



NSW Agriculture

Introduction to Irrigation Management

Evaluating your surface irrigation system



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These materials are part of the WaterWise on the Farm education program *Introduction to Irrigation Management*. They were developed by staff from the water management subprogram of NSW Agriculture. ww0317

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The information contained in this publication is based on knowledge and understanding at the time of writing (June 2002). However, because of advances in knowledge, users are reminded of the need to ensure that information upon which they rely is up to date and to check currency of the information with the appropriate officer of New South Wales Department of Agriculture or the user's independent adviser.

Contents

Introduction.....	v
Learning outcomes	vi
Introduction to surface irrigation	1
Basic components of a surface system	2
Activity 1. Principles of surface irrigation.....	2
Farm supply	3
Flow rate and volume into the farm supply system	3
Calculation 1: Flow required per shift.....	4
Calculation 2: What area can be irrigated?.....	4
Activity 2. Available irrigation area	4
Calculation 3: Flow rate from two Dethridge wheels	6
Activity 3. Supply flow rate.....	6
Head and head loss	7
Calculation 4. Head loss in the supply system	11
Command over the land	12
Calculation 5. Calculating comand	13
Activity 4. Command.....	13
Farm supply system design and maintenance	14
Flow rate and volume out of the farm supply system	18
Calculation 6. Directly measuring flow onto the field	18
Calculation 7. Determining flow onto the field.....	21
Activity 5. Determining flow rate	22
Distribution efficiency	23
Activity 6. Distribution efficiency	23

The irrigated field	25
Activity 7. Depth of irrigation.....	25
Uniformity of water application	26
Infiltration of water applied.....	27
Improving uniformity of border check & furrow irrigation	30
Infiltration is too deep at the top of the field.....	30
Infiltration is too deep at the bottom end of field	31
Infiltration is too deep over the whole field.....	32
Improving uniformity of contour irrigation	33
Infiltration is too deep over the whole bay	34
Field application efficiency	35
Activity 8. Field application efficiency	35
Surface drainage and reuse systems	37
Watertables	38
Border check irrigation drainage	41
Furrow irrigation drainage.....	41
Contour irrigation drainage	42
Tailwater drain design	42
On-farm storage	45
Conclusion	46
Activity 9. Irrigation system checklist	46

Introduction

The aim of the workshop is to introduce you to skills and techniques for improved water use efficiency and irrigation system management.

The workshop highlights the importance of efficient surface irrigation and the methods available to manage or modify a surface system for efficient operation and improved production.

The skills you learn in this workshop will help you to perform tests on your own system, and identify whether you need to change equipment, or how you operate it, to improve your irrigation efficiency.

Learning outcomes

On completion of this workshop, you will be able to:

- identify the importance of irrigation efficiency
- measure and record the performance features of an irrigation system
- discuss measures of irrigation system performance and their impact on total water use

Workshop activities

To help you achieve these learning outcomes, there are a number of workshop activities for you to complete, including:

- describing the various components of a surface irrigation system and outlining important design features
- completing measurements and calculations of head loss and flow rate to assess system performance
- calculating distribution efficiency and field application efficiency

Assessment

This course is competency-based. By completing workshop activities during the course, you will demonstrate that you have met the learning outcomes. This method of training and education benefits both you and the trainer, as any topics that have not been clearly covered may be quickly reviewed.

Program

This workshop is made up of three topics:

1. farm supply
2. the irrigated field
3. surface drainage and reuse

The topics include workshop activities, notes, practical application of material, and assessment tasks.

In your workbook for evaluating your surface irrigation system, you will find a worked example for each of the activities.

Introduction to surface irrigation

The *Introduction to Irrigation Management* course was developed to help irrigators improve the water use efficiency of the irrigation industry.

The Irrigation Association of Australia (IAA) define **water use efficiency** (WUE) as:

$$\text{Water use efficiency} = \text{volume of product} \div \text{unit of water applied}$$

Water use efficiency is typically described in terms of tonnes per megalitre, or bales of crop per megalitre. It represents a combination of the irrigation system and agronomic efficiencies for a crop.

Managing our water more efficiently (increasing WUE) may lead to increased production and greater control over the quality of our produce from a given amount of water. In this workshop we look at two areas of **irrigation system efficiency**:

Distribution efficiency

The comparison between the amount of water at the supply point and the amount of water that is delivered onto the field. The Irrigation Association of Australia (IAA) defines distribution efficiency as:

$$\text{Distribution efficiency} = \frac{\text{water delivered to irrigated field}}{\text{total inflow to supply system}}$$

Field application efficiency

The comparison between the amount of water delivered to the field and the amount of water that is used by the crop. The Irrigation Association of Australia (IAA) define field application efficiency as:

$$\text{Field application efficiency} = \frac{\text{crop water use}}{\text{water delivered to irrigated field}}$$

In this workshop, we investigate the distribution efficiency and field application efficiency of our surface irrigation systems. We also discuss the impact of our system efficiency on our water use.

Basic components of a surface system



border check



furrow (and bed)



contour

A surface irrigation system applies water by **flowing** it across the irrigation field. This may be done by a variety of methods, which can be grouped in three main categories:

1. **border check**
2. **furrow (and bed)**
3. **contour**

In general, there are three major components of an irrigation system. Each component has its own management and efficiency issues. The three components are:

- **the supply component**, which delivers the water from the source to the irrigation field. Distribution efficiency is an indicator of the performance of this part of the system.
- **the irrigated field**, where the crop is grown. Field application efficiency is an indicator how well this part of the system has met the crop water requirements without excessive water loss.
- **the drainage component**, which removes surplus water from the field for reuse.

To determine the efficiency of an irrigation system we deal with each component of the irrigation system in turn.

If the irrigation systems used on a property are appropriate for the soil type and crop, and are installed and maintained correctly, the correct amount of water can be applied to the crop without excessive losses.

This is the goal of efficient irrigation: to ensure the greatest amount of water that is delivered to the farm is used by the crop rather than being lost to groundwater or off the farm as drainage.

Activity 1. Principles of surface irrigation



In your workbook, complete activity 1 on the important principles of surface irrigation.

Farm supply

Water for irrigation may be supplied from a river, bore, pumped or gravity-fed irrigation scheme, or from on-farm storage. The farm supply component of an irrigation system includes the source, channels, and structures.

In this section we discuss:

- flow rate and volume into the farm supply system (also known as the **on-farm distribution system**)
- head and head loss, and command
- farm system design and maintenance: channels and structures
- flow rate and volume delivered to the field
- distribution efficiency

Flow rate and volume into the farm supply system

Volume: The amount of water your crop needs is measured as a volume. Knowing the volume of water available and the seasonal water requirements of the crop you want to grow will help you estimate your cropping area.

Flow rate: The flow rate onto the farm limits how quickly water may be applied, and so how much area can be irrigated in a given time.

Flow rate is the volume delivered, divided by the time taken to deliver it.

When planning any development or upgrade, you must make sure that the flow rate and volume can meet your crop's water requirements, particularly during periods of peak water demand.

First, find out whether you can get access to enough water for the production you want. If you can, then you need to determine the flow rate to put through the supply channels, structures and field or bay outlets to meet your crop's peak water requirements.

Flow from pumps is generally fixed, but variations in water levels, pump condition and pump speed can change it.

The available flow from a **district supply system** can vary with changes to supply levels, outlet sizes, and location on the system, so it is especially important to consider what flow is available during peak demand periods. Your system needs to be designed and managed to account for these limitations.

To calculate the required flow at peak times, or the area that can be irrigated with a known flow, you need to put your own figures into one of the two calculations shown below:

Calculation 1. Flow required per shift

To determine how much water (volume) you need to irrigate your field you need to know your soil RAW, the area to be irrigated, and the efficiency of your supply component and field application component.

Flow required per irrigation (shift) = soil water volume × area ÷ efficiency

Calculation 2. What area can be irrigated?

If we know what volume is available, we can determine the area that can be irrigated.

Area that may be irrigated per shift = flow × efficiency ÷ soil water volume

Activity 2. Available irrigation area



In your workbook, complete activity 2 on the available irrigation area. Look through the worked example for each calculation.

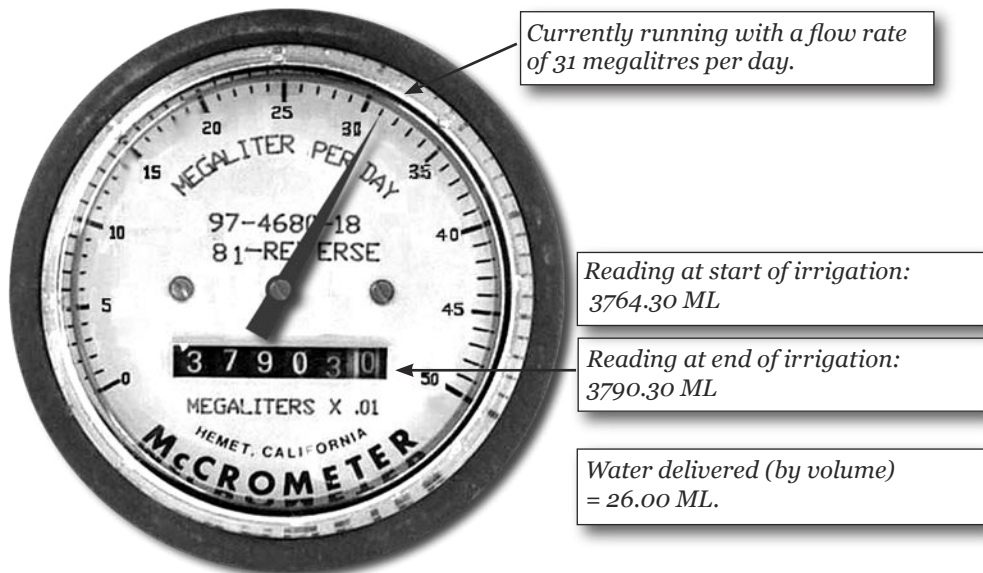
Measuring volume of water delivered into the farm supply system

To manage your water efficiently you need to know how much water is being delivered to your farm. For this, you need some form of meter: three types commonly used are:

- propeller meter
- dethridge wheel
- ultrasonic (Doppler)

Propeller meters have a counter that records the volume of water in megalitres and in some cases provides a way of determining flow rate in megalitres per day (Figure 1). The propeller meter generally reads to one-thousandth of a megalitre.

Figure 1. Reading a propeller meter



(Your workbook sets out a worked example of finding the supply flow rate from a propeller meter.)

The **Dethridge wheel** has a counter that either measures the number of megalitres directly, or measures the number of revolutions of the wheel. For meters that record revolutions, a multiplying factor is used to convert from wheel revolutions to flow rate (ML/d).

Calculation 3. Flow rate from two Dethridge wheels

(Note: These are Dethridge long meter outlets.)

		Time	Wheel 1	Wheel 2
Reading at start of irrigation (ML)	A	Monday 10 am	1088.55	935.00
Reading at end of irrigation (ML)	B	Tuesday 6 am	1102.55	947.00
Water delivered per wheel = end of irrigation – start of irrigation			B – A 1102.55 – 1088.55 = 14.00 ML	B – A 947.00 – 935.00 = 12.00 ML

$$\begin{aligned}
 \text{Total water volume delivered} &= \mathbf{C} \\
 &= \text{wheel 1 plus wheel 2} \\
 &= 14 + 12 \\
 &= 26 \text{ ML}
 \end{aligned}$$

$$\text{Delivery time in hours} = \mathbf{D} = 20 \text{ hours}$$

Conversion to ML/day:

$$\begin{aligned}
 \text{Water delivered} \div \text{delivery time} \times 24 \text{ hours} \\
 &= \mathbf{C} \div \mathbf{D} \times 24 \\
 &= 26 \div 20 \times 24 \\
 &= 31.2 \text{ ML/d}
 \end{aligned}$$

$$\text{Flow rate per day} = 31.2 \text{ ML per day}$$

Ultrasonic (Doppler) meters determine the flow rate of water by measuring the travel time of sound waves within the flowing water. They display a cumulative volume in megalitres, and sometimes the flow rate as well.

Activity 3. Supply flow rate



Complete activity 3 in your workbook.

Head and head loss

Head is the energy that drives water through an irrigation system. Put simply, it is a measure of water pressure. Head is measured in millimetres, metres or kilopascals (1 m = 9.806 kPa = 1.42 psi).

In surface systems, we are mainly interested in the head associated with elevation and gravity. Maintaining head in surface irrigation is important, because the energy maintains flow rate and the movement of water through the system.

Head loss results from the drop in the level of the water (Figure 2) as it moves along a channel or through a structure as well as from the friction of water moving in channels and structures and through weeds and other obstructions.

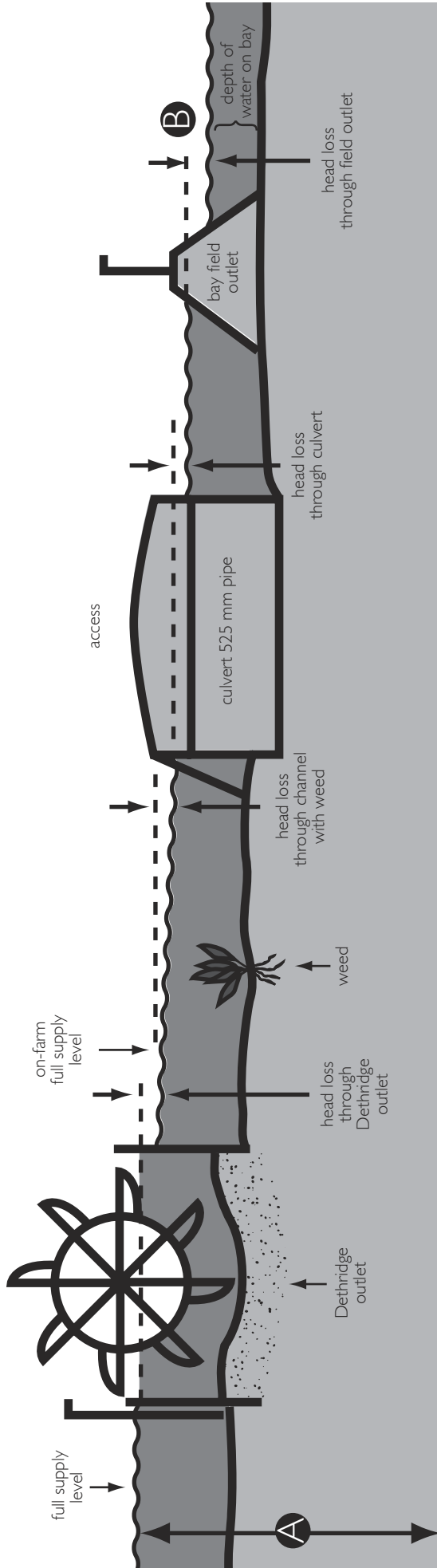
Head loss does occur in systems that work well, but may be excessive in systems that are incorrectly designed or poorly maintained.

Minimising head loss in your irrigation system is important:

- to maintain head, allowing you to irrigate distant or higher elevation blocks. This is very important in gravity supply irrigation schemes and supplies.
- to reduce pumping costs
- to reduce pipe flow velocities, minimising erosion
- to keep within channel freeboards
- to make the most of the flow rate. Flow rates through outlets from channels to fields vary with the head available. If the head is high, the flow through the outlets is greater and fewer outlets may be needed. Where the water level in the supply channel is high, you may be able to use smaller siphons.

The total headloss in the supply component of a surface system is the difference between the level of the water at the supply end of the channel (A) and the level of water at the field or bay outlet of the irrigated paddock (B) (Figure 2).

Figure 2. Head loss at the Dethridge wheel, culvert, and channels



Head loss in channels

Most surface irrigation systems are designed with supply channels that have a slope of 1:10,000 or 1 cm of fall for every 100 metres. This slope is adequate for water to flow at a velocity that will not cause erosion. Standard channel dimensions, slopes, and capacities may be provided by agricultural departments or other agricultural advisers on request.

Structures or restrictions in a channel reduce the cross-sectional area of the channel and increase friction, reducing the flow rate in the channel.

Head loss varies with flow rate and channel size. For example, if the flow rate increases, the head loss increases; if the cross-sectional area of the channel is increased, the head loss will decrease.

Head loss occurs in systems that work well, but severe or excessive head loss can be caused by

- poorly maintained channels, such as those with weeds and silt build-up
- undersized channels
- any restrictions such as bends in the channel path

Head loss in structures

As with channels, head loss through structures such as pipes, culverts, outlets, and siphons is caused by friction as water flows through. Head loss through an outlet increases if there are restrictions.

When designing, maintaining, or upgrading structures, remember:

- Correct design and installation is very important to maintain water capacities. For example, installing a culvert too high results in a major increase in head loss.
- A pipe runs most efficiently when full and both ends are submerged. Keeping the pipe full, particularly at the lower end, keeps water velocities to a minimum, reduces erosion, and maximises capacity.
- Changing the dimensions of structures affects head loss. If the structure size is increased, the head loss decreases. A small increase in pipe diameter causes a large decrease in head loss.
- Doubling the flow rate will multiply the head loss by four. As the flow increases through a structure, the head loss increases, due to increased friction.
- Increasing the pipe length causes only a small increase in head loss.
- Head walls may decrease head loss by up to 25%. A headwall or wingwall streamlines the flow, and when installed on culverts, acts like a funnel to greatly reduce head loss.

Determining total head loss from the farm supply

The total head loss in the system is the head loss from structures in the system plus the channel head loss (Figure 2: losses from A to B).

To determine total head loss, you need to start from a common reference point, and measure the difference in water levels (or head loss) at each section of your supply system:

- through the Dethridge wheel (or stilling box)
- through any structures
- along the channel

Calculation 4. Head loss in the supply system

Record all measurements and then add up the total losses. For example:

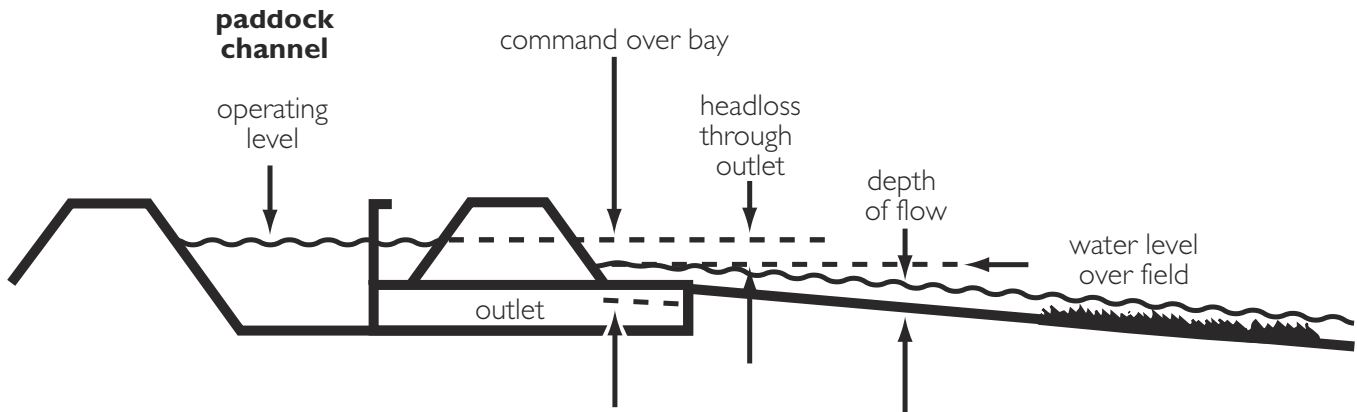
Structure	Headloss		
Dethridge wheel	0.08 m		A
Culvert	+ 0.035 m	(pipe diameter 525 mm)	B
Channel check	+ 0.035 m	(opening width 0.6 m)	C
Channel losses	+ 0.05 m	(slope of 1:10000, distance 500 m)	D
Total losses	= 0.2 m		A + B + C + D

The total losses in the example are 0.2 m.

Command over the land

Command (Figure 3) is a term used to describe the difference between the water level in the supply channel and the ground level of the field or bay. This term is often confused with head. For water to flow, the command available must be greater than head.

Figure 3. Command over the bay or field



Commanded land is the land that can be irrigated by gravity. If land is to be irrigated by gravity-fed water, then the source of that water must be higher than the land to be irrigated. Supply system head losses can be very important for land situated away from the water source. The greater the system head losses, the less land can be commanded.

No command = No flow!

To provide command for irrigation and improve watering efficiencies in new developments, it is recommended that the highest design level of an irrigated bay or field should be at least 250 mm below the supply level in the delivery channel. In this situation, the command over the field is 250 mm.

There has to be enough head left, after the head loss through the outlets, to provide the required flow (150–250 mm) onto the field or bay.

Example: Subclover irrigation

For example, the height of an annual subclover pasture affects the head. The subclover paddock needs less head for the first few irrigations than it does when there is 50 mm of growth.

During the first irrigations when the paddock is bare or the pasture is short, head is adequate, and the field is irrigated quickly (high flow rates).

A month later, when the pasture has grown to a dense 50 mm high, the water level on the bay rises. This reduces the difference in water levels between the supply channel level and that on the bay.

Reduced head = reduced flow rate and irrigation is slower, but the command over the bay has remained the same.

Calculation 5. Calculating command

To determine the available command of the supply point (pump, or scheme supply level), we need to determine the total head losses within the supply system and the level of the irrigated bay or field.

$$\text{Available command} = \text{start of supply level} - \text{field or bay level} - \text{total head losses}$$

Sample data: If our irrigation supply has the following features:

- start of the supply system (the supply point) is at a reduced level (RL) of 10.0 m (*'Reduced level' is a surveying term. The starting value of 10.0 is an arbitrary figure.*)
- field or bay is 0.5 m lower, at 9.5 m
- total head loss from supply system is 0.2 m

then:

Available command

$$\begin{aligned} &= 10.0 \text{ m} - 9.5 \text{ m} - 0.2 \text{ m} \\ &= 10.0 - 0.2 - 9.5 \\ &= 0.3 \text{ m} \end{aligned}$$

Activity 4. Command



In your workbook, complete activity 4 on calculating the command over the field.

Farm supply system design and maintenance

The channels and structures of the supply system need to be designed and maintained for efficient supply. Inefficient irrigation water supply will cost you water and time.

Channels

Efficient channel designs include the following points:

- Capacity can meet the crop's peak water requirement.
- Command in the system can cope with head losses between the in-flow point and the field or bay.
- There is adequate freeboard (at least 0.15 m) above operating level.
- There are a minimum number of structures, with well-designed head walls, to minimise head loss.
- Channel is large enough to handle high pump flows, high rivers, tailwater flows, and any future expansion, with minimal head loss.
- Velocity of the water, which is related to the grade, is between 0.15 and 0.6 metres per second (m/s).

The efficient design of channels will reduce your head loss and improve the water use efficiency of your system, but there are other factors to consider when designing your channels. These considerations include reducing water losses from your supply and the system's management.

Other factors to consider in channel design are listed below:

- Higher velocities caused by steeper grades may cause erosion, although velocities up to 1 m/s may be acceptable on heavier clay soils. (Drop check structures or secondary channels are used to lower head.)
- Very slow flows (0.1 m/s or less) can result in excessive silting in pipes and culverts.
- Channels crossing lighter soils, such as prior streams, are lined with clay to prevent seepage or relocated.
- Pads may be used to reduce seepage or carry channels across depressions.
- Channels need to be able to completely drain water to reduce weed problems, and have good access to fields and structures. Avoid locating channels across a drain.

Designing channels: Supply channels constructed using earth are only a small expense in the total cost of an irrigation scheme, but if they are not designed correctly, they may reduce the efficiency of the system.

To maintain efficient operation the channels also need to be maintained. A good maintenance schedule will keep your channels operating at their designed efficiency.

To **maintain satisfactory operation of your channels:**

- Prevent weeds growing in a channel because they reduce capacity. This is more pronounced in channels less than 1 m wide or less than 200 mm deep.
- Drain channels when not in use, and de-silt them regularly to maintain capacity.
- Check pipes regularly for fractures or damage.

Flexible woven polyethylene pipe may be used as an alternative to earthen channels for transferring water from the pump to the field. These pipes have outlets that may be varied to control flow to suit the crop and soil type. They can substantially reduce water losses on permeable soil types.

Structures

An irrigation system should have adequate access for water control, stock, and machinery, but each structure will cause some head loss. Your system should have the minimum number of structures feasible for your management purposes.

In general, there are three types of structures:

- culverts
- checks
- outlets

Culverts: Pipe culverts are installed to allow access across supply channels and tailwater drains. They should:

- have minimal head loss
- flow full without sucking air (vortexing)
- be large enough in capacity and length for future developments
- incorporate headwalls (these reduce head losses and erosion and make crossings more visible)
- be constructed to combine checks and drop checks to reduce the number of structures used
- be long enough to allow ease of access across for machinery and trucks.

Checks: Checks are used to reduce the earthworks needed in channel construction and to control height and thus manage flow. Overshot drop board checks are used to control upstream channel levels. Undershot checks (gated) control downstream levels and flow, particularly where supply rates fluctuate.

Checks should:

- have minimal head loss at full flow
- be large enough for any future development
- be easily accessible

Outlets: Outlets are used to transfer water from the supply channel to a field or bay. There are three main types employed in surface irrigation.

- **Gates or doors**

Gates or doors are mostly used in border check systems where large flows are needed. A slide gate or door usually comes in a pre-fabricated structure that is installed into the channel bank or head ditch. The gate or door is adjusted vertically to control water flow onto a bay. For efficient operation the difference in water level between the field and the channel should not be greater than 350 mm, since this leads to erosive velocities, and probably not less than 150 mm, since this limits how quickly water can get onto the field.

- **Through-the-bank pipes**

Through-the-bank pipes, commonly high-density polyethylene, are installed through or below the channel bank. The flow rate is affected by the head difference between the supply channel and the field or bay. The pipes should be installed with the top on the field or bay side level with the ground. Through-the-bank pipes are easily operated from the channel bank. The control valve can be positioned on the inlet or outlet end.

- **Siphons**

Siphons are pipes of various compositions, lengths and sizes that convey water over the channel bank by using the head difference to cause flow. The channel end must be fully submerged and, for maximum flow, the field or bay end should be too.

Flow rate and volume out of the farm supply system

If you can measure flow rate and volume out of the supply system, then you can calculate distribution efficiency and field application efficiency.

The actual flow of water onto the field is directly related to the difference in water levels (head) between the supply channels and water level in the field or bay.

There are three ways to measure how much water is being applied through field outlets.

- direct measurement of flow
- head measurement method
- alternative methods

Calculation 6. Directly measuring flow onto the field

This method can only be used with siphons.

Place a container of known volume in a hole near the siphon outlet and make sure the top of the container is only just above the field water level. The flowing siphon is then directed into the container and the time taken to fill it recorded.

$$\text{Flow rate (L/s)} = \text{volume (L)} \div \text{time (s)}$$

For example, if we used a four-litre bucket and the siphon took 2 seconds to fill it, then to determine the flow rate using direct measurement our equation is:

Flow rate (L/s) =

$$\begin{aligned} &= 4 \div 2 \\ &= 2 \text{ L/s} \end{aligned}$$

We usually think in terms of megalitres per day; to convert the litre-per-second figure into megalitres per day, do these calculations:

Convert L/s to L/min: multiply by 60 seconds.

$$\begin{aligned} &2 \times 60 \\ &= 120 \text{ L/min} \end{aligned}$$

Convert L/min to L/h: multiply by 60 minutes.

$$\begin{aligned} &120 \times 60 \\ &= 7200 \text{ L/h} \end{aligned}$$

Convert 7200 L/h to L/d: multiply by 24 hours.

$$\begin{aligned} &7200 \times 24 \\ &= 172\,800 \text{ L/d} \end{aligned}$$

Convert 172,800 L/d into ML/d: divide by 1 000 000.

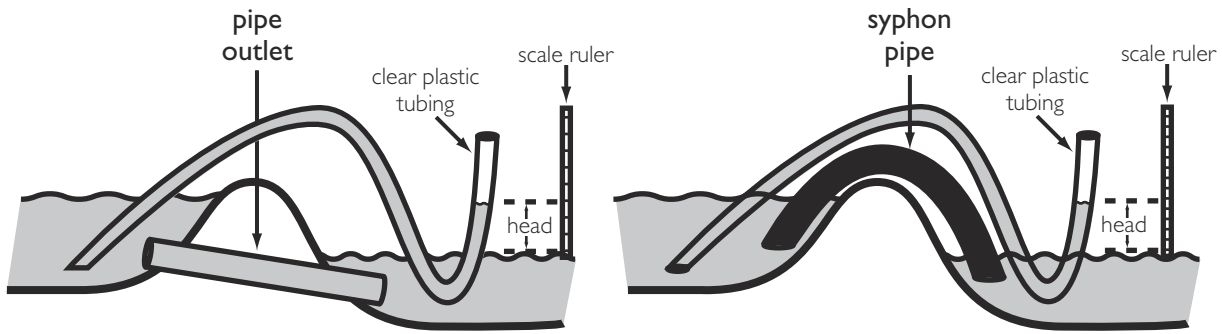
$$\begin{aligned} &172\,800 \div 1\,000\,000 \\ &= 0.17 \text{ ML/d} \end{aligned}$$

The siphon, then, has a flow rate of around 0.2 megalitres per day.

Measuring head and calculating flow onto the field

This method may be used for all systems. With this method, you measure the difference in water level between the supply channel or head ditch and water level on the field or bay. You can use an engineer's level, or a clear plastic tube (Figure 4).

Figure 4. Measuring head over a field or bay



A piece of clear plastic tube (12-mm to 19-mm diameter), long enough to reach from the bed of the supply channel over the channel bank or head ditch to the field or bay, is filled with water to create a syphon. Once the water is flowing, it is lifted above the level of water in the supply channel.

The height difference (head) between the water in the clear plastic tubing and the water on the field or bay can then be used to determine the flow rate through the outlet using the information in Tables 1 to 3.

Example: Siphons

Say our siphons have an outside diameter (od) of 63 mm, 57.5 mm internal diameter (id). If we measured a head of 350 mm, then, according to Table 1, our flow rate is 4.0 L/s.

Table 1. Theoretical flow from siphons (L/s)

Head (mm)	Siphon diameter (mm)		
	50 outside diameter 45.5 inside diameter	63 outside diameter 57.5 inside diameter ↓	75 outside diameter 68.5 inside diameter
100	1.7	2.2	2.9
150	2.1	2.6	3.5
200	2.4	3.0	4.1
250	2.7	3.4	4.6
300	3.0	3.7	5.0
→ 350	3.2	4.0	5.4
400	3.4	4.3	5.8
450	3.6	4.6	6.1
500	3.8	4.8	6.5

Adapted from P. Dalton, University of Southern Queensland.

Note 1: Outlet controlled flow, nominal siphon length 4 metres.

Note 2: Siphons are sensitive to variations in entry and exit conditions, so these flows are only approximate. If there is grass in the channel or the inlet or outlet end is too close to the ground, the flow will be restricted.

Example: Pipe

If a through-the-bank pipe has a diameter of 380 mm, and we measured a head of 150 mm, then the flow rate, from Table 2, is 140 L/s.

Table 2. Through-the-bank pipe outlet flow (L/s)

Head (mm)	Pipe diameter (mm) ↓					
	150	200	225	300	380	450
100	16	29	38	70	114	162
→ 150	19	36	46	85	140	199
200	22	42	54	99	162	229
250	25	46	60	110	181	256
300	27	51	66	121	198	281

Note: Inlet controlled flow

Example: Door outlet

If we measured a head of 250 mm, and the door opening is 525 mm wide, then, from Table 3, the flow rate is 121 L/s.

Table 3: Door outlet flow (L/s)

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

The number of outlets operating determines the total flow rate into the bay or field. For example, if we determined that:

- the flow rate of our siphon was 4.0 L/s
- the field had 30 siphons operating

then the total flow onto the field or bay would be 30×4.0 , or 120 L/s. This may then be converted into ML/d.

Flow rates from different outlet types

Two identical fields with identical crops are irrigated: one uses siphons, the other has door outlets.

	Siphons	Door outlet	
Average head measured over field or bay	350 mm	250 mm	A
Outlet size	63 mm od (57.5 mm id)	525 mm	B
Flow through outlet (from Tables 1 to 3)	4.0 L/s	121 L/s	C
Number of outlets operating	60	2	D

Calculation 7: Determining flow onto the field

Total flow = flow through outlet × number of outlets operating from outlet(s)			
	Siphons	Door outlet	
Total flow	$= C \times D$ $= 4.0 \times 60$ $= 240 \text{ L/s}$	$= C \times D$ $= 121 \times 2$ $= 242 \text{ L/s}$	
Flow rate (ML/d) = total flow (L/s) × 60 (s) × 60 (min.) × 24 (h) ÷ 1,000,000 (L)			
Flow rate onto field	$= E \times 60 \times 60 \times 24 \div 1,000,000$ $= 240 \times 60 \times 60 \times 24 \div 1,000,000$ $= 20.88 \text{ ML/d}$	$= E \times 60 \times 60 \times 24 \div 1,000,000$ $= 242 \times 60 \times 60 \times 24 \div 1,000,000$ $= 20.9 \text{ ML/d}$	

Alternate methods

Flow rates may also be measured with flumes in furrows or flow meters in siphons.

Figure 5. Measuring siphon flow using a flume



Activity 5. Determining flow rate



In your workbook, complete activity 5 on determining flow rate onto the field.

To find out the efficiency of distribution, you need to know the total flow delivered to the field, and the supply flow rate (see, for example, the daily supply through the propeller meter in Figure 1).

Distribution efficiency

Distribution efficiency is the efficiency of delivering water within the farm supply system.

Distribution efficiency

= water delivered to irrigation field ÷ total in-flow into supply system × 100

The higher the distribution efficiency, the greater the volume of water that is getting to your field.

If an irrigation system has poor distribution efficiency, there may be unacceptable losses from the channels. Losses may also be caused by overtopping, leakage, seepage or evaporation. Use the distribution efficiency figure with care, because the equipment used to measure it may be inaccurate.

Activity 6. Distribution efficiency



In your workbook, complete activity 6 on calculating volume delivered to the field, and distribution efficiency.

The irrigated field

In this section we discuss:

- depth of water applied
- uniformity of water application
- infiltration of water applied
- field application efficiency
- watertables

Surface irrigation systems may be divided into two broad categories according to the way fields and bays are irrigated.

The first category (furrow, beds and border check) fill from the highest point in the field and drain from the lowest point.

The second, which includes contour systems, fill and drain from the lowest point in the field.

Because these systems drain and fill differently, their evaluation and management is different.

Calculation 9. Depth of water applied

To evaluate your system, you need to calculate whether the water applied to the surface of the field during each irrigation is enough to meet the crop water requirements (without excessive losses to run-off or deep drainage).

Calculations for depth of irrigation:

$$\text{Run-off amount (ML)} = \text{water delivered} \times \text{estimated run-off (\%)}$$

$$\text{Water remaining (ML)} = \text{water delivered} - \text{run-off}$$

$$\text{Volume applied per hectare (ML/ha)} = \text{water remaining} \div \text{area irrigated}$$

$$\text{Depth of water applied (mm)} = \text{volume applied} \times 100$$

Activity 7. Depth of irrigation



In your workbook, complete activity 7 on calculating depth of irrigation water applied.

Uniformity of water application

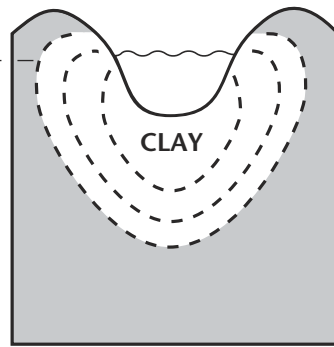
The uniformity of water application is affected by

- the flow rate
- bay or field length and slope
- how long water is on each part of the field
- drainage volume.

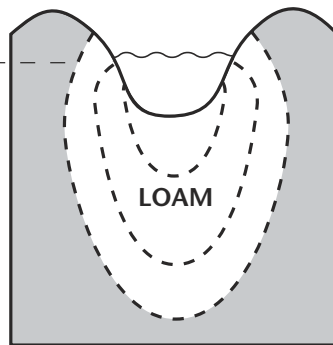
For uniform application, an irrigator must operate the system within a narrow range of these factors. Often, a factor needs to be changed to maximise application uniformity.

Figure 6. Wetting patterns within furrows

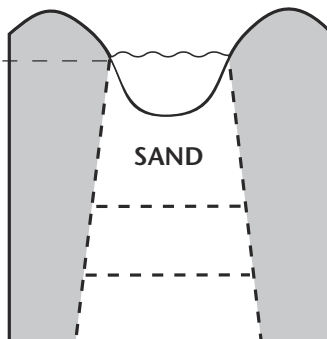
natural surface level



natural surface level



natural surface level



Applying water in a uniform manner is important for the infiltration of water into the soil and managing run-off. Uneven application of water will result in areas having different times of exposure to the water. This means the opportunity for the water to infiltrate into the soil varies.

The time the soil is exposed to the water is referred to as the **infiltration opportunity time (IOT)**.

If alternate furrows are irrigated, seepage into adjacent dry furrows may be a problem in recently tilled and/or highly permeable soils. This seepage will reduce some of the desired benefits of using higher flow rates and alternate furrow irrigation (Figure 6).

Infiltration of water applied

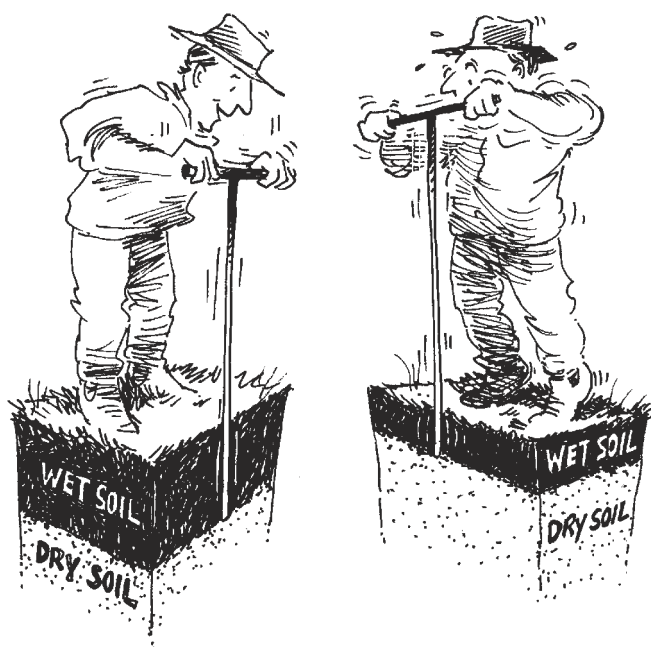
Infiltration of water into the soil differs from soil to soil. It is influenced by changes in soil type, soil condition, farming practices, field slope, and existing soil water content. This variability must be considered when developing and managing an irrigation system. It is common, for instance, to reduce the effects of variability in infiltration by designing an irrigation bay to take in only one soil type, where possible.

We should aim to match the distance to which irrigation water penetrates and the plant's effective root depth. Wetting beyond root depth will result in nutrient leaching, water wasted beyond the root zone and increased watertable accessions: infiltration that is too shallow means irrigation will need to be more frequent.

To check infiltration of an irrigation we need to measure how evenly water is infiltrating into the soil and how long it takes. If possible, the infiltration rate should be measured after several irrigations during a season. This is due to changes in soil conditions and crop development.

A simple method of judging the depth of infiltration after irrigation is to use a soil probe. By pushing the probe into the soil at points in the field, we may assess the soil's resistance. Less resistance indicates wet soil (Figure 7).

Figure 7. Judging the infiltration depth using a soil moisture probe



After the field has drained to field capacity (say 24 hours), push the probe into the soil until resistance is felt. The probe can be made from a 1-m length of 3/8" steel rod, making a handle at one end and a sharpened tip at the other. The tip should be slightly larger in diameter than the rod so that the rod provides no resistance to being pushed into the soil.

Soil water monitoring devices can also indicate the depth of infiltration of an irrigation event.

Infiltration rate

How fast the soil can take in water is referred to as the infiltration rate. The infiltration of water into soil over time is measured in millimetres per hour. This rate can vary considerably with the soil's texture, porosity, bulk density, and structure. Groundcover, slope, and dispersion may also influence rates.

Some soils that are open and porous will have very high infiltration rates. On the other hand, soils prone to slaking can have extremely low infiltration rates due to finer particles forming crusts on the surface, making irrigation difficult. These variations in infiltration rates can lead to variations in infiltration depth or wetting depth.

The salinity of the irrigation water may also influence the infiltration rate. Irrigation water with small concentrations of salts (EC less than 0.2 $\mu\text{S}/\text{cm}$) can result in soil infiltration problems because the water will dissolve soluble salts, causing finer particles to disperse. Irrigation water with high sodium concentration can also cause severe infiltration problems.

In addition to managing the depth of irrigation, we also need to ensure that the infiltration is uniform. To check infiltration uniformity you need to measure how evenly water is infiltrating into the soil over the paddock or bay.

Infiltration opportunity time (IOT), advance and recession

In border check and furrow irrigation, there is usually more infiltration at the higher end of the field. This is because the high end of the field is being continually irrigated during the time it takes the water to reach the bottom of the field. The greater the time spent exposed to the irrigation water, the greater the infiltration.

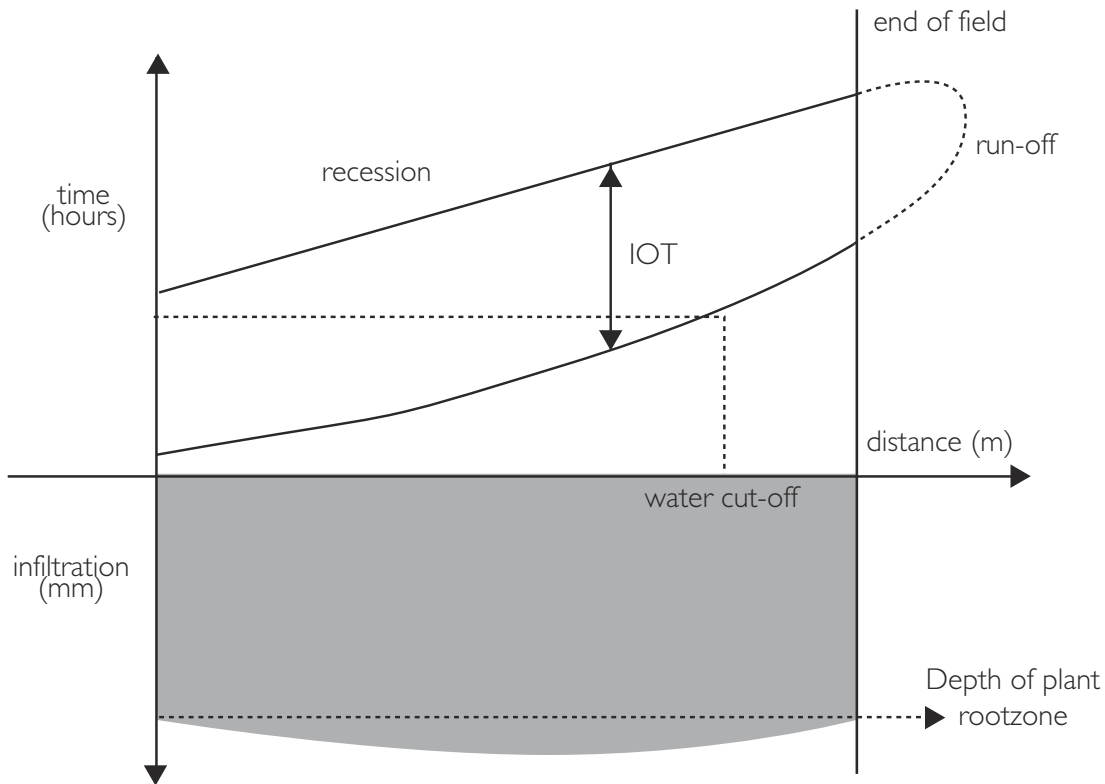
The time allowed for water to infiltrate the soil at a particular point before it runs off is known as **opportunity time**.

To achieve uniform infiltration the opportunity time should be even across the whole field. This is especially so in sandy loams because relatively small differences in opportunity time can lead to large differences in the amount of water applied.

Movement of a wetting front down a furrow or bay is called **advance**. Drainage of the last free water from the surface is called **recession**. Even infiltration is achieved when the advance and recession rates are the same (Figure 8). This is achieved by adjusting the inflow rate, which affects advance but

not recession. Recession is hard to observe and may never occur as water may pond and soak in rather than flow down the bay. The stage of crop growth and the type of crop also influence advance and recession time: plant material can slow down both advance and recession, thereby increasing infiltration opportunity time.

Figure 8. Ideal irrigation: advance and recession nearly parallel, adequate irrigation, minimal run-off



IOT = infiltration opportunity time

The **cut-off point** is the location down the field to which the water is allowed to advance before on-flow is shut off. When water is shut off, recession begins at the top of the field.

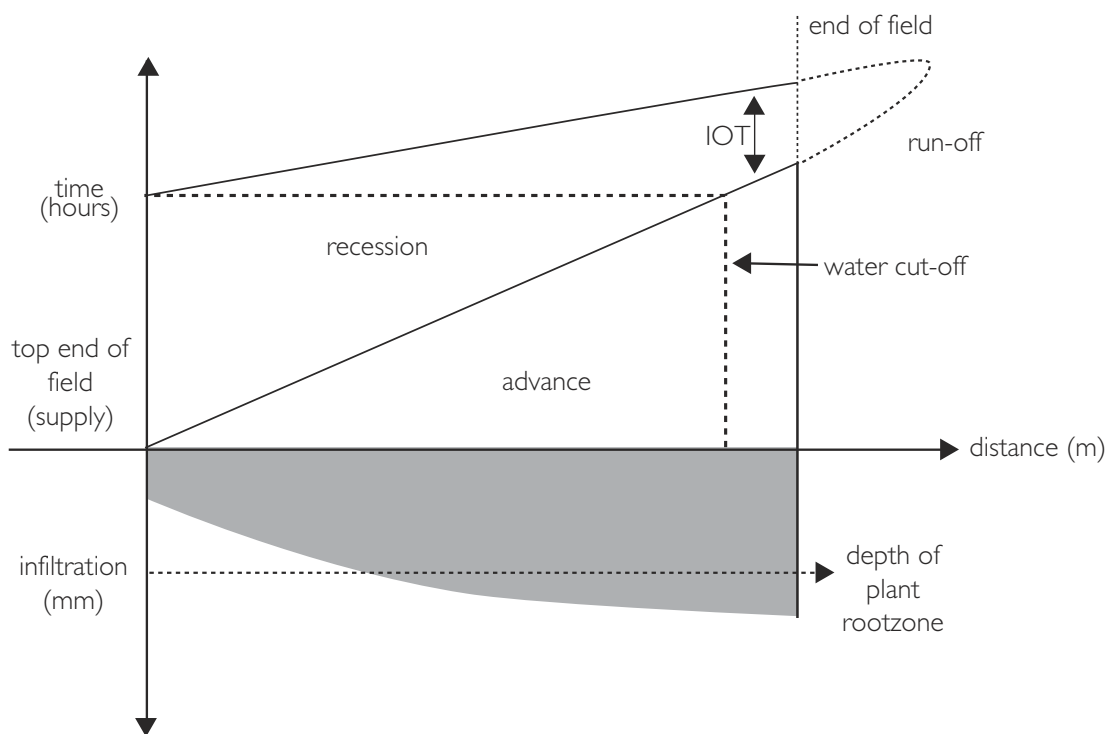
Growers can minimise run-off by shutting the water off soon enough or by blocking the ends of the bays/furrows. In all cases, efficiently managed tailwater recovery systems can eliminate run-off 'losses'.

Improving uniformity of border check and furrow irrigation

On the following pages are advance/recession curves that illustrate the most common problems that occur during surface irrigation. Common problems include too much or not enough IOT at the ends of the field, resulting in varying infiltration depths over the whole field.

Problem 1: Infiltration is too deep at the top of the field.

Figure 9. Advance and recession not parallel: too much IOT at top of field



Due to a steep advance curve, the advance and recession curves are not parallel. This results in more infiltration opportunity time at the top end of the field than at the bottom (Figure 9).

Solution: Increase the rate of flow onto the field to speed up the advance (this will flatten out the curve).

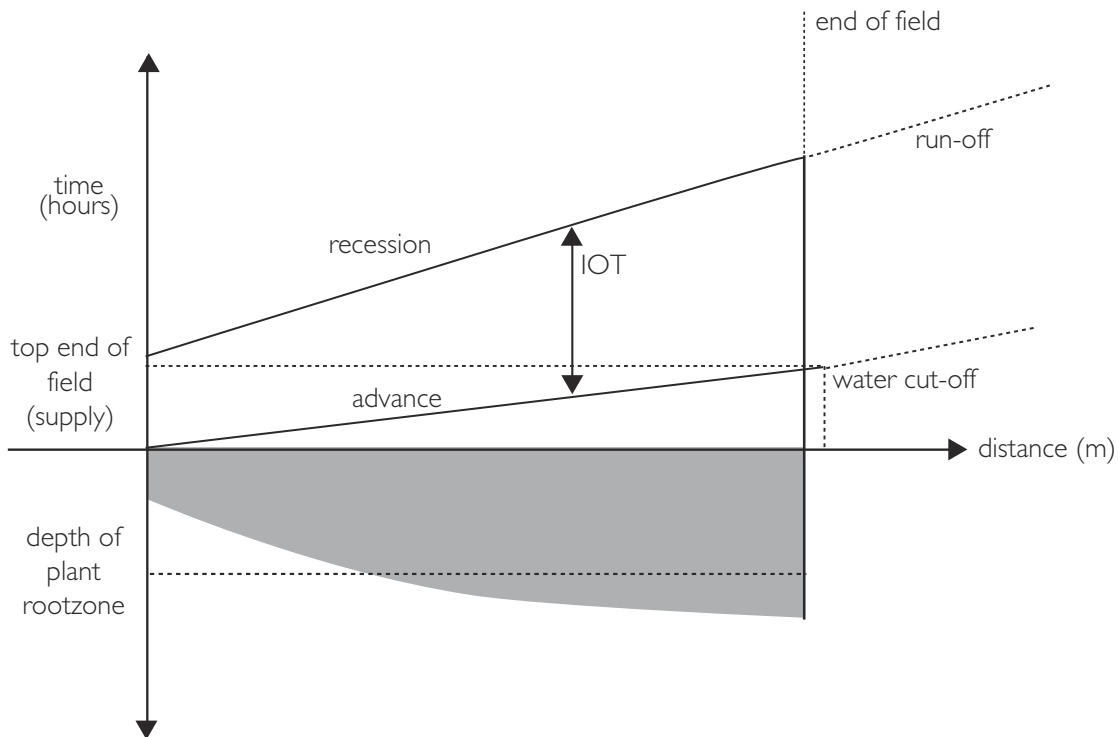
With higher on-flow rates, the water needs to be shut off sooner to minimise run-off and deep percolation. In border check systems, reducing the number of borders irrigated during each set or shift may increase on-flow rates.

If supply cannot be increased, or supplemented from on-farm storage, one design solution would be to have a shorter furrow or a smaller bay. If the field is too long for the amount that needs to be applied, then the lower part of the field could be under-irrigated, and there would be little or no run-off.

Before making any change to flow rate, consider the chance of increased soil erosion or overtopping of hills or check banks.

Problem 2: Infiltration is too deep at the bottom end of field.

Figure 10. Advance curve flat, too much run-off; depth of infiltration too deep at end of field



The advance curve in this situation (Figure 10) is very flat, indicating that the advance was too fast. This means that the on-flow rate was too high. The result is reduced opportunity time at the top of the field and excessive run-off and opportunity time at the bottom of the field.

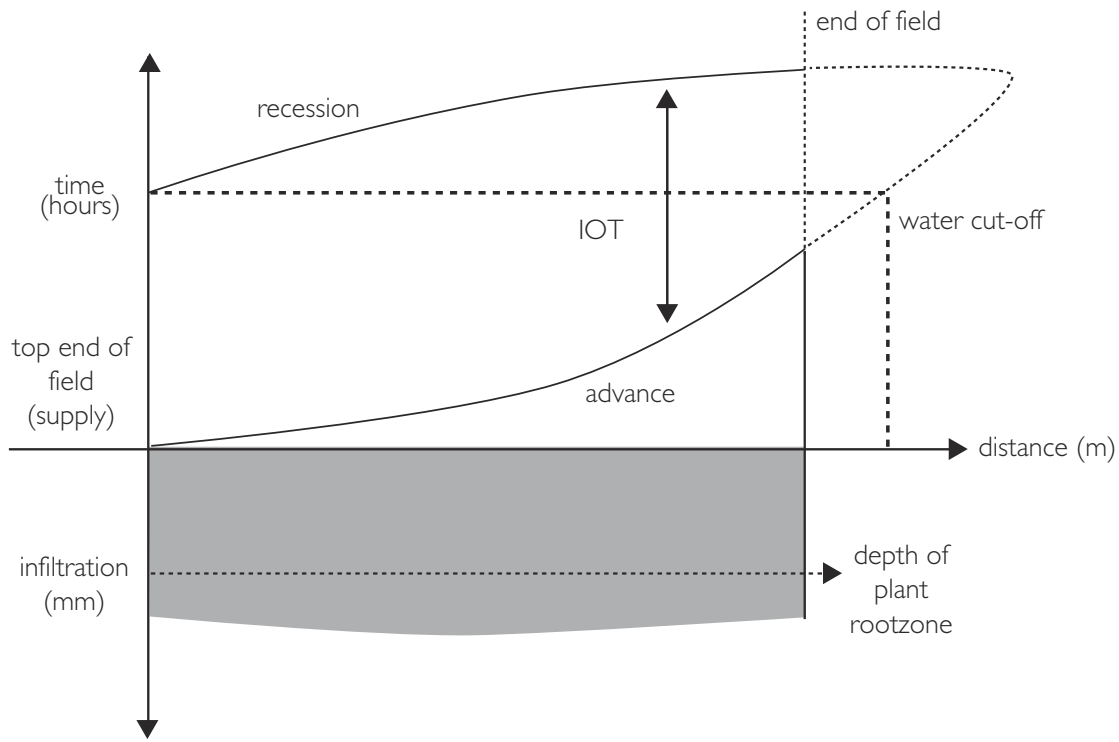
To avoid this excessive run-off, the cut-off could be earlier, but this would result in the upper end of the field being under-irrigated.

Solution: Reducing the on-flow rate will steepen the advance curve. If the border/field length and application amounts are correct, reducing the on-flow rate will reduce run-off without under-irrigating the lower end.

This situation may also arise where the water is 'backing up' because of poor surface drainage off the field.

Problem 3: Infiltration is too deep over the whole field.

Figure 11. Infiltration too deep over the whole field with too much run-off



In Figure 11, the advance and recession curves are nearly parallel, indicating a uniform infiltration. The irrigation line is also parallel to the advance curve, giving equal infiltration opportunity time down the entire field.

The cut-off, however, was too late: the infiltration opportunity time at the top of the field was met long before cut-off. This late cut-off over-irrigates the entire field, and produces far too much run-off.

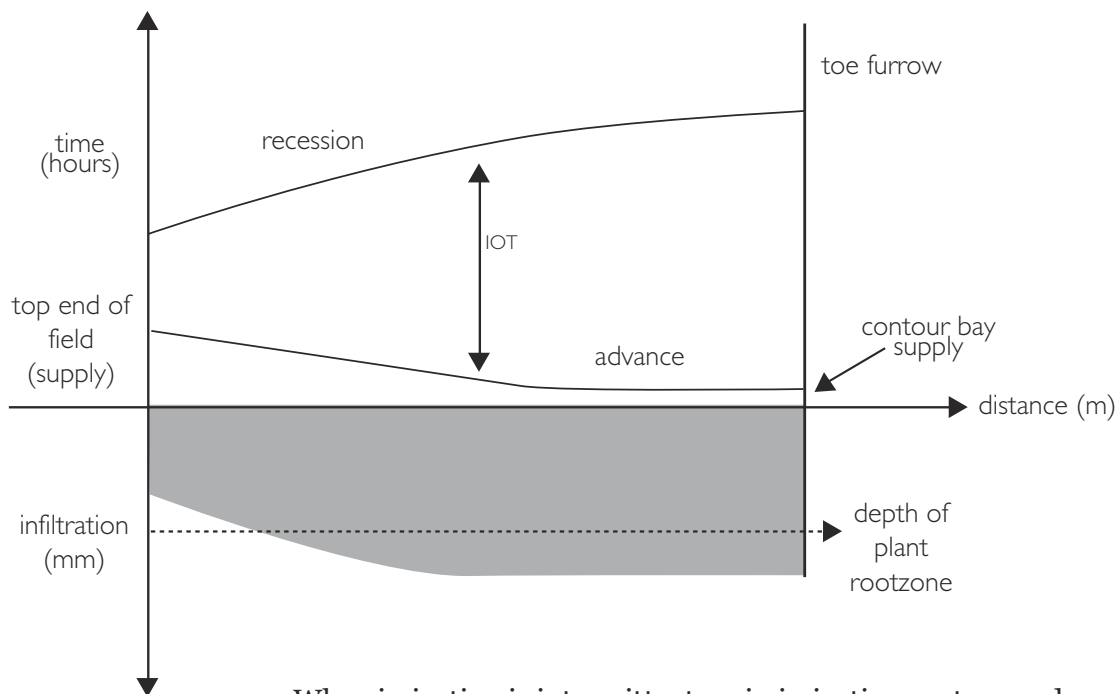
Solution: The cut-off should have occurred when the infiltration opportunity time was met at the top of the field.

Improving uniformity of contour irrigation

Contour irrigation should only be used on soil with low infiltration rates. It is best suited for growing rice on heavy soil. Other crops are grown in rotation with rice, and so irrigation and design should be managed to maximise irrigation efficiency for these crops.

The land within the contour banks may be landformed to improve drainage.

Figure 12. Ideal infiltration profile in contour bay



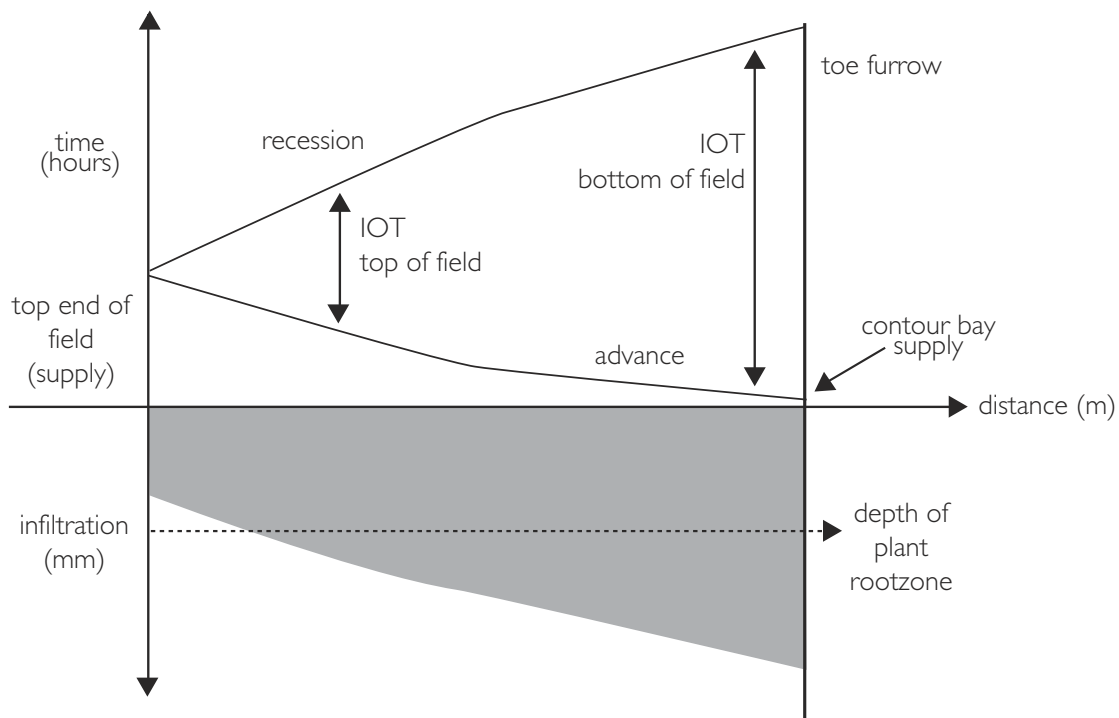
When irrigation is intermittent, as in irrigating pasture and other crops, the opportunity time will vary across the bay length because water remains in the lowest part of the bay for a lot longer than on the high side of the bay.

Application uniformity may be improved by landforming to remove any cross-fall and to produce an even grade. Areas that have not been landformed may have uneven application as well as poor drainage.

Sometimes infiltration rates can vary because of landforming, where cut and fill operations change soil profiles. Replacing topsoil and organic matter and nutrients on heavy cut areas minimises this variability.

Problem 4: Infiltration is too deep over the whole bay.

Figure 13. Infiltration too deep at lower end of bay



Solutions:

Landform. An even grade minimises ponding. (Ponding areas are often indicated by waterweeds.)

Improve drainage. Toe furrows (or borrow ditches) beside the contour bank are the key to drainage of the bay. They should be as large as practical and kept clean and free of obstructions. They should also be connected the rest of the system by a drainage point or outlet.

Outlets need to be large enough to carry the flow, and installed with the sills well below the ground level (near the base of the toe furrow) to maximise flow area. More than one outlet per bay may be needed.

Bay area. If the bay is too large, filling and drainage off will take too long.

Field application efficiency

Field application efficiency is the efficiency of the water application within the boundaries of the field. You can determine the field application efficiency for a single irrigation event, or for a whole season (note, however, that it may vary through the season).

By adopting the techniques discussed in this workshop, you will be able to measure the amount of water being delivered to a field. Once you have learned about crop water use, covered in the workshop on scheduling and benchmarking, you will be able to determine how much water your crop is using.

It is difficult to measure crop water use and flow onto the field accurately.

The estimated crop water use (CWU) and volume of irrigation water delivered to the field are used to calculate the field application efficiency:

$$\text{Field application efficiency} = \frac{\text{crop water use (ML)}}{\text{water delivered to irrigation field (ML)}} \quad (\text{IAA definition})$$

To convert this into a percentage, multiply by 100.

$$\text{Field application efficiency} \times 100 = \text{field application efficiency \%}$$

Determining field application efficiency

To calculate the field application efficiency we need to collect information on crop water use and the irrigated field. The information you need includes:

- estimated daily crop water use
- volume delivered to field
- area irrigated
- days between irrigations

Activity 8. Field application efficiency



Look through the worked example 'A. Without recycling' in activity 8.

Field application efficiency may be significantly improved by collecting run-off and recycling water.

In your workbook, complete activity 8 on calculating field application efficiency, worked example 'B. With recycling'.

Surface drainage and reuse systems

In this section we discuss:

- waterlogging
- border check irrigation drainage
- furrow irrigation drainage
- contour irrigation drainage
- drainage capacity
- excess volume options
- drainage structures
- on-farm storage

The aim of a drainage/reuse system is to remove all surface water from the fields or bays within a short period and to move the drained water into storage or the supply system for reuse.

The two main reasons for surface drainage and reuse are:

- Drainage water is a resource which, if not reused, represents a cost to the irrigator.
- As a condition of any water licence, drainage water must be retained on-farm.

Drainage water may contain sediments, chemicals (nutrients, pesticides and salt), and bacteria, and the possible contaminants should be considered before reusing drainage water.

The drainage system must cater for the current layout and for any developments, and must be considered in the initial design. While it may be years before the full irrigation system is developed, some aspects of the drainage system must be incorporated from the start.

Watertables

Waterlogging within fields and subsequent rising watertables is a problem for both irrigators and the environment. A watertable is a zone of soil that is saturated by groundwater. Watertables may be shallow, deep, or perched (due to underlying restrictive layers).

Why are high watertables a problem?

Trees are generally the first to suffer from high watertables as their deep roots become flooded and starved of oxygen. The water is usually saline, as it has dissolved the naturally occurring salts found in the soil. This, combined with the lack of oxygen and other associated waterlogging effects, can have a serious impact on production and the natural environment.

If the watertable continues to rise to within 1–2 metres of the soil surface, the groundwater of the watertable can move into the rootzone of other plants such as crops and pastures through a process known as capillary rise.

It then evaporates from the surface or is used by plants, leaving salt on or near the soil surface. Over time, the concentration becomes high enough to affect plant growth. In worst case scenarios, plant growth can be restricted to plants that are highly salt-tolerant. In these situations, the land is often unproductive for agricultural use.

What causes watertables to rise?

Watertables rise when the amount of water entering the system is greater than the water draining from the system. Water can increase from irrigation infrastructure seepage – around 25% of accessions in NSW occur as seepage from channels, drains and dams – or from poor irrigation practices leading to percolation or deep drainage.

Drainage can be reduced when tree-covered plains are cleared and trees replaced with shallow-rooted crops and pastures, and when roads, channels, levees, and on-farm earthworks are constructed that block natural drainage flows.

Irrigation practices that may contribute to rising watertables and salinity can include:

- Over-irrigating – applying more water than the crop or pasture needs. If this surplus water does not drain away, it seeps through the soil to the watertable.
- Irrigating on incorrect soils – sandy soils have larger pore spaces that let water seep through more easily.
- Uneven ground/poor drainage – if a paddock does not drain freely after irrigation and water lies in depressions, the only way the water will leave the paddock is by evaporation or by seeping through the soil to the watertable.
- Inadequate grades – if grades are too flat for the soil type and bay length, irrigation may take too long, giving water more time to seep past the root zone.
- Infrequent irrigation – if the soil is allowed to dry out and then a large amount of water applied, much of it will flow straight through cracks in the soil to the watertable. Another effect of dry soil is the death of many plant roots that further reduce the ability of the plants to use the water when it is applied.

Effects of waterlogging on plants

Most plants do not respond well to periods of waterlogging. A waterlogged soil is deficient in oxygen, which is essential for plant roots to actively uptake nutrients. Waterlogging can cause temporary nitrogen and sulfur deficiencies and can cause some trace elements to become deficient or toxic, depending on the element. Waterlogging can also interrupt the process of organic matter breakdown.

Short-term symptoms:

- slow and poor germination
- yellowing of crop or pasture
- less vigorous plant growth with plants often appearing stunted and thin, resulting in varying crop yields

Long-term symptoms:

- tree death, especially in low-lying areas
- changes in pasture composition (for example, less subclover)
- extreme stunting of crop or crop death
- waterlogging-tolerant species dominate (for example, pin rush, dock, umbrella sedge)
- bare patches appearing where water lies

Border check irrigation drainage

How well a bay drains following an irrigation event depends upon several factors:

Bay length: In some soil and crop situations, bays longer than 350–400 metres on flat grades (>1:1250) do not drain well, especially in the winter when evaporation is slow. In long bays, the use of spinner cuts running down the bay effectively reduces the distance that water has to travel before entering a drain. The cuts need to connect with the formed drain at the bottom of the bay.

Bay grade: In general, the steeper the grade, the better the surface drainage. With flatter grades, reverse grades may occur, causing ponding. Even when grades are constant, tillage or sowing will cause ridges to form. A ridge of 1 cm high across a 1:1000 grade will hold water back for a distance of 10 metres.

Soil type: Coarse-textured soils, such as sands and loams, have better internal drainage than fine textured clay soils. Internal drainage of clays varies substantially, depending on the structure, sodicity, organic matter content, and mineralogy. Clays that are not self-mulching and transitional red-brown earth clay soils are usually poorly drained. These soils need good surface drainage system (for example, steep grades or beds) to compensate for their poor subsurface drainage.

Groundcover: Crop or pasture height and density affect surface drainage substantially. Thick swards slow water movement and therefore drainage. Pasture paddocks, particularly those that will be watered frequently, such as summer pasture, need to be designed with bay grades and lengths that are steeper and shorter than normal, and preferably restricted to soils with good drainage and infiltration rates.

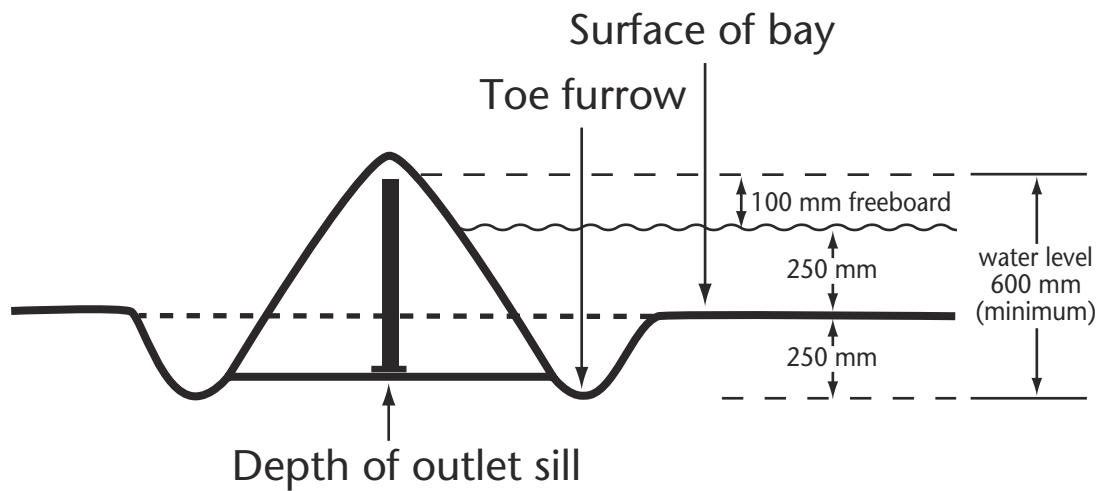
Furrow irrigation drainage

In developing a furrow-irrigated farm, the natural drainage process from the field is altered so that up to 80–90% of rainfall becomes run-off, compared with 10–20% under natural conditions. This generally means run-off is speeded up during heavy rainfall, giving a quick surge of a large amount of water through the drainage system, and this may result in an overflow of water.

Contour irrigation drainage

Drainage cannot occur without the toe furrows at the base of the contour bank. An efficient contour layout needs to ensure that the toe furrows are clean and interconnected to a drain deep enough to empty them (Figure 14). Layouts that drain bay-to-bay remain waterlogged longer than layouts that drain each bay separately.

Figure 14. Drainage factors affecting contour layouts



Tailwater drain design

The tailwater return drain should meet the expected run-off volume during a typical irrigation.

The furrow level at the drainage end of the lowest field controls the depth of a tailwater return system. If the drain starts at this point, use a minimum depth of 0.7 m below furrow level to allow complete drainage from the field. Increase the depth of the tailwater drain, usually at a grade of 1:5000, as the tailwater from additional fields is added.

Drainage capacity

In most areas, drain capacity is dictated by storm flows. The capacity of a drain depends on the time over which drainage must occur. Unlike supply channels, the flow rates in surface irrigation drainage systems fluctuate rapidly and often. Most crops need stormwater to drain within 24 to 48 hours. For high value crops that are sensitive to waterlogging, it is desirable to achieve a more rapid drainage.

Drainage systems are usually designed for a one-in-five-year storm. Because the cost of drains and culverts increases with size, it may not pay to provide a bigger capacity for a rare storm event.

For a drainage system to operate effectively there must be a well-defined drain at the end of the bay to remove run-off and prevent water from backing up the bay: this is the tail drain. The capacity of a tail drain depends on soil conditions, the area it is draining and management practices. For an area of up to 40 hectares laid out to border check, the drain should have a capacity of at least 6 ML/d.

For areas of 40–100 hectares, the capacity should be at least 10 ML/d.

For areas larger than 100 hectares, drains should be constructed to cope with 0.25 ML/d for every hectare drained.

Tail drains should have grades greater than 1:5,000 with little capacity at the beginning and increasing to maximum capacity at the bottom of the field. Drain batters should be very flat to allow access for machinery across the drain when it is dry and to provide a turning area at the bottom of the field during cultivations. Generally, a 10:1 batter is used on the field side and 5:1 batter on the roadside.

Taildrains must also be low enough to drain the field without causing erosion into the drain from the furrows or bays. Generally, the depth between the drain and the field level should not exceed 500 mm. If the drain is too shallow, water may back up into the field.

You need to know the carrying capacity of all the components of a furrow irrigation system to prevent or solve tailwater drainage, stormwater run-off, and potential contamination problems.

Excess volume options

Surge areas are an extension of a tailwater return system. They are designed to extend the storage capacity to delay the flow of run-off back to a pump site, when it exceeds the capacity of the normal system.

They provide an area to allow the run-off water to slow down to a speed (< 0.2 m/s) where suspended material can drop from the water and be retained on-farm.

The principle behind the construction of a surge dam or surge area is to store excess water below crop levels with the option of allowing this water to flow back into the tailwater return system and then on to a relift pump. Surge systems are therefore usually located on the lowest part of the farm, or in a position where surplus tailwater flow can be directed under gravitational flow.

Drainage structures

Structures within drains that are too small or set too high make water back up onto the field, and incorrectly sized pipes and culverts with low velocities are likely to silt up. Table 4 shows the preferred culvert sizes for various flow rates.

Table 4. Approximate flow rate of 12-m long culverts based on head available

Head	Culvert diameter (mm)							
	9	13	19	25	40	59	82	109
0.1								
0.15	10.5	16	23	31	49	72	101	133
0.2	12	19	27	36	57	83	116	154
0.25	13.5	21	30	40	64	93	130	172
0.3	15	23	33	44	70	102	142	188
0.4	17	27	38	50	81	118	164	217
0.5	19	30	42	56	90	132	184	243

Barrett, Purcell & Associates Pty Ltd, Narrabri.

On-farm storage

On-farm storages range from excavated tanks holding only a few megalitres to large ring tanks holding more than 1000 megalitres.

Storages can allow you to make the most of all available water, including:

- ordered water that is not needed
- off-allocation water
- rainfall and irrigation run-off
- water from non-perennial streams
- underground water

Storage can have many advantages but can also be a major cost, so consider carefully whether developing one is justified.

On-farm storage can help you manage your system more efficiently:

- by allowing you to comply with regulations that require all irrigation drainage to be retained on-farm
- by ensuring a supply when district channels are shut down for maintenance
- where the supply is regulated or restricted

Information on storage siting, design, costing, construction and management can be found in

- NSW Agriculture's *Guidelines for siting, design, construction and management of on-farm storages*
- Irrigation Association of Australia's *Guidelines for Ring Tank Storages*
- Irrigation salinity fact sheet 5: *On-farm Storages*.

Conclusion

This workshop has introduced ways to evaluate your surface system and has identified opportunities for improvements in irrigation performance.

By applying these principles, you can improve irrigation efficiency on your farm and achieve improved productivity.

Activity 9. Irrigation system checklist



Complete your evaluation by working through the irrigation system checklists in your workbook.