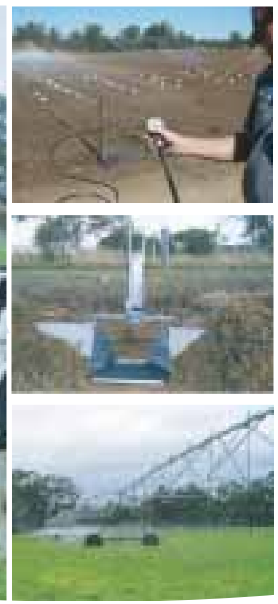
DairyingForTomorrow
DairyCatch

A Partnership for Sustainable and Profitable Dairy Farming in Western Australia

ENVIRONMENTAL BEST PRACTICE GUIDELINES
5.0 EFFICIENT IRRIGATION



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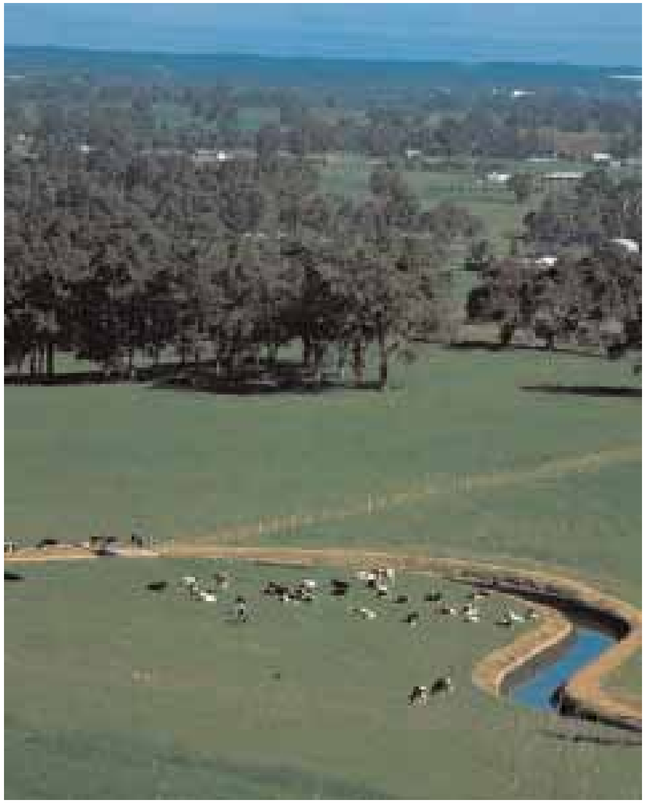
5.0 EFFICIENT IRRIGATION

The aim of irrigation is to provide a pasture or crop with the amount of water it requires for optimal growth. The efficiency of your irrigation depends on a number of factors that include

- type of irrigation system
- application rate
- scheduling and
- the presence of a recycling system.



Irrigation efficiency can be greatly improved in most situations. Some changes will produce a large and direct improvement, while others rely on a series of indirect changes to produce a positive response.

Three key areas aimed at improving irrigation efficiency are addressed in this document. These are

1. irrigation system design
2. improving irrigation efficiency and
3. irrigation scheduling.

The cost of implementing efficient water use will vary according to individual farm designs and component costs. The presentation of case studies provides a meaningful assessment of what others have done and what it cost them. The case studies presented in section 5.4 are provided as an indication of the budget for those planning similar investments. All dollar figures listed in these guidelines are based on January 2006 values.

These guidelines have been developed in collaboration with the Western Australian component of the national WaterWise Program.

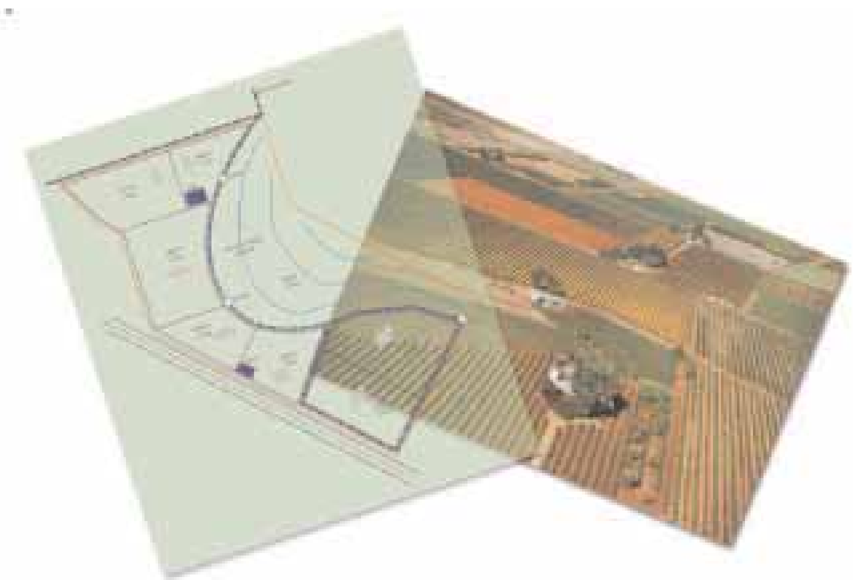
5.1 DESIGNING IRRIGATION AND DRAINAGE SYSTEMS

Correct design underpins the effectiveness of any irrigation system. You need to consider the operational environment of the system, its efficiency and the amount of money you have to spend.

The operational environment includes land use, soil characteristics (water holding capacity and drainage), water availability and quality, irrigation objective, crop type and labour requirements.

Implementation

Certified Irrigation Designers (CID) are available in WA for all systems except flood irrigation. You should use a certified designer if you are planning to install a new irrigation system or changing your existing one. These professionals can design an efficient irrigation system that satisfies your needs most cost-effectively. A listing of service providers is presented at the end of this section.



Irrigation designs should incorporate a drainage system to quickly remove excess water during winter. Understanding your soil characteristics will allow a system to be created that will remove additional surface water quickly and minimise irrigation water runoff in tail drains.

To ensure you end up with the best value for money you should:

- Only irrigate your best suited land
- Use a certified irrigation designer (CID)
- Make sure that your irrigation drainage management plan fits in with your whole farm plan
- A detailed drainage system must be incorporated into any irrigation development at the design stage
- Identify and complete any soil management required before installing your irrigation and drainage systems
- Calculate irrigation requirements of intended production system to ensure your irrigation system can meet these requirements
- Check to see that the distribution uniformity of your irrigation system is as good in reality as it is on paper
- For greater flexibility and accuracy, consider automating your pressurised or flood irrigation system
- Examine the potential for fertigating nutrient applications
- Consider trading unused irrigation water

A poorly designed irrigation system can lead to extensive additional costs, whether due to pumping costs, poorly matched sprinkler packages or simply an inability of the system to provide the required amount of water. So if you are changing the purpose of your irrigation system it will often require a complete overhaul.

A correctly designed irrigation and drainage system will provide efficient water use with least environmental impact and deliver the best return on investment. The design must also take into account the irrigator's ability to finance the work and your attitude to risk.

Listing of Certified Irrigation Designers

The contact details of a certified designer closest to you are available from the IAA website www.irrigation.org.au/CIDLocate. Please note that this list is constantly updated.

Further Information

Moorhead, S. D. and Aylmore, P.M. Unpublished, 'What price sprinkler uniformity?', Western Australian Department of Agriculture, WA.

Western Australian Department of Agriculture. 1992. Design guidelines for fixed sprinklers & micro-irrigation systems. Farmnote 30/1992.

Website

www.irrigation.org.au

5.1.1 IRRIGATION AND THE WHOLE FARM PLAN

Ideally, your irrigation and drainage system design will be part of your whole farm plan. It will fit in with all of your other operations and make use of the vast amount of information contained in your whole farm plan.

The system design should be an integral part of your irrigation and drainage management plan (IDMP). It should resemble an owner's manual for the irrigated farm enterprise, describing the resources available, the management procedures needed to achieve the best management practice and the direction for future development.

An IDMP will help you match your soils and irrigation system(s) with your land use and other resources. It will also help you identify opportunities to improve your irrigation management. It should contain a management analysis, physical mapping details and an action plan.

Implementation

You need to bring all your information together and create a plan for efficient and effective management. For irrigators, this means building on your irrigation and drainage system design, and covering all aspects of your irrigated enterprise to create an irrigation drainage management plan. Guidelines for developing an IDMP are referenced below.

An IDMP should contain a management analysis, physical mapping details and a plan for action. Consisting of both a map with overlays and a written report, the IDMP outlines the features of your irrigation area and exposes opportunities, limitations and other relevant details.

Your IDMP is a tool to help you set and achieve production and performance targets. Once integrated into your property management plan, it will show how the irrigation enterprise fits in with your other farm management such as grazing system or animal production, and environmental management.

Having an irrigation and drainage system design as part of your whole farm plan

- ensures the IDMP aligns with the rest of your farming operation and is working towards your general goals and aspirations
- maximises usefulness of related information
- reduces the need for several copies of the same information

Further Information

IDMP guidelines can be downloaded from www.agric.wa.gov.au/IDMPGuidelines.

NSW Agriculture (2003). *Irrigation and drainage management planning*, 'Introduction to irrigation management', Training Notes, edited 2004 for WA, Dept of Agriculture WA.

5.1.2 SELECTING THE BEST SOIL TYPES AND LAND MANAGEMENT UNITS

Good farming relies on understanding the capability of your physical resources. Mapping your soil types or land management units will allow you to identify which areas are most suited to different uses.

This will also help identify any potential seepage or waterlogging sites that should be avoided when irrigating.

When designing your irrigation system, always conduct a soil survey to determine the soil characteristics across your property. Ideally, you want a well drained, highly fertile area that is not prone to flooding, salinity or nutrient issues.

Irrigating only your best land units will boost your chances of getting a decent return on your investment.

Implementation

You should avoid:

- seasonally wet areas
- poor draining areas
- areas with shallow water tables
- saline soils

Below are some general issues to consider for three common soil types.

Table 5.1 Land management and irrigation considerations related to soil type

Soil Type	Land management	Irrigation considerations
Sand	Erosion potential (especially along the coast)	Low storage potential. Best suited to sprinkler or drip systems
Loam	Generally fertile	High storage, suited to all systems
Clay	Waterlogging can lead to reduced crop production Water tables less than 2 m from the surface can lead to salinity problems over time	High storage, suited to all systems Flood irrigation may reduce infiltration in the long term due to sodicity Heavy clay soils require extensive ponding time to allow sufficient infiltration when flood-irrigated

FIGURE 5.1 Drip irrigator

Shallow soils are best irrigated using sprinkler or drip systems (Figure 5.1), as they have a lower total water storage capacity and an ability to provide only the required amount of water.

Deep homogenous loam or clay soils with medium infiltration are preferred for border irrigation. Heavy clay soils can be difficult to irrigate with border irrigation due to the time required for infiltration of sufficient water, so sub-surface drip irrigation is often considered a better option, except for pasture, for these heavy soils.

Seasonally wet areas are likely to have waterlogging problems when flood irrigating and often are the result of high water tables. Issues with high or perched water tables include capillary rise through fine soil types, leading to long term problems with soil salinity.

EM38/31 survey maps provide salinity risk assessments and likely yield losses due to salinity. As such, they can be useful tools for targeting areas for future expansion.

Irrigating poor soils often results in extensive costs for little return. Although systems can be designed to manage certain aspects of a less than ideal area, this will always result in a poor financial return. Variations in soil type across a paddock can often limit the development of an area for irrigation.

Further Information

Brouwer, C, Prins, K, Kay, M and Heibloem, M.
Training Manual No 5, *Irrigation Water Management: Irrigation Methods,* online at www.fao.org/docrep/S8684E/s8684e00.htm

5.1.3 CALCULATING IRRIGATION REQUIREMENTS

Crops require a certain amount of water for optimal growth. The irrigation requirement is the amount of water that is *not supplied by natural rainfall.* The irrigation requirements for a specific crop can be estimated by comparing crop requirements with expected rainfall for wet, average/median and dry years.

Given Western Australia's typical dry summers, it is usually safe to assume that the irrigation requirement over this season will be equal to the crop requirement. You will also need to note any critical periods in plant development when the crop or pasture will not be able to sustain reduced water intake without affecting yield or quality.

Seasonal and peak irrigation requirements of the crop on any given area should always be considered when designing an irrigation system, to ensure the system has the capacity to meet the irrigation water requirement.

Implementation

A water budget will allow you to determine either the amount of water you will need to irrigate a specified area (Formula 1), or to calculate the area you can irrigate with a specified amount of water (Formula 2). To apply for a license to access irrigation water, the area that can be irrigated should be known to determine the amount of water you will need. If you already know how much water you will have available, you should use the second formula to calculate the crop area you will be able to adequately irrigate.

Formula 1								
Irrigation water required	=	area to sow	÷	irrigation system efficiency*	x	annual crop water use		

Formula 2						
Area	=	irrigation water available	÷	annual crop water requirement	x	irrigation system efficiency*

* **irrigation** system efficiency can either be estimated or calculated. (See section 5.2.2)

Once you have determined the annual irrigation requirement, you also need to identify any peak periods during the irrigation season when limited water could most restrict crop growth. Crops will vary their water use during different growth stages and it is important to ensure that the irrigation system can meet the plants' peak demands. For example, pasture uses more water at that point where full ground cover is reached. If the irrigation system cannot supply the required water volume at this point, production will drop.

Calculating a monthly water budget will help you determine whether your irrigation system can deliver the water required over the summer peak periods. In the example presented in Table 5.2, a peak demand of 203.8 mm is required in January. This budget also highlights the need to start irrigating earlier in the season in years of low rainfall.

In Table 2, values for both Decile 1 and Decile 5 are listed. Decile 1 figures relate to dry conditions and are needed when developing an irrigation plan. Decile 5 figures related to average moisture conditions and are useful for the day to day management of a system.

Table 5.2 Example water budget

Rainfall						Crop Water Use			Irrigation	
Month	Decile 5 Rainfall mm	Decile 1 Rainfall mm	Effective Rainfall factor	Effective rain Decile 5 mm	Effective rain Decile 1 mm	Evap mm	Kc	ETcrop mm	Irrigation requirement Decile 5 mm/ha	Irrigation requirement Decile 1 mm/ha
Data Source	Table 4	Table 4		A x C	B x C	Table 4	Table 7	F x G	H - D	H - E
	A	B	C	D	E	F	G	H	K	L
July	178.2	105.6	0.6	106.9	63.4	55.3	0.75	41.5	0	0
August	132.1	68.3	0.7	92.5	47.8	65.9	0.75	49.4	0	1.6
September	90.7	46.8	0.8	72.6	37.4	81.6	0.80	65.3	0	27.8
October	55.4	22.8	0.8	44.3	18.2	115.9	0.85	98.5	54.2	80.3
November	30.4	11.6	0.9	27.4	10.4	153.0	0.85	130.1	102.7	119.6
December	9.6	1.6	0	0	0	205.5	0.85	174.7	174.7	174.7
January	3.4	0	0	0	0	239.8	0.85	203.8	203.8	203.8
February	6.6	0	0	0	0	212.0	0.85	180.2	180.2	180.2
March	13.0	1.4	0	0	0	179.2	0.85	152.3	152.3	152.3
April	48.6	8.6	0.9	43.7	7.7	109.7	0.80	87.8	44.0	80.0
May	133.5	58.3	0.9	120.2	52.5	71.1	0.80	56.9	0	4.4
June	187.1	106.3	0.7	131.0	74.4	53.6	0.80	42.9	0	0
								Total(mm/ha)	912	1025

Further Information

WaterWise on the Farm. 2004. Water Budgeting. WA workshop training notes.

5.1.4 MAXIMISING DISTRIBUTION UNIFORMITY IN PRESSURISED SYSTEMS

The spacing between your sprinklers/emitters and the operating pressure of your irrigation system will determine your distribution uniformity. This is an important factor in ensuring the best crop yield and quality.

Distribution uniformity indicates how evenly your sprinklers/emitters are operating (or overlapping), by comparing the drier portion of the irrigated area with the average.The higher the distribution uniformity, the more evenly your water is being distributed.

Another way of assessing application uniformity is called the co-efficient of uniformity (CU). This measures the variation in application depths and provides a better indication of non-uniformity.

Milani (1991) reported that more than 70% of the designed irrigation systems surveyed had incorrect spacing and operating pressures that resulted in poor uniformity and additional annual electricity costs of up to $400 per hectare. This prompted the additional training of designers to ensure that their advice was in line with the latest irrigation technology.

Implementation

A correctly designed pressure system should meet the following distribution uniformities:

System Type	New system	Older system
Drip	95%	85%
Sprinkler	85%	75%

The distribution uniformity should be checked each year as part of the regular maintenance of the irrigation equipment.

Precipitation rates or water outflow can be measured using catch cans as follows:

1. Place catch cans in a pattern appropriate for the irrigation system being evaluated. Pivots and lateral movers require a single line of cans placed along the length of the arm, while a grid pattern is usually used for gun and single canon sprinklers, and drippers.
2. Operate the irrigation system for its usual time period.
3. Measure and record volume contained within each catch can, together with its relative location.
4. Calculate and record the distribution uniformity/coefficient of uniformity using the relevant equation below. Be sure to record which measure of uniformity you have used.

The distribution uniformity (DU) is calculated using the following equation:

$$DU = \frac{\text{average of lowest 25\% precipitation readings}}{\text{average of all precipitation readings}} \times 100$$

The coefficient of uniformity (CU) is calculated by relating the water caught in each can with the average catch of all cans. The total variation is calculated by adding the difference and is used to determine the non-uniformity of the application (see Equation below).

$$CU = \frac{(1 - \text{total of variation of each reading from the average})}{\text{average value of can readings X number of can readings}} \text{ X } 100\%$$

CU will normally have a lower value than DU due to the method of calculation. A CU of 84% is accepted as standard by the indus try. Having a highly uniform distribution will deliver improved, consistent growth over the irrigated area.

Further Information

Calder, T. 2005. Efficiency of sprinkler irrigation systems. Farm Note 48/92. Department of Agriculture WA.

Connellan, G. 2002. Efficient irrigation: a reference manual for turf and landscape, University of Melbourne, online: http://www.sewl.com.au/sewl/upload/document/WaterConManual.pdf

Milani, S. 1991. Survey of irrigation efficiencies on horticultural properties in the Peel-Harvey catchment. DAWA Technical Report 119.

Water Management Team. 2004. Evaluation your pressurised system. Irrigation Management training notes. NSW Agriculture (edited WaterWise WA)

5.1.5 APPLICATION UNIFORMITY IN FLOOD SYSTEMS

An efficient irrigation system is one that evenly applies the correct amount of water to an area at the right time. If application is not uniform, some areas will be over-watered while others don't get enough.

Uniformity of application can be measured as distribution uniformity (DU) or coefficient of uniformity (CU) for sprinklers and emitters (see 5.1.4 *Maximising distribution uniformity in pressurised systems*), but there is no accurate method of measuring application uniformity for flood systems.

Flow rate and head pressure, bay dimensions, how long water is on each part of the paddock and drainage volume all affect the uniformity of water application in flood irrigation systems. Uniform application is important for infiltration of water into the soil and for managing run off. Uneven application of water results in areas having different opportunities for water to infiltrate into the soil. Infiltration is the major factor influencing application uniformity in flood irrigation systems and varies between soil types.

Implementation

Although there is no accurate means to determine uniformity of flood applications, the following method will give you a rough idea about differences in wetted depth both down and across the bay. This is an important basic measure of your field application efficiency and can also indicate how much applied water is actually lost below the root zone as deep percolation.

Select three sites along each of the top, middle and towards the end of a given bay

Following an irrigation event, dig down, using a shovel or auger, to the point where the soil profile has been wetted. This depth will likely vary along the length of the bay

Record the depths of the wetted soil profile and the presence of effective roots at each site.

If you are irrigating several bays at a time through the same dethridge wheel, you will probably find very large differences in wetted depths between the top and bottom of a bay. This reflects the time available for water to infiltrate at the top of the bay and indicates poor application efficiency. Ideally you want to minimise the difference in wetted depth down the bay. Improvements can be made by increasing the rate of flow onto the bay, reducing irrigation intervals and modifying the bay gradient. This would lead to improved overall production.

Benefits

Improved consistency of water application across the paddock will result in more consistent growth across the entire irrigated area.

Improving application efficiency will usually also increase the amount of water applied to the paddock that is actually used by the crop. This is a pronounced issue for flood irrigation systems due to the volume of water applied with each irrigation event.

By applying water as uniformly as possible in flood systems, you will be reducing the excess water infiltrating at the top of the bay. Excess water moves below the effective root zone, adding to the recharge of the underlying water table. In areas with a high water table, such as the South West Irrigation Area, this increases the risk of salinisation by capillary rise. Minimising loss of water below the effective root zone also reduces nutrient loss down the soil profile.

Knowing the uniformity of your system allows you to manage your irrigation appropriately and promptly attend to system maintenance detected by variations in application uniformity.

Further Information

Willis, A. 2002. *Management of irrigation systems*, 'Module 3 (Option 1) Product selection'. Charles Sturt University, NSW.

Water Management Program. 2002. *Evaluating your surface irrigation system.* Irrigation Management training notes. NSW Agriculture, NSW.

5.1.6 LASER-GRADING OF FLOOD IRRIGATION BAYS FOR IMPROVED DISTRIBUTION

Laser grading or levelling refers to moving soil to achieve a uniform grade both down and across a paddock or field. The topsoil is generally removed and stored at a nearby site and the subsoil levelled with a small rate of fall down the paddock or bay. The topsoil is then evenly re-applied to produce a level paddock with a rate of fall suitable for flood irrigation of the soil type involved.

Implementation

The layout of a border irrigation system involves reaching a balance between soil type, slope, border strip dimensions and flow of water, so that the desired depth of water is applied uniformly to the entire paddock without losses to deep percolation or surface runoff (Booher, 1974).

Soil surfaces are uneven by nature, with many undulations caused by weathering and other processes. The aim of laser grading is to level the surface of an irrigation bay while providing the bay with an even slope downwards and across to improve water movement.

Laser grading is used by many flood irrigators to improve the efficiency of irrigation and minimise recharge. It improves surface flow of water by reducing undulations down the bay, reducing the time it takes for the wetting front to reach the end. It also improves surface drainage (Figure 5.2).

Laser levelling allows you to flood irrigate paddocks that may not have been previously suitable. It can also improve the efficiency of your irrigation system by reducing height differences across the paddock and providing a constant fall for ease of water movement down the bay.

FIGURE 5.2 Paddock being laser-graded

The down-side is that the effects can be medium term only if the graded surface is used for grazing animals or annual pasture/deep rooted crops that require constant tillage or ripping.

Further Information

Booher, L J. 1974. *Surface Irrigation*. FAO Publication No. 95, 162 pp

5.1.7 AUTOMATION OF FLOOD IRRIGATION BAYS

Automation of flood irrigation is the use of a device to operate irrigation structures so the flow of water can be changed from one bay, or set of bays, to another in the absence of the irrigator.

The prime benefits of automated flood irrigation are savings in time and labour. With less need to constantly check how far water has flowed or to regulate flow, the technology aims to improve farmer lifestyle while also improving farm-level irrigation efficiency.

Implementation

Flood irrigation can be very time consuming. Automation allows greater flexibility within farming operations and can often improve irrigation scheduling.

The main advantages of automating, from an efficiency point of view, relate to increased reliability of irrigation, potentially faster irrigation of each bay and correct shutdown of water flow once water reaches a predetermined trigger point.

If installed and maintained correctly, automation can reduce labour requirements and the need to be up at all hours of the night.

There are different ways of automating your flood irrigation system, with differing levels of technical requirements and varying considerations for each.

There are four main types of automation equipment currently available. These are hydraulic systems, pneumatic systems, mechanical timers and electronic systems (Table 5.3).

Hydraulic systems use an arm activated by changes in water pressure through solenoid valves controlled by a computer. Hydraulic systems are fixed and, although suitable for most (if not all) outlet types, the pressure of the water supply is critical.

Pneumatic systems operate on air pressure, controlled by the bay sensor. They normally require manual start-up but they can be further automated using mechanical timers to start the irrigation. These systems are suited to pipe or flap outlets. Installation and design recommendations must be met to ensure condensation does not cause blockages (Figure 5.3).

FIGURE 5.3 Padman pneumatic flood irrigation gate

Mechanical timers generally have half hour graduations with a range from zero to 24 hours on both start and stop timers. Multiple bays can be set at one time for continual watering of individual bays over a 24 hour period. A comprehensive understanding of the factors affecting rate of movement down the paddock or bay is needed to determine the correct shut-off time (Figure 5.4).

FIGURE 5.4 Automated gate with mechanical timer

FIGURE 5.5 Electronic flood gates

Water babies are a type of mechanical timer that come with an alarm device that you carry with you like a pager. When the water reaches a predetermined point, a bay sensor alerts you via radio that it is time to shut off water flow. This reduces the time spent checking on irrigation progress, but you still have to turn the water off manually.

Electronic systems are best suited to gates or flaps and are a portable system, allowing movement around the farm. With some of these, the door/gate is controlled by radio signal sent from the bay sensor. With others, the bay sensor is used with a backup timer. Depending on the setup of these systems, a full irrigation cycle can be automated, or just a single bay (Figure 5.5).

EFFICIENT IRRIGATION

When deciding on the system that best suits your requirements, you need to consider the reliability, operational aspects and engineering principles involved.

- Has the system been tested for similar applications and, if so, were the results good?

All systems should be evaluated in terms of suitable outlet applications, external influences critical to operation, whether the system is fixed or portable and the degree of automation, duration control and mode of activation.

Beyond this technical assessment, a number of other questions need to be asked.

- Is the supplier/installer local?
- Is there evidence of after-sales service (backup for repairs, problems and maintenance)?
- Is there a local reputation for the equipment and/or provider?
- Can the system be extended or upgraded?
- Is it compatible with other equipment?

Benefits

- Range of options available with differing skill and labour requirements
- Reduced time/labour needed for irrigation
- Improved irrigation control
- Improved farm level irrigation efficiency
- Less wastage

Liabilities

- High maintenance requirement
- Use of automation may imply an adequate understanding of soil infiltration characteristics and how long the bay will take to irrigate
- Irrigator may develop a false sense of security in terms of irrigation scheduling. There is still a need to schedule your irrigation events according to weather or soil moisture status.

TABLE 5.3 Characteristics of the four main types of flood irrigation automation systems

System	Suitable outlet types	External influences critical to operation	System fixed or portable	Potential degree of automation	Irrigation duration control	Mode of activation
Hydraulic systems						
- Miles	Most outlets	Water supply pressure	Fixed	7 day span auto cycle	Timer	Water computer controls water to hydraulic ram.
- O'B	Any outlet	Water supply pressure	Fixed	Auto cycle	Bay sensor	Timer and bay sensors control the water pressure that activates a valve controlling a hydraulic ram.
- Watermate Irrigation Control	Most outlets		Fixed	Auto cycle	Timer	Controller and solenoid valves control hydraulic rams.
Pneumatic systems						
- Padman	Pipe or flap		Fixed	Auto cycle	Bay sensor	Bay sensor signal transmitted by air pressure. Timer or manual start.
Mechanical systems						
- Padman	Pipe or flap	Water supply rate	Portable	Auto cycle	Timer	Mechanical timers open and close gate.
Electronic systems						
- Electronic Irrigation Systems P/L	All doors		Portable	Full cycle	Bay sensor	Bay sensor transmits radio signal to door controller.
- Vapod	Rectangular gate		Portable	One bay	Bay sensor with timer backup	Tank on gate empties to open gate, fills with water to close again.
- Baywatch	Rectangular gate or flap		Portable		Timer	

Adapted from Agbodo et al. (1997).

Further Information

Agbodo, E., Cape, J. & Willis, A. 1997 'Performance testing of automatic irrigation equipment for surface irrigation', Technical Report, Australian Irrigation Technology Centre, SA.

Standen, R. and Roberts, G. 1997. Establishing a process to improve irrigation automation. Institute of Sustainable Irrigated Agriculture, Victoria.

5.1.8 AUTOMATION OF PRESSURISED IRRIGATION SYSTEMS

Pressurised irrigation systems can be automated to reduce labour input and give greater flexibility to the irrigation management of the business. The most common form of automation for pressurised irrigation systems is the use of a controller. A controller is a small computer that sets what area of the irrigation layout will be watered and the duration of the irrigation event. In general, the larger the irrigation system the more complex the controller needs to be.

Implementation

When selecting an automation system, you need to consider the infrastructure it will be controlling, the level of desired automation, the environment in which it will operate and the reliability of the automation.

Advances in telemetric technology have led to the use of radio transmissions, whereby an irrigation system can be controlled from a remote location using a computer or even a mobile phone.

Automation of pressurised irrigation systems is usually decided at the time the irrigation system is put in place. As part of the irrigation system, choices should be discussed with the system designer before the installation takes place.

Benefits

- Ability to water on time and shut water off even if unexpected events call you away from the farm
- May reduce labour requirements but will not eliminate it altogether

Liabilities

- Fully automated systems that are not closely monitored can lead to a false sense that everything is working fine
- Can lead to poor scheduling if 'paddock checks' are not maintained, to ensure the crop is growing well and there are no system problems (either the irrigation or automation system).

5.1.9 FERTIGATION

Fertiliser can be added to irrigation water to provide a nutrient-rich supply of water to pasture and crops. This can be through the addition of chemical fertiliser or effluent that is mixed or diluted with fresh water before irrigating.

Application of fertiliser or effluent (Figure 5.6) with the irrigation water can improve uptake by the plant by providing required nutrients in small amounts in a soluble form that the plants can easily uptake. The nutrients can be distributed more uniformly across the paddock.

If you intend to apply nutrients with your irrigation water, special care must be taken to minimise drainage and runoff. Aside from the obvious waste of nutrients, such losses are highly detrimental to the environment and should be avoided.This is particularly important in intensively used agriculture land where eutrophication of waterways is an evident problem (such as the current case in the Peel-Harvey, and Vasse-Wonnerup catchments). There is also the potential to compromise agricultural water quality when recycling contaminated water from tail drains. The wastes from a high density of stock on irrigated pasture, together with supplementary seasonal feriliser application to enhance pasture quality, poses a significant risk of nutrient loss into waterways. The Department of Water has developed Water Quality Protection Notes that recommend precautionary measures you need to have in place. These are referenced under Further Information and can be downloaded online.

FIGURE 5.6 Effluent fertigation using a travelling irrigator

Implementation

It is important to ensure your irrigation system is designed to deal with fertigation. If it isn't, adding fertiliser or effluent will cause costly problems due to blockages, breakdown and excessive wear and tear on your irrigation equipment.

Where injecting fertilisers into solid set systems, a simple rule of thumb is to inject only in the middle two quarters of an irrigation event, to ensure water is through the entire system beforehand and that the fertiliser is flushed out afterwards. This is not possible with centre pivot systems. Obviously the fertiliser or chemical needs to be soluble and, if mixing different fertilisers or chemicals, care should be taken to ensure they are compatible in solution.

Benefits

- Improved uptake and utilisation of soluble nutrients by the plant
- Nutrients distributed more uniformly across the paddock
- Nutrients supplied incrementally through crop life cycle, matching delivery with plant needs
- Nutrients able to be supplied when conventional equipment cannot enter paddock
- As less labour and machinery is required, crop damage associated with conventional methods is avoided

Liabilities

- Greater care needed for correct irrigation amount to reduce risk of nutrient losses through profile
- Measures need to be taken to avoid contamination of water supplies and soils

Further Information

Christen, E. 2002. Drip irrigation for row crop vegetables', *Irrigation Practice Training* Module 2B. Charles Sturt University, NSW.

Department of Water. 2006. Vegetation buffers to sensitive water resources. WQPN 6. Available online at www.water.wa.gov.au

Department of Water. 2006. Nutrient and irrigation management plans. WQPN 33. Available online at www.water.wa.gov.au

5.1.10 DRAINAGE

Drainage is the surface or subsurface movement of excess water from the paddock or farm. It is a major consideration when designing an irrigation system. The design must ensure water is removed quickly from the paddock during winter to avoid waterlogging while avoiding the potential for erosion.

FIGURE 5.7 Subsurface pipe drains.

Surface drainage systems can simply involve a small fall across a paddock to provide downward flow of water to a collection point, usually some sort of tail drain, from where it is directed to a collection, storage or disposal point.

Subsurface drainage is the installation of mole or pipe drains below the soil surface, providing a pathway for water to move along. These pathways will also direct water to a drainage system for storage or disposal (Figure 5.7).

Implementation

Surface drainage systems can be simple or complex, depending on the soil type and topography of the area and the irrigation system to be used. Flood irrigation systems have a greater requirement for quick drainage to reduce the length of time paddocks are inundated (Figure 5.8). Sprinkler systems apply a smaller amount of water at each application, so their drainage systems will only be needed to move surplus winter rainfall.

FIGURE 5.8 Flood irrigation surface drain.

Mole drainage is used to drain excess water from the subsoil through a series of stable earthen pipes or 'mole' channels between 0.5 to 1.2 m below the surface (Figure 5.9) and with even or low grade down the paddock (Bennett, 1999). The channel should be formed at least 0.2 m into suitable clay (Schwab, 1981).

Only soils containing more than 30% clay are considered suitable for moling and, although this is a good way to ameliorate waterlogging, it is not suitable where soils have high slaking or dispersive characteristics. Highly dispersive soils lose their stability in water, so mole drains will quickly collapse.

Further information is available in Bulletin 4610 – Mole drainage for increased productivity in the south west irrigation area.

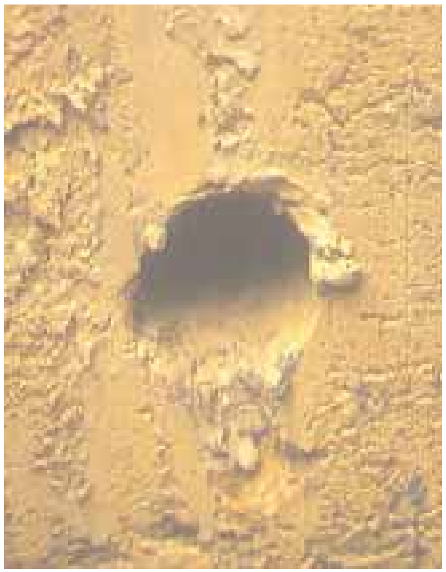


FIGURE 5.9 Mole drain

FIGURE 5.10 Buried pipe drain

Buried pipe drains consist of slotted pipe buried in the soil profile (Figure 5.10). A continuous sheet of tarpaper or fibreglass cloth is placed over the top of the pipe to allow water but prevent soil entry into the slots (Cox 2001). Alternately, the pipe may be bedded in gravel (or similar coarse sand pack) to act as a filter.

Benefits

- Improved flow of water off the irrigated paddock (whether winter rainfall or over irrigation)
- Removal/movement of stored salt together with water drainage

Liabilities

- Mole drains may require re-doing every few years
- Mole drainage not suited to all soil types

Surface and sub-surface drainage of irrigated pastures at Benger.

Further Information

Bennett, D, George, R, and Russell, B. 1999. Mole drainage for increased productivity in the South West Irrigation Area. Agriculture Western Australia, Bulletin 4610.

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5.1.11 VALUING WATER AND WATER TRADING

With the value of water used in agriculture being recognised by other water users, the option of "trading" water rights has been added to the Council of Australian Governments (COAG) Water Reform Agenda. A key objective of the Water Reform Agenda is to encourage cost effective and sustainable water use.

The irrigation industry is the major user of freshwater in Australia, consuming between 70 and 80 per cent of all water used. In Western Australia it accounts for approximately 30 per cent of the State's water use. It provides many benefits to the nation, but there are also a number of challenges facing the industry. These include:

- infrastructure decline (with insufficient public funds to pay for refurbishment)
- low profitability in the industry generally; and
- natural resource and environmental degradation such as declining water quality, rising water tables and increased river and groundwater salinity

Water trading was introduced to address these issues, allowing people to buy and sell water entitlements or allocations.

Previously the only way that water could be traded was by selling land with a linked water entitlement to an existing irrigator and the subsequent amalgamation of the two water entitlements. This linkage between water and land is being broken by COAG's Water Reform Agenda.

Implementation

Water can now be traded temporarily or permanently within the Harvey Water (HW) Cooperative area. This trading has the potential to increase prices as any irrigating shareholder can bid for saleable water allocations.

Water trading enables water to be redirected to sites of higher value usage. This, and the fact that irrigators will be able to financially benefit from the sale of water they do not need, should lead to greater water use efficiency. The resulting economic benefits to water users will have a positive effect on the sustainability of irrigation production. Equally important, permanent water trading gives irrigators, as well as other water users, the opportunity to increase the flexibility of their operations. With permanent trade, an irrigator will be able to buy water to expand operations. Conversely, some irrigators may wish to sell water they don't need. They can sell all or part of their water entitlement for financial gain.

Competition for water for uses other than farming will likely result in higher prices in the long term. As others show a willingness to pay more for water in anticipation of higher returns, competition may become fierce. High water prices will force farmers into using the scarce resource as efficiently as possible.

Initially, Harvey Water began encouraging irrigators with excess water to list it for trade on the Voluntary Register it maintained, but only a low number of irrigators chose to be involved. Consequently, members passed a resolution at the 2003 AGM to change the company Articles of Association. Presently, if irrigators use less than 75% of their total water entitlement for irrigation or trade, their contact details are automatically listed on a register that potential buyers can access. Transactions can be either temporary (lease) or permanent (transfer of ownership) and standard trade conditions apply.

Allocation trading can take place at the Harvey Water Office, via the internet or at the water trade auctions held regularly during the irrigation season. Harvey Water does not get involved in trade negotiations and traders are required to sign a indemnity release form recognising this.

More information about water allocation trading is available from:

Harvey Water Office
James Stirling Place (opposite the Visitors' Centre)
HARVEY WA 6220

Tel 08 97290100, Fax 08 97290111 & www.harveywater.com.au

5.2 MAXIMISING IRRIGATION EFFICIENCY

Irrigation efficiency can refer to the efficiency of a single irrigation event, the entire season, or simply your irrigation system.

With the rising demand for water and community aspirations to use water wisely, there is a need to use irrigation water in the most effective manner to get the best possible return on it.

Maximising your irrigation efficiency involves:

- Irrigating your best land that supports pastures and crops suited to both the soil type and irrigation system
- Running your irrigation system efficiently and maintaining it
- Correctly scheduling your irrigation events
- Minimising losses of water in the system, also through runoff and deep percolation
- Ensuring product returns are greater than the cost of irrigation.

Implementation

To ensure that you are maximising your irrigation efficiency, there a number of key things that you can do.

- Test water quality frequently
- Measure the actual system efficiency of your irrigation system at least once or twice a year
- Check the uniformity of application of your irrigation system before the start of the irrigation season and at regular intervals throughout the season
- Measure and record inputs and outputs of the system (fertiliser, water, evaporation, yield) so you can calculate and record water use efficiency indices
- Conduct regular checks of the irrigation system to ensure it is still operating at design specifications for pressure, flow rate and application rate
- Understand the role infiltration rate plays in irrigation, and recognise how the rate can vary across areas and over time
- Determine the water requirement for the pasture or crop you wish to grow and calculate the readily available water within its effective root zone
- Manage your irrigation events to minimise surface drainage runoff and deep drainage past the effective root zone
- Where drainage runoff occurs due to irrigation system limitations, implement some form of tail water recovery to reuse drained water

5.2.1 WATER QUALITY

The important thing to note with water quality is that it is not just the quality of the water that is important; it is the interaction between the water, soil and plants.

When referring to irrigation water quality, salinity is usually the main issue that comes to mind. However, any ion in large quantities can become toxic to plants and has potential to cause soil structural problems.

Within the Harvey Water irrigation area, a number of producers are using saline water from Wellington Dam. Due to the high levels of salt introduced onto the farm with this water, irrigation events needs to be carefully managed to ensure salts are leached from the plant's effective root zone. Most flood irrigation systems in the area are not very efficient and do not require any additional applied water for leaching purposes. However, once high efficiency gains have been made, a leaching fraction will be required.

Irrigating with saline water can have a number of effects, usually resulting from the changes within the physio-chemical properties of the soil. Salinity and sodicity are the two main effects of irrigation with saline water over time, as soils that become saline through secondary salinisation invariably become sodic.

Salinity

All irrigation water contains some salts, which will be left within the soil profile during evaporation of water. The build up of salts in the soil profile reduces the plant's ability to take up water, limiting plant growth. Plants absorb water by osmosis, taking in salt particles to draw water from the soil. If the salt content of the surrounding soil/water medium is too high, water can no longer move into the plant roots.

Measuring salinity in the field

Sodicity

Sodicity is a term that describes soils that contain a disproportionate amount of sodium ions relative to other anions. Soils are generally termed sodic if they have an Exchangeable Sodium Percentage (ESP) above 6%. Soils can be naturally sodic or develop sodicity following long term application of water containing elevated levels of sodium chloride or salt, as is the case in the Wellington Dam supplied areas of the HWIA. Sodic soils often have poor soil structure (and therefore bad porosity), particularly in the presence of low salinity irrigation water or winter rainfall. This is because the clay minerals are de-flocculated (or disperse) on contact with fresh water, blocking up the pathways of water movement and resulting in reduced infiltration, poorly drained soils and also limiting plant root growth.

Replacement of sodium ions with the more strongly bonded calcium ions via the application of high rates of gypsum is a way of reversing sodicity. However it has been found that typical HWIA clay soils require 15-20 t/ha of gypsum applied. Ripping before application and then watering-in allows the gypsum to be incorporated into the soil better increasing its rate of effect, however it is still likely to take several years for the calcium to penetrate deeply enough in the profile to have a measurable impact, even with deep ripping. Lime can also be used, but it is far less soluble and generally much slower in being effective. Interestingly, research has also shown that Wellington water has enough salt content (electrolytic concentration) to maintain flocculation in the SWIA. This means that porosity and infiltration rates may be maintained by this water during the irrigation season. However the fresh winter rains rapidly cause de-flocculation and the commonly observed symptoms of poor drainage and waterlogging.

It should be noted that poor soil structure can result from both dispersion (from sodicity) and slaking which is caused by poor mechanical strength. Sodicity can be reduced by the addition of calcium but slaking characteristics are more problematic as the only current practical treatment is to greatly increase soil organic matter to depth. Growing deep-rooted species and annual deep ripping to encourage deeper roots and incorporating organic matter to depth are possible techniques. Farmers from the SWIA report that this technique, when applied over many years, has resulted in soils with better structure and internal drainage characteristics.

Prior to undertaking any soil structure remediation, it is recommended that Cation Exchange Capacity and associated major cation analyses (particularly Na - to determine the ESP), together with dispersion and slaking tests be undertaken to determine the precise cause of poor soil structure.

Iron and acidity

People drawing irrigation water from aquifers in the South West may have problems with dissolved iron. Iron may cause nozzle blockages at levels above 1 ppm. This can be managed by regularly servicing the nozzles or installing aeration and settling systems to oxidise the iron and remove it from the water.

Acidic water can corrode the interior of irrigation system components which can be prevented by lining them with inert material.

Nutrients

Irrigation water from natural bodies (surface or ground) may contain nutrients that affect plant performance. It is important to test the water periodically and take appropriate action such as reducing the amount of a fertiliser nutrient if it present in significant amount in the irrigation water.

Water quality testing in the laboratory

Implementation

Salinity

In dealing with salinity resulting from secondary salinisation, it is often hard to economically reverse the problem. Rather, the aim should be to minimise further problems while maintaining the best possible production. Irrigating to crop water requirements will reduce the amount of water adding to the high/perched watertable, thus reducing the potential for further salinisation by capillary rise. Of course, if irrigating highly efficiently then a small leaching fraction will be required to move salts past the root zone of the crop.

Sprinkler irrigation creates further management issues, as even water with quite <u>low</u> levels of salt can produce leaf damage in sensitive crops if the system is irrigating the canopy. It is important to match your crop to the prevalent salinity level as **all** water contains some level of salt.

Sodicity

Treatment or amelioration of sodic soils with gypsum may be required if being irrigated. Application rates should be based on soil tests, however typical rates of up to 15-20 t/ha of gypsum is commonly recommended for highly sodic soils. Ripping at application allows the gypsum to be incorporated into the soil increasing its rate of effect. Lime can also be used, but it is far less soluble and generally much slower in being effective.

Gypsum treatment is applicable to sodic soils that have clay dispersion as the main cause of their poor structure. Gypsum is not useful for soils that slake. The structure of these soils can only be improved by adding organic matter. This can be through retention of previous crop stubble or mulching dead crops into the soil. Annual deep ripping programs that encourage deeper rooting and allow organic matter to drop deep into the profile have proven very effective on clays in the south western irrigation area.

Nutrients

Where nutrients such as nitrogen, phosphorus and potassium are found in irrigation water, consider how this will affect your fertiliser regime. Is less nitrogen, phosphorus or potassium needed? If potentially toxic elements are found in the water, can the water be 'shandied' to reduce the concentration?

Cost considerations

Salinity has been shown to reduce crop yields by up to 75% in badly affected areas. Applying highly saline water increases the salts within the root zone, making it much harder for the crop to obtain water for growth.

Benefits

- Awareness of potential for water quality issues allows management responses to address them
- Management of water quality issues can lead to improvement in production levels

Liabilities

- Ongoing requirements to ameliorate or prevent sodic soils resulting from long term irrigation resulting in salinity problems
- Difficulty of addressing areas with both salinity and sodicity

Further Information

Rengasamy, P and Bourne, J. 1997. Managing sodic, acidic and saline soils. Cooperative Research Centre for Soil & Land Management. Hyde Park Press. SA.

Scholz, G and Moore, G. 1998. Soil alkalinity and soil sodicity *In* 'Soil guide: a handbook for understanding and managing agricultural soils', (ed. G. Moore), Agriculture Western Australia, Bulletin No. 4343.

Websites

www.harveywater.com.au/Irrigator%20information/irrigator_information.asp

5.2.2 SYSTEM EFFICIENCY

To make the most of the irrigation water applied, you need to ensure that your irrigation system is efficient. Check the components of the irrigation system where inefficiencies may exist.

When assessing the efficiency of a particular irrigation system, the different components that make up the system will have different efficiency levels. As such, the overall *system efficiency* is calculated by multiplying the efficiency of each individual component.

Implementation

Flood irrigation (Border check)

System efficiency for surface systems is determined by combining the distribution uniformity and field application efficiency.

System efficiency = Distribution uniformity x Field application efficiency

The *distribution uniformity* can be calculated by comparing the amount of water entering the supply system and the amount of water that is actually delivered to the paddock.

Distribution uniformity = Water delivered to irrigated paddock x Total inflow to supply system

For most flood irrigation systems, it is not possible to measure the flow onto the paddock. At best, only estimated distribution uniformity can be determined. To estimate the flow onto your paddock, you can measure the depth of infiltration at points down the irrigated bay and use this to estimate the amount of water applied.

The *field application efficiency* is determined by comparing the amount of water actually delivered to the paddock with the amount of water available to the crop after runoff losses.

Field application efficiency	=	Water remaining on paddock	x	Water delivered to irrigated paddock

Fixed Sprinklers

Calculating the *system efficiency* for fixed sprinklers involves determining how much water is applied (*mean application rate*; *MAR*) and how evenly it is distributed (*distribution uniformity*; *DU*).

MAR is the average rate in mm/hr that water is applied to the soil and should not exceed the infiltration rate of the soil. To calculate MAR, you will need to use the catch can method to determine water application depth (see *5.1.4 Maximising distribution uniformity in pressurised systems*).

Calculating MAR

STEP 1 Add up all the volumes of water (mm) collected in your catch cans.

STEP 2 Change this volume into an *application depth* by using the appropriate catch can conversion factor (Table 5.4).

STEP 3 Divide this by the number of catch cans to get the *average application depth*.

STEP 4 If the test duration was NOT exactly one hour, divide the average application depth by the test duration (minutes) and multiply by 60 to obtain a per hour equivalent **MAR**.

Diameter of Catch Cans (mm)	Figure to divide the collected amount by
75	4.40
80	5.00
90	6.40
100	7.90
102	8.20
104	8.50
106	8.80
108	9.20
110	9.50
112	9.90
113	10.00
114	10.20
115	10.40
120	11.30
125	12.25
145	16.50
165	21.30
200	31.40

TABLE 5.4 Catch can volumes (ml) to irrigation depth (mm) conversion values

For example, let's assume the total volume of water collected using 36 catch cans (113 mm diameter) over a 45 minute test period was 1029 ml.

Using a conversion factor of 10 obtained from Table 5.4,

Application Depth = 1029 ÷ 10 = 102.9 mm

and

Average Application Depth = 102.9 ÷ 36 = 2.86 mm

MAR = Average Application Depth ÷ test duration) X 60

(2.86 ÷ 45) X 60 = 3.60 mm/hour

*Distribution uniformity (DU)*is calculated based on catch can readings using the equation:

$$DU = \frac{\text{Average of lowest 25\% precipitation readings}}{\text{Average of all precipitation readings}} \times 100$$

For more detail see *5.1.4 Maximising distribution uniformity in pressurised systems*

Centre Pivots

For travelling irrigators, *system efficiency* involves determining *instantaneous application rate (IAR*) and *distribution uniformity (DU*).

Instantaneous application rate is measured in mm/hour and is based on the average application amount, the travel speed and wetted width. The instantaneous application rate must not exceed the infiltration rate. Detailed sheets are available to help calculate Centre Pivot *system efficiency*. A centre pivot calculator is also available for use as the calculations are quite complex.

Distribution Uniformity (DU) is calculated based on catch can readings, using the equation:

$$DU = \frac{\text{Average of lowest 25\% precipitation readings}}{\text{Average of all precipitation readings}} \times 100$$

For more detail see *5.1.4 Maximising distribution uniformity in pressurised systems*

Inefficient systems due to incorrect pressure or flow values that ultimately affect distribution uniformity will result in increased pumping costs. Systems operating within design specifications will be more efficient and less costly. As part of a regular maintenance schedule, checking the system efficiency allows you to respond quickly to reductions in operating efficiency.

Using plastic containers to measure distribution uniformity of a centre pivot

Further Information

Water Management Program. 2002a. Evaluating your surface irrigation system. Irrigation management training notes. (Edited WaterWise WA). NSW Agriculture.

Water Management Program. 2002b. Evaluating your pressurised irrigation system: Systems 5&6. Irrigation management training notes. (Edited WaterWise WA). NSW Agriculture.

Water Management Program. 2002c. Evaluating your pressurised irrigation system: System 3 - Centre Pivots. Irrigation management training' notes. (Edited WaterWise WA). NSW Agriculture.

5.2.3 WATER USE EFFICIENCY

Under the nationally accepted framework of terms and definitions developed to allow consistent evaluation and monitoring of irrigation systems throughout Australia, water use efficiency (WUE) should be used as a generic label for water use indices and irrigation system efficiencies (Purcell and Currey, 2003). As long as the units used are recorded, any measure of production can be compared to the water used. This includes irrigation water applied, total water applied, evaporation or evapotranspiration.

Irrigation system efficiency is defined by FAO as being made up of two parts: conveyance efficiency (or *Distribution Efficiency*) and field canal/conduit efficiency (*Field Application Efficiency or Mean Application Rate*). When combined, these make up the *Distribution System Efficiency* or *System Efficiency*.

Implementation

To determine your water use efficiency you will need to maintain accurate records of production levels and water volumes used. Calculating your WUE is essentially an exercise in benchmarking.

Common WUE indices include:

- production (kg DM) per ML irrigation water applied
- production (kg DM) per ML total water applied, including rainfall
- production (kg DM) per mm evaporation.
- gross income ($) per ML irrigation water applied

The Department of Agriculture has developed a simple spreadsheet to calculate pasture production per ML irrigation water applied, based on back calculation of pasture dry matter. This provides an index of WUE in terms of pasture production (kg DM) per ML irrigation water applied or milk production (kg Milk Solids) per ML irrigation water applied.

Estimating irrigated pasture production

Benefits

- Calculating your WUE each irrigation season allows you to determine any variations in production, indicative of changes. If production levels are decreasing or vary greatly from the local median, it highlights the need to identify potential problems with the irrigation system or management.
- Calculating your WUE each irrigation season also allows you to compare your system with others in similar environment.
- Comparing regional WUE indices can be a powerful tool to assess the potential of alternative systems or pasture crops.

Further Information

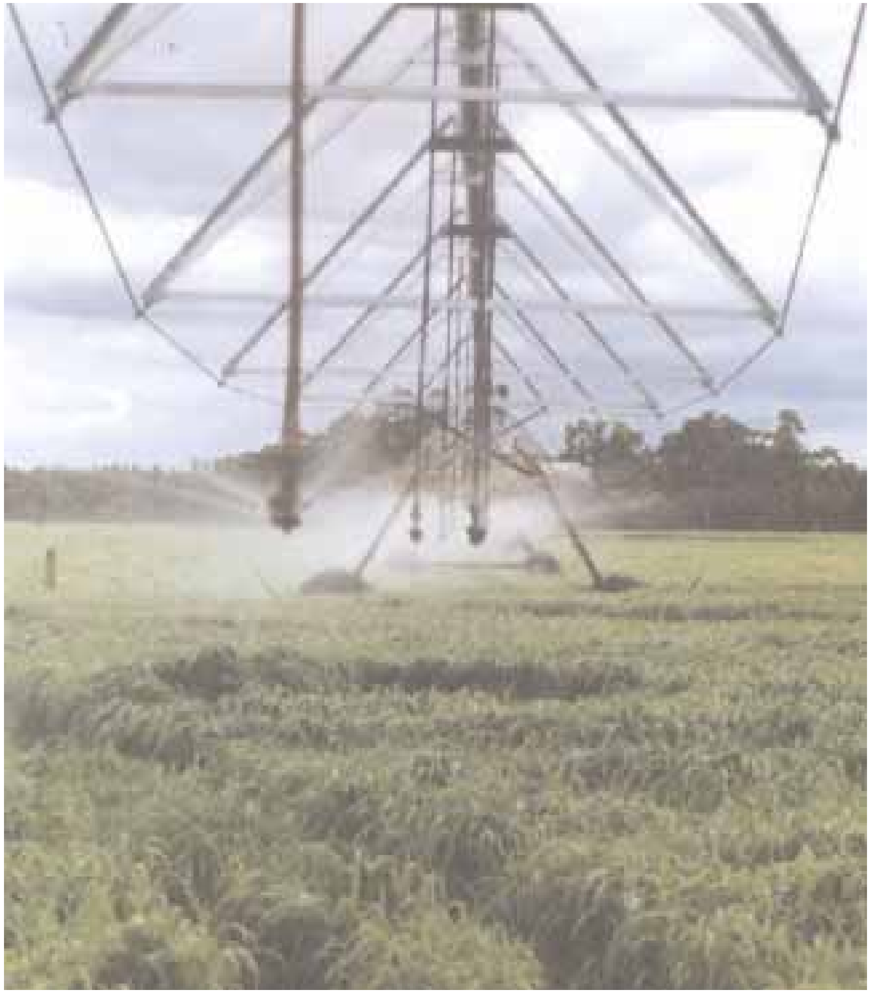
Purcell, J. and Currey, A. 2003. Gaining acceptance of water use efficiency framework. Terms and definitions. Final Report. National Program for Sustainable Irrigation.

Water Resource Team. 2001. Irrigation management training notes. (Edited WaterWise WA), NSW Agriculture, NSW.

5.2.4 APPROPRIATE APPLICATION RATES

Applying the correct amount of water at a rate at which it can infiltrate the soil is important to maximise pasture or crop production, minimise evaporative losses and reduce the risk of soil structural problems.

The term *application rate* is usually associated with sprinkler systems, where water should be applied at a rate similar to infiltration. For flood irrigation, as the name suggests, applying the appropriate volume of water to the area is important.



Implementation

Sprinkler applications should match the soil type. Higher application rates generally mean larger droplets. On soils prone to crusting, these larger droplets can break up the soil particles, leading to 'fines' filling the soil pores, thus limiting infiltration and creating or exacerbating soil structural problems.

Sprinklers used on sodic soils need careful management, as application rates can often exceed infiltration rates. By using a finer droplet, there is less chance of soil 'fracture' on impact.

Although infiltration rates at any given location will vary over time, in general heavier soils will have a slower infiltration rate than coarser sands. There are exceptions to this rule, such as the non-wetting sands common in the south west.

Most sprinkler systems are set in terms of the instantaneous application rate (IAR) or mean application rate (MAR), and the difference in the amount of water that can be applied is varied only through operating time. This needs to be considered in the design of the irrigation system to ensure the system is well matched to the pasture or crop to be irrigated.

Determining appropriate application rates can be a balancing act with sprinkler systems to apply the required volume of water while matching infiltration rates on heavier soil types.

Further Information

Raine, Steven (2004). 'Fundamentals of Irrigation' training, Bunbury District Office, December 13 & 14 2004, NCEA.

5.2.5 CLIMATE CONSIDERATIONS

Irrigation is meant to replace water used up by plants during evapotranspiration. Transpiration of water occurs mainly through the light-sensitive stomata, so water use at night is very low while the stomata are closed.

Of the various factors that affect the rate of transpiration, prevailing weather conditions usually have the most influence. Vapour pressure deficit indicates the drying power of the atmosphere, being large on hot, dry days and low on cool wet and dry days. Evaporation also increases with high wind speeds as the wind moves moist air away from the plant leaves.

In Mediterranean and more temperate climates, sunshine and ambient temperature are related. Solar radiation provides the energy that drives photosynthesis. Plants convert more minerals into food on sunny days than cloudy ones and therefore require more water. Aspect also plays a role; plants most exposed to sunlight have the greatest water requirements.

During rainfall events, plants can readily take up water from the soil. On wet days, evaporation is at a minimum. As the rain intercepted by foliage evaporates, a moist atmosphere is created and this reduces transpiration losses.

Weather stations such as this are becoming increasingly common on farms that rely on irrigation

Implementation

The two common measurements used to describe weather conditions that affect plant water use are:

Pan evaporation (Epan) that measures the amount of water evaporated from an open water surface contained within a *US "Class A" pan* (Figure 5.11) and,
Evapotranspiration (ET) calculated using wind speed, humidity, temperature and solar radiation.

FIGURE 5.11 US Class A Epan

Epan and *ET* values are commonly measured at most WA weather stations. Using these measures in conjunction with various *crop coefficients* has enabled a number of WA farmers to effectively estimate crop water use, irrigation water requirement and scheduling. Studies have shown that typical flood irrigated clover ryegrass pastures in the south west irrigation area (SWIA) require irrigating after 70 mm of Epan. Daily Epan measurements are recorded at three sites across the SWIA. These can be accesses through the Harvey Water website.

5.2.6 SOIL INFILTRATION

Soil *infiltration rate* or *intake rate* is a measure of the soil's ability to absorb a given amount of water over a certain time period. This movement of water into a soil is *the most important factor* affecting irrigation and normally dictates the design and management of any irrigation system.

Infiltration rates vary according to soil physical characteristics. When water is applied to an initially dry soil, the rate of infiltration is usually very high but declines with time to reach a 'steady-state' or basic infiltration rate. Cumulative infiltration describes the total depth of water entering the soil and is sometimes a more useful measure than infiltration rate.

Efficient irrigation involves matching water flow rate and duration of the irrigation event to the soil's infiltration characteristics, to maintain the soil water content at levels needed by the plant and below field capacity.

Implementation

For flood irrigation, the best way to ensure correct infiltration is to match the soil's inherent infiltration ability with application rate, bay slope and time of application. If poor infiltration is being caused by excessive slope, application rates can be reduced or earth works implemented. For example, paddocks at the Harvey Agricultural College have steep slopes with high natural drainage. To maintain soil water content, infiltration has been increased by reducing irrigation flow rate by minor earth works to create an uneven surface. Another way to manage this would be to irrigate more frequently while a higher soil moisture content exists, allowing better infiltration and movement throughout the soil profile.

FIGURE 5.12 Decompacting soil to improve infiltration rate

Poor soil infiltration rates are likely to be a problem caused by poor soil structure. These are often related to dispersion (caused by soil sodicity, see 5.21) and slaking characteristics of the soil. These can be inherent soil characteristics or occur as the result of past management such as irrigation with saline water (sodicity and dispersion), over cultivation or pugging and compaction (slaking).

Before attempting amelioration, soil tests should be done to determine if the structure problem is cause by dispersion, slaking or a combination. Replacement of sodium ions with the more strongly bonded calcium ions via the application of high rates of gypsum is a way of reversing sodicity. However it has been found that typical HWIA clay soils require a gypsum application rate of 15-20 t/ha. Ripping before application and then watering-in allows the gypsum to be incorporated into the soil and increases its rate of effect. However, it is still likely to take several years for the calcium to penetrate deeply enough in the profile to have a measurable impact, even with deep ripping. Lime can also be used, but it is far less soluble and generally much slower in being effective. Interestingly, research has also shown that Wellington water has enough salt content (electrolytic concentration) to maintain flocculation in the SWIA. This means that porosity and infiltration rates may be maintained by this water during the irrigation season. However, the fresh winter rains rapidly cause de-flocculation and the commonly observed symptoms of poor drainage and waterlogging.

It should be noted that poor soil structure can result from both dispersion (from sodicity) and slaking which is caused by poor mechanical strength. Sodicity can be reduced by the addition of calcium but slaking characteristics are more problematic as the only current practical treatment is to greatly increase soil organic matter to depth. Growing deep-rooted species and annual deep ripping to encourage deeper roots and incorporating organic matter to depth are possible techniques. Farmers from the SWIA report that this technique, when applied over many years, has resulted in soils with better structure and internal drainage characteristics.

Regular deep ripping also reduces the compaction layer caused by pugging and stock and machinery traffic.

Increasing soil infiltration and drainage also has important implications in managing salt build up. Most salt is removed from irrigation areas during the winter runoff period. Maximising soil porosity and natural drainage characteristics will greatly assist with the management of soil salinity and sodicity.

In many situations during flood irrigation in the HWIA, water infiltrates quickly at the top of the bay moving down to a perched layer, where it travels laterally to the base of the paddock where the water gradually seeps out over the cycle (Figure 5.13). This results in the commonly observed salinity and waterlogging problems in the lower part of the bay. Managing irrigation to reduce deep infiltration in the top half of the bay and/or improving drainage in the bottom third of the bay by using mole or sub-surface drainage is the best way to manage this problem.

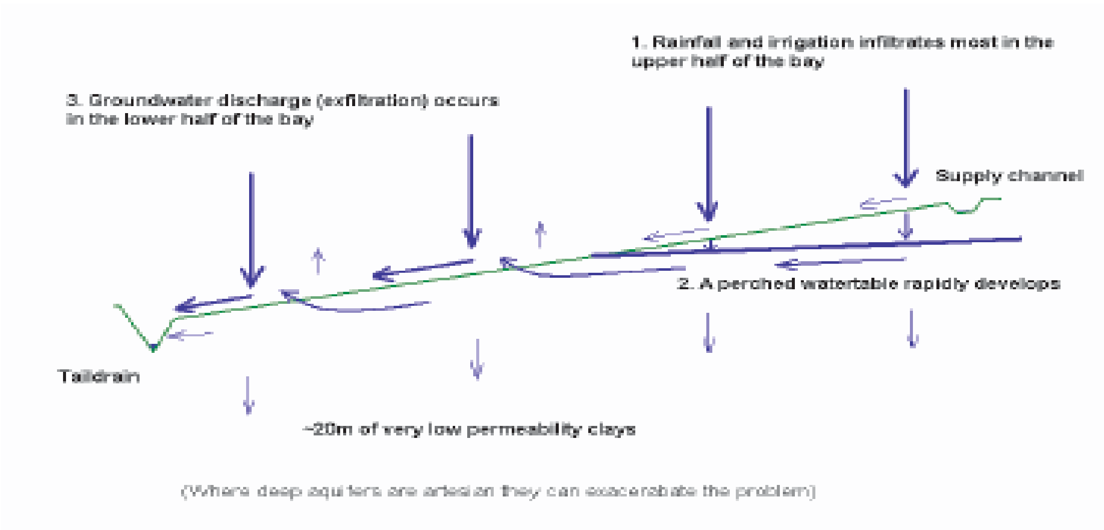


FIGURE 5.13 Perched water tables commonly cause salinity and waterlogging problems for flood irrigators in the HWIA.

For **sprinkler systems**, maximum infiltration is generally going to be desirable. You are only providing the amount of water that the crop requires. If infiltration is reduced, a greater proportion of water will be lost to evaporation. Maintaining soil structure free from any crusting, dispersion or compaction will enhance the infiltration in this situation.

Further Information

Austin, Nick. 2003. Irrigation 3: Critical factors in irrigation. Module 1: Drainage and infiltration. Charles Sturt University, Wagga Wagga. NSW.

5.2.7 EFFECTIVE ROOT ZONES AND PLANT NEEDS

Different plants have different water and nutrient requirements. Such information is normally available from your local seed supplier or DAWA office. To maximise irrigation efficiency, you should apply sufficient water to meet plant requirements. To do this, you need to know how much water plants need for optimal growth and how much moisture can be held in soil and readily accessible to the plant's effective root zone.

The effective root zone is that part of the soil profile where the greatest proportion of fibrous roots is contained. There will often be a few roots growing further down the profile, but these are not part of the *effective* root zone (Figure 5.14). Exceptions to this include plants with tap root systems.

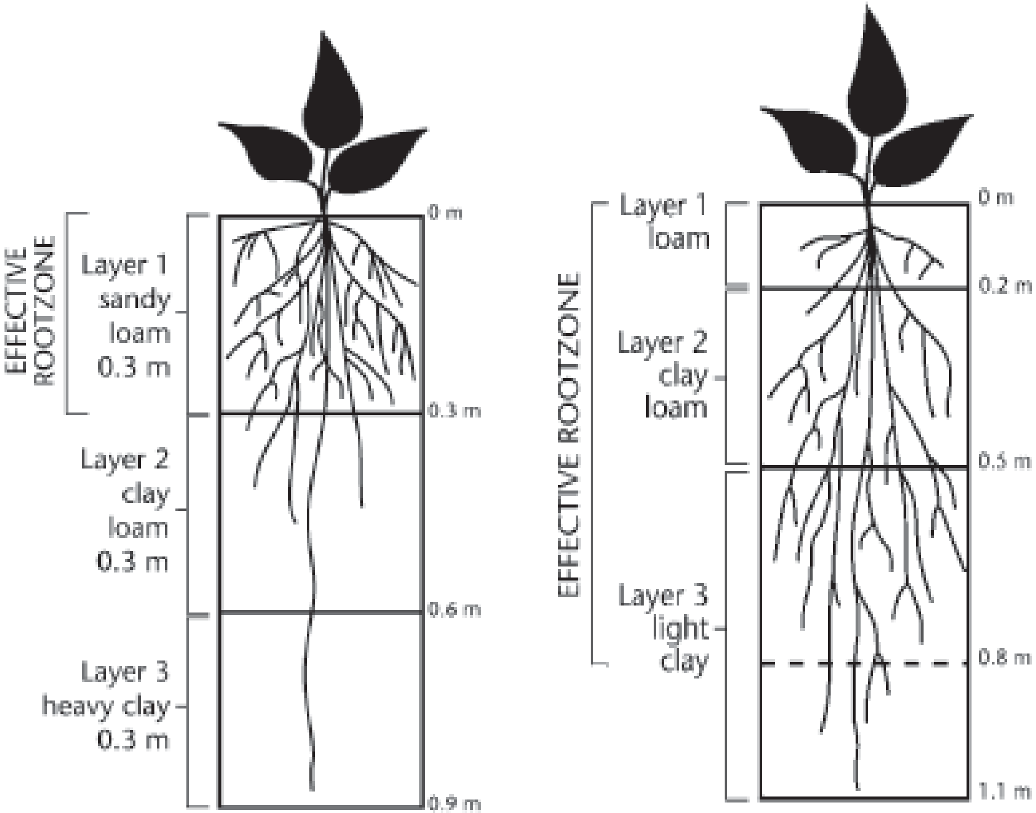


FIGURE 5.14 Effective root zone for two different plants (after Water Management Team, 2002).

Implementation

The intention of irrigation scheduling is to keep the soil water within an acceptable range while making optimal use of the irrigation water. This can best be done by monitoring the soil water balance, or the amount of water retained in the soil based on inflows and outflows from the soil system (see Equation 1 and Figure 5.15).

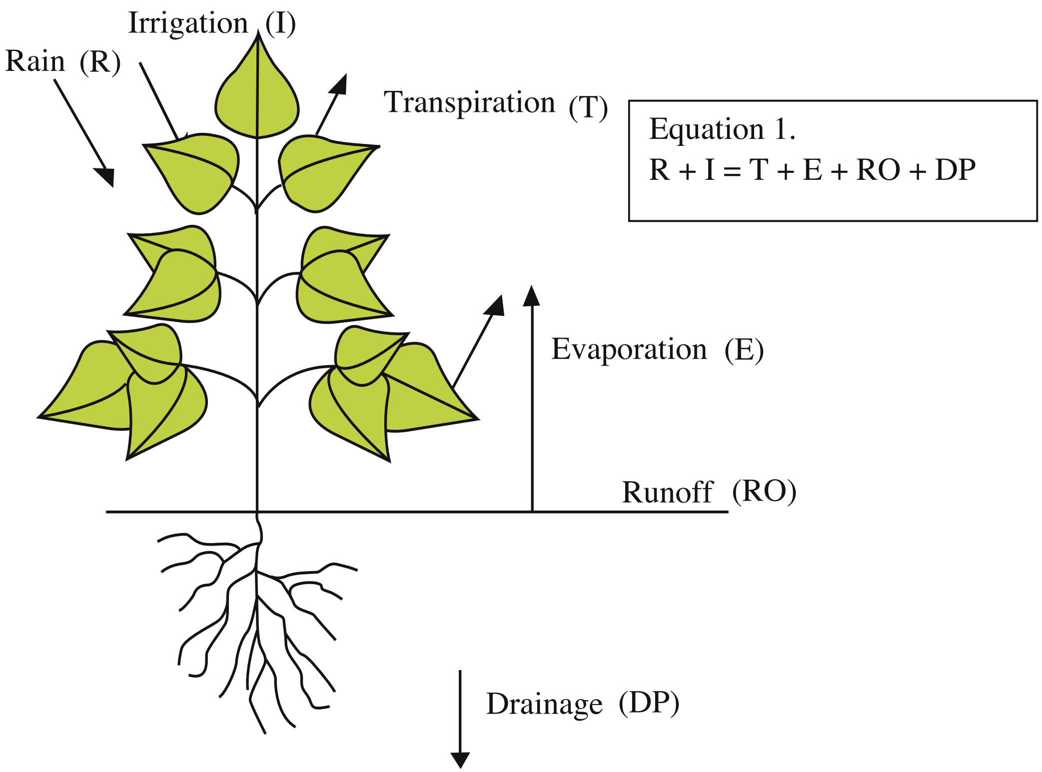


FIGURE 5.15 Soil water balance - inflows & outflows (after Water Management Team, 2002).

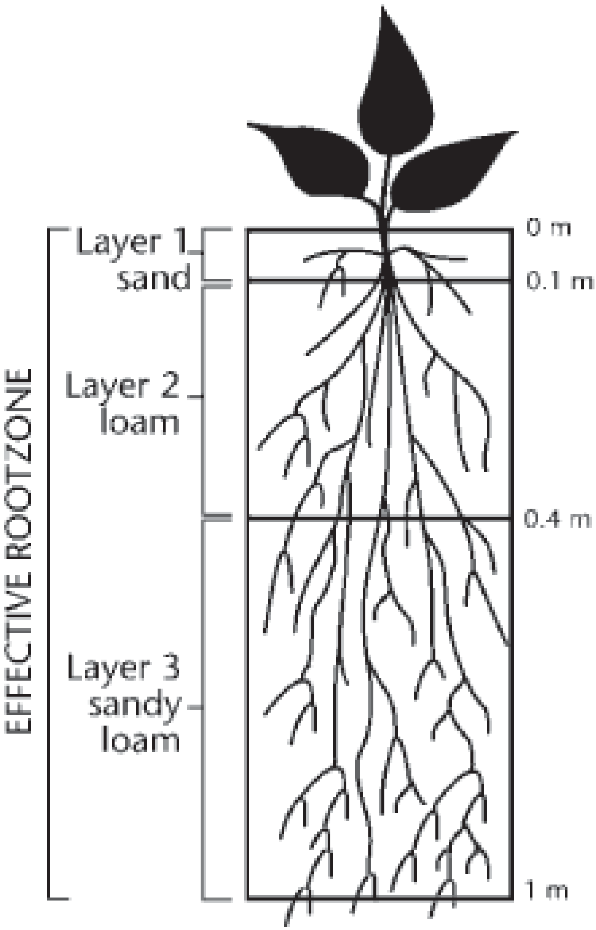
As the soil water is depleted, the plant must work harder to extract water from the soil. Knowledge of the readily available water and the crop's ability to extract water will help determine the frequency of your irrigation events. Table 1 provides an indication of the tension levels at which different plants can readily extract water from the soil.

Monitoring the amount of water actually held by the soil within the effective root zone, known as the readily available water (RAW), and the plant's ability to extract this water, will determine when you need to irrigate. It will also provide valuable information on how long to water for when combined with your irrigation system capacity, as you should only be adding enough water to refill the effective root zone. For most pastures, this is the top 10 to 20 cm of soil.

Calculating the *total profile RAW* for a deep rooted crop such as maize is fairly simple as outlined in the steps and example below.

1. Identify and measure thickness of the soil layers
2. Determine soil texture of each layer
3. Identify the effective root zone
4. Identify the estimated RAW for each soil layer (Table 5.5)
5. Multiply thickness of each soil layer by its RAW value
6. Add results of Step 5 for each soil layer to obtain the *total profile RAW*.

Assume a maize crop is growing in a shallow layer of sand over layers of loam and sandy loam. The effective root zone has been found to be 1 metre. Calculating the total profile RAW is as follows:



Depth of sand (layer 1) = 0.1 m

RAW of layer 1
= 0.1 m X 35 mm/m
= 3.5 mm

Depth of loam (layer 2) = 0.3 m

RAW of layer 2
= 0.3 m X 85 mm/m
= 25.5 mm

Depth of sandy loam (layer 3) = 0.6 m

RAW of layer 3
= 0.6 m X 65 mm/m
= 39.0 mm

Total Profile RAW for this site
= RAW 1 + RAW 2 + RAW 3
= 3.5 mm + 25.5 mm + 39.0 mm
= 68.0 mm

The values presented in Table 5.5 do not take into account organic matter content in the soil that is known to increase both soil water and nutrient holding capacity. The extent of this increased capacity depends on the amount and composition of the organic matter. As such, using the values presented in Table 1 will most likely result in an underestimated RAW.

Capillary rise can provide additional water to the root zone as it moves upwards through the soil profile where the water table is less than two metres deep. Such water may carry dissolved salts into the root zone. Where this occurs, sufficient water must be applied periodically to leach any salts that accumulate in the root zone. This involves a good understanding of where the effective root zone extends to. If saline soil or water exists within the root zone area, growth will likely be limited. For most flood irrigators in the south west irrigation area, the main means of salt removal is by winter run-off. Therefore, it is important to budget for about 10% runoff when irrigating to prevent salt build up over summer.

*Tension is 0 kPa at saturation point. The values are approximations.

Source: Water Management Team NSW Agriculture (2002).

Plant water requirements also vary according to growth stage (Figure 5.16). There is a steep increase in water use from establishment to flowering after which water requirements taper off.

TABLE 5.5 Readily available and available water values for different soil textures

Water Tension *	To - 60 kPa	To -100kPa	To -1500 kPa
	C	D	E
	Lucerne, most pasture species and crops such as maize	Annual pastures and hardy crops such as sorghum	AW is the total water available in the soil. Plants stress well before this level is reached
Soil texture	**Readily Available Water RAW (mm/m)**		**AW (mm/m)**
Sand	35	40	60
Sandy loam	65	70	115
Loam	85	90	150
Clay loam	65	80	150
Light clay	55	70	150
Medium to heavy clay	55	65	140

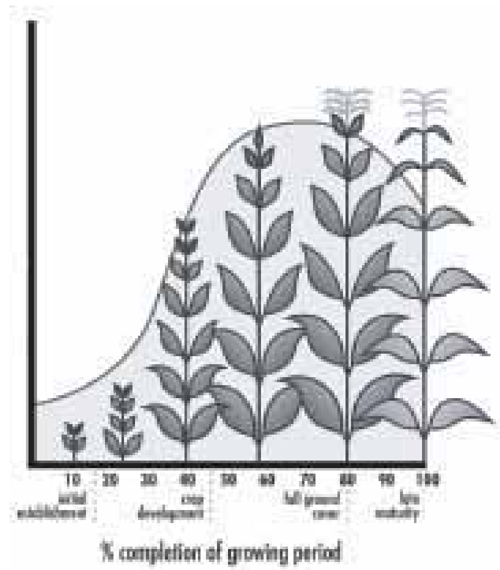


FIGURE 5.16 Water requirements relative to plant growth stage (after Water Management Team, 2002).

DairyingForTomorrow
DairyCatch

Benefits

- Determining effective root zones and understanding plant water requirements will allow you to calculate RAW, an essential piece of information for scheduling irrigation events

Liabilities

- Little data is available on plant water requirements under local conditions. Most of the information on hand is based on research done elsewhere and has been extrapolated to fit to our environment.

Determining effective root zone is essential to providing plant water needs

Further Information

Water Management Team. 2002. Assessing your soil and water resources. Irrigation management training notes. (Edited by WaterWise WA). NSW Agriculture

5.2.8 PRESSURE AND FLOW RATES

Irrigation systems are designed to provide the crop with water at a rate that fits the individual situation. For sprinkler and drip systems, this means that the system should be operating at the designed pressure with the correct sized sprinklers or emitters.

The operating pressure of the system dramatically affects sprinkler and emitter pattern and output, as these are manufactured to create a specific sized droplet and wetting pattern at a designated pressure. A variation in pressure of more than 10% normally renders the system inefficient, as does a variation in flow of 5%.

If the system is operated below its designed pressure, an increased number of large droplets are formed which tend to be thrown further than small droplets, resulting in an uneven distribution. Some areas will receive too much water while others don't receive enough. This reduces paddock productivity and is a waste of water and energy.

Operating the system above the designed pressure level will also cause an irregular wetting pattern, with fine droplets or a mist being produced that will drift with wind and is prone to evaporation. Conversely, small droplets land close to the sprinkler causing an over-wetted area in the absence of prevailing winds.

Implementation

You should have all of the original design figures for your irrigation system. An acceptable minimum would be the pressure and flow charts for the sprinklers or emitters you are using.

Evaluate the pressure and flow of the irrigation system during the off season and carry out any maintenance needed before the irrigation season.

Measure pressure and flow at a number of positions within the block, making sure the system is operating at normal pressure. Position the Pitot tube and gauge (Figure 5.17) with the point of the tube about 3 mm from the nozzle in the stream of water. Flow can be measured by placing a length of flexible plastic tubing over the nozzle and directing the discharge into a container for a minimum of 15 seconds. Record the volume and time.

FIGURE 5.17 Pressure gauge used to measure irrigation system pressure.

Calculation of average pressure and flow rates can be compared against the manufacturer's correct rates for the sprinklers/emitters being used. A pressure variation of more than 10% is unacceptable and indicates either poor system design or that the valve unit has a problem. A flow variation of more than 5% is equally unacceptable.

Pressure variation comparisons are only valid if all sprinklers or emitters are the same. If you are using pressure compensators, these need to be accounted for. If you are using filters on your pressure system, flow rates should be tested both before and after installing the filters to ensure efficiency is maintained.

If your pressure and/or flow rates vary from the manufacturer's correct rates, your system will be operating inefficiently.

Some common reasons why pressure and flow may vary include:

- Wear and blockages in sprinklers and emitters
- System incorrectly designed
- System not being used as designed
- System leakages
- Pump not performing

If you detect a problem, each of these possible reasons will need to be checked. If the variation is due to wear, blockages, leakages or a badly performing pump, the problem can usually be fixed relatively easily. If the system has been poorly designed, you will need to consider how to change the system so it can operate more efficiently. Seeking the assistance of a certified irrigation designer will avoid this. If the system is being used differently to the purpose for which it was designed, you need to consider altering the design to match your current needs.

Further Information

Water Management Program. 2002. Evaluating your pressurised system. WaterWise on the Farm Training notes. (edited WaterWise WA). NSW Agriculture, NSW.

Willis, Ailsa. 2002. Management of irrigation systems, Module 3 (Option 1) Product selection. Charles Sturt University, NSW.

5.2.9 OPTIMAL DURATION OF IRRIGATION

The duration of irrigation events is a function of irrigation system specifications and soil characteristics. All irrigation systems are capable of providing a certain amount of water within a given time period, normally expressed in millimetres per hour. The optimal duration of an irrigation event is the length of time it takes the irrigation system to deliver pasture requirements.

Implementation

To determine the optimal duration of an irrigation event, you will need to know plant requirements, mean application rate (MAR) or instantaneous application rate (IAR) of your system, together with the current readily available water (RAW) in the effective root zone.

These are covered in the following sections:

5.1.3 Calculating irrigation requirements
5.2.2 System efficiency
5.2.6 Soil infiltration characteristics
5.2.7 Effective root zones & plant needs
5.2.8 Pressure & flow rates
5.3 Irrigation scheduling

Knowing the refill point together with an understanding of the amount of water required to fill the profile (RAW) will determine the amount of irrigation water needed. The flow or application rate is the amount of water that can be delivered by your irrigation system. The optimal duration is the time it will take to deliver the volume of water based on your system's capability.

Flood irrigation is a relatively inefficient means of supplying water to plants. Table 5.6 provides some of the sources of inefficiency and their relative contribution errors in measurement.

Table 5.6 Sources of inefficiencies and percent variation in accuracy of flood irrigation systems.

Source	% Variation in Accuracy
Dethridge wheel readings	5 - 10
Channel leakage	0 - 20
Surface runoff as proportion of irrigation water applied	0 - 30[1]
Infiltration variation [2]	see *5.2.7 Soil infiltration characteristics*

Step-by-step example calculations for flood and sprinkler irrigation systems are presented below.

[1] *Five hectares irrigated at 1 ML/ha with 30% surface runoff will lose 1.5 ML of the water applied.*
[2] *Low flow rate increases the level of infiltration. The greater the movement of water beyond the root zone through to the underlying water table, the higher the risk of future salinity problems.*

Example 1. Flood irrigation

Consider a loam soil over clay, growing perennial ryegrass and clover. The effective root zone is 23 cm (within loam soil layer) and the bay area is 0.9 ha.

From Table 5.5 in Section 2.5.7, the loam layer RAW = 85 mm/m and the available water (AW) = 150 mm/m

Step 1: Estimating water requirement

Water Requirement = RAW X Depth

Water Requirement = 0.23 m x 85 mm/m = 19.55 mm (or 20 mm)

Alternatively, a water budget or scheduling aid may be used to determine irrigation requirement – *See 5.1.3 Calculating irrigation requirements*.

It is usually not feasible to flood irrigate every 2nd or 3rd day to replenish the RAW. Most bays are waterlogged for 24 to 36 hours after being flooded and the plants should use most of the water stored in the soil before the next irrigation event can be scheduled. If you flood your paddocks, you need to look at AW, not just RAW.
If AW is 150 mm/m and we assume soil water status is at plant wilting point, the required wetting depth will be:

150 mm/m X 0.23 m = 34.5 mm (or 35 mm)

To wet the 0.9 ha bay are to a depth of 35 mm will require:

(35 mm x 0.9 ha) ÷100 = 0.315 ML of water

Finally, we need to correct for system efficiency. Multiply the 0.315 ML with the appropriate correction factor:

Irrigation system efficiency:	40%	50%	60%	70%
Efficiency correction factor:	2.5	2	1.7	1.43
Corrected water requirement (ML):	**0.79**	**0.63**	**0.54**	**0.45**

This calculation assumes permanent wilting point is reached. It is expected that a maximum of 75% of available water would be used before the next irrigation event was scheduled. Table 5.7 provides irrigation requirements at this level of soil water replacement.

Step 2: Determining flow or application rate

Determining flow rate in flood irrigation systems can be very difficult. Maximum flow on to the property is easily determined by the number of revolutions of the dethridge wheel or by measured output from the pipe system. Measurement of flow onto the paddock is much more difficult, unless it is being piped or siphoned where it can be measured. At best, with gates you can estimate your flow rate.

Step 3: Calculating optimal duration

To work out the optimal duration for an irrigation event, divide the irrigation requirement by the flow or application rate.

For this example let's assume a reduction in flow rate from the dethridge wheel to the paddock outlet of 30%. With a flow rate of 11 ML/day measured at the dethridge wheel, the paddock flow rate will be 7.7 ML/day, or 0.32 ML/hr.

Thus, for each of the irrigation requirements above, the optimal duration is:

Irrigation requirement (ML)* of:	**0.79**	**0.63**	**0.54**	**0.45**
Divided by*	0.32	0.32	0.32	0.32
Optimal timing of irrigation (hrs)	**2.5**	**2.0**	**1.7**	**1.4**

* system efficiency value calculated earlier

Example 2. Sprinkler irrigation

Consider a loam soil over clay, growing perennial ryegrass and clover. The effective root zone is 23 cm (within loam soil layer) and irrigated area is 0.9 ha.

From Table 5.5 in Section 2.5.7, the loam layer RAW = 85 mm/m and the available water (AW) = 150 mm/m

Step 1: Estimating water requirement

Water Requirement = RAW X Depth

Water Requirement = 0.23 m x 85 mm/m = 19.55 mm

As sprinkler systems are designed to provide a given water application rate evenly across over the entire irrigated area, there is no need to calculate the total water volume required. The required wetting depth is equal to the irrigation requirement of 19.55 mm.

Step 2: Determining application rate and duration

Application rate should be equal to the sprinkler specifications. For this example assume the sprinkler mean application rate to be 3.5 mm/hour.

Therefore, the <u>optimal duration</u> of irrigation is:

19.55 mm ÷ 3.5 mm/hr = 5.6 hours.

TABLE 5.7 Irrigation requirements (mm) for 75% available water according to soil type, profile depth and flood irrigation system efficiency.

Soil Type	Profile depth (cm)	System efficiency				
		30%	40%	50%	60%	70%
Loamy sand	10	21.5	16.1	12.9	10.8	9.2
	15	32.3	24.2	19.4	16.1	13.8
	20	43.0	32.3	25.8	21.5	18.4
	25	53.8	40.3	32.3	26.9	23.0
	30	64.5	48.4	38.7	32.3	27.6
	35	75.3	56.4	45.2	37.6	32.3
	40	86.0	64.5	51.6	43.0	36.9
Clay sand	10	25.3	18.9	15.2	12.6	10.8
	15	37.9	28.4	22.7	18.9	16.2
	20	50.5	37.9	30.3	25.3	21.6
	25	63.1	47.3	37.9	31.6	27.1
	30	75.8	56.8	45.5	37.9	32.5
	35	88.4	66.3	53.0	44.2	37.9
	40	101.0	75.8	60.6	50.5	43.3
Sandy loam	10	28.8	21.6	17.3	14.4	12.3
	15	43.1	32.3	25.9	21.6	18.5
	20	57.5	43.1	34.5	28.8	24.6
	25	71.9	53.9	43.1	35.9	30.8
	30	86.3	64.7	51.8	43.1	37.0
	35	100.6	75.5	60.4	50.3	43.1
	40	115.0	86.3	69.0	57.5	49.3
Loamy sandy clay loam	10	34.3	25.7	20.6	17.1	14.7
	15	51.4	38.5	30.8	25.7	22.0
	20	68.5	51.4	41.1	34.3	29.4
	25	85.6	64.2	51.4	42.8	36.7
	30	102.8	77.1	61.7	51.4	44.0
	35	119.9	89.9	71.9	59.9	51.4
	40	137.0	102.8	82.2	68.5	58.7
Loam	10	58.5	43.9	35.1	29.3	25.1
	15	87.8	65.8	52.7	43.9	37.6
	20	117.0	87.8	70.2	58.5	50.1
	25	146.3	109.7	87.8	73.1	62.7
	30	175.5	131.6	105.3	87.8	75.2
	35	204.8	153.6	122.9	102.4	87.8
	40	234.0	175.5	140.4	117.0	100.3
Sandy clay loam	10	35.8	26.8	21.5	17.9	15.3
	15	53.6	40.2	32.2	26.8	23.0
	20	71.5	53.6	42.9	35.8	30.6
	25	89.4	67.0	53.6	44.7	38.3
	30	107.3	80.4	64.4	53.6	46.0
	35	125.1	93.8	75.1	62.6	53.6
	40	143.0	107.3	85.8	71.5	61.3
Clay loam	10	37.0	27.8	22.2	18.5	15.9
	15	55.5	41.6	33.3	27.8	23.8
	20	74.0	55.5	44.4	37.0	31.7
	25	92.5	69.4	55.5	46.3	39.6
	30	111.0	83.3	66.6	55.5	47.6
	35	129.5	97.1	77.7	64.8	55.5
	40	148.0	111.0	88.8	74.0	63.4
Sandy clay	10	37.3	27.9	22.4	18.6	16.0
	15	55.9	41.9	33.5	27.9	23.9
	20	74.5	55.9	44.7	37.3	31.9
	25	93.1	69.8	55.9	46.6	39.9
	30	111.8	83.8	67.1	55.9	47.9
	35	130.4	97.8	78.2	65.2	55.9
	40	149.0	111.8	89.4	74.5	63.9
Light clay	10	37.3	27.9	22.4	18.6	16.0
	15	55.9	41.9	33.5	27.9	23.9
	20	74.5	55.9	44.7	37.3	31.9
	25	93.1	69.8	55.9	46.6	39.9
	30	111.8	83.8	67.1	55.9	47.9
	35	130.4	97.8	78.2	65.2	55.9
	40	149.0	111.8	89.4	74.5	63.9
Medium clay	10	37.3	27.9	22.4	18.6	16.0
	15	55.9	41.9	33.5	27.9	23.9
	20	74.5	55.9	44.7	37.3	31.9
	25	93.1	69.8	55.9	46.6	39.9
	30	111.8	83.8	67.1	55.9	47.9
	35	130.4	97.8	78.2	65.2	55.9
	40	149.0	111.8	89.4	74.5	63.9

Further Information

Department of Primary Industries Victoria. 2001. Irrigation scheduling for vegetable crops. ISSN 1329 8062.

WaterWise on the Farm. 2004. Workshop 3 training notes.

Western Australian Department of Agriculture. 2000. Scheduling irrigation of potatoes using tensiometers on light/medium to heavy soils. Farm Note 107/2000.

Western Australian Department of Agriculture. 1990. Irrigation scheduling: How and why. Farm Note 23/1990.

5.2.10 OPTIMISING DRAINAGE RUNOFF

Drainage runoff results from either over irrigation or natural rainfall that failed to infiltrate the soil. When flood irrigating, a proportion of the applied water will always leave the paddock as runoff if distribution uniformity is maximised. By capturing and reusing this water, the overall farm irrigation efficiency can be greatly improved provided it is not too salty (as it is in Collie, SWIA).

Irrigation aims to supply sufficient water to the soil to replenish the soil water deficit caused by plant demands. The application rate of irrigation water directly affects the irrigation uniformity and the duration of the irrigation events. This controls the volume of water applied and as a result the volume of runoff.

This runoff often contains high levels of nutrients and salt, that can result in reduced quality of water downstream. High levels of runoff also mean that you are paying for both water and fertiliser that you are not using.

Implementation

Flood irrigation should be managed so that the incoming flow is turned off well before the advancing water reaches the end of the field. If not, more than 30% of applied irrigation water may be lost to runoff.

Some level of drainage runoff may periodically be required if irrigating with saline water (such as from Wellington Dam), with a recommended additional 10% for leaching. This is applied to remove any excess salts from the surface that can reduce crop production.

High levels of runoff following an irrigation event indicate system inefficiency. Two ways of improving efficiency are by reducing the volume of drainage runoff or reusing drainage runoff.

Runoff can easily be reduced by closing the flood gate earlier. However, if you need the water to be on for a longer period to allow infiltration to a particular depth, you will need to examine alternative ways of improving efficiency. If flow rate can be reduced then infiltration opportunity time will be increased.

If flow rate is predetermined due to system design and flow needs to be maintained to maximise infiltration, then capturing and reusing water from the tail drain is a good option. A drainage system can be designed to transport drainage runoff to a central location for reuse. For most irrigators, this will require changes to their drainage system design. Alternatively, the tail drain of one set of bays can be used as the head ditch for subsequent bays to enable easy reuse of the tail water. You should always measure the salinity level in drainage water before reusing it.

Further Information

Robertson, DM, M Wood, P MacDonald, N Austin and M Bethune. 2001. Development of a Decision Support Timer for Flood Irrigation Management. Final Report: Technical component. Department of Natural Resources and Environment, Tatura. Project I7048.

5.2.11 SALINITY MANAGEMENT

Salinity refers to the presence of harmful quantities of sodium chloride within the soil and water bodies. Salts have always occurred naturally within the landscape. However, agriculture has resulted in salt build-up in many of the world's major irrigation areas.

Flood irrigation systems often apply more water than is required by plants, adding greatly towards recharge of the underlying water tables. As the water table reaches within two metres of the soil surface, water begins moving upwards due to a process called capillary rise. This water normally contains various soluble particles (including salt), and as water is used by plants or evaporated from the soil surface, salt and other minerals left behind begin to build up over time.

Soluble salts commonly associated with soil salinity can affect growing plants in two ways. Firstly, the presence of salt in the soil reduces the plant's ability to extract water by osmosis, retarding its growth and vigour. Secondly, saline water contains ions other than sodium and chloride (such as borate), that are toxic to plants at high concentrations. These ions are also often responsible for lowering soil pH, which indirectly results in nutrients such as iron, phosphate, zinc and manganese becoming unavailable to the plant.

Proper management of saline soils can reduce the recharge of shallow water tables, increase productivity and lead to higher returns. Concentration of salts in water is usually expressed as milligrams of total dissolved salts per litre of water (mg/L). A good and inexpensive indirect method of estimating salt concentration is to measure electrical conductivity (EC, expressed in micro Siemens per centimetre: ÌS/cm at 25^{o}).

Implementation

Management of saline land needs to be flexible to take into account all the contributing factors that cause salinity. There are a range of techniques for managing saline areas. Some are aimed at preventing or limiting the problem by addressing causes while others seek to mitigate the effects already in place.

In areas prone to salinity, prevention techniques may include deep drainage or revegetation and land works to redirect surface water so that it does not pond or travel across the area.

When irrigating salt affected areas using sprinklers, additional water may be required to leach salts from the crop root zone if winter leaching is not adequate. If adequate drainage is in place then continued leaching of soil with irrigation water will remove salts from the plant root zone, but remember that the salt still needs to 'go' somewhere. In some situations, subsurface drainage may be required and, in severe cases, groundwater pumping may be required to keep groundwater levels down. If pumping, you need to be aware of where the water is being pumped.

Irrigation scheduling (section 5.3) is all about knowing when and how much water to apply to meet the needs of a plant. It is also a great way to reduce the amount of water reaching the water table. You may need to look at quicker ways of applying water to stop it filtering through to the water table. Use soil moisture probes, tensiometers and observation bores to gauge and monitor soil moisture movement.

Monitoring soil moisture allows you to water to plant needs and reduces the risk of salinisation

If this is done before, during and following irrigating events if this is done, you can provide crop water requirements without adding to the underlying water table.

Further Information

Lantzke, N and T Calder. 1999. Water salinity and crop irrigation. Farmnote 46/99, Department of Agriculture WA.

O'Donnell, R and T Lacey. 2005. The cost of salinity calculator - your tool to assessing the profitability of salinity management options by delaying saline impacts to the farm business. Agribusiness crop updates. Department of Agriculture WA.

Russell, B. and D Bennett. 2005 Drainage project update winter 2002. Dairynotes 2/2003, Department of Agriculture WA.

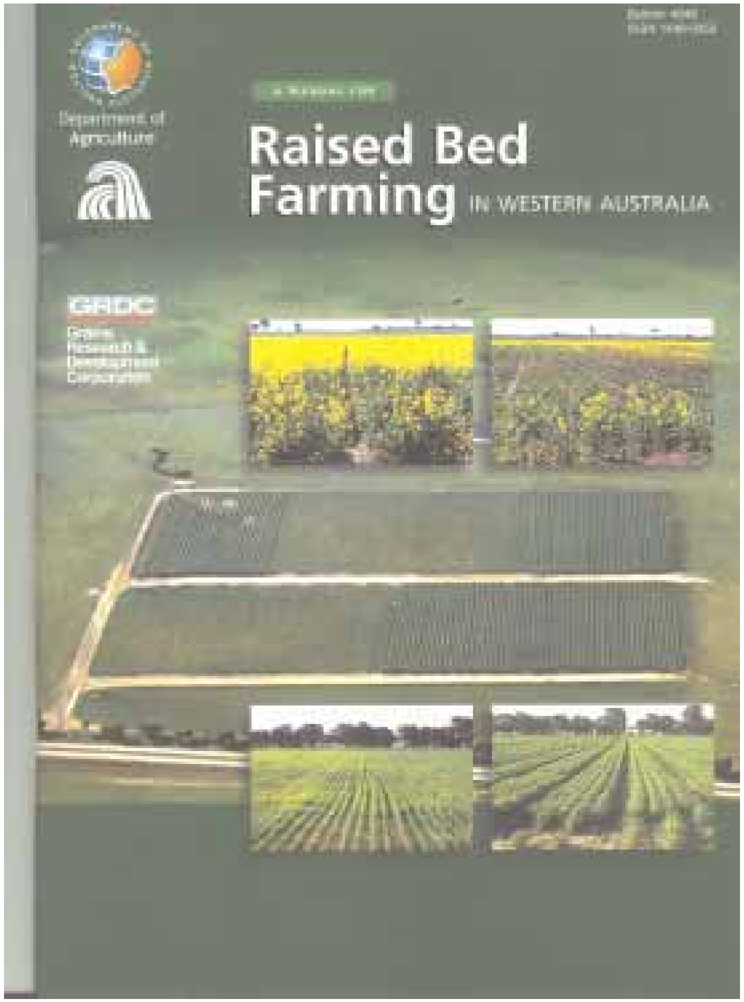
Russell, B. and D Bennett. 2004 Drainage project update summer 2002. Dairynotes Issue 26. Department of Agriculture WA.

Williams, M. 2003. Irrigation 3: Critical factors in irrigation. Module 2: Salinity and groundwater. Charles Sturt University, NSW.

Most internet search engines will provide multiple links for information.

5.2.12 RAISED BEDS

The creation of furrows with raised "beds" has been developed as a means of addressing waterlogging. A manual for raised bed farming was released by the Department of Agriculture in February 2005.



Implementation

Irrigating raised-bed pastures is not very common because of the *perceived risk* of cows slipping and falling and that trampling will damage the beds themselves. Contrary to this, raised beds have been and are still being used for pasture on a few farms around Harvey (Figure 5.18).

FIGURE 5.18 Raised bed pasture

Raised beds can be a useful tool for growing cereal crops for silage and if you are interested in this you should contact your local Department office for a copy of Bulletin 4646.

Further Information

Hamilton, G, Bakker, D, Houlbrooke, D & Spann, C. 2005. A manual for Raised Bed Farming in WA. Bulletin 4646. Department of Agriculture Western Australia.

5.2.13 WATER REUSE AND TAIL WATER RECOVERY

Drainage runoff results from over irrigation or natural rainfall events that have not infiltrated. When flood irrigating, part of the water applied often leaves the paddock as drainage water. Collecting this water as it moves into the tail drain makes it possible to irrigate further paddocks or store it in ponds for later use. Such reuse is an effective risk management tool for irrigation water supply in dry years.

Implementation

The recycling of drainage water can improve water use efficiency and reduce the risk of nutrient off-site impacts. If you plan to irrigate with this reclaimed water, you should assess its nutrient content first and adjust your fertiliser applications to avoid wasteful over-fertilising.

By collecting and recycling drainage water, less is available to penetrate to the water table. This minimises recharge that, in some areas, is high enough to create issues with rising water tables, waterlogging and salinity.

Further, irrigation water always contains some salt and concentrations become higher as the drainage water runs off the end of the field. The salinity of tail water is of particular concern to producers in the Harvey Water irrigation area, where water from Wellington dam is already high in salt. Reclaimed water should be monitored for salt levels because increased salinity is greatly detrimental to both the plants and soils.

Further Information

Robertson, DM, M Wood, P MacDonald, N Austin and M Bethune. 2001. Development of a Decision Support Timer for Flood Irrigation Management. Final Report: Technical component. Department of Natural Resources and Environment, Tatura. Project I7048.

5.3 IRRIGATION SCHEDULING

Water is becoming an increasingly scarce resource to farmers by virtue of smaller amounts being available and increasing competition by other users such as mining companies and residential properties. Irrigation water must therefore be used efficiently and effectively, which means using it only where and when it is needed.

Irrigation scheduling is about providing your crop with the right amount of water at the right time. Managers need to consider soil type, the plant, the layout of the property, the capacity of the irrigation system, the weather and, more importantly, the desired production outcome, whether that be yield or quality or a balance of the two. Dairy irrigators also need to consider their fertiliser applications and grazing management.

The intention of irrigation scheduling is to keep the soil water within an acceptable range and achieve productivity targets. The correct amount of water to apply can be best estimated using a combination of plant, climate and soil based methods.

By scheduling your irrigation events to refill the soil profile within the effective root zone as it reaches its 'refill point', you will be maximising paddock production.

Implementation

- To ensure that you are scheduling your irrigation events appropriately:
- Irrigation scheduling should be based on information derived from a combination of plant, climate and soil based methods
- Irrigate to plant requirements
- Recognise wilting point and field capacity. Understand what these mean for the soil and the plant
- Determine your *refill point* based on yield or quality targets and irrigate accordingly
- Make use of the various scheduling tools available to assist in the timing of your irrigation events

Further Information

Charlesworth, P, 2000. 'Soil water monitoring', *Irrigation Insights No 1.*, Land and Water Australia, Canberra, ACT.

Websites

www.fao.org/docrep/W4367E/W4367E00.htm

www.fao.org/docrep/T7202E/T7202E00.htm

5.3.1 SELECTION OF SCHEDULING METHOD

Irrigation schedules can be developed using plant, weather or soil moisture based methods. Each of these will vary in accuracy and using a combination of all these delivers the best scheduling result.

Plant based methods include visual assessment of wilting and growth, estimating sap flow and using pressure bomb meters. Of these, only visual assessment is commonly used by irrigators.

Weather based methods involve the use of crop coefficients and evapotranspiration (ET) data. As most WA weather stations measure evaporation, a pan factor of 0.85 can be used to estimate ET. When scheduling according to weather data, you calculate the daily water balance within a scheduling sheet (Table 1) that allows you to track plant water use, irrigations and rainfall events. Monitoring this allows you to predict when available water will run out and signals the need to irrigate.

There are several soil moisture monitoring methods that involve three basic approaches:

- **Gravimetric** methods estimate soil moisture content based on weight differences between fresh and oven-dried soil samples
- **Volumetric:** looks at the soil water by volume, using nuclear or electrical methods to calculate water present in the soil
- **Potential:** measures how tightly the water is held by the soil, using such tools as tensiometers and gypsum blocks

Implementation

When deciding which method is best for you, you need to consider the accuracy, cost, skill and time involved.

Visual assessment of plants can be very misleading as wilting is not necessarily a sign of water stress due to low soil moisture. Excessive heat during the day may cause the stomata to close and the plant to wilt, even though sufficient water is available. Extension growth is a very sensitive indicator of onset of stress. A well-watered reference will help you distinguish between water effects and the possibility of nutrient deficiency and natural variation between plants.

Weather based methods require knowledge of local *plant factors* and weather data for the property. *Plant factors* relate to pan evaporation and should only be used as a guide. There will always be some inaccuracy here due to variation in rainfall and other factors that affect evaporation often vary across a given paddock. However, some general figures can be used as a starting point and as you start recording data you will get a more accurate picture of your pasture's water use that you can use to schedule your irrigation.

The use of a monthly weather schedule can assist in determining when a soil water deficit occurs and an irrigation event required. An example weather schedule for Wokalup is presented in Table 5.8, demonstrating how to calculate the soil water balance. Daily Soil Water Balance = RAW from the previous day – Crop Evapotranspiration + Irrigation Applied and Effective Rainfall

Crop Evapotranspiration is calculated by multiplying Reference Crop Evapotranspiration (ET?) by a specific Crop Coefficient (K_C)

For pressurised systems - Irrigation Applied is calculated by multiplying the length of time the irrigation system is operating (hours) by the Mean Application Rate (MAR – mm/hr)

For surface irrigation systems it is the volume of water applied (litres) divided by the area (m?) equals mm applied

The following table explains how the daily soil water balance is calculated and when irrigation needs to be applied.

It is recommended that a soil-based method be used alongside this to check that water requirement estimates are valid. Fine tuning will usually be needed for every particular situation, especially at the start of the season to ensure soil water levels are correctly estimated.

Soil moisture based methods vary greatly in their accuracy, labour and technical requirement. Using a dig stick to look at the soil moisture is low tech but labour intensive. Tensiometers are relatively easy to use, but care must be taken at installation to ensure useful readings. A range of soil moisture monitoring tools are available that offer low labour input and the ability to monitor soil moisture on an ongoing basis, but these automated systems are costly. They also require a reasonable skill level in order to graph and interpret the readings. Many require accurate calibration before they can be used for irrigation scheduling. Soil moisture monitoring tools that log moisture content at frequent intervals give the most benefit in scheduling irrigation as they provide a detailed picture of pasture water use. Further information on the various soil moisture based monitoring tools is provided in section *5.3.6 Selection of soil moisture monitoring tools*. It would be worthwhile contacting your local irrigation equipment supplier too.

TABLE 5.8 Weather Schedule for Wokalup

Irrigation scheduling data sheet: ***Wokalup***

Month: December	**Crop: Pasture**
Block: Wokalup	**RAW: 18 mm**
Irrigation MAR: 5 mm/hour	**Remaining RAW: mm**

	A	B	C	D	E
Date	ET	K_c	ET crop (A x B)	Effective rain or irrigation	Remaining RAW mm (E from previous Day - C + D) (Carried over 6.2)
1	*4.8*	*0.85*	*4.1*		*6.2 – 4.1 = 2.1*
2	*6.2*	*0.85*	*5.3*	*Rainfall, 2.4 mm 4 hours irrigation = 20mm 20 + 2.4 = 22.4 mm)*	*2.1 - 5.3 + 22.4 = 19.2 (18 mm RAW, 1.2 mm lost to runoff/deep drainage)*
3	*7.6*	*0.85*	*6.5*		*18 – 6.5 = 11.5*
4	*8.6*	*0.85*	*7.3*		*11.5 - 7.3 = 4.2*
5	*7.4*	*0.85*	*6.3*	Rainfall, 1.2 mm 4 hours irrigation (21.2 mm)	*4.2 – 6.3 + 21.2 = 19.1 (18 mm RAW, 1.1 mm lost to runoff/deep drainage)*
6	*6.6*	*0.85*	*5.6*		*18 – 5.6 = 12.4*
7	*7.0*	*0.85*	*6.0*	*Rainfall, 5.4 mm*	*12.4 – 6.0 + 5.4 = 11.8*
8	*4.2*	*0.85*	*3.6*		*11.8 – 3.6 = 8.2*
9	*3.5*	*0.85*	*3.0*		*8.2 – 3.0 = 5.2*
10	*4.2*	*0.85*	*3.6*		*5.2 – 3.6 = 1.6*
11	*4.9*	*0.85*	*4.2*	*4 hours irrigation* (20 mm)	*1.6 – 4.2 + 20 = 17.4*
12	*3.9*	*0.85*	*3.3*		*17.4 – 3.3 = 14.1*
13	*5.2*	*0.85*			
14	*7.1*	*0.85*			
15	*5.8*	*0.85*			
16	*2.9*	*0.85*			
17		*0.85*			
18		*0.85*			
19		*0.85*			
20		*0.85*			
				Continues to days of the month	

When combined with a weather based schedule, you should be able to predict when an irrigation event will be required well in advance. This does not mean you should stop visually monitoring your pastures however, as the visual monitoring will provide the initial sign of any problems that may occur.

Remember that no one system is perfect – combine them all and make use of each of the strengths.

When tracked over time, all of these methods will provide valuable information on the soil water status, allowing you to better determine paddock capacity and wilting point. This information, combined with the application capacity of the irrigation system, will enable you to accurately schedule an irrigation event.

Scheduling when to flood dairy pastures is not simply a matter of refilling the root zone as the soil water content reaches its 'refill point'. Scheduling a flooding event is a delicate balance between irrigating to provide your pasture with water, applying fertiliser and allowing your cows to graze without damaging the soil or exposing them to potential health problems.

Normally, fertiliser is applied ten days before or after an irrigation event to ensure applied fertiliser is not washed away in the tail water. On heavier soils, grazing should be delayed following a flood event to minimise the possibility of soil pugging or compaction. Waterlogged soils should never be grazed and the soils generally remain inundated for at least two to three days.

Further Information

Charlesworth, P, 2000. 'Soil water monitoring', *Irrigation Insights No 1.*, Land and Water Australia, Canberra, ACT.

Norton, S., Harvey, M. and Stevens, R., 2003. 'Module 1: Irrigation Scheduling', *Management of Irrigation Systems*, Charles Sturt University, NSW.

NSW Agriculture. (2004) 'Introduction to Irrigation management: Scheduling your irrigation', *WaterWise on the Farm*, Workshop 3 Training Notes, edited by P Richards, Department of Agriculture, Western Australia.

Websites

http://www.fao.org/docrep/W4367E/W4367E00.htm

http://www.fao.org/docrep/T7202E/T7202E00.htm

5.3.2 IRRIGATING ACCORDING TO PLANT REQUIREMENTS

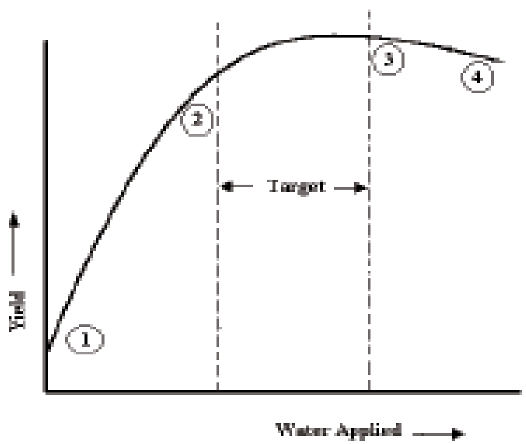
Plants that are irrigated appropriately have the best chance to survive and grow to their full potential. The intention of irrigation is to replace the water used by the plant through evapotranspiration. As such, irrigation scheduling is highly influenced by plant water requirements.

Implementation

To effectively irrigate according to plant requirements it is important to understand the various factors that affect pasture water use, including meteorological, plant, soil and cultural factors. Climatic factors affect the rate of evapotranspiration. Plant growth, together with its size and shape, affects its water use. The various characteristics of soils give them different water holding capacities. The amount of water and the strength with which it is held, together with the ability of the plant to access the water, determines how long it is available to the plant. The different practices you use to prepare, cultivate, protect and harvest your pasture also affect its water use.

As many of these factors will vary to some extent with every irrigation, local crop factors can be used that estimate a pasture's water requirement based on climatic, soil and plant factors. With this information you can determine the amount of irrigation water required for the season *(see sections 5.1.3 Calculation irrigation requirements and 5.3.4 Weather monitoring)*.

The application of irrigation water can affect the yield (Figure 5.19). This is why irrigation events must be scheduled correctly. A lack of water reduces yield as insufficient water is available for plant metabolic processes. At the other end of the scale, over watering reduces yield as the soils become waterlogged and oxygen required by the plants is unavailable.



1. Without irrigation, yield depends on rainfall
2. Irrigation contributes to continued yield increase
3. More water causes no increase in yield
4. Too much water and yield declines due to waterlogging

FIGURE 5.19 Crop yield to amount of water applied

Weather monitoring and soil water monitoring are two methods that can be used to help schedule your irrigation events to best meet pasture requirements. Further information is available in sections 5.3.4 Soil moisture monitoring and 5.3.5 Weather monitoring.

To best manage your irrigation to meet pasture requirements use a combination of weather and soil moisture monitoring

Further Information

5.2.7 Effective root zones & plant needs

5.3.3 Field capacity & refill point

5.3.4 Weather monitoring

5.3.5 Soil moisture monitoring

Norton, S.W., Harvey, M.R. and Stevens, R.M. (2003) 'Module 1 Irrigation scheduling', *Management of irrigation systems*, Charles Sturt University, NSW.

5.3.3 FIELD CAPACITY AND REFILL POINT

The water content of soil has three key definitions relevant to irrigation scheduling. These are:

Saturation point is when the soil is completely filled with water, including all pore spaces.

Field capacity is that point at which the soil holds water in the smaller pores but the larger pores have drained through gravity.

Permanent wilting point (PWP) is when the soil no longer contains enough available water to readily satisfy plant needs and its cell structure begins to irreversibly collapse.

Implementation

Irrigation scheduling aims to keep the soil water content between field capacity and permanent wilting point. Given that you do not want the soil to reach PWP, there is a point at which you will need to refill the soil profile, known simply as the refill point (Figure 5.20).

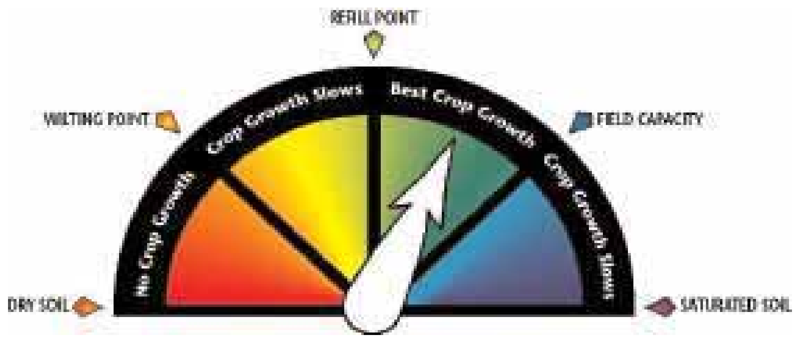


FIGURE 5.20 Critical irrigation periods for optimal plant performance

Figure 5.21 provides a graphical representation of the rate of water depletion in the soil. Following irrigation or rainfall, the graph shows a point where the steep fall in soil moisture lessens as the saturated soil drains through gravity (A). This is known as field capacity and is easier to pinpoint after a few wetting and drying patterns have been recorded. Determining the refill point (B) is a little more subjective. Between points A and B, water content falls at a fairly similar rate. However, once at point B, the rate of depletion of water content decreases at a slower rate of decline in the graph. This is where the individual preference comes into play. There is a need to keep the water content above the wilting point (C), but beyond this there is no 'correct' answer.

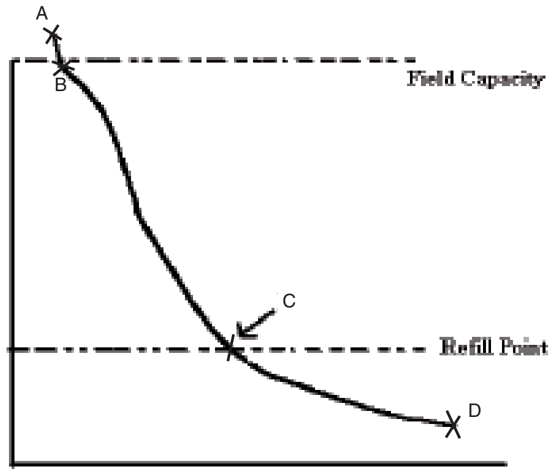


FIGURE 5.21 Graphical representation of the rate of water depletion in the soil.

Your productivity schedule and the capacity of your irrigation system will influence when you irrigate. If you are looking to maximise production or maintain specific quality, you will likely chose to maintain a higher level of moisture. For example, flood irrigation systems will often have a lower refill point to compensate for their inefficiency and avoid constantly inundating the soil profile.

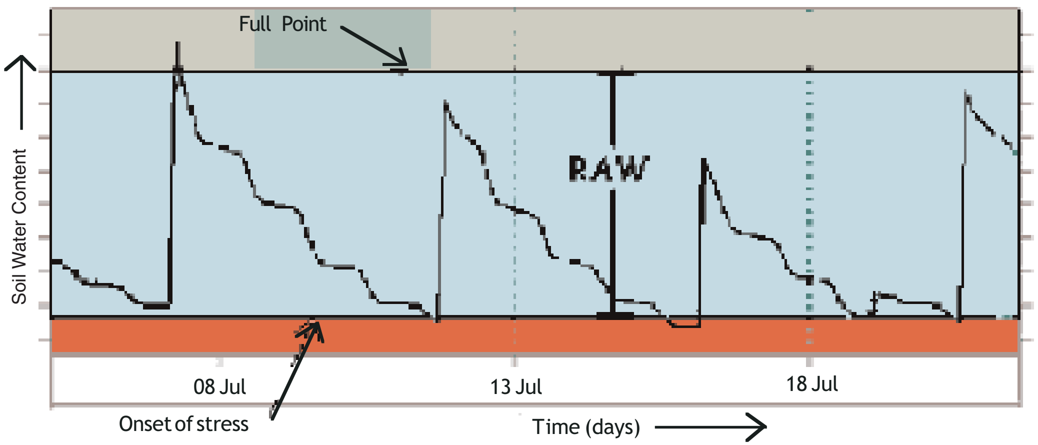


FIGURE 5.22 Graphical depiction of the rate of water depletion in the soil over time.

Further Information

Charlesworth, P. (2000) 'Soil water monitoring', Irrigation Insights No 1., Land and Water Australia, CSIRO Canberra, ACT.

NSW Agriculture. (2004) 'Introduction to Irrigation management: Scheduling your irrigation', WaterWise on the Farm, Workshop 3 Training Notes, edited by P Richards, Department of Agriculture, Western Australia.

5.3.4 WEATHER MONITORING

Effectively monitoring evapotranspiration and rainfall can help you better schedule your irrigation events. Water budgets provide an average monthly indication of the irrigation requirements. To manage the irrigation effectively, a monthly scheduling sheet that records rainfall, evapotranspiration and crop water use will help you determine when irrigation is required on a daily basis.

A simple rule used by many flood irrigators in the Harvey area is to irrigate every 70 mm of evaporation. This assumes water storage within the effective root zone is 83 mm and allowing for a pan factor of 0.85. Evaporation and rainfall data is available from a number of websites, including Bureau of Meteorology, Harvey Water and Department of Agriculture.

Implementation

By tracking the amount of water a pasture has used together with any rainfall events, you can estimate when the next irrigation event will be required. Crop factors are used estimate how much water the pasture has used based on weather conditions. They are essentially a ratio of plant water use to pan evaporation.

Crop Water Use = Pan Evaporation X Crop Factors

As little research has been done on crop factors for pasture varieties grown locally, we are obliged to use imported information. Crop coefficients are one source, as are crop factors from other areas. In using these figures however, we introduce an error into the scheduling. While we can convert crop coefficients to crop water use by multiplying by the pan factor to give an estimate of the crop factor, it will not be entirely accurate. Similarly, converting crop factors from one area to another will introduce errors as you attempt to compensate for differing climatic conditions. That stated, these figures do provide a very useful starting point and with effective monitoring they can be refined to be more accurate for your local conditions.

Monitoring with soil moisture based tools in conjunction with weather monitoring is highly recommended. This will provide more accurate information on water requirements and timing of irrigation events, while also allowing you to 'fine tune' the irrigation scheduling for your irrigated area, including an indication of more accurate crop water use figures.

In monitoring weather, key things to consider are all those climatic factors that affect evapotranspiration of the crop, which is calculated using:

- Rainfall
- Temperature
- Humidity
- Wind speed

Increased humidity reduces evaporative losses (or crop water use), while higher wind speeds and temperature increases crop water use. These climatic measurements are used in the Penman – Monteith equation to calculate crop evapotranspiration.

Climate information is available for a large number of areas and can usually be extrapolated for areas that are not covered. However, if you wish to install a weather station on your own property for accurate conditions of your own site, then installation and running costs will be incurred.

Further Information

5.2.6 Climatic considerations
5.2.7 Soil infiltration characteristics

Norton, S., Harvey, M. and Stevens, R. (2003) 'Module 1: Irrigation Scheduling', Management of Irrigation Systems, Charles Sturt University, NSW.
NSW Agriculture. (2004) 'Introduction to Irrigation management: Scheduling your irrigation', WaterWise on the Farm, Workshop 3 Training Notes, edited by P Richards, Department of Agriculture, Western Australia.

Harvey Water (for local weather information) – www.harveywater.com.au

Bureau of Meteorology (for local weather information) – www.bom.gov.au

Department of Agriculture and Food WA (for local weather information) -
Http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/LWE/CLI/AWSSITE.HTM

5.3.5 SOIL MOISTURE MONITORING

Combined with monitoring of weather data, monitoring of soil moisture will provide detailed information to help with scheduling your irrigation events.

Measuring the amount of water held by the soil over frequent intervals allows you to plot the moisture information on a graph. This graph provides a picture of the pasture water use.

Implementation

Multiple soil moisture measurements can be graphed to provide a clear picture of what is happening with soil moisture over time (Figure 5.23). A brief explanation of what is happening during the various periods is provided in Table 5.9.

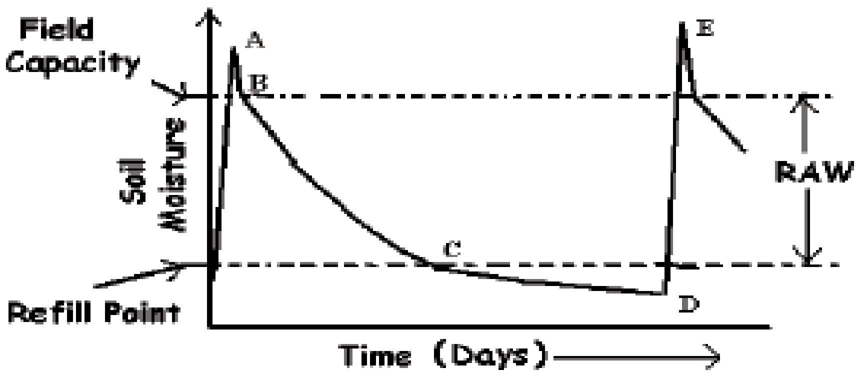


FIGURE 5.23 Soil drying cycle.

TABLE 5.9 Explanation of events during the soil drying cycle presented in Figure 1.

Period	Explanation of events
A - B	Immediately after the initial irrigation or rainfall, water exceeds the 'full point' and some water is rapidly lost to vertical drainage or run-off.
B - C	Water is held by the soil and is readily available to the crop, so there is unrestricted growth. Gradual decrease in water lost from the soil as it is taken up by the plant. RAW
C - D	The readily available water has been used and the crop now has difficulty extracting more. The daily use is lower and the crop is under stress.
D - E	Irrigation (or rain) has entered the profile after D.

This cycle is repeated throughout the season. Using the soil water data in conjunction with other information such as Mean Application Rate (MAR, see section *5.2.2 System Efficiency*) and Readily Available Water (RAW, see section *5.2.7 Effective root zones and plant needs*) can help you manage your water use more efficiently.

Dale and Taylah Hanks at the Hanks Monitor Farm in Harvey checking soil moisture monitoring equipment used to schedule pasture irrigation.

Further Information

Charlesworth, P. (2000) Soil water monitoring, 'Irrigation Insights: Number One', CSIRO Land and Water, Canberra ACT.

Water Management Team. (2004) 'Scheduling and benchmarking', Irrigation Management training notes, (edited 2004 by Richards, P, Dept of Agriculture WA) NSW Agriculture, NSW.

5.3.6 SELECTION OF SOIL MOISTURE MONITORING TOOLS

Monitoring soil moisture ranges from digging a hole in the ground and making a visual assessment to installing soil moisture sensors connected to a data logger that feeds information back to your computer. Automated systems that log moisture content at frequent intervals give the most benefit for scheduling irrigation but they require a reasonable level of skill to graph and interpret the readings and are relatively expensive. They also require accurate calibration before they can be used. Be sure to select a tool that most matches needs and resources.

Implementation

You need to consider a number of factors when selecting soil moisture monitoring tools. These include:

- Reading range
- Stated accuracy
- Measurement sphere
- Output reading
- Installation method
- Logging capability
- Power source
- Country of origin
- Remote access
- Link to other equipment
- Interface to PC
- Affected by salinity
- Expansion potential
- Technical support
- Irrigation system compatibility
- Best soil type
- Application
- Capital cost
- Annual operating cost

Monitoring soil moisture visually introduces a large margin of error and is relatively labour intensive.

Tensiometers can be used to measure soil moisture over time (Figure 5.24). Data can be graphed manually to illustrate soil water status. Tensiometers are relatively inexpensive, transferable and low tech. Because these basically measure tension, you will need to learn how to convert soil tension readings to soil moisture indicator values. At least one season is required to fine-tune the scheduling based on tension measurements. Different crops extract water at different tensions. Annual pastures are readily able to obtain water at up to 60 kPa. Perennial pastures can get water at up to 100 kPa. Gypsum blocks also measure soil moisture based on soil tension and are very easy to install. Logging options are also available for gypsum blocks.

FIGURE 5.24 Adding a dye to water inside a tensiometer makes reading levels easier.

Tensiometers are generally suited to perennial pastures, with different ceramic tips available for the different soil types. Tensiometers are not suited to annual pastures, however, as they can extract water readily at a higher tension and most porous media only work to 80 kPa. Two options now exist with gypsum blocks, at two tension ranges, with the 'heavy' option being suited to turf and pastures. Both tensiometers and gypsum blocks require at least two devices to be installed at each site, one within the root zone and the other below the root zone.

The use of capacitance probes is increasing (Figure 5.25). These measure the dielectric capacity of a non-conductive material to transmit electromagnetic waves or pulses. The dielectric of dry soil is much lower than that of water and small changes to soil moisture content produce large changes to its electromagnetic properties. Capacitance probes are normally permanent installations and can log the information collected. Generally, they have three or four sensors at different depths on the single probe. Correct installation at a representative site is extremely important for accurate and meaningful data as measurements are taken from a 10 cm area.

Figure 5.25 Capacitance probe with tension lysimetre.

Capacitance probes need to be calibrated to your specific soil with wet-dry gravimetric sampling. Many brands are provided with a 'universal calibration' that can give you an idea of what is happening with your soil moisture once you learn how to interpret the graphs produced. You will need to calibrate the probes for your particular farm soil to get an absolute value of your soil moisture content.

Portable capacitance probes are also available that you can lower down access tubes to obtain data, but these are more labour intensive than the permanently installed probes.

Frequency domain reflectometry (FDR) measures the soil dielectric by placing soil between two electrical plates and measuring the frequency differences caused by soil moisture content. FDR-type meters represent the largest expansion in terms of soil moisture monitoring equipment and brands such as Aquaflex™ and Campbell™ are readily available.

The speed of an electromagnetic signal passing through a material various according to its dielectric. Time domain reflectometers (TDR) measure the time taken for a signal to pass through the soil. This time is closely related to soil moisture content. TDR instruments provide the best soil water content data and often do not need soil type calibration. However they are expensive and often require additional electronic equipment to operate. Their use is generally restricted to high value crops with critical water requirements.

Heat probes such as the Aquasensor™ measure the heat input and peak temperature change following a burst of heat energy. With a very small measurement sphere (1 cm) these are useful when many are installed together. These probes require sophisticated loggers for measurement and control of the measurement timing.

A much simpler version of soil moisture monitoring is the wetting front detector, which activates a switch as soil moisture increases. As the soil dries the detector switches off again. These provide valuable information to irrigators as a warning signal, for regulation of the amount of water irrigated and for collection of soil-water samples.

Further Information

Charlesworth, P. (2000) Soil water monitoring, 'Irrigation Insights: Number One', CSIRO Land and Water, Canberra ACT.

All leading irrigation equipment suppliers

5.4 FINANCIAL ANALYSES

The cost of implementing or upgrading an irrigation system will vary according to individual farm designs and component costs. The presentation of case studies provides a meaningful assessment of what others have done and what it cost them. This is provided merely as an indication of the budget for those planning similar investments.

5.4.1CASE STUDY 1 (AUTOMATION OF FLOOD IRRIGATION) DEPIAZZI DAIRY DARDANUP

Phil & Leanne and Kevin & Belinda Depiazzi run 180-250 milking cows on their property at Dardanup. Their vision for their business is to run an efficient, profitable and productive dairy operation while maintaining a balanced lifestyle that is both challenging and rewarding. The property has been flood-irrigated since 1950 and the system has been progressively upgraded over time with laser levelling, automation and sub-surface drainage. This analysis is concerned only with the automatic irrigation system.

Kevin, Bernie and Phil Depiazzi at their farm in Dardanup

Currently 35 ha of the property is irrigated and 15 ha of this has been automated. The Automation was installed in 1997 and has lead to reduced water usage and reduced labour requirement. While pasture production has improved since the installation of the automatic irrigation system, Phil identified improvements in nutrient management and grazing management as the primary drivers of this and not the automatic irrigation.

The estimated cost of the automated system is

Equipment (stops, pipes ect.)	$6,500
Installation	$3,000
Total	$9,500
Annual Maintenance cost	$ 400

The main benefits of the automated system as identified by Phil are decreased water usage in the region of 1 to 3 ML/ha and a decrease in labour of around 4 hours per irrigation. On average there are 20 irrigations per year so that equates to around 80 hours of labour saved annually.

Automated flood gates installed on the Depiazzi farm

The location of the Depiazzi farm means that extra water can be purchased and delivered relatively cheaply at $26/ML. Therefore this analysis values the water saved by the automatic irrigation system at $26/ML as it reduces the requirement to purchase extra water.
Labour is estimated to cost $25 per hour including on-costs.
The benefit net of annual maintenance cost over a fifteen year period are calculated in Table 5.10 using a range of water savings of 1, 2 and 3 ML/ha and labour savings of 3, 4, and 5 hours per irrigation.

Table 5.10 Benefits of the flood irrigation automation installed on the Depiazzi farm over 15 years, net of annual maintenance cost.

		Reduced labour per irrigation		
		3 hours	4 hours	5 hours
Reduced Water	1 ML	$22,350	$29,850	$37,350
	2 ML	$28,200	$35,700	$43,200
	3 ML	$34,050	$41,550	$49,050

The above calculations do not take into account any form of discounting as the discount on future benefits may well be compensated for by increased labour costs.

Table 5.11 establishes the Benefit to Cost Ratio of such an investment, solely from an economic point of view.

Table 5.11 Benefit to Cost Ratios for the Depiazzi automated system

		Reduced labour per irrigation		
		3 hours	4 hours	5 hours
Reduced Water	1 ML	2.35	3.14	3.93
	2 ML	2.97	3.76	4.55
	3 ML	3.58	4.37	5.16

The results in Table 5.11 show that under all of the scenarios tested here the investment in automatic irrigation returns benefit cost ration greater than one.

Research by the Department of Agriculture has shown that reducing the amount of water applied to pasture by installing an automatic irrigation system also reduces the quantity of salt applied. This can be a benefit for properties that are irrigated from Wellington Dam, however it has not been considered in this analysis.

5.4.2CASE STUDY 2 (DRYLAND AND FLOOD IRRIGATION TO CENTRE PIVOTS) HANKS DAIRY, HARVEY

The Hanks family have been milking cows on their property at Harvey for close to 65 years. Their vision for their business is to achieve sustainable growth to remain viable without curtailing their quality of life. The Hanks' milk between 200 and 250 cows and flood irrigate 60 ha across two properties. This year they intend to flood an additional 30 ha between March and the end of April to get an early germination. As well as the flood irrigation the Hanks' have an 8 ha centre pivot which was installed on their property as part of a research project to compare centre pivot and flood irrigation.

Dale and Leanne are currently considering investing in a 43 ha centre pivot irrigator and this possible investment will be the focus of this analysis.

Of the 43 ha that the centre pivot will irrigate 33 ha is currently dryland growing annual pasture, 2 ha is irrigated by flood irrigation and is growing perennial pasture and 8 ha is irrigated by the existing centre pivot. Dale expects the per hectare pasture harvest under the new centre pivot to be 8 to 10 tonnes per hectare greater than that achieved on the dryland and 6 to 8 tonnes greater than that for the flood irrigated portion. The section that is already under centre pivot irrigation is expected to continue its current level of production. In total, the centre pivot is expected to increase the pasture harvested by 300 to 360 t DM annually.

Dale Hanks (cap and gumboots) next to his centre pivot system

To efficiently use this extra pasture production more cows will be require and the Hanks' are currently considering increasing the herd by 80 milkers. To comfortably milk the extra cows extra capital will be required to increase both milking shed and vat capacity.

The Hanks' intend to increase their herd by retaining heifers however for ease of calculation this analysis will assume that the extra 80 cows are purchased along with 20 yearlings to be the following years' replacements.

The estimated capital cost of the investment is as follows:

Centre Pivot (installed)	$ 90,000
Installing Power	$ 15,000
Removing trees and re-arranging fences	$ 20,000
Altering laneways	$ 10,000
Establishing Pasture (est @ $400/ha)	$ 17,200
Upgrading the dairy	$ 60,000
Installing an extra vat	$ 20,000
Extra Cows	$100,000
Total Extra Capital Cost	**$332,000**

Dethridge wheel at the Hanks Dairy in Harvey

Manual flood gate at the Hanks Dairy in Harvey

Manual flood gate at the Hanks Dairy in Harvey

The estimated extra annual costs are as follows:

Power	$ 5,000
Maintenance	$ 3,000
Labour	$15,000
Herd Costs	$10,640
Shed Costs	$ 4,650
Water (est. for an extra 200ML)	$ 8,400
Fertiliser	$17,000
Concentrate (@ $270/t)	$34,560
Growing replacements (est. at $600 per replacement)	$12,000
Total Extra annual costs	**$93,160**

The extra pasture expected to be harvested under the centre pivot equates to about 3.8 to 4.5 t DM for each of the extra cattle. With 1.8t of grain the total intake for the extra cows is about 5.6 to 6.3 t DM. Dale and Leanne are currently in the process of adjusting to a more spring dominant calving pattern and do not expect that the introduction of a centre pivot will result in a significant change in the quantity of forage conserved on the property.

Extra milk income was calculated assuming that the per cow production of the extra cows would match that currently achieved by the herd. A milk price of 29c/l was used. The extra cows would be expected to produce extra income from sales of bull calves surplus heifers and cull cows.

The estimated extra annual income is as follows:

Milk	$198,650
Livestock sales	$ 30,000
Total extra annual income	**$228,650**

Experience has shown that it is very difficult to achieve maximum yields in the first years of installing a centre pivot irrigator. The management skill required by the operator to developing the optimal irrigation scheduling comes with experience. Dale has already had experience in managing a centre pivot irrigator and would be expected to quickly achieve good results with the proposed new centre pivot. However, the extra cows added to the herd would be heifers and they would initially have lower production capability and the establishment of new pasture can be difficult. To allow for these factors this analysis reduces the extra milk production by 30% in the first year and 10% in the second year.

A 10 year discounted cash flow analysis has been prepared using a discount rate of 10%. It was assumed that at the end of the 10 year period the centre pivot would have a salvage value of 20% of the purchase price and the extra livestock would have a salvage value of 70% of their purchase price. Given the assumptions described above the benefit cost ratio was calculated to be 1.4.

Because this is an ex-anti analysis the extra costs and benefits are only estimates. A sensitivity analysis is used to investigate the how the investment performs under other estimates. Table 5.12 shows the benefit cost ratio for the investment under with different variations of annual income and annual cost. The allowances made for the capital requirement are thought to be adequate.

Table 5.12 Benefit to Cost Ratios for the Hanks' farm investment

		Extra annual costs		
		- 15%	Expected	+15%
Extra annual income	-15%	1.3	1.2	1.1
	Expected	1.5	1.4	1.2
	+15%	1.7	1.6	1.4

The above table indicates that the investment has a benefit cost ratio greater than 1 at a discount rate of 10% for all of the scenarios examined above. This suggests that the investment could be worthwhile and a financial analysis is warranted.

Head irrigation ditch at the Hanks Dairy in Harvey

5.4.3 CASE STUDY 3 (DRYLAND TO CENTRE PIVOT) STAGE 1*.

This analysis is on a family farm whose long term business vision is to be profitable with a good lifestyle. Over recent years the Farm has undergone significant development including the installation of 3 centre pivots, the construction of a new dairy and a doubling of the herd size to approximately 750 milking cows. There are also plans to increase the herd size further and increase the irrigated area by a 120 ha over the next 3 years.

In such situations it is difficult to determine where to start and finish an analysis. It was decided to examine the investment in the first 2 centre pivots which coincided with the construction of the new dairy and the increase of the milking herd by 135 cows. Another scenario was also compared investigating the investment if the new dairy was not required.

In reality the old dairy had reached the end of its functional life and a new dairy was a necessity.

The increase in herd size was achieved by retaining heifers and leasing cows some of which have since been purchased. For ease of calculation this analysis will assume that the extra cows are purchased from the start along with sufficient yearlings to provide the following years replacements.

The estimated capital cost of the investment is as follows:

Hydro-geological survey	$ 25,000
Bore (400 m)	$ 138,400
Removing trees and re-arranging fences	$ 25,654
Centre Pivots (installed)	$ 262,418
Electrical CT Meter	$ 18,000
Submersible pump	$ 68,000
Rock breaking	$ 6,200
New dairy	$1,220,000
Other plant	$ 153,000
Extra Cows	$ 185,625
Total Extra Capital Cost	**$2,102,297**

In undertaking a partial analysis we are interested in the extra income and costs that are generated by the investment. To determine these values we compare the annual costs and income from the year prior to the investment to those of the two years of the investment for which we have data.

*The owners of this business wish to remain anonymous

In the first year of the investment the pivots were sown down to millet and annuals while in the second year perennials and millet were sown. The performance of the perennial pasture was such that in hindsight it would have in fact been better to sow the perennials from the start rather than annuals.

Extra annual costs

	Year 1	Year 2
Hay purchases	$ 33,000	$ 8,000
Grain	$ 25,746	$ 33,600
Pasture Seed	$ 11,041	-$ 3,248
Fertiliser	$ 30,000	$ 35,000
Silage Expenses	-$ 3,000	-$ 637
Hay Expenses	$ -	$ -
Insurance	$ 3,965	$ 8,275
Wages	$ 28,013	$ 22,773
Electricity	$ 38,999	$ 18,055
Dairy Requisites	$ 4,000	$ 4,000
Dairy Repairs	$ 9,000	-$ 1,000
Herd Costs ($100/cow)	$ 12,500	$ 13,500
Cost of raising support stock	$ 15,625	$ 16,875
Total extra annual cost	$ 208,889	$ 155,193

Less Total Mix Ration and more fertiliser meant that repair and maintenance on vehicles was much the same as before the investment as was fuel and oil. To date the new pivots have not required any significant repairs or maintenance however an allowance of $7,000 per year has been made to cover extra R&M costs that may be incurred from year 3 on. The cost of raising replacements has been estimated at $500 per replacement and the replacement rate is assumed to be 25%.

The costs were higher in the first year due to the production from the pivots being below expectations necessitating the purchase of extra fodder. The extra electricity cost was also much greater in the first year because the pivots had to be run for more of the year due to below average rainfall.

Extra annual income

	Year 1	Year 2
Milk (@ 27c/l)	$ 173,745	$ 313,875
Stock sales	$ 43,750	$ 47,250
Total extra annual incom	$ 217,495	$ 361,125

Milk production per cow was lower in the first year of the investment and it is thought that this was due to a change in concentrate mix (oats were used instead of barley or wheat) and a reduction in grain feeding on a per cow basis brought about by high grain prices. In the second year milk production per cow surpassed that achieved in the year before the investment.

A 10 year discounted cash flow analysis has been prepared using a discount rate of 10%. It was assumed that at the end of the 10 year period the centre pivot, dairy and improvements would have a salvage value of 20% of the purchase price and the extra livestock would have a salvage value of 70% of their purchase price. Given the assumptions described above the benefit cost ratio (BCR) was calculated to be 0.8.
Part of the reason that the BCR for this investment was less than 1 is that the entire cost of the dairy was attributed to this investment. In reality the investment in the dairy was a step in a larger investment strategy that has involved or will involve the purchase of extra land, the development of more centre pivots and a further increase in herd size and per cow production. Without the construction of the dairy these developments would not have been possible.

A second scenario was investigated in which it was assumed that the new dairy was not built and the extra 135 cows were milked through the existing dairy (assumes the existing dairy was adequate). In this scenario there was no capital cost for the dairy and the annual cost for dairy requisites and dairy repairs were increased by 30% from the pre investment level to allow for the extra cows. Other costs and incomes are the same as in the previous scenario. Given these assumptions the BCR was calculated to be 1.2 at a discount rate of 10%.
A sensitivity analysis for each of the scenarios is presented below.

Table 5.13 indicates that the investment has a BCR less than 1 for all of the combinations examined. This suggests that at a discount rate of 10% the investment, without further expansion to make use of the capital invested in the dairy, is probably not worthwhile.

Table 5.13 Benefit to Cost Ratios for the "with the new dairy" scenario

		Extra annual costs		
		- 15%	Expected	+15%
Extra annual income	-15%	0.72	0.68	0.65
	Expected	0.83	0.79	0.75
	+15%	0.94	0.89	0.85

Table 5.14 indicates that the investment has a benefit cost ratio greater than 1 for all of the combinations examined. This suggests that at a discount rate of 10% the investment in irrigation and herd expansion is probably worthwhile and warrants financial analysis.

Table 5.14 Benefit to Cost Ratios for the "without the new dairy" scenario

		Extra annual costs		
		- 15%	Expected	+15%
Extra annual income	-15%	1.1	1.1	1.0
	Expected	1.3	1.2	1.1
	+15%	1.5	1.4	1.3