5.3 Surface irrigation performance and operation

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Key points

- Efficient surface irrigation requires management and maintenance of all system components between the head ditch and the tail drain.
- Irrigation performance is controlled by a number of variables which influence performance to differing degrees.
- Efficient irrigation involves careful management of these variables and an understanding of how they interact.
- Evaluating the performance of a surface irrigation system can be complex, but is essential to improve efficiency.
- Some practices used to improve performance must be managed precisely otherwise performance may actually be reduced.

Surface irrigation is the process of applying irrigation water to the field surface and using the field itself to distribute the water. Common forms of surface irrigation include furrow irrigation, where water flows down narrow furrows between crop rows, or border-check irrigation, where water flows down strips of the field that may be up to 100m wide. Systems such as bankless channel can be more challenging to evaluate because the water is applied from the bottom of the slope, making the surface hydraulics more complex. Further information on bankless channel irrigation is included in WATERpak Chapter 5.4.

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

In reality, furrow irrigation systems can sometimes be quite capital intensive, and a high labour requirement can often result in reasonably high operating costs. Perhaps most importantly, the performance of surface irrigation systems can be very high, rivalling drip and CPLM systems with the right management.

However obtaining the optimal performance of a surface irrigation system can be a challenging management task and this chapter aims to give a better understanding of the process.

Furrow irrigation system components

Head ditch

The purpose of a head ditch is to consistently deliver sufficient water at an appropriate head. The aim is to achieve a steady flow rate onto the field. Maintaining a constant flow rate requires specific management and maintenance. Management involves regulating flows in the system and selecting and operating outlets appropriately, while also maintaining adequate freeboard. Regular maintenance such as desilting, weed control and removal of obstructions must also be done.

Head ditch flow is regulated at the source, while head ditch levels are determined by downstream control structures. Water level should be kept as constant as possible while irrigating, as fluctuations cause the outlet discharge to change. Consequently, to maintain a constant head, discharge from all outlets should equal the head ditch inflow. A minimum 0.15 m freeboard should be maintained in the head ditch.
Because soils other than heavy clays are more susceptible to erosion, head ditches in these soils should be designed to keep water velocity below 0.6 metres per second (m/s). Heavy clays should be limited to flows below 1 m/s. A velocity above this may cause scouring. Velocity should also be kept above 0.15 m/s, or silting may occur.

Measurement of flow in head ditches is quite complex and is typically achieved using ultrasonic flowmeters (for example, Doppler meters: see WATERpak Chapter 1.7.) or by measuring depth through calibrated control structures such as flumes or weirs. It may be possible in some circumstances to measure flow over irrigation checks, whilst modern channel gates often incorporate measurement technology.

Obstructions in the head ditch can cause scouring and increase the system head loss. While head ditches less than 1 metre wide or less than 0.2 m deep are most susceptible, obstructions in all head ditches should be avoided. Obstructions can be caused by silting, weeds and embankment slumps.

Head loss occurs whenever water flows. It increases when water goes from a broad slow flowing channel into a fast-flowing pipe. Bends, restrictions and sudden changes in channel size or pipe diameter all increase head loss.

In surface irrigation systems, head loss is evident as a drop in water level from upstream to downstream. This means it can be measured reasonably across any structure, such as through-the-bank pipes, culverts or checks.

Understanding the interaction of head and flow rates is important for correct application of water onto a field. Flow through siphons and culverts increases as head increases, and decreases as head decreases. It is important to install culverts so they run at their full capacity, as culverts running partially full have greater head loss and restrict flow.

This is an important and seemingly counter-intuitive concept which means that culverts should be placed at sufficient depth so as to operate with full flow. For example, culverts used to drain a field should be placed with the top inside level of the culvert set equal to the lowest level of the field.

**Siphons**

Siphons can operate under two situations: submerged flow and free flow conditions (Figures 5.3.1 and 5.3.2).

- When operating under submerged flow conditions, the available head is the difference between the upstream water level and the downstream water level.
- Under free flow conditions the head is the difference between the upstream water level and the level of the siphon outlet.

**Siphon and culvert hydraulics**

Water movement requires energy. Overcoming the resistance or friction as water moves through channels or pipes accounts for most of this energy use. The energy driving a system is called 'head' and the loss in energy is called 'head loss'. Careful design and management of a system can reduce the head loss of a system. Irrigation systems are usually designed and operated to limit the total system head loss, which usually minimises energy costs, channel and pipe sizes, and prevents the overtopping of channels.
In most cases, with typical irrigation head ditch layouts, siphons will be operating with submerged flow (Figure 5.3.1). Under these conditions, siphon flow rates can be affected by water level in the furrow stream and the head ditch, siphon length and diameter, and the internal roughness of the siphon. In one trial, variations ranging from 27% to 152% of the mean siphon flow rate occurred as a result of these variables. This has obvious implications for the distribution uniformity of a given field.

Pipe diameter has a significant influence on siphon capacity. Siphon flow rates can be measured using methods outlined later in this chapter. Siphon placement can affect flow rate. Placement of siphons at different angles to the flow of the head ditch causes a preferential flow into some of the siphons that results in flow variation. Placing all siphons perpendicular to the head ditch can help overcome this problem.

Any variation in cross-sectional area will affect flow rate. Walking on siphons or accidentally pushing them into the ground when starting them may cause kinks, reducing their cross-sectional area. Extreme heat may cause them to become oval, also reducing the cross-sectional area.

Also note that siphons are available in both metric and imperial sizes. Although these siphons may look to be a similar size, their internal diameter varies which will result in different flow rates (also see here).

For example two inch and 50 mm siphons can be easily confused, but flow can vary by up to 27%. For one example in the referred article, this resulted in an additional application of 0.37 ML/ha in only one irrigation. Also note that different manufacturers produce different wall thickness pipe which also results in small differences even within the same size classification.

Theoretical flow rates for a range of siphon sizes are presented in WATERpak Appendix 1.

### Pipes through the bank

Pipes through the bank (PTBs) operate like conventional culverts and may be either inlet- or outlet-controlled depending on the water level in the head ditch and the irrigation field as well as the pipe geometry. The relationship between head and pipe size on the theoretical flow of PTBs again demonstrates the importance of pipe diameter and amount of head (Table 5.3.1).

PTBs are different to most other culverts on an irrigation farm. Flow rates in PTBs are often controlled from the inlet. As a result, changes in supply level can have significant effects on PTB flow rates. Preferential flow down some furrows, caused by wheel tracks and trash build-up, and maintaining adequate head are two problems often encountered with PTBs.

A recent case study of successful PTB application can be found on page 29 of the Australian Cotton Water Story and a video is also available. The case study includes a number of design considerations and is highly recommended for those with an interest in PTB systems.

### Table 5.3.1 Theoretical flow (L/sec) for pipes through-the-bank (PTBs)

<table>
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</table>

Note: Inlet controlled flow
Furrows

Furrows and bed dimensions can assist in improving water use efficiency and crop health on farm. Cotton has traditionally been grown on 1 metre beds, however there are a number of alternative bed configurations being used to achieve a variety of outcomes to suit local conditions and soil types.

While weed control in furrows is important, the presence of stubble or a root mat on bed edges can reduce the incidence of erosion while creating biopores (holes created by roots and soil organisms) that improve infiltration.

Deep furrows may promote adequate drainage of the field. However, deeper furrows mean steeper bed edges, which are difficult to maintain and be prone to slumping. Slumping encourages erosion and may dam furrows, resulting in waterlogging of the bed. More information on furrow design can be found in SOILpak D1.

Reduced in-crop cultivations in Roundup® Ready cotton sometimes results in hill slumping. Cultivation reforms hills, helping to prevent slumping and subsequent damming of furrows. Blocking off a furrow leads to poorer DU. Where two or more rows are irrigated using one siphon, preferential flow into one furrow may result, leading to poor DU. Slumping or silt build-up in one furrow can also cause preferential flow.

Waterlogging can result in dramatic production losses (see WATERpak Chapter 3.4). This should be considered on very flat fields (flatter than 1:1500) both from an irrigation perspective and a rainfall drainage perspective. Furrow lengths that are too long may result in excessive deep drainage and waterlogging at the top end of the field. This is because the infiltration opportunity time is too long.

Fields are laser graded to a certain slope for good drainage and high DU. Fill areas and gilgai country suffer slumping over time. Fields should be re-laser-graded or polished as required to ensure a high DU is maintained. Steep slopes or application rates that are too great can result in furrow water velocities that may cause erosion of the furrow and siltation problems elsewhere.

Fields with point rows (non-square fields) need to be carefully managed. The varying furrow lengths will require different irrigation times to avoid waterlogging. This has a greater labour requirement as siphons will need to be cut at different times but a high DU can be maintained. A different approach is to reduce the siphon sizes on the shorter rows to slow the flow rate. This may be appropriate, however remember that the aim in these sections of the field is to have an infiltration opportunity time equal to that of any point in the remainder of the field. These furrows do not necessarily need to come out at the same time as longer furrows provided the infiltration opportunity time is managed correctly.

Tail drain

Tail drains remove run-off from the field created by both irrigation and rainfall events. Tail drains are typically designed to drain run-off generated by a one-in-five-year, 24 hour storm event. Rapid removal is necessary to prevent in-field waterlogging and reduce the yield penalty created by waterlogging (see WATERpak Chapter 3.4).

In order to correctly design tail drains, stormwater run-off needs to be estimated. Climatic factors, current soil moisture content and the size of the field will influence the total run-off. It must be appreciated that designing tail drains is site specific with many factors to consider. Tail drains should be constructed with a minimum gradient of 1:3000. Drain capacity should increase from the beginning of the drain with maximum capacity at the end of the tail drain. Batters should be shallow, 10:1 on field side to minimise erosion and 5:1 on road side to allow machinery access. Drains should be sufficiently deep to prevent water backing up into the field, yet sufficiently shallow to prevent erosion occurring between the furrow and the drain. Generally the depth between the furrow and the tail drain should not exceed 250 mm.

There is a compromise between the cost of constructing large tail drains to cope with rare storm events against the penalty of suffering yield losses associated with water backing up onto field due to smaller tail drains.

Tail drains should drain into the tailwater return system with a minimum depth of 700 mm between the furrow level and the drainage return system. This will ensure complete drainage of the field is achieved, minimising waterlogging. It is important that the tailwater return system and pump are designed to cope with the large volumes of water storms can generate. Construction of surge areas is an option to minimise drain and pump sizes and allow settling of sediment. The water in the surge area can then be pumped once the immediate storm water is removed.

As in head ditches, water velocity in the tail drain should be kept below 0.6 m/s in soils other than heavy clays, which should be limited to flows below 1 m/s. Flows above these
velocities can cause scouring. In contrast, flows should be kept above 0.15 m/s or excessive silting may occur.

Culverts should be adequately sized to cope with drainage requirements and high trash loads. High volumes of trash in undersized culverts may lead to blockages and result in field waterlogging problems caused by backed up water. Blockages can also lead to scouring and significant head loss. Some design considerations for trash management include:

- Install drainage culvert upstream of the channel end to allow trash accumulation at the end of the channel while preventing culvert blockage.
- Enlarged culverts allow trash to be carried through rather than causing blockages.
- Ensure regular maintenance is carried out to limit blockages.

### Surface Irrigation Hydraulics

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

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

1. Useful water is applied to the root zone, which may continue until the soil profile is filled to field capacity.
2. Additional water applied to the root zone, may increase the soil profile to saturation and cause waterlogging (WATERpak Chapter 3.4).
3. Excess water infiltrates through the soil profile, leaving the root zone as deep drainage (WATERpak Chapters 1.4 and 1.5). (This process may continue after application ceases, as the saturated soil drains to field capacity).
4. Excess water leaves the field as runoff (tailwater).
5. Water is used through evapotranspiration (WATERpak Chapter 2.8).

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

### Infiltration

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

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

The infiltration characteristic can be represented by a cumulative infiltration curve. A cumulative infiltration curve shows the total amount of water that can infiltrate into a soil over a given period of time. Figure 5.3.3 is an example of some cumulative infiltration curves.

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

**Figure 5.3.3.** A range of cumulative infiltration curves showing different soil infiltration characteristics. (Source – P Dalton, NCEA)
Opportunity Time

The infiltration opportunity time is the length of time that water is present on the soil surface for infiltration to take place. To achieve the best performance, the opportunity time for an irrigation should equal the amount of time necessary to apply the required depth of water. In Figure 5.3.3, if the amount of water required is indicated by 'A', then the time required to apply that amount of water is indicated by 'B'.

The opportunity time for a furrow irrigation event often varies along the furrow. This is because the length of time that the water is present on the surface of the soil at any location is the difference between the time the water arrives (advance) and the time the water leaves (recession). As illustrated in Figure 5.3.4, the rate at which the water advances down the field is different to the rate at which it recedes.

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

Distribution Uniformity

Distribution uniformity, which has been previously discussed in WATERpak Chapter 1.2, is a measure of how evenly water has been applied and is expressed as a percentage (%). Low distribution uniformity is caused by an uneven opportunity time along the length of the furrow. The result is either part of a field being under-watered or part being over-watered, in an attempt to apply sufficient water to the rest of the field. It is this practice that most often causes waterlogging to significant parts of a field, which in turn results in potential yield loss. Calculating distribution uniformity for furrow-irrigated fields typically requires computer modelling to simulate an irrigation event.

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

In addition to the variation in uniformity along the length of a furrow due to differences in infiltration opportunity time, infiltration may vary between furrows across the width of a field. For example, greater compaction in wheel tracks decreases infiltration compared with non-wheel track furrows. Similarly, head may vary along the length of a head ditch, resulting in different inflow rates to furrows in different parts of a field.

Irrigation duration may also vary, particularly between different siphon sets, and this variation is often correlated to the time of day that sets are started. When evaluating distribution uniformity of a furrow or group of furrows, it is important to understand how representative these furrows are of the remainder of the field.
Application Efficiency

Application efficiency, also previously discussed in WATERpak Chapter 1.2, relates the amount of water applied in an irrigation to the amount of water available to the crop for use and is expressed as a percentage. A high efficiency means that most of the water applied has remained in the root zone available for plant use.

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

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

For example, an irrigation may be almost perfectly uniform, in that the same amount of water is applied to every part of a field. However if the total amount of water applied were twice that required, the application efficiency would only be 50% (Figure 5.3.5).

In contrast, an irrigation may be perfectly efficient, such that all of the water applied to the field remains in the root zone available for use. However if this water only made it across half of the field, the uniformity will be extremely low (Figure 5.3.6).

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

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

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

A requirement efficiency of less than 100% is perfectly acceptable, especially if the distribution uniformity is high. This simply means that the soil moisture deficit has not been completely refilled, and the timing of the next irrigation should reflect this.

Figure 5.3.7 demonstrates the components of an irrigation event. Potential water losses are represented by the evaporation, drainage and runoff arrows. The volume of water that is applied to the root zone is indicated by the light blue coloured area.

Evaluating Surface Irrigation Performance

The theory behind these surface irrigation processes is actually reasonably straightforward. However, most of the action is happening below the soil surface. This makes many of the variables virtually impossible to measure. Perhaps the most important variable used for evaluating performance is the volume of water represented by the blue region in Figure 5.3.7. But how can you physically measure this volume? You would need to measure the volume of water that has infiltrated the soil vertically, at every location down the length of the field!

These parameters can be determined by making some much simpler measurements and then modelling the irrigation event. This process is offered commercially as the Irrimate™ service. It is also possible to take some basic measurements by hand to determine information such as water use indices and the volume of water applied.

Basic measurements and benchmarks

There are a number of measurements that can be taken with relative ease that are important for making tactical irrigation management decisions and to calculate water use indices (see WATERpak Chapter 1.2) that can be used to broadly benchmark performance.

Measurement of applied and runoff water volume is perhaps the most critical piece of water information that can be collected for a surface irrigated field, although practical issues often mean that accurate measurements are difficult to obtain. This is especially the case for tailwater, which can be very difficult to measure without specialised equipment. The most practical method is to measure the amount of tailwater that is recycled using a storage meter (see WATERpak Chapter 1.6) or a flow meter on the pump used to return tailwater to the storage. However, tailwater re-lifted into storages is usually a combination of runoff from a number of fields, which makes individual field analysis difficult.

In contrast, measurement of water applied to a field can generally be achieved in two ways. The first method involves measurement of bulk flows; that is, the total water delivered to a field. This can be achieved by installing a meter on a supply point to a field, which may be a pump, bore, culvert or other similar structure. Measurement can be complicated where more than one field is irrigated by a particular water source at any one time, as it can become expensive to install separate meters for each field. On the other hand, the usefulness and accuracy of data will be compromised if fields are grouped together in order to reduce the number of measuring points as the performance of individual fields can vary greatly. It may be possible to minimise physical metering by using WaterTrack™ to model water flows around the farm. When used in conjunction with storage meters and carefully selected metering points, this...
tool can be calibrated to accurately reflect on farm water movements. Further information on WaterTrack™ is available in WATERpak Chapters 1.2 and 2.3.

Figure 5.3.8. One of the commercially available water flow meters capable of measuring bulk flows onto and off an individual field

The second measurement method involves measuring flow for a selection of individual furrows or bays and then extrapolating that data across the field. By measuring a selection of furrows located at points across the field, this method also provides a good indication of the potential differences in flow rate that may occur within individual fields and is extremely useful for managing irrigation events. Simple techniques for measuring water flow from a single siphon include using a bucket and stopwatch (Figure 5.3.9) or by measuring head height (Figure 5.3.10) and relating this to flow using a siphon head-discharge chart (see Appendix 1).

Figure 5.3.9. Using a stopwatch and bucket to calculate siphon flow rate

To measure flow using a bucket and stopwatch, dig a hole for a bucket under the discharge point of the siphon. Time how long the bucket takes to fill with a stopwatch. It is important that the discharge point of the siphon remains at the normal height so that the flow rate is not modified. Flow rate is equal to the volume of bucket (litres) divided by the time taken to fill (seconds).

Figure 5.3.10 Measuring head height and using theoretical flow charts to estimate siphon flow rate

It is probably simpler to determine flow by measuring head by using a ‘brickies’ level (Figure 5.3.11). Start by filling the tube with water from the head ditch and then let the water siphon through the tube to remove any air bubbles. The tube is then held up so that the water level in the tube can be measured against the ruler. The measurement is taken from the middle of the discharge point of the siphon (or the water level in the furrow if the siphon is submerged) to the top of the water level in the clear plastic tubing. Then refer to the siphon flow chart in Appendix 1 to determine the flow rate for the particular siphon size and length.

For bay irrigation, flow rate for different door sizes and head heights can be obtained from Table 5.3.2.
5.3 Surface irrigation performance and operation

It is important when taking these measurements to understand that head height may vary during an irrigation event. This means that if a single measurement is taken at a time when the head is at its lowest and extrapolated over the entire event, the volume applied will be underestimated and vice-versa when the head is high. Furthermore, flow from different siphons can vary substantially due to differences in head, siphon placement, siphon diameter or siphon length. It is therefore important to measure the flow rate for a number of siphons and use an average value when extrapolating data across an entire field.

This process will often highlight the magnitude of these flow variations across a field which can be a useful insight for irrigation management. To minimise variations due to siphon placement, it is important to ensure the position of all siphons is as similar as possible to ensure uniform flow rates from each. In particular, ensure that the outlet height of all siphons is similar.

Surface irrigation evaluation services such as Irrimate (see below) include inflow monitoring as part of the evaluation procedure. This not only saves time compared to manual measurements, but the data is typically logged over the entire irrigation event so that any variation can be readily identified.

Once you have measured applied water, you will be able to calculate some basic water use indices (see WATERpak Chapter 1.2 for definitions and further information). The total water applied per hectare can be calculated by either:

1. dividing the bulk inflow by the number of hectares watered, or
2. taking the average individual furrow flow and dividing by the area watered by this furrow

As every irrigation throughout the season will be different, the total water should be calculated for each event separately and summed for the seasonal total.

**For example**

- **Total Inflow** = 120 ML
- **Area Irrigated** = 100 ha
- **Total Water Applied** = 120 ÷ 100 = 1.2 ML/ha
- **Average furrow flow rate** = 4.0 L/s
- **Irrigation Duration** = 9 hours

**Total Inflow**

\[
= 4.0 \times 9 \times 60 \times 60 \text{(convert hours to seconds)}
\]

\[
= 129600 \text{ L} = 0.1296 \text{ ML}
\]

- **Furrow Length** = 600 m
- **Furrows irrigated every 2 metres**
- **Area irrigated by 1 furrow** = 600 x 2 = 1200 m²

\[
= 0.12 \text{ ha}
\]

**Total Water Applied** = 0.1296 ÷ 0.12

\[
= 1.08 \text{ ML/ha}
\]

### Table 5.3.2. Door outlet flow (L/s) for a range of door sizes and head heights.

<table>
<thead>
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<th>Head (mm)</th>
<th>300</th>
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</tr>
</tbody>
</table>

**Figure 5.3.11 – A ‘brickies’ level**

Source: NSW DPI, 2003

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<td>227</td>
<td>272</td>
</tr>
</tbody>
</table>

**Figure 5.3.11 – A ‘brickies’ level**

Source: NSW DPI, 2003

Once you have measured applied water, you will be able to calculate some basic water use indices (see WATERpak Chapter 1.2 for definitions and further information). The total water applied per hectare can be calculated by either:

1. dividing the bulk inflow by the number of hectares watered, or
2. taking the average individual furrow flow and dividing by the area watered by this furrow

As every irrigation throughout the season will be different, the total water should be calculated for each event separately and summed for the seasonal total.

**For example**

- **Total Inflow** = 120 ML
- **Area Irrigated** = 100 ha
- **Total Water Applied** = 120 ÷ 100 = 1.2 ML/ha
- **Average furrow flow rate** = 4.0 L/s
- **Irrigation Duration** = 9 hours

**Total Inflow**

\[
= 4.0 \times 9 \times 60 \times 60 \text{(convert hours to seconds)}
\]

\[
= 129600 \text{ L} = 0.1296 \text{ ML}
\]

- **Furrow Length** = 600 m
- **Furrows irrigated every 2 metres**
- **Area irrigated by 1 furrow** = 600 x 2 = 1200 m²

\[
= 0.12 \text{ ha}
\]

**Total Water Applied** = 0.1296 ÷ 0.12

\[
= 1.08 \text{ ML/ha}
\]
Irrigation water use index (IWUI) can be calculated by dividing the total production from a field by the total seasonal water use. For very large fields, or where variations in yield are observed between different parts of a field, it may be more useful to calculate individual IWUI for sections of a field as illustrated in the example below.

**Example**

<table>
<thead>
<tr>
<th>Crop Yield</th>
<th>Total Water Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6 bales/ha</td>
<td>7.2 ML/ha</td>
</tr>
<tr>
<td>11.4 bales/ha</td>
<td>7.8 ML/ha</td>
</tr>
<tr>
<td>10.0 bales/ha</td>
<td>7.9 ML/ha</td>
</tr>
</tbody>
</table>

In top section

Yield = 9.6 bales/ha  
Water use = 7.2 ML/ha

Irrigation water use index = 9.6 ÷ 7.2 = 1.33 bales/ML

In middle section

Yield = 11.4 bales/ha  
Water use = 7.8 ML/ha

Irrigation water use index = 11.4 ÷ 7.8 = 1.46 bales/ML

In bottom section

Yield = 10.0 bales/ha  
Water use = 7.9 ML/ha

Irrigation water use index = 10 ÷ 7.9 = 1.27 bales/ML

Calculating Gross Production Water Use Index (GPWUI) follows this exact same procedure except that the total water use includes effective or total rainfall. Note that rainfall can vary substantially even across a farm, so it is useful to place a rain gauge at the field to measure rainfall more accurately.

**What is happening under the soil surface?**

Whilst basic measurements and calculations can help you to make tactical irrigation decisions, strategic decision making about surface irrigation systems requires more detailed information about irrigation performance, uniformity and efficiency. However as previously mentioned, it is particularly difficult to measure what is happening in every part of a field directly. Surface irrigation performance evaluation techniques, such as the commercially available Irrimate service, allows irrigation performance to be evaluated by making a series of practical measurements.

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

- Inflow rate (flow meters are used to collect siphon or bay flow for the duration of the irrigation event)
- A number of advance points (the time it takes water to reach a certain distance down the field, collected by automated advance sensors)
- The dimensions of the furrow
- The depth of flow in the furrow
- Field length and slope

Advanced simulation techniques can also utilise outflow data (collected with automated flumes) and variable inflow data to improve the ability to model some irrigation events.

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

Following data collection, the simulation model is calibrated against the measured advance data to ensure accuracy. The modelling technique has been used successfully for more than ten years across hundreds of irrigation events in the Australian cotton, grains, sugar and pasture industries.

Further information and examples of surface irrigation performance evaluation can be found in the following case studies:

**Economic benefits of performance evaluation**

Want a bigger farm? Buy it with furrow optimisation

Improving performance of bay irrigation through higher flow rates
Improving Surface Irrigation Performance

The performance of a surface irrigation event is influenced by a number of design and management factors. Each of these factors has a different amount of influence over the performance of an irrigation event, as illustrated in Table 5.3.3.

### Table 5.3.3 – Effect of surface irrigation variables on irrigation performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Influenced by</th>
<th>Impact on Performance</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil infiltration</td>
<td>Usually cannot be</td>
<td>***</td>
<td>High infiltration soil – slow advance &amp; rapid recession</td>
</tr>
<tr>
<td>characteristic</td>
<td>influenced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflow rate</td>
<td>Management &amp; design</td>
<td>***</td>
<td>High flow rate – fast advance rate, potential for increased tailwater run off</td>
</tr>
<tr>
<td>Time to cut-off</td>
<td>Management</td>
<td>***</td>
<td>Determines total opportunity time, deep percolation loss and tailwater volume</td>
</tr>
<tr>
<td>Length of field</td>
<td>Design</td>
<td>**</td>
<td>High efficiency &amp; uniformity can be difficult on long fields.</td>
</tr>
<tr>
<td>Application Depth (deficit)</td>
<td>Management</td>
<td>**</td>
<td>Irrigating to a deficit which is very small or very large may reduce performance</td>
</tr>
<tr>
<td>Field Slope</td>
<td>Design</td>
<td>*</td>
<td>steep slope – increases rate of advance &amp; recession</td>
</tr>
<tr>
<td>Surface Roughness</td>
<td>Usually cannot be</td>
<td>*</td>
<td>Rough surface – slower advance</td>
</tr>
<tr>
<td>Furrow Dimensions and Shape</td>
<td>Design &amp; management</td>
<td>*</td>
<td>Furrow shape has little impact, although changes in infiltration characteristic (e.g. through compaction) may do.</td>
</tr>
</tbody>
</table>

*** – more impact, * – less impact
Source – Raine and Smith, 2004

Figure 5.3.12 – Cumulative Irrigation Curves demonstrating a change in infiltration characteristic over the course of a season. (Source – D. Richards, CSIRO)

Infiltration Characteristic

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

If the infiltration characteristic does change throughout the season (Figure 5.3.12), then you should have an estimate of how these infiltration characteristics change and what management strategies should be applied, as management may need to vary.

The use of Polyacrylamide (PAM) (see WATERpak Chapter 1.9) also affects the infiltration characteristic. PAM maintains an open soil structure, usually resulting in increased infiltration. For any soils where deep drainage already occurs, this will lead to increased deep drainage. It is important when using PAM to understand that this product will change the infiltration characteristic, and thus affect performance. If you have already evaluated performance without PAM, then you will need to re-evaluate the performance with PAM. The effect of PAM is typically reduced or removed following cultivation.
5.3 Surface irrigation performance and operation

Inflow rate

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

Irrigation performance can be affected through both a gross change to the inflow rate as well as variations to the inflow rate during the irrigation event. Often a variable inflow rate occurs when the water level in a head ditch is not kept constant. Variable inflow may have a range of effects on different performance measures. As an example, Figure 5.3.13 shows a reduction in distribution uniformity due to an unintentional variation in inflow rate.

Figure 5.3.13. (A) Infiltrated depth profile for variable and constant (0.825 L/s) inflow (B) variable inflow hydrograph for this example (Source – M. Gillies, NCEA)

Time to Cutoff

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

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

Figure 5.3.14 demonstrates the effect on a number of parameters of changing only time to cutoff for an irrigation event. In this case the optimum strategy is to cutoff at 320 minutes (5 hours and 20 minutes). Cutting off at 240 minutes (4 hours) meant that the water did not reach all the way to the end of the field. Cutting off at 400 minutes (6 hours and 40 minutes) resulted in more than twice the amount of tailwater and additional deep drainage. The application efficiency calculations assume an 85% efficiency in tailwater recycling.

Figure 5.3.14. The effect of cutoff time for an event where inflow = 6 L/s and field length = 520m. Optimum cutoff time is 320 minutes.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Cutoff (mins)</td>
<td>240</td>
<td>320</td>
<td>400</td>
</tr>
<tr>
<td>Inflow (ML/ha)</td>
<td>0.83</td>
<td>1.11</td>
<td>1.38</td>
</tr>
<tr>
<td>Outflow (ML/ha)</td>
<td>0.00</td>
<td>0.17</td>
<td>0.41</td>
</tr>
<tr>
<td>Infiltration (ML/ha)</td>
<td>0.83</td>
<td>0.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Deep Drainage (ML/ha)</td>
<td>0.01</td>
<td>0.07</td>
<td>0.11</td>
</tr>
<tr>
<td>Application Efficiency (%)</td>
<td>&gt; 95</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>Requirement Efficiency (%)</td>
<td>90</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Figure 5.3.14.** The effect of cutoff time for an event where inflow = 6 L/s and field length = 520m. Optimum cutoff time is 320 minutes.
Field Length

Field length can influence distribution uniformity because the advance rate becomes slower as the irrigation water has to travel further down the furrow. This makes it more difficult to obtain advance and recession rates which provide for a similar opportunity time along the length of the furrow. Such non-uniformity can impact upon efficiency by increasing deep drainage at the top end of the field. Field length cannot be managed between irrigation events. However, modifying existing furrow lengths may be an appropriate strategy for some situations in the design phase (Table 5.3.4).

Table 5.3.4. Improved performance due to a change in field length and management

<table>
<thead>
<tr>
<th>Original Field Performance</th>
<th>Performance following change in field length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Length (m)</td>
<td>885</td>
</tr>
<tr>
<td>Flow Rate (L/s)</td>
<td>2.70</td>
</tr>
<tr>
<td>Time Water Applied (hr)</td>
<td>20</td>
</tr>
<tr>
<td>Deficit (mm)</td>
<td>60</td>
</tr>
<tr>
<td>Inflow (mm)</td>
<td>110</td>
</tr>
<tr>
<td>Tailwater (mm)</td>
<td>27</td>
</tr>
<tr>
<td>Water Infiltrated (mm)</td>
<td>83</td>
</tr>
<tr>
<td>Application Efficiency (%)</td>
<td>69</td>
</tr>
<tr>
<td>Distribution Uniformity (%)</td>
<td>92</td>
</tr>
<tr>
<td>Potential Water Saving (ML/ha)</td>
<td>0.22</td>
</tr>
</tbody>
</table>

(source – R. Jackson, NSW DPI).

Application Depth (Deficit)

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

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

2. Conversely, some soils have poor infiltration where deficit irrigation is likely to occur as a matter of course. In these situations, performance may well be high, although there is insufficient water infiltrating the soil and being made available for the crop.
Be careful – deficit irrigation may allow for improved performance and ability to capture rainfall, but there is less moisture buffering in the soil and a greater number of smaller irrigations will be required.

Figure 5.3.15. Example of a deficit irrigation event where the amount of water applied is less than the deficit at the time of irrigation

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4 Deficit (ML/ha)</td>
<td>Deficit 1.06 ML/ha (106 mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source – R. Jackson, NSWDPI).

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

Sometimes irrigation intervals are stretched so that less irrigations are required during the season. However, stretching irrigation events may have a negative impact on the performance of surface irrigation systems because the larger soil moisture deficit will decrease the rate at which irrigation water will advance down the furrows, subsequently affecting opportunity time and distribution uniformity. It may be possible to increase the inflow rate to help to offset these effects.

Table 5.3.5. Example of water applied to different irrigation strategies on the Darling Downs

<table>
<thead>
<tr>
<th></th>
<th>Early Strategy</th>
<th>Normal Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficit at Irrigation (mm)</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Number of Irrigations</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Water Applied each Irrigation (ML/ha)</td>
<td>1.4</td>
<td>1.65</td>
</tr>
<tr>
<td>Total Water Applied (ML/ha)</td>
<td>7.0</td>
<td>6.6</td>
</tr>
<tr>
<td>GPWUI (B/ML)</td>
<td>1.66</td>
<td>1.63</td>
</tr>
</tbody>
</table>

(Source J. Hare, QDPI&F)

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

Field Slope

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

For the irrigation event in Figure 5.3.15, there was absolutely no difference in performance between a slope of 1 in 10000 (0.01%) and a slope of 1 in 1000 (0.1%). The water arrived 28 minutes sooner on the steeper slope (309 mins vs 347 mins), but this did not impact on performance.

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

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

The roughness of the soil surface provides a resistance to the flow. Typically the surface roughness is not something that can be readily controlled, although it may be modified somewhat due to cultivation practices, stubble retention, etc. An increase in surface roughness leads to a reduction in the speed of advance across the field and usually only slightly influences performance.

Evaluation Results

When you have a surface irrigation performance evaluation performed, it is typical to receive a report that demonstrates the measured performance, as well as one or more alternative management strategies that could be implemented, and the likely performance of these strategies. Interpreting these results is usually a matter of comparing the various performance measures (as discussed earlier) for the different optimised scenarios and determining which of the options can be practically and economically applied.

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

Case study

Data from fields in two different cotton-growing regions was collected and analysed to determine the application efficiency and distribution uniformity as well as the maximum inundation time (Table 5.3.6). Maximum inundation time (the largest infiltration opportunity time) is important to many growers, as longer periods of inundation are likely to be detrimental to crop productivity (and indicate potential waterlogging). The strategies investigated for improved performance included (where appropriate):

- cut-off when water reached the end of the field
- cut-off one hour before water reached the end of the field
- increased application rate (inflow)
- increased application rate, and cut-off when water reached the end of the field

It should be noted that these strategies were selected as representative of the types of changes possible and whilst leading to increased performance in these situations may not be the choices that lead to optimum performance. Optimum performance needs to be assessed on an individual basis. Field 1 data is sourced from Raine and Walker (1998).
5.3 Surface irrigation performance and operation

Table 5.3.6 - Case Study: Irrigation performance for a selection of different management strategies on two fields.

<table>
<thead>
<tr>
<th></th>
<th>Typical management</th>
<th>Cut-off when reached end</th>
<th>Cut-off one hour before end</th>
<th>Increased application rate</th>
<th>Increased application rate and cut-off when reached end</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application rate (L/s/furrow)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Cut-off time (min)</td>
<td>918</td>
<td>745</td>
<td>685</td>
<td>552</td>
<td>377</td>
</tr>
<tr>
<td>Inundation time (min)</td>
<td>990</td>
<td>810</td>
<td>732</td>
<td>600</td>
<td>396</td>
</tr>
<tr>
<td>Application efficiency (%)</td>
<td>70</td>
<td>86</td>
<td>93</td>
<td>58</td>
<td>84</td>
</tr>
<tr>
<td>Requirement efficiency (%)</td>
<td>100</td>
<td>99</td>
<td>99</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Distribution uniformity (%)</td>
<td>93</td>
<td>92</td>
<td>90</td>
<td>97</td>
<td>95</td>
</tr>
<tr>
<td><strong>Field 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application rate (L/s/furrow)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Cut-off time (min)</td>
<td>680</td>
<td>380</td>
<td>320</td>
<td>300</td>
<td>232</td>
</tr>
<tr>
<td>Inundation time (min)</td>
<td>692</td>
<td>392</td>
<td>335</td>
<td>315</td>
<td>245</td>
</tr>
<tr>
<td>Application efficiency (%)</td>
<td>46</td>
<td>82</td>
<td>89</td>
<td>68</td>
<td>87</td>
</tr>
<tr>
<td>Requirement efficiency (%)</td>
<td>100</td>
<td>99</td>
<td>91</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>Distribution uniformity (%)</td>
<td>94</td>
<td>86</td>
<td>63</td>
<td>92</td>
<td>88</td>
</tr>
</tbody>
</table>

For both fields, the data indicates the variations in application efficiency and distribution uniformity. It should be noted that some strategies may have improved either efficiency or uniformity but not all strategies improved both. For both of these fields, the best strategy of those tested in terms of application efficiency, distribution uniformity, requirement efficiency and inundation time was an increased application rate and decreased cut-off time. In both cases the period of inundation was reduced by over half and the application efficiencies were increased substantially with little effect on the already high requirement efficiency and distribution uniformity.

The strategy of having a cut-off time one hour before the water reached the end of the field was unsuccessful for Field 2 because insufficient water was applied to the bottom of the field: hence the values for distribution uniformity and requirement efficiency are reduced.
Implications of Management Changes

Precision – Stick to the Prescription

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

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

One of the major secondary effects that occurs when increasing inflow rate is that the opportunity for larger volumes of tailwater is increased. This is illustrated in Table 5.3.7, where a measured irrigation event had an inflow rate of 2.63 L/s for a duration of 860 minutes. In optimising this irrigation event, the recommended change was for an inflow rate of 6 L/s for a duration of 320 minutes. Management for this scenario must be more precise to capitalise on the benefits of the recommendation.

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

The infiltrated amount and potential for deep drainage may also be adversely affected.

<table>
<thead>
<tr>
<th>Additional Time to Cutoff (hr)</th>
<th>Measured Event (ML/ha)</th>
<th>Optimised Event (ML/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inflow</td>
<td>Outflow</td>
</tr>
<tr>
<td>0</td>
<td>1.31</td>
<td>0.25</td>
</tr>
<tr>
<td>0.5</td>
<td>1.35</td>
<td>0.29</td>
</tr>
<tr>
<td>1</td>
<td>1.39</td>
<td>0.33</td>
</tr>
<tr>
<td>1.5</td>
<td>1.44</td>
<td>0.37</td>
</tr>
<tr>
<td>2</td>
<td>1.49</td>
<td>0.40</td>
</tr>
<tr>
<td>2.5</td>
<td>1.53</td>
<td>0.44</td>
</tr>
<tr>
<td>3</td>
<td>1.58</td>
<td>0.48</td>
</tr>
</tbody>
</table>

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

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

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

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

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

Figure 5.3.16 shows the results of the analysis of irrigation tailwater for every event of a single field in the Dawson Valley for the 2005-06 season. The concentration of various contaminants was measured over the duration of the runoff event and was scaled up by the volume of tailwater measured to give the total amounts indicated below.

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

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

Figure 5.3.16. The total amount and concentration of (A) Total Solids (B) Potassium (C) Nitrogen and (D) Phosphorus removed from a field trial site in a single season (Source – A. McHugh, NCEA).

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

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

- A smaller irrigation deficit will influence performance by typically increasing the rate of advance. This may lead to a greater number of smaller applications. Agronomically, smaller deficits may promote rank growth in indeterminate crops, such as cotton, due to the balance between vegetative and reproductive growth.

- A large irrigation deficit will influence performance by typically decreasing the rate of advance. This may lead to fewer large irrigations. If the deficit is too large the plant may stress too much before the irrigation takes place.

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

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

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

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

Future developments in surface irrigation performance

The past decade has seen a dramatic increase in the performance of surface irrigation within the industry, largely because of improved measurement techniques as well as a better understanding of the implications of irrigation management decisions such as waterlogging and deep drainage.

Whilst the improvements in surface irrigation management and measurement have been significant, ongoing research has identified a number of further improvements that have the potential to offer a ‘second wave’ of improved surface irrigation management.

Measurement and simulation

The techniques used to evaluate surface irrigation performance have continually evolved since their introduction to the industry in the late 1990’s. Hardware has been continually upgraded to be more robust and user friendly. Similarly, the techniques used to determine soil infiltration characteristics and to simulate irrigation events have been improved to broaden their application and ensure the highest degree of accuracy.

For example, the current generation of simulation modelling, SISCO, provides enhanced functionality and the ability to automatically optimise irrigation management for a given set of management constraints.

Performance measurement techniques have typically involved sampling a small number of furrows (typically four to eight). To ensure that the results from this approach can be applied across an entire field, measurements are usually taken in a section of field that is believed to be representative. Whilst this approach has undoubtedly been successful, the ability to investigate variability across entire fields is likely to lead to even greater improvements in the future.

Recent research by the National Centre for Engineering in Agriculture (NCEA) has led to the development of techniques that build on existing data to reduce the amount of information required from individual furrows. For example it is now possible to predict soil infiltration characteristics using only a single advance point instead of four or more as is the typical current practice.

In addition, NCEA researchers have developed a whole field simulation model called IrriProb, which expands existing techniques to measure performance across the entire field and to optimise irrigation management so that whole field performance can be maximised.
Automation

Automation is the application of technology to undertake actions that would normally be performed by a human. Conceptually, automation is not new, although it has not historically been applied to surface irrigation systems within Australia in a substantial way. However automation systems are becoming more widespread in bay irrigation systems in Southern Australia, where it is possible to quite simply provide automatic control of irrigation inlets. A range of systems are now available which will allow irrigation events to be operated according to a set program or via a transmitter from the farm office or, potentially, mobile phone. Such systems are seen as attractive as a labour saving device.

Automation is somewhat more difficult to establish in furrow irrigation systems due to the fact that these systems are generally supplied by siphons. However a recent trial in the Gwydir valley applied automation to a pipe through the bank system. Combined with some of the lessons learned in PTB management from the case study referenced earlier in this chapter, automation of furrow irrigation systems seems achievable.

In addition to in-field labour savings, automation also has the advantage of potentially being able to streamline irrigation management of the whole farm. For example, it is possible to apply automated components to storages and channels, as well as fields, so that water can be managed around the whole farm. Combined with accurate water metering, such a system could ensure that releases from storages are accurately matched to in-field requirements, minimising fluctuating water levels in channels and preventing excessive losses through channel overflow structures.

Precision irrigation and adaptive control

Perhaps the most exciting future opportunity for surface irrigation is the combination of advances in these categories. Adaptive control systems allow individual irrigation events to be automatically and continuously re-adjusted so that irrigation performance can be optimised and variability can be accounted for.

Just like other precision agriculture systems, precision irrigation involves a system that can adapt to the field conditions and can be managed to achieve the desired level of performance. It is possible for any type of irrigation system to operate as a precision system and recent research at the NCEA has demonstrated this concept on both CPLM and surface irrigation systems (also see page 41 of the Australian Cotton Water Story).

For surface irrigation systems, adaptive control requires:

- the ability to automatically control the irrigation (e.g. through automation);
- the ability to measure the progress of the irrigation;
- the ability to simulate and optimise the irrigation event as it occurs; and
- the ability to modify the control of the irrigation event to match the optimised conditions.

Full precision is realised by monitoring and modelling crop growth and response to irrigation throughout the season and using this information to determine the amount and timing of irrigation that gives the desired results.

Practically, this means that the irrigation system of the future will be able to predict when irrigation is needed, and then optimise the performance of the irrigation event whilst it is underway. This approach provides the potential for significant performance advantages. For example a trial in 2011-12 showed yield improvements of 10 per cent and water savings of 12 per cent when compared with the grower treatment.
Further Information


NSW Agriculture 2003, Introduction to Irrigation Management, course notes, WaterWise on the Farm, NSW Agriculture

