IRRIGATION EFFICIENCY TRAINING MATERIAL

Report to the

WATER RESEARCH COMMISSION

by

Isowat Consulting CC

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WRC Report No, KV 342/1/15

ISBN 978-1-4312-0716-9

October 2015

Obtainable from
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The publication of this report emanates from a project entitled *Irrigation Efficiency Training Material (*WRC Project number K8/1059//4)

ACKNOWLEDGEMENT

This report is the product of a short term project initiated and funded by the Water Research Commission of South Africa (WRC), within the Key Strategic Area (KSA) Water Utilisation in Agriculture, and was completed under guidance of the KSA Executive Manager, Dr Gerhard Backeberg.

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List of acronyms and abbreviations

ARC-IAE	Agricultural Research Council – Institute for Agricultural Engineering
BC	Beneficial consumption
CI	Confidence Interval
CMA	Catchment Management Agency
DWA	Department of Water Affairs (2014-: DWS – Department of Water and Sanitation)
GWCA	Ground Water Control Area
IB	Irrigation Board
ICID	International Commission on Irrigation and Drainage
IWMI	International Water Management Institute
NBC	Non-beneficial consumption
NRF	Non-recoverable fraction
NWA	National Water Act, Act 36 of 1998
RF	Recoverable fraction
SC	Storage change
WC/WDM	Water conservation and water demand management
WRC	Water Research Commission
WUA	Water Users Association

Background

Dear Irrigation Water User

South African water resources will be coming under severe pressure in the next 5 to 15 years. The main drivers of envisaged water shortages are population growth and global warming, which in combination are leading to both greater demand and reduced supply of water. The potential results of water shortages effecting society as a whole include reduced water quality, food shortages, health risks and social unrest.

Making better use of our available water is now becoming imperative and not negotiable. As users within the biggest water sector (in terms of annual volumetric use) in South Africa, irrigation water managers are often called upon to "improve efficiency"; however, when the question is asked what this request practically implies, answers are not as forthcoming.

Major constraints include the lack of a common understanding of the term "efficiency", inadequate information available for water effective management because of a lack of measurements, the perception that any efficiency initiative will cost the water user money but the benefit goes to the authorities, and also the fear of reduced water use allocations if greater efficiency is achieved.

In practice it has been found that commercial farmers and irrigation scheme management are quite willing to invest in practices and technologies that make business sense. However, lack of knowledge on technologies and insufficient human capacity in agricultural water management often prevent this from happening.

This material is therefore aimed at assisting both water users and authorities to obtain a better understanding of how irrigation water management can be improved, thereby building human capacity, so that targeted investments can be made with fewer social and environmental costs, by introducing the water balance approach to improved system performance.

The material presented here is the result of more than 10 years of research funded by the WRC (Water Research Commission of South Africa).Using lessons learnt during the WRC projects, best practices and technologies are introduced and illustrated.

More information and updates can also be obtained from the project website, www.waterbalance.org.za.

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What the learning material consists of

This training material aims to provide a step by step guide for improving the performance of irrigation infrastructure by applying the water balance framework, and consists of the following chapters:

1 Understanding irrigation water management

2 In-field irrigation systems

3 On-farm water conveyance systems

4 Irrigation schemes

5 Measurements for data collection

6 The water balance

The water balance framework can be implemented using a newly developed spreadsheet based tool of which irrigation water measurement and data collection are key inputs. This learning material should therefore be read in conjunction with the spreadsheet, as well as five pamphlets on irrigation water measurement provided with this learner guide.

How to use this material

This material has been prepared from more comprehensive research reports, with only the essential information compiled into this training material to make its application simpler and to facilitate the training process. The research reports that were used are the following, and can be obtained from the WRC (telephone number +27 12 3300340 or www.wrc.org.za):

- TT 248/05: Guidelines for irrigation water measurement in practice
- TT 550/12: Guidance for sustainable on-farm and on-scheme irrigation water measurement
- TT 466/10: Standards and guidelines for improved efficiency of irrigation water use – Guidelines
- TT 467/10: Standards and guidelines for improved efficiency of irrigation water use – Supplementary information

In order to obtain a better understanding of certain aspects of the material presented here, it is recommended that the learner obtain copies of these WRC reports and refer to the relevant sections when instructed to do so in this manual, when the following text box is encountered:

For more information on this topic, please refer to…

The material presented here is illustrated with examples, where appropriate material and data was available. Examples are included in text boxes as follows:

Example

Learning outcomes

At the end of this learning experience, the learner should:

- Have a good understanding of the management levels and infrastructure found in irrigation water management systems
- Understand the importance of improving irrigation system performance at all levels
- Know the characteristics of efficient in-field, on-farm and on-scheme irrigation systems
- Have a good understanding of the types of water measuring devices used for irrigation water measurement and their application
- Be able to compile a water balance and make recommendations for improvement of irrigation infrastructure based on the results of the water balance.

Learning assumed to be in place and further reference

It is expected that the learner taking part in the learning experience has a basic understanding of irrigated agriculture in South Africa, with specific reference to the following:

- The National Water Act (Act 36 of 1998)
- Types of irrigation systems used on farms (sprinkler, micro-sprinkler, drip, centre pivot, travelling irrigators and flood irrigation)
- Irrigation scheduling principles (soil-plant-water-climate interactions)
- Hydraulic principles (pressure and flow)
- Irrigation equipment (pipes, fittings, filters, emitters, valves, pumps and motors)
- Energy (power consumption, electricity tariffs)
- Open channel irrigation infrastructure (canals, sluice gates, dams)
- Drainage systems (surface and subsurface methods)

The following publications can be consulted for more information on these topics:

- Irrigation Design Manual (2003). Published by the Agricultural Research Council – Institute for Agricultural Engineering. Telephone number +27 12 842 4000.
- Guidelines for the design of canals and related structures (1980). Published by the Department of Water Affairs and Forestry.

1 Understanding irrigation water management

In this chapter we will cover the following concepts:

- Different levels of irrigation water management systems
- Definition of irrigation efficiency
- Optimising the performance of irrigation water management systems

Irrigation water infrastructure usually includes the following components, applicable to the different levels of water management as shown in Figure 1:

- An in-field irrigation system to apply the water to the crop.
  - The purpose of the in-field irrigation system is to apply the right amount of water at the correct application rate to all the plants in the field with as little non-beneficial consumption (losses) as possible – timing of applications, application rate (accuracy) and distribution uniformity are therefore important considerations of an in-field irrigation system
- An on-farm water conveyance system to transport water to the field edge.
  - The purpose of the on-farm conveyance system is to convey the water from the source to the field at the lowest possible energy requirement – operational economy and conveyance efficiency of the system components are therefore of importance
- An on-scheme water distribution system such as a canal or river, shared by a number of water users to convey the water to the farm edge
  - The purpose of the on-scheme system is to be a reliable and sustainable source as well as conveyance system of water – the operational economy, conveyance efficiency, and quantity and quality of the water delivered by this system are therefore be important aspects at this level of management.

It is important to recognise the *purpose* of the different components, so that optimisation can take place effectively.

The implications of decisions made during both development (planning and design) and management (operation and maintenance) of the components at different levels must be considered carefully and holistically.

Every decision that is made when developing and managing water supply and application systems has an effect on the water and energy demand of the whole system. Every level of the management system should be optimised to serve its specific purposes in an integrated manner so that synergy is achieved.

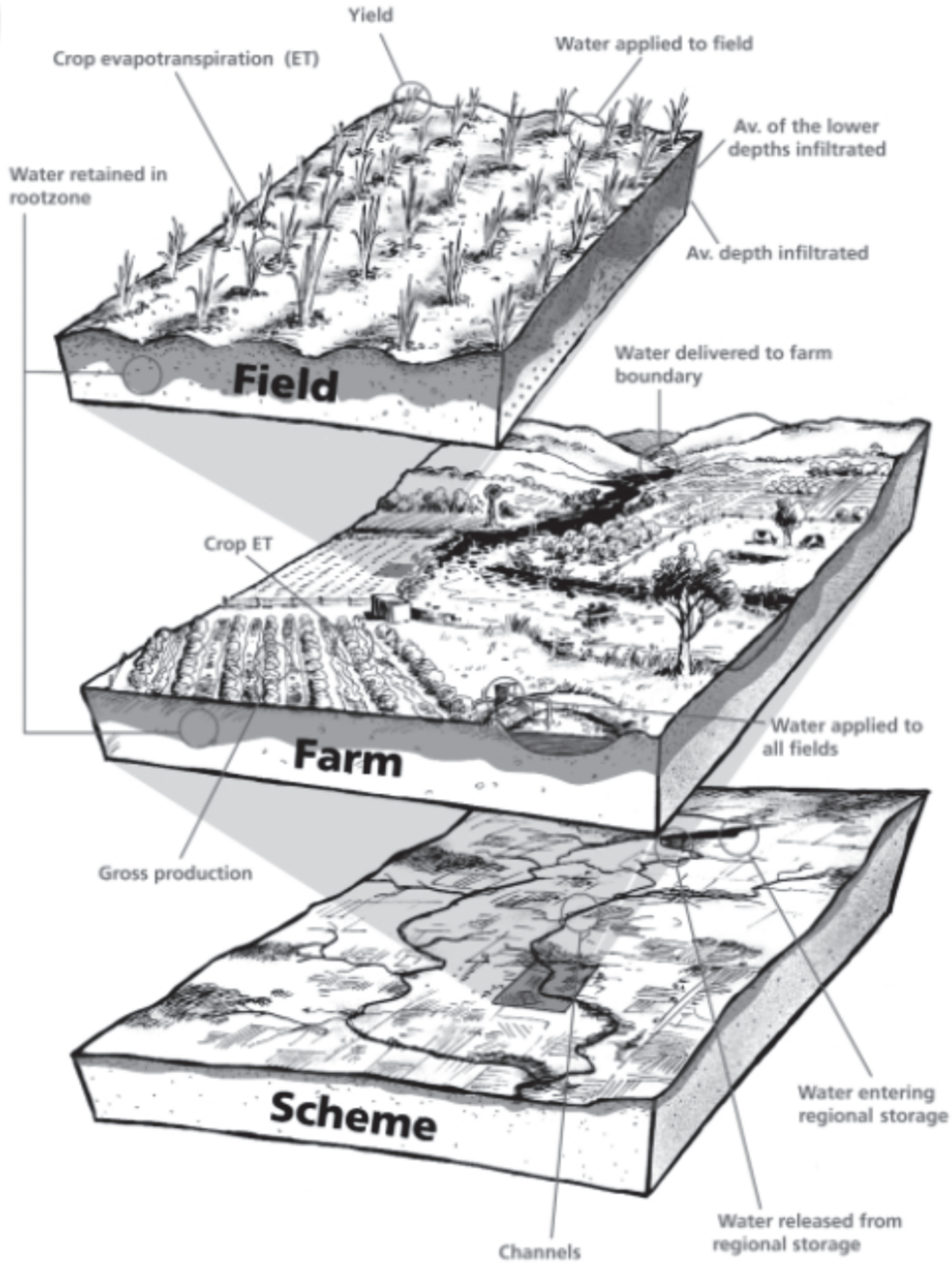

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Figure 1 Levels of agricultural water management systems (Fairweather, Austin & Hope, 2003)

1.1 The need for improved performance

Engineering efficiency is defined as the ratio of benefits derived (output) relative to input. Efficiency is therefore an indicator of losses within a specified boundary in a system (Figure 2).

High efficiency implies that the output is relatively similar to the input and the losses are low. Low efficiency implies higher losses.

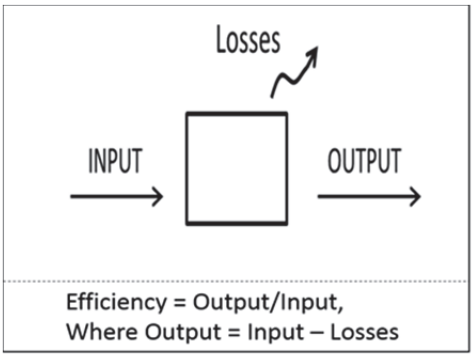


Figure 2 Schematic diagram illustrating efficiency as a concept

In the case of irrigation, losses occur at different levels of water management as shown in Figure 3.

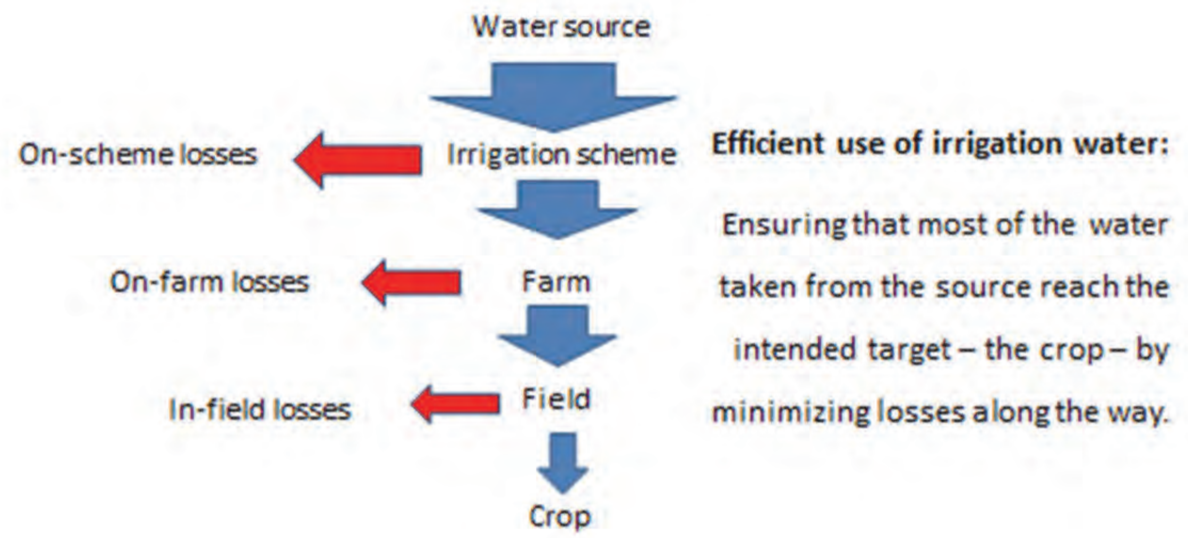


Figure 3 Definition of irrigation efficiency

Unfortunately, historically reporting of irrigation efficiencies (such as “application efficiency”, “system efficiency”, “distribution efficiency”, “transportation efficiency”, etc.) have resulted in the diminished understanding and scrutiny of the source or causes of losses. There is a widespread illusion that efficiency is fixed by the type of irrigation infrastructure used rather than to the way a particular system has been designed and managed. In the past, improving performance and efficiency was, incorrectly, only associated with an upgrade in infrastructure (a change in irrigation system, for example).

As can be seen in Figure 3, not all the water that is abstracted from a source reaches the intended destination. For irrigation, the intended destination of water is the crop, usually for transpiration purposes, and in some cases for climate control (which is linked to transpiration).

The fraction of water that can be utilised by the plant is called the beneficial water use component.

Irrigation water management should therefore be aimed at optimising this component and implies that water must be delivered from the source to the crop both efficiently (with the least amount of loss along the supply system) and effectively (at the right time, in the right quantity and at the right quality). In order to achieve this, water managers at all levels should be aware of the sources and destinations of water within their area of jurisdiction, which is best achieved by compiling a water balance – the basic tool for assessing irrigation efficiency.

The water balance framework allows for a closer analysis and refinement of existing systems and strategies, which would often yield far greater benefits at a much lower cost than switching from one system to another.

There are many reasons why water managers at scheme or farm level may be interested in improving the performance of the water management infrastructure. The private sector is primarily driven by a desire to improve return on investment or return to shareholders; in the public sector the aim is to improve the level of service provision. In the irrigation and drainage sector, improving the performance water management infrastructure enables water users to maintain or increase levels of agricultural production (Malano & Burton, 2001).

1.2 Fundamental concepts for improved performance

Taking the current situation regarding water management into account, the following fundamental principles apply when improving irrigation system performance at all management levels:

- Lawful water use

  For integrated water resources management to work, all water users should ensure that they comply with the lawful use allocated to them.

- Water and energy demand management

  In order to make best use of available water and energy, it is imperative that we develop and manage irrigation water supply and application systems with demand in mind, so that we can minimise our water footprint – to see how little we can demand from the sources rather than how much we can supply.

- Systems approach

  Every decision we make when developing and managing water supply and application systems has an effect on the water and energy demand of the system. Every level of the management system should be optimised to serve its specific purposes in an integrated manner so that synergy is achieved.

- Appropriate technologies

Appropriate modern technologies should be used as far as possible to improve water management.

- Incentives

Higher yields, greater water productivity and reduced input costs are incentives that water users should be made aware of, together with the added benefits of good irrigation management practices.

- Water balance

On-farm infrastructure should be developed and managed in such a way that the right amount of water is applied to the crop at the right time so that energy is used as efficiently as possible, production is optimized, and as little water as possible is lost to non-beneficial consumption and the non-recoverable fraction, while the recoverable fraction is re-utilized or minimalised.

On-scheme infrastructure should be developed and managed in such a way that the users receive the right amount of water at the right time, with as little unaccounted-for (non-beneficial and non-consumed) water as possible.

These concepts are discussed in more detail in the next chapters, focussing on in-field, on-farm and on-scheme irrigation infrastructure, leading up to the compilation of the water balance.

Self-assessment questions:

- What is the purpose of each level of irrigation water infrastructure (in-field, on-farm and on-scheme systems)?
- Define irrigation efficiency

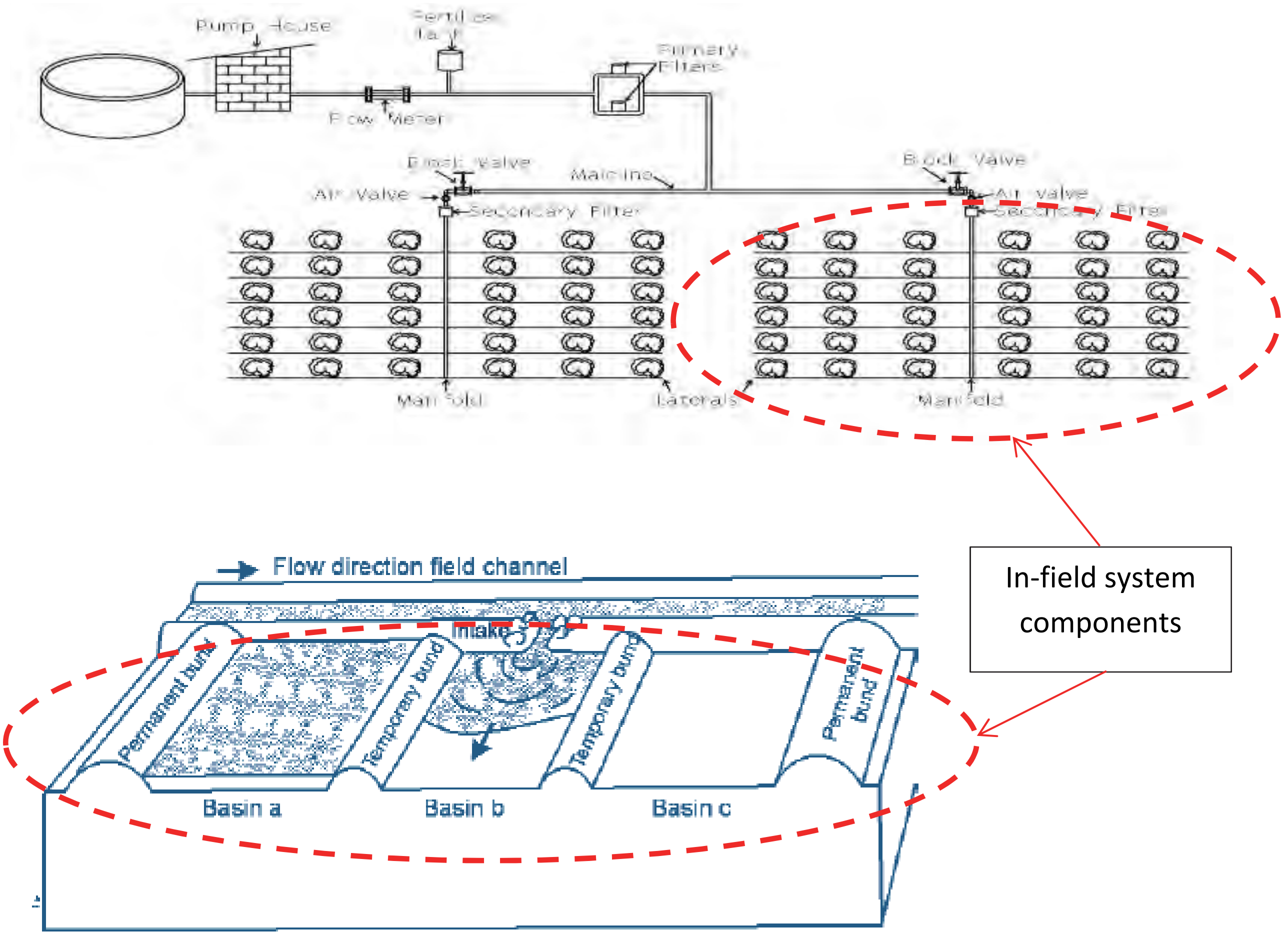
2 In-field irrigation systems

In this chapter we will cover the following concepts:

- Typical in-field irrigation system components
- System efficiency
- Irrigation uniformity
- Irrigation scheduling strategies and monitoring methods
- Irrigation system maintenance
- Irrigation system evaluation

The in-field irrigation system is the part of the system that applies the water to the crop and typical components include the following, as shown in Figure 4 below:

- emitters,
- lateral and manifold pipes, and
- earth furrows, beds or basins.



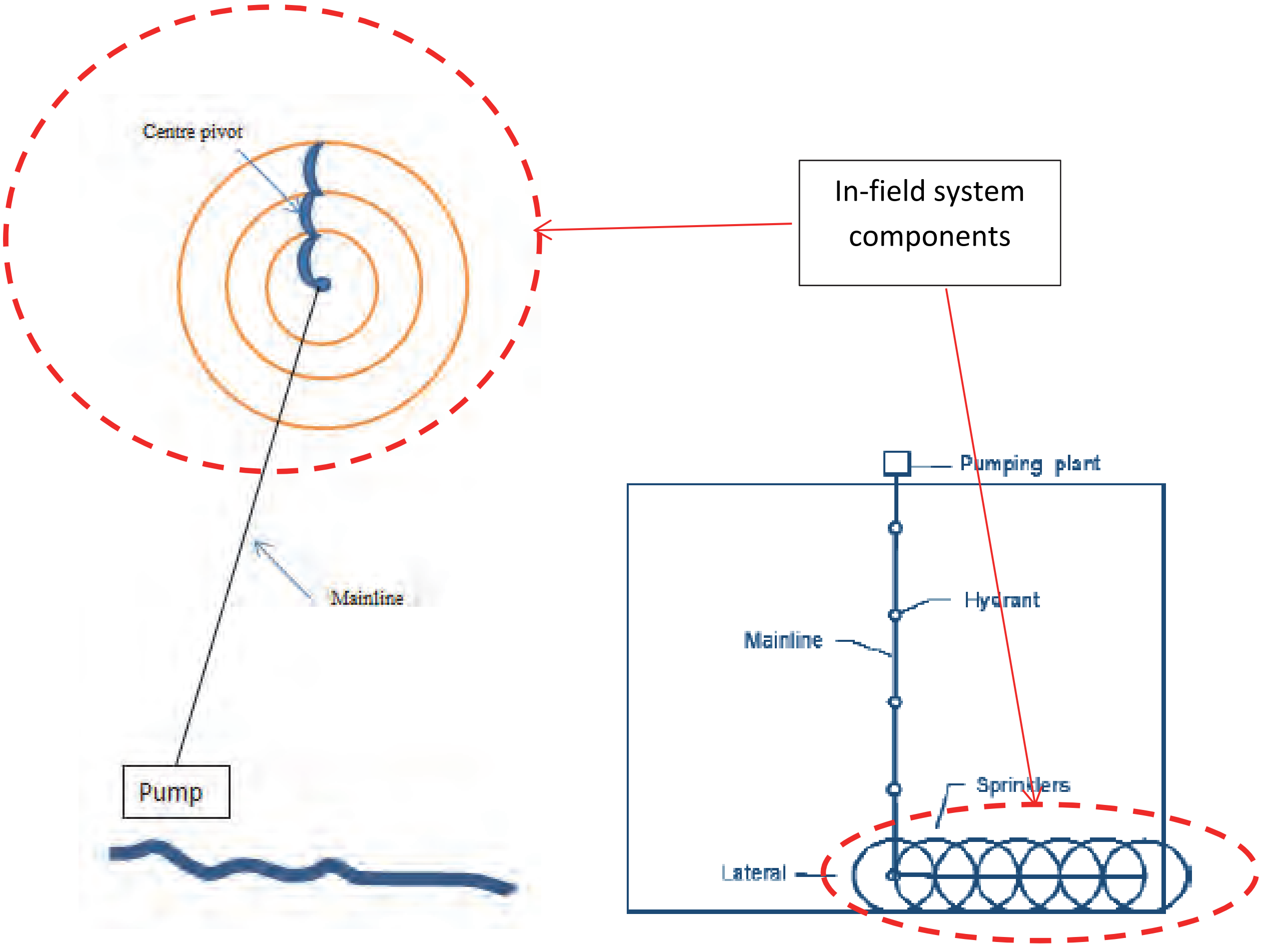


Figure 4 Typical in-field system components

The purpose of the in-field irrigation system is to apply the right amount of water, at the correct application rate, to all the plants in the field, with as water loss (non-beneficial consumption) as possible: Consideration should therefore be given to characteristics of an in-field irrigation system such as application efficiency, application rate (accuracy) and distribution uniformity.

The most efficient in-field irrigation system will therefore be one that:

- Is planned to take the natural resources available in the field, and the management requirements of the irrigator into account,
- Is designed according to sound design principles, based on limiting discharge variation and energy requirements in the field, and maximising distribution uniformity,
- Consists of quality components manufactured to a high standard with low coefficients of variation and low energy requirements,
- Is operated according to the design specifications and site-specific irrigation water requirements of the crop,
- Is maintained according to the equipment manufacturers' and/or irrigation designer's recommendations, and
- Is regularly evaluated to assess the level of performance and to detect problems as early as possible.

2.1 *Planning and design*

The correct planning and design of the in-field irrigation system components is of great importance as it determines the amount of water, energy and finance required to develop and manage an irrigation system.

The planning process involves gathering information on the soil, climate, crop and water associated with the new irrigation system, and combining it with the management requirements of the water user to select an appropriate irrigation system and prepare for the design thereof (see Figure 5).

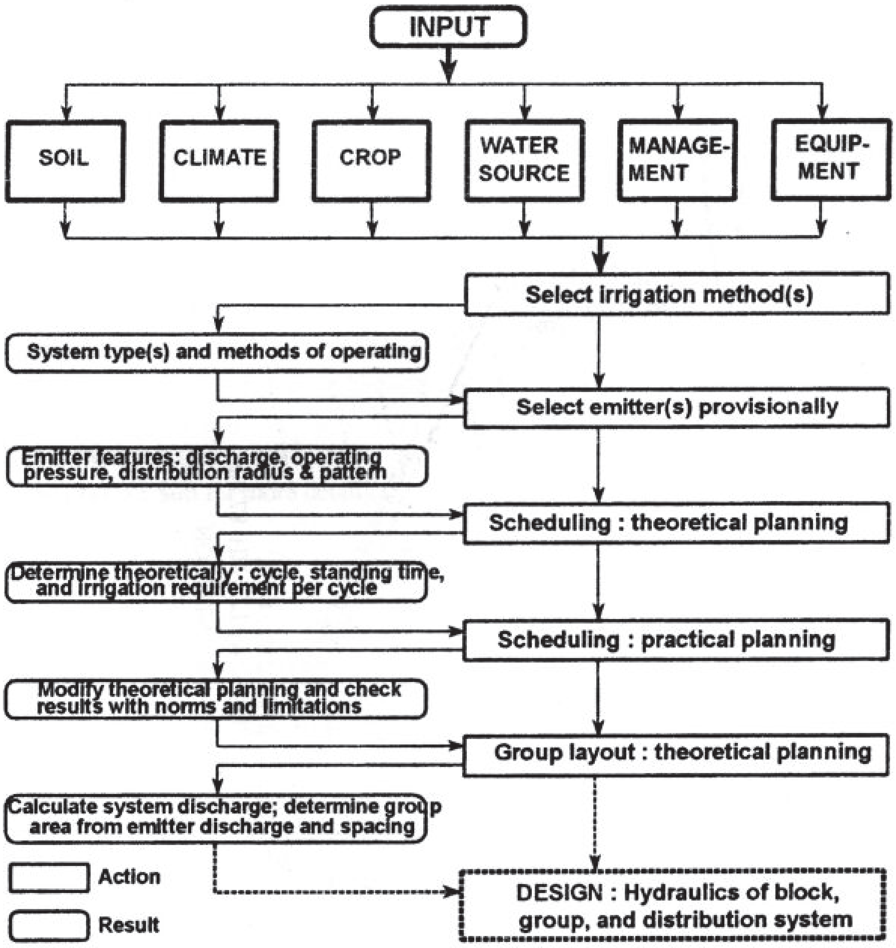


Figure 5 The planning process (Burger et al, 2003)

It is important to take note of the following:

- Not all soils are suitable for irrigation and should be surveyed and classified before a new irrigation system is designed.
- Water quality in South Africa is deteriorating and can negatively influence the crop yield (quantity and quality), the fertility of the soil, and the operation of the irrigation system. Samples of the water to be used for irrigation should be taken and analysed before designing an irrigation system.

- A water user should lawfully have access to the amount of water he/she intends to use for irrigation. This may require a permit from the Department of Water and Sanitation.
- The amount of water to be applied by the irrigation system, called the irrigation requirement, largely depends on the climate in which the crop is to be grown and should be calculated for each situation to ensure the irrigation system is not under or over designed. The design standard in South Africa is the Penman-Monteith method to determine crop evapotranspiration, with the SAPWAT3 computer program widely used to calculate ET_c.
- An appropriate irrigation system should be selected on the basis of its suitability for the crop, available resources as well as the water user's management requirements.

2.1.1 System performance at field level

2.1.1.1 System efficiency

When considering the performance of irrigation systems, it is helpful to think in terms of the components of the water balance, or the destinations of applied water. Ideally, the bulk of the applied water should contribute to the objective of irrigating: i.e. to preventing undesirable crop water stress. This relates to keeping stomata open, so that photosynthesis is not inhibited.

Figure 6 illustrates the various fractions of water applied which are involved in defining irrigation performance at the field level. The various components of the water balance (destinations of applied water) are:

- Deep percolation
- Surface runoff/stormflow
- Evaporation from the exposed soil surface
- Spray evaporation, wind drift and plant interception
- Transpiration

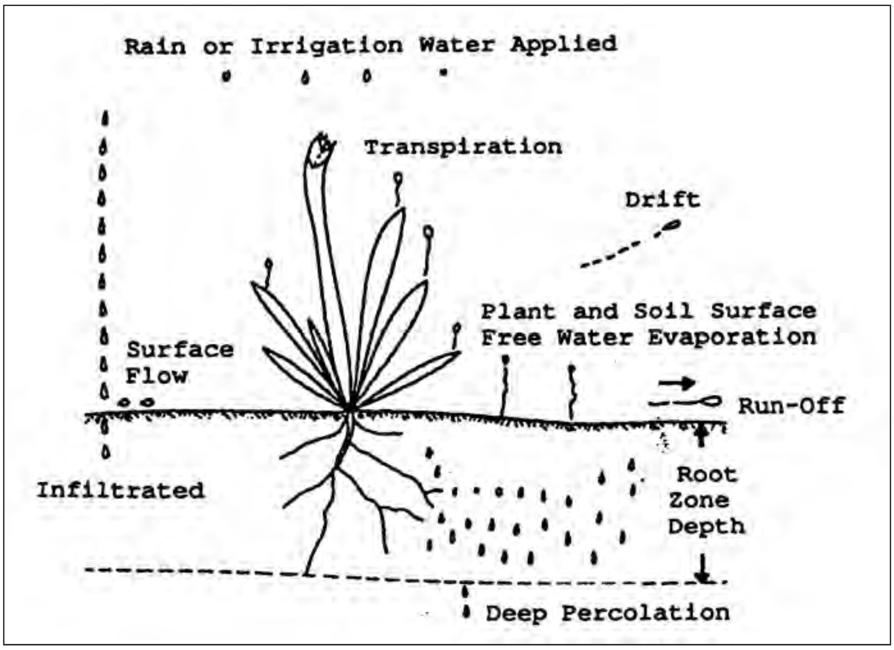


Figure 6 Various destinations of water in the soil-plant-atmosphere system

A well planned and designed irrigation system will ensure that water lost to these components listed above are minimised, thereby ensuring the lowest possible demand from the water source. Some loss of water, however, cannot be avoided and is an inherent characteristic of the irrigation system. The performance of an irrigation system in this regard is defined by means of its system efficiency – the ratio between the amount of water contributing to the objective of irrigation (the net irrigation requirement, NIR), and the amount of water entering the irrigation system (the gross irrigation requirement, GIR). Therefore:

$$\text{System efficiency}(\%)=\frac{\text{NIR}}{\text{GIR}}\times 100$$

The difference between the NIR and GIR usually consist of various amounts of the following unavoidable losses that can occur in-field:

- Non-beneficial spray evaporation and wind drift losses,
- In-field conveyance losses,
- Filter backwash and other minor losses

For example, overhead sprinkler systems lose water through wind drift and evaporation of spray. Drip systems lose water through filter backwashing, and flood irrigation systems with earth canals lose water through seepage. Other minor losses may also occur.

Figure 7 In-field losses such as spray evaporation and backwash water affect efficiency

The system efficiency figures published in Table 1, therefore, are associated with the generally acceptable level of losses which are inherent and unavoidable for each irrigation system. These efficiency figures are used to convert net irrigation requirements (NIR) to gross irrigation requirements (GIR) during the design process.

With recent advances in emitter technology, application losses of especially sprinklers have become significantly less and high efficiencies are achievable. During the evaluation process, if a system is operating at a lower efficiency (compared to Table 1), the water loss is excessive and can be prevented or avoided. Sources of excessive water loss include burst or leaking pipes, worn out rubber seals, nozzle wear and over irrigation resulting in runoff or deep drainage.

Table 1 Default irrigation system efficiency values

Irrigation system	Losses				Default system efficiency (net to gross ratio) (%)
	Non-beneficial spray evap. and wind drift losses (%)	In-field conveyance losses (%)	Filter and minor losses (%)	Total Losses (%)	
Drip (surface and subsurface)	0	0	5	5	95
Micro sprinklers	10	0	5	15	85
Centre Pivot, Linear move	8	0	2	10	90
Centre Pivot LEPA	0	0	5	5	95
Flood: Piped supply	0	0	5	5	95
Flood: Lined canal supplied	0	5	2	7	93
Flood: Earth canal supplied	0	12	2	14	86
Sprinkler permanent	8	0	2	10	90
Sprinkler movable	10	5	2	17	83
Traveling gun	15	5	2	22	78

2.1.1.2 Irrigation uniformity

Irrigation uniformity refers to how evenly water is applied across the field. Non-uniform irrigation implies that some parts of the field are receiving too little water while other parts may be receiving too much. Irrigation can be very uniform and have a low efficiency – one can uniformly over irrigate. However, irrigation cannot be non-uniform and efficient. Ideally irrigation must be both uniform and efficient. Poor uniformity can be caused by poor design or system hardware operation. An irrigation system should be installed, operated and maintained according to specification. From a management perspective, it can also be affected by soil infiltration characteristics and by land preparation.

During the design process, the irrigation designer will select emitters that will apply water at a minimum, system specific uniformity. In the case of sprinkler and centre pivot systems, this minimum requirement is given in terms of the uniformity coefficient (CU) value, and in the case of micro irrigation (drippers and micro sprinklers), it is given in terms of the emission uniformity (EU) value. The industry standard in most cases requires that the discharge of individual emitters in a system should not vary by more than 10% (±5% from the design average).

The performance of surface irrigation systems is influenced by infield factors such as inflow rates, field lengths, furrow shape (for furrow irrigation), field slope, surface roughness and soil infiltration properties. For effective surface irrigation, the designer and operator should ensure that the water applied to or flowing into individual basins, border strips or furrows does not vary by more than 10%.

Figure 8 Good design and management will result in uniform water applications and growth

2.1.1.3 Equipment selection

In the design process, emitters, pipes and fittings have to be selected, and the specific components' characteristics used in the design calculations. When selecting irrigation equipment, some of the criteria that should be considered include:

- Quality and performance
- Availability of spares and after sales service
- Theft risk

2.2 Design results

Each irrigation system is characterised by a specific flow rate and operating pressure, which is the outcome of the planning and design functions respectively. Together, the flow rate and the operating pressure determine the energy requirements of the system, as well as the size of all the water supply and conditioning infrastructure required for the system.

Irrigation engineering is a highly specialised design discipline, with every type of irrigation system having its own specific design norms that have to be adhered to, to ensure an efficient system is designed. The South African Irrigation Institute (SABI) is the custodian of irrigation design norms in South Africa, and members that have passed an exam based on these norms are recognised as SABI Approved Irrigation Designers. In order to be ensured of a high quality design, water users should make use of qualified engineers or technicians with experience in irrigation design or SABI Approved Designers.

A professional irrigation designer should provide the irrigator with a design report that contains at least the following information:

- Layout plan of the irrigation system
- Detailed drawings for installation
- List of quantities for equipment to be purchased
- Pump curve with the duty point(s) indicated
- Maintenance and management manuals for the equipment specified in the design
- SABI peak design form for the specific type of irrigation system
- Cost estimation

2.3 Operation, maintenance and evaluation of systems

The operation of the system requires that the irrigator should apply a scheduling method to make decisions regarding water applications. Operation should be monitored with appropriate technologies to assess whether the system is performing as the designer intended (by measuring flow and pressure), and if it is having the desired effect on the soil water content, as indicated/predicted by the scheduling system (by measuring soil water content).

2.3.1 Irrigation scheduling

Irrigation scheduling is commonly defined as determining when to irrigate and how much water to apply, as described in detail in this section based on the concepts published by Steyn & Annandale (2008).

Soil water management is probably one of the most important management decisions on the irrigation farm. It is important to understand the different strategies that can be followed to ensure good soil water management, including the timing, amount and method of irrigation.

2.3.1.1 When should irrigation take place?

The irrigator can follow different strategies in making a decision on when to irrigate. The timing can be based on three strategies, namely to irrigate when a certain depletion level has been reached, or at a fixed time interval, or when a fixed amount is depleted (Steyn & Annandale, 2008).

- **Fixed depletion level**

When a fixed depletion level strategy is followed the crop is irrigated whenever a certain predetermined percentage of plant available water is depleted from the root zone. The amount of water held between the field capacity and the wilting point of the soil is known as the plant available water (PAW). The depletion of soil water between irrigation events, for maintenance of a non-stress or low stress environment for crop growth is called the allowable depletion level (ADL). This level depends on factors such as the soil texture and structure, type of crop, crop growth stage, crop rooting depth and atmospheric evaporative demand.

Soil water content or plant water usage is monitored regularly, using any of the scheduling devices commercially available, and the profile is refilled whenever the pre-determined ADL is reached. Figure 9 illustrates a scheduling strategy where a 50% depletion of PAW is allowed.

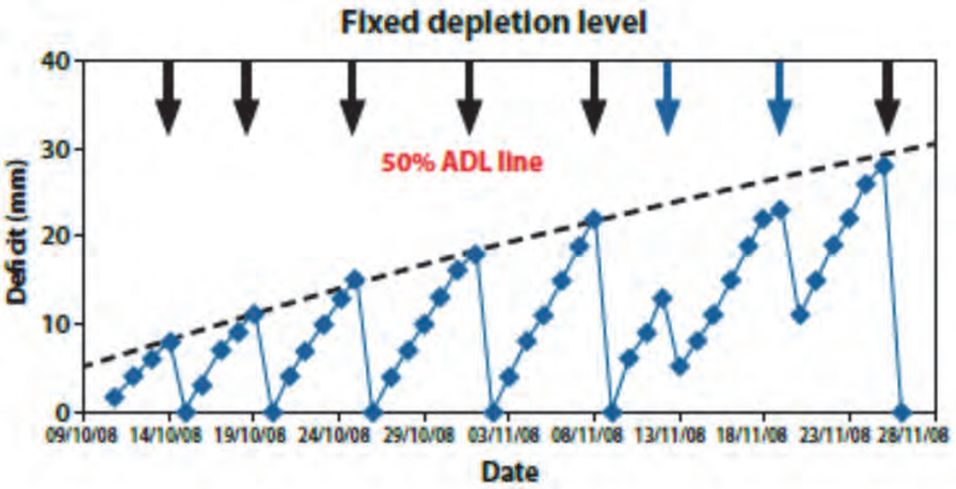


Figure 9 Irrigation scheduling where a 50% ADL is applied. The dotted line indicates 50% ADL and the arrows indicate irrigation (black) and rainfall (blue) events.

Note that the deficit amount increases as the season progresses. This can be ascribed to the fact that the rooting depth increases as the crop gets bigger, resulting in a larger soil reservoir and more water available to the plant.

- **Fixed time interval**

Irrigators sometimes use a fixed time interval between irrigations, every 7 days for example. Farmers who receive water allocations on specific days, like those participating in irrigation schemes, usually follow this type of schedule. Plant water usage is monitored using any of the soil or atmospheric based scheduling methods and the profile is refilled by the deficit amount on the day of irrigation. An example of a 7 day fixed irrigation interval is illustrated in Figure 10.

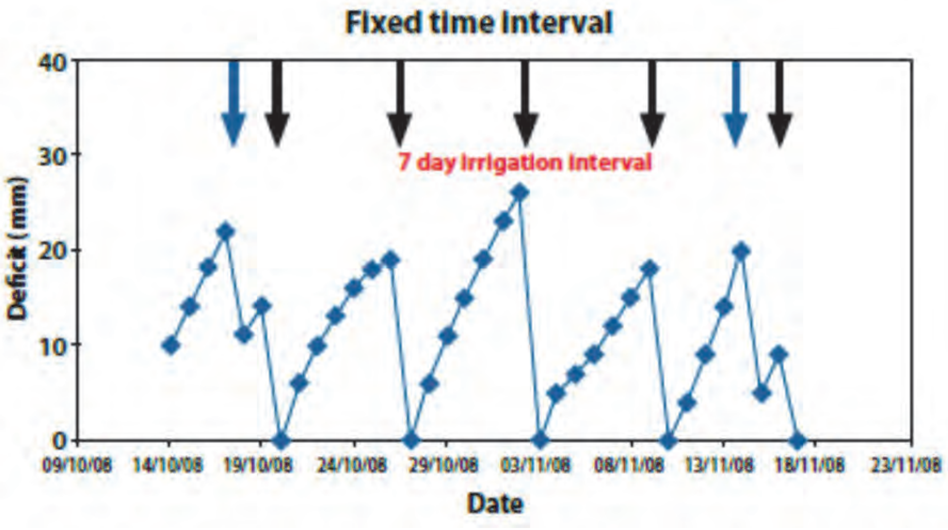


Figure 10 Irrigation scheduling where a 7 day fixed time interval is applied. The arrows indicate irrigation (black) and rainfall (blue) events.

- **Fixed irrigation amount**

The fixed irrigation amount scheduling strategy is employed when the irrigator decides on a certain fixed depletion amount before irrigation is initiated. The fixed amount is usually based on practical on-farm limitations, such as the limited capability of the irrigation system, storage capacity of reservoirs, etc.

Plant water usage is monitored using any of the soil, plant or atmospheric based scheduling methods. Irrigation is initiated when the cumulative crop water usage reaches the fixed irrigation amount. A fixed irrigation amount of 20 mm is used in the example illustrated in Figure 11.

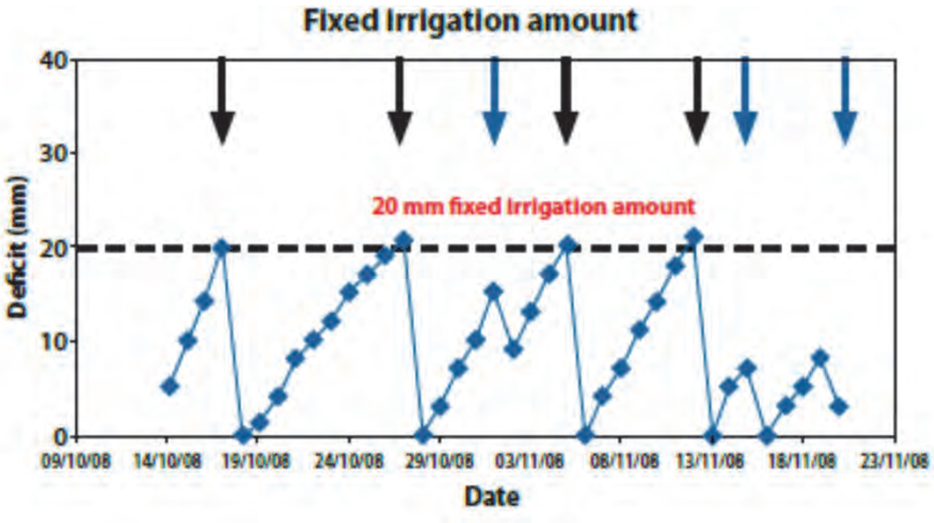


Figure 11 Irrigation scheduling where a 20 mm fixed irrigation amount is applied. The arrows indicate irrigation (black) and rainfall (blue) events.

2.3.1.2 How much to irrigate?

After making the decision of when to irrigate, the irrigation manager can decide whether he/she want to refill the soil to field capacity (FC), apply a deficit irrigation strategy (DI) or apply a leaching fraction (LF) when determining the irrigation amount (Steyn & Annandale, 2008).

- **Refill the soil to field capacity (FC)**

The concepts of plant available water (PAW), field capacity (FC) and the profile deficit were explained above. FC can be seen as the 'full point' of the soil profile, while the deficit is the amount of water required at any time to refill the soil to FC. If the irrigation amount exceeds this deficit, we can expect percolation (or deep drainage) of the excess water beyond the root zone.

When the soil profile is refilled to field capacity, the irrigation amount will be equal to the deficit measured or estimated with any of the soil or atmospheric based scheduling tools. We therefore expect minimal percolation to occur. This refill strategy is the one most commonly followed by irrigators. Figure 12 illustrates an example where a fixed irrigation amount of 30 mm was chosen. As soon as the measured deficit reaches 30 mm, the profile is refilled to field capacity by irrigating 30 mm. The deficit then returns to zero after each irrigation event.

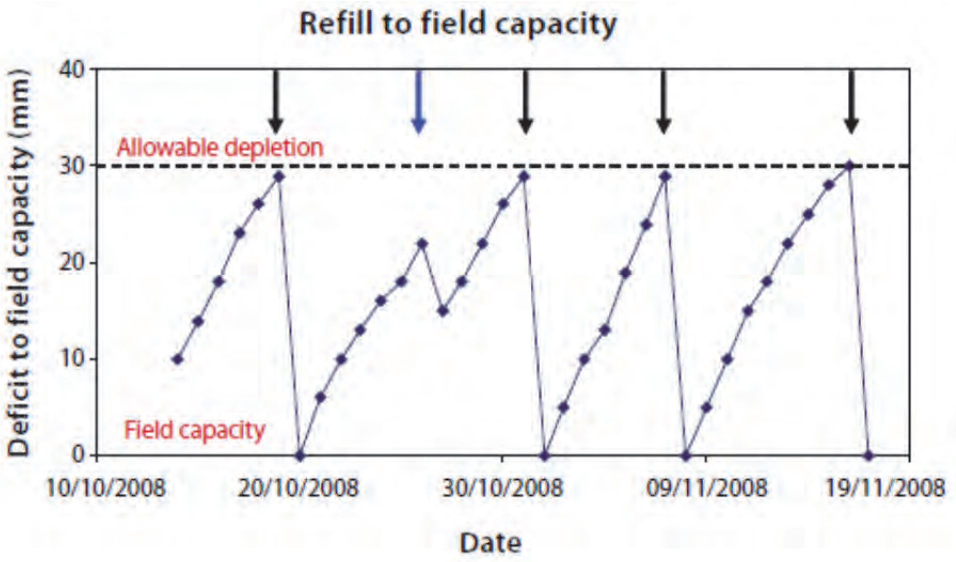


Figure 12 Irrigation scheduling where the soil profile is refilled to field capacity with every irrigation event. Arrows indicate irrigation (black) and rainfall (blue) events.

- **Applying a deficit irrigation strategy**

Deficit irrigation refers to a water management strategy where, on purpose, the root zone is not refilled to field capacity by irrigation.

Soils are 'leaky systems', which means that any water in excess of field capacity will percolate or 'leak' beyond the root zone and be lost for crop uptake. Rainfalls directly after irrigation will, most likely also result in water loss due to deep drainage. If there is a good chance of rainfall occurring during the growing season, rainwater use can be optimised by not completely refilling the profile to field capacity ('full point') with irrigation. This is called deficit irrigation or a 'room for rain' strategy.

The selected 'room for rain' amount depends on factors such as the sensitivity of the crop to water stress, the water holding capacity of the soil, the chance of rain falling and the expected quantity of rain. This strategy will obviously only be sensible if there is a good chance of substantial rainfall events during the growing season of a crop.

In the example illustrated in Figure 13, a fixed irrigation interval of once every seven days is used and 5 mm 'room for rain' is allowed. Two instances of rainfall occurred shortly after irrigation events. Since there was provision for 'room for rain', the rainwater could be utilised effectively, with little or no drainage.

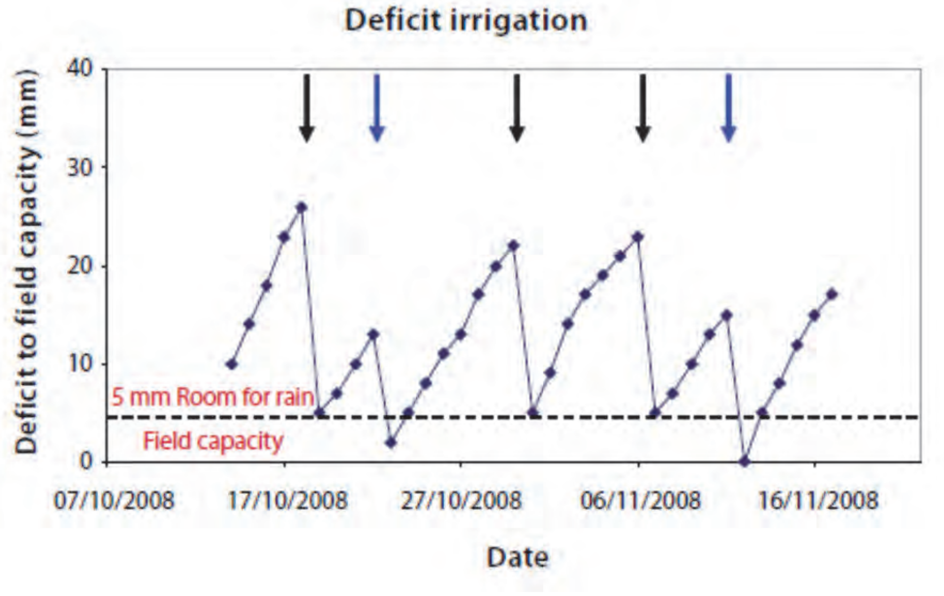


Figure 13 Irrigation scheduling where 5 mm 'room for rain' is kept on every irrigation event. Arrows indicate irrigation (black) and rainfall (blue) events.

- **Applying a leaching fraction (LF)**

When this approach is followed, the irrigation amount exceeds the measured profile or root zone deficit by a certain fraction. A leaching fraction is usually added to the irrigation amount to leach salts out of the root zone or when water of a poor quality (high salt content) is used for irrigation. A build-up of salt in the root zone is detrimental to crop production in the long-term, and if present, should be leached from the root zone from time to time, but preferably not when the profile is loaded with nutrients. In the context of the water balance framework, over irrigation according to a leaching fraction is, therefore, beneficial.

The desired leaching fraction is usually determined by factors such as the quality of irrigation water, salt tolerance of the crop, long term rainfall and the ability of the soil profile to transmit water. For the example illustrated in Figure 14, the allowable depletion level is 24 mm and an ‘over irrigation’ (leaching fraction of 20%, equivalent to 6 mm) is applied with each irrigation event. It is important to realise that one may choose to leach the profile only occasionally, and not with each irrigation event, as it is in no one’s interest to leach when expensive nutrients have been applied but not yet taken up by the crop.

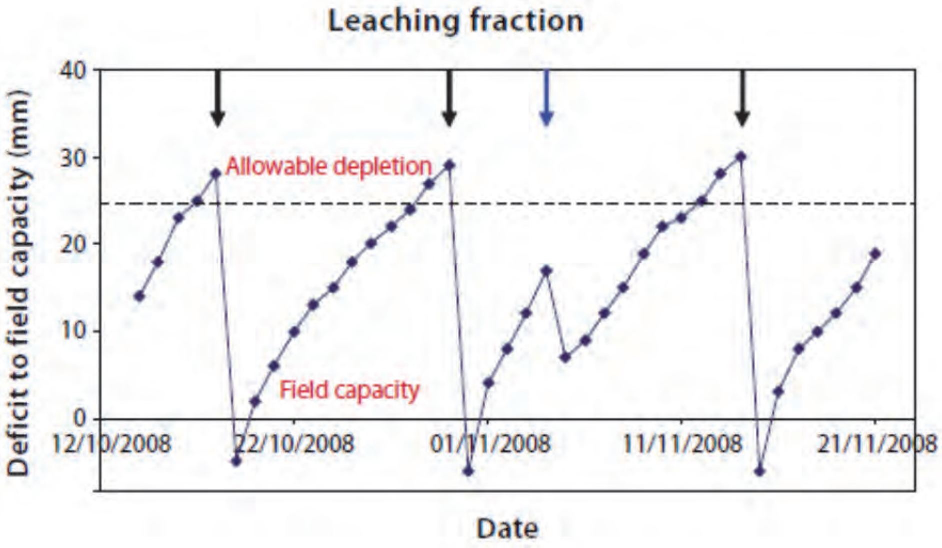


Figure 14 Irrigation scheduling where a leaching fraction of 20% (6 mm) is applied to leach salts from the root zone. Arrows indicate irrigation (black) and rainfall (blue) events.

2.3.2 Monitoring

The purpose of irrigation system monitoring is to ensure that the system functions as described in the design report. Monitoring is a continuous process, consisting of activities undertaken on a daily basis by the system operator, and should therefore be simple and easy to do so as to not interfere with the operator’s other tasks. The in-field irrigation system can be monitored at the following locations:

- At the inlet to the irrigation system (moving systems), block (drip/micro/permanent sprinkler), lateral (portable sprinkler) or furrow
- On the soil surface
- In the soil profile
- At the outflow of the drainage system, if applicable

In the case of pressurised irrigation systems, the pressure in the system should be monitored and compared against the design inlet pressure provided in the design report. A system operating at the correct pressure should supply the correct amount of water. Deviation from the design inlet pressure will provide the operator with an early warning of leakages or pipe bursts (low pressure), worn nozzles (low pressure), blocked emitters (high pressure) and other in-field problems.

Pressure in pipes can be measured with a pressure gauge, either permanently installed or portable, which has to be manually read at the point of measurement. Piezo-electric pressure gauges can also be used and the electronic readings conveyed to a central point via telemetry. Similar to pressure, refer back to Chapter 3 for details on flow measurement.

The data from the monitoring activities should be stored in a suitable data management system for easy access and analysis. Monitoring data, in particular of the amount of irrigation water applied and soil water content, are fundamental to irrigation scheduling and is needed to assess the effectiveness of an irrigation strategy and to make improvements if necessary.

It is important to note that no amount of measurements can replace the value of first-hand observations made in the field or orchard, and the irrigator should verify the results of their operational activities by observing the condition of the soil and the plants.

Figure 15 Pressure being checked at the irrigation block inlet (Koegelenberg & Breedt, 2003)

2.3.2.1 Soil water content monitoring

Several approaches can be followed to estimate crop water use. Most methods attempt to measure or estimate one or more components of the soil-plant-atmosphere system. Irrigation scheduling methods are therefore plant, soil or atmosphere based. Preferably, a combination of more than one approach should be used.

In practice, soil or atmospheric methods are most often used for irrigation management. Atmospheric methods are useful to establish the upper limits of crop water use. This means that crop water use cannot be higher than the atmospheric evaporative demand.

With soil measurements, spatial variability within a field can be a major problem. Site selection for measurement or instrument installation is critical. Measurements should be made in areas that are representative of the field, in terms of soil type, irrigation uniformity and plant growth.

Tools to monitor soil water can provide pertinent data on how a particular irrigation scheduling strategy/system is performing. It is recommended that at least two soil water content measurements be made in the soil profile – one in, and one below, the root zone. By monitoring the root zone, the irrigator ensures that there is adequate water available to the roots; by monitoring below the root zone, the irrigator can control excess irrigation and manage soil health.

With advances in communications technology, it has now become easier to obtain continuous soil water content or soil water potential readings than when measuring devices had to be read manually. Continuous measurement provides many advantages over the manual methods and should be used if possible. An overview of different technologies available for soil water content monitoring is shown in Table 2.

Table 2 Overview of soil water content measurement methods (Stevens & Buys, 2012)

Method	**Measured parameter**	**Equipment needed**	**Irrigation criterion**	**Advantages**	**Disadvantages**
Hand feel and appearance of soil	Soil water content by feel	Hand probe	Soil water content.	Easy to use: can improve accuracy with experience	Low accuracies; fields work involved to take samples.
Gravimetric soil moisture sample	Soil water content by taking samples.	Auger, caps, oven	Soil water content	High accuracy	Labour intensive including field work; time gap between sampling and results.
Tensiometers	Soil water tension.	Tensiometers including vacuum gauge	Soil water content	Good accuracy; instantaneous reading of soil moisture tension.	Labour to read; needs maintenance; breaks at tensions above 0.7 at/n.
Electrical resistance blocks. (Porous matrix sensors)	Electric resistance of soil moisture	Resistance blocks like gypsum block, granular matrix sensors (Watermark, Aquaprobe)	Soil water content	Instantaneous reading; works over larger range of tensions; can be used for remote readings	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Neutron thermalisation	Percentage moisture through the measurement of neuron scattering	Neutron probe	Soil water content	Accurate, clear picture of soil water measurements at different depths	Expensive; limitations related to safety rules that have to be followed. Labour intensive.
Di-electric sensors (Capacitance)	AC field applied to soil in order to detect properties linked to variations in soil water content	C probes, Enviroscan, Diviner, Gopher, DFM, AquaCheck	Soil water content	Real time continuous logging.	Relatively expensive.

Capacitance probes, otherwise known as frequency domain reflectometers, are relatively inexpensive compared to neutron probes and TDR instruments, and are becoming increasingly popular. These probes monitor the soil water content at various depths in the soil profile. An example of a capacitance probe is shown in Figure 16.

Figure 16 Example of a capacitance probe (DFM, 2008)

There is a concern that dielectric sensing instruments such as capacitance probes generally have a relatively small measurement sphere. Typically, the measurement sphere ranges up to about a 10 cm radius, with 95% of the sphere of influence within 5 cm. Since the sampled area is generally representative of the soil which is disturbed during sensor installation, correct installation with the least amount of disturbance to the surrounding soil is therefore critical. Care should also be taken to install probes in areas that are representative of the field, in terms of soil type, irrigation uniformity and plant growth.

As with all soil water content sensors, it is risky to use absolute values of readings or changes in readings without a detailed and site/soil specific calibration of the particular sensor. However, for most practical management purposes, careful analysis of trends in the sensor readings is normally adequate to determine when the soil water is below the stress point or above the drained upper limit. If results are doubted, the sensor should be calibrated against data from a more accurate source, such as a neutron probe or gravimetric samples.

2.3.3 Maintenance

Poor irrigation performance is often linked to a lack of maintenance. Irrigation hardware will inevitably degrade over time. Reaching the end of the design life of components, damage from contaminants in the water, or routine wear and tear are some of the reasons why maintenance is necessary. Maintenance can be subdivided into either preventative or corrective action.

Corrective maintenance is any action required to return a system's performance to a desired level and preventative maintenance is any action required to keep a system's performance at a desired level. As can be expected, budgeting for corrective maintenance, which arises from unforeseen circumstance, can be difficult. Preventative maintenance, however, is a periodic and recurring activity, which can be pre-planned. Diligent preventative maintenance can substantially reduce the need for corrective maintenance.

Lack of preventative maintenance results in decreased system performance, for example by:

- increased blockages in micro irrigation emitters (resulting in lower uniformity);
- increased losses through leaks or worn sprinkler nozzles (resulting in higher flow rates, lower pressures, low uniformity, and higher energy requirements), and
- reduced flow rates / higher friction loss in unflushed pipes.

An effective maintenance program for irrigation systems includes:

- Servicing schedules (including an inventory and spares in stock to be kept), and
- Replacement schedules for the different components.

Some general guidelines on preventative maintenance of in-field irrigation systems are provided below as published in the ARC-IAE's Irrigation User Manual, but complete information on the maintenance of different irrigation system components can be obtained from manufacturers who provide specific maintenance schedules for their products.

Table 3 indicates intervals for maintenance actions appropriate to micro-irrigation systems.

Table 3 Maintenance schedule for micro-irrigation systems (manual control)*

Action	**With each cycle**	**Monthly**	**Annually**
Inspect system for leakages	X		
Check system pressure and flow rate	X		
Flush laterals (depending on the water quality		X (or weekly)	
Service air valves and pressure control valves			X
Check hydraulic and electrical connections			X

Action	With each cycle	Monthly	Annually
Check functioning of hydraulic valves on filter bank and inspect moving parts			X
Chlorine treatment (depending on the water quality and method of application)			X
Take water sample at end of system and evaluate water quality changes			X

*The recommended maintenance schedule can be adapted for automatic systems, e.g. system pressure can be monitored monthly.

Table 4 indicates intervals for maintenance actions appropriate to sprinkler irrigation systems.

Table 4 Maintenance schedule for sprinkler irrigation systems (manual control)*:

Action	With each cycle	Annually
Inspect the system for leakages	X	
Check system pressure and system flow	X	
Service air valves and hydrants		X
Check sprinklers for wear and replace springs, washers and nozzles where necessary		X
Flush mainlines		X
Replace rubbers at quick coupling pipes where necessary		X

*The suggested maintenance schedule can be adapted for automatic permanent systems, e.g. system pressure can be monitored monthly.

After the irrigation season, and before the pipes are stored, the following must be done:

- Mark all the holes in quick coupling pipes with paint so that they can be repaired.
- Remove all gaskets from pipes if they are stored in the sun.
- Replace all damaged and hardened gaskets.
- Replace all worn male and female pipe fittings.
- Replace all dragline pipes that have more than three joints.
- Check standing pipes for corrosion and replace if necessary.
- Ensure that all standing pipes are the same length and straight.

Table 5 indicates intervals for maintenance actions appropriate to moving irrigation systems.

Table 5 Maintenance schedule of centre pivots

Action	**After each revolution**	**After each 4th revolution**	**Seasonal**
Electrical			
Switch on pivot and listen to each motor and starter. If any abnormal sound is heard, remove and service.			X
Replace end tower's electric bulb (if out) and remove dust, insects and water where necessary.			X
Check tower panel and main control cabinet. Clean panels, remove dust, insects, e.g. wasps, etc.			X
Inspect condition of wiring of pivot			X
Inspect electrical motor cable condition, earth conductor and connections			X
Structure			
Tighten all bolts and nuts where necessary. Ensure that earth conductors are clean.			X
Grease pivot		X	X
Grease pin that holds swing mechanism of towable pivots to prevent rusting		X	X
Check system for leakages. Repair if necessary			X
Replace gearbox oil			X
Drain and replace lubricants in motors			X
Grease moving parts and roller bearings	X		X
Check U-couplings, grease if necessary			X
Check wheel bolts and adjust as prescribed	X	X	X
Check wheel pressure and adjust as prescribed	X		X
Check flange fittings for leakages, secure and replace if necessary	X		X

Action	**After each revolution**	**After each 4th revolution**	**Seasonal**
Inspect framework for sturdiness – tighten bolts if necessary	X		X
Check that all the safety switches work			X
Check that all the drainage valves work	X		X
Clean sand trap if necessary	X		X
Sprinklers			
Check nozzles for wear, replace if necessary			X
Check that the pressure meter works correctly			X
Check the condition of the sprinklers			X
Check pivot pressure and pressure at beginning of towers			X
Check for blockages in nozzles	X	X	X
Flush the system			X
Equipment			
Check functioning of end nozzles and check nozzle for wear			X
Inspect cut-off action of end nozzle – repair or replace if necessary			X
Check stop in slot micro switch, adjust if necessary	X		X
Test the automatic reverse-action movement of pivots by switching the hand lever forward and back			X
Fill wheel tracks deeper than 150 mm with timber or stones		X	

2.4 System performance evaluation

Evaluation differs from monitoring, in the sense that it is performed periodically rather than continuously. Irrigation system evaluation is an important tool that should be applied to assess whether the system is performing as intended by the designer and whether the irrigator's maintenance practices are effective.

The information from an evaluation should help a farmer reduce input costs, increase returns and, if necessary, provide motivation for a designer to implement remedial measures if a design was not up to standard.

There are a number of published evaluation methodologies for the various types of irrigation systems. The recognised evaluation methods for different irrigation systems in South Africa are described in detail in the Manual for the Evaluation of Irrigation Systems published by the ARC-IAE (Koegelenberg and Breedt, 2003).

Evaluation of in-field systems focuses on measuring flow and pressure, and assessing the distribution uniformity of the system. Flow and pressure measurements are compared with the design values as stated in the design report while uniformity tests can be used to assess representative irrigation application amounts and whether or not there are problems with uniformity. The most commonly used indicator used to assess uniformity, is the distribution uniformity of the lower quarter (DU_{lq}) calculated from data as shown in Figure 17. The DU_{lq} should exceed 70% for all irrigation systems.

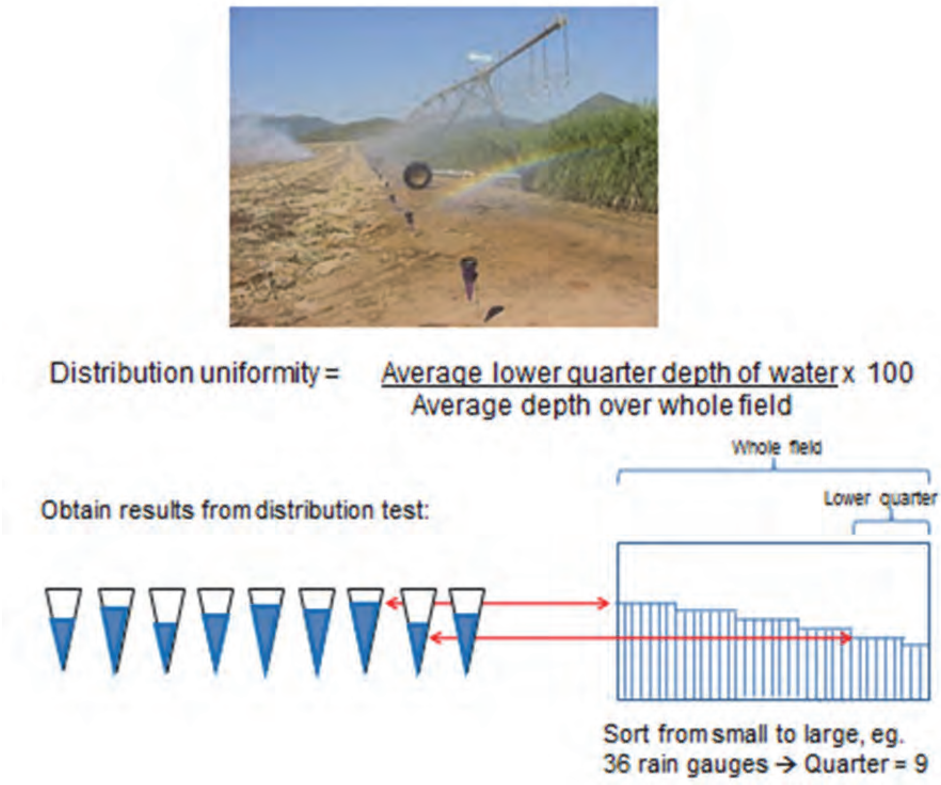


Figure 17 Determining the distribution uniformity of the lower quarter

It is recommended that irrigation systems are evaluated immediately after installation and thereafter if regular monitoring practices or crop observations indicate less-than-desired system performance.

2.5 Summary

The following guidelines should be adhered to when planning, designing and managing in-field irrigation systems:

- Assess the suitability of soils for irrigation, according to the irrigation potential classification system, and determine the soil water holding capacity and infiltration rate
- Assess the water requirements of the crop to be irrigated
- Assess the suitability of water quality for irrigation, according to the South African Water Quality Guidelines for agricultural use
- Use an appropriate computer programme to determine irrigation water requirements, (for example the SAPWAT3 program, incorporating the Penman-Monteith equation, quaternary weather station data and irrigation system specific application efficiency parameters)
- Use the SABI irrigation design norms to design the irrigation system components
- Apply a sound scheduling strategy supported by reliable soil water content measurements and verified with in-field check when operating the irrigation system
- Regularly monitor the irrigation system's performance against the design parameters
- Periodically evaluate the performance of the irrigation system and perform the necessary maintenance and trouble-shooting to ensure optimal performance

For more information on in-field irrigation systems, please refer to WRC Report number TT 466/10 Module 2.

Self-assessment questions:

- What are the 6 characteristics of an efficient in-field irrigation system?
- Explain the difference between efficiency and uniformity.
- What are the three different scheduling strategies regarding the timing of irrigation events?
- What are the three different scheduling strategies regarding irrigation amounts?

3 On-farm water conveyance systems

In this chapter we will cover the following concepts:

- Typical on-farm conveyance infrastructure
- How flow rate, pressure head, and pump and motor efficiency influence power demand
- Electricity tariffs
- Maintenance and evaluation of on-farm systems

The on-farm conveyance system includes:

- main pipelines or canals
- control valves and automation systems
- filters,
- pumps and motors,
- switchgear, transformers and cables,
- farm dams, and
- drainage systems.

Typical components are shown in Figure 18. In South Africa, more than 85% of irrigation systems are pressurised, requiring a pumped water supply. Electricity use and costs is therefore closely coupled with irrigation performance and the water balance framework.

The purpose of the on-farm conveyance system is to convey the water from the farm edge to the field at the lowest possible energy requirement. Operational economy and conveyance efficiency of the system components are therefore of importance. By keeping volumetric and pressure losses to a minimum, the demand of flow, pressure and thereby energy can be minimised.

The most efficient on-farm conveyance system will therefore be one that:

- Is planned and designed in size and lay-out with the lowest capital and operating costs in mind to supply and remove water to and from the in-field irrigation systems,
- Consists of quality equipment with high inherent energy efficiencies,
- Is installed according to the designer and/or manufacturer of the equipment's instructions,
- Is operated according to the design specifications and the flow and pressure requirements of the in-field irrigation systems,
- Is maintained according to the equipment manufacturers' and / or irrigation designer's recommendations, and
- Is regularly evaluated to assess the level of performance and detect problems as early as possible.

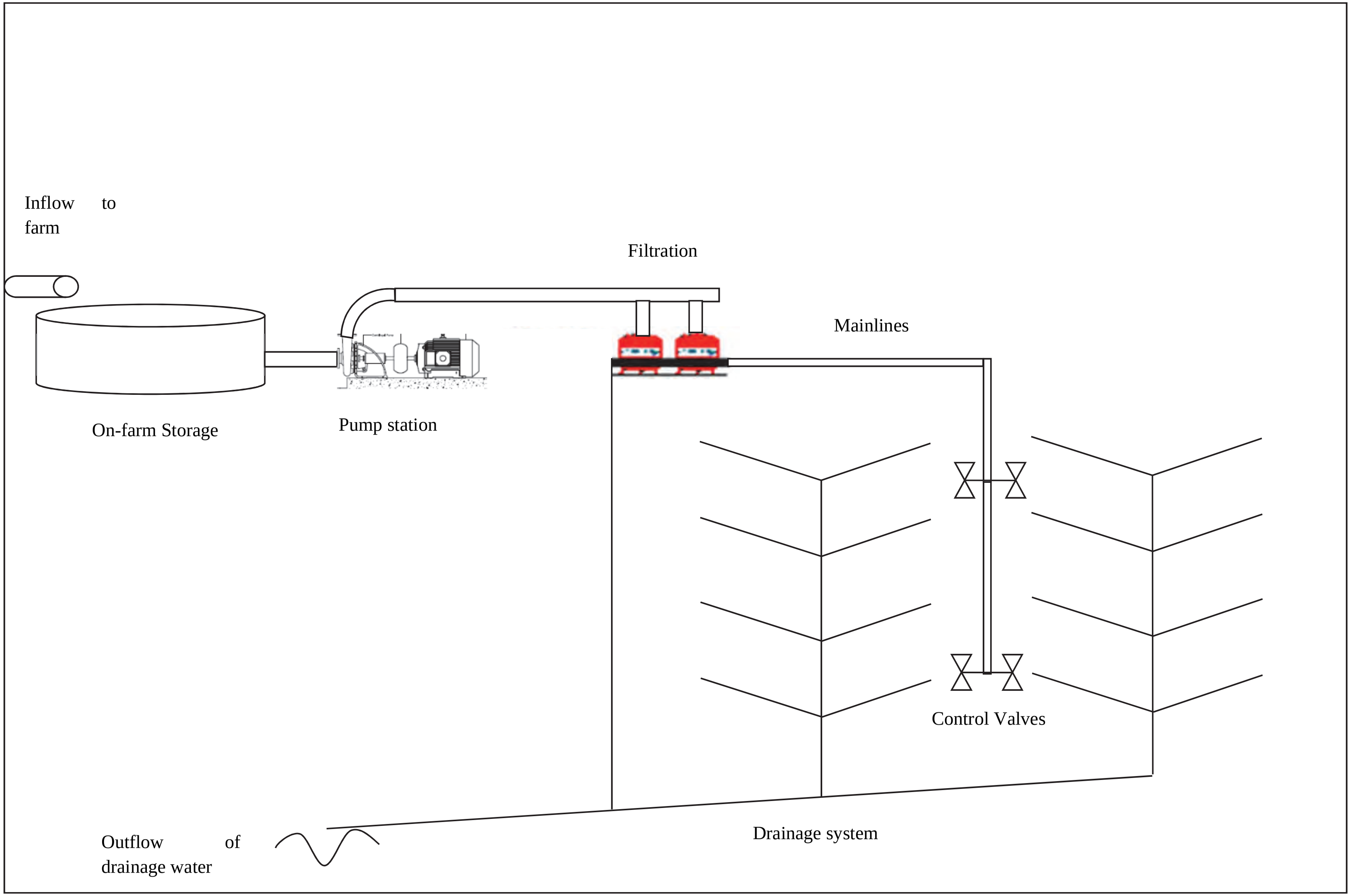


Figure 18 Typical components of the on-farm conveyance system

3.1 Planning and design

Correct selection, design and location of the different on-farm conveyance system components will have an effect on the total amounts of water and pressure (and therefore also the energy) required to operate the system. Some of the aspects that should be taken into account by the irrigation designer and the water user include:

- using farm dams to balance supply and demand,
- the amount of energy required to supply water to the hydraulically most remote point on the farm,
- pressure and flow required to flush filters,
- flow rates required by fertigation systems,
- automated controls, and
- improved sustainability through the installation of drainage systems.

3.1.1 Volumetric demand

The flow rate (Q) of the system is simply the volume of water to be applied in one irrigation cycle, divided by the time available to do so.

The number of hours available within an irrigation cycle to apply the required amount of water has a major impact on the flow rate for which the system has to be designed. The recommended maximum number of hours per week (ARC-IAE, 2003) that could be used to irrigate, are:

- Micro and permanent sprinkler systems: 144 hours
- Centre pivots systems: 144 hours
- Portable sprinkler and other portable systems: 110 hours
- Flood irrigation systems: 60 hours

These hours may have to be adjusted to take into consideration the applicable electricity tariff (Ruraflex, Nightsave, etc.) or in cases of a shared water supply.

The flow rate of the system determines what portion of the total area can be irrigated at any given time in the cycle. The whole area is therefore divided in groups, which are irrigated one at a time on a rotational basis. More time available in the cycle means a larger number of smaller groups, which means smaller flow rates and therefore smaller mainline pipe sizes (but longer pumping hours).

Balancing dams can be used to store water for use during times when demand exceeds supply from the water source; however, additional evaporation losses and pumping costs must be considered when considering this option.

3.1.2 Pressure requirement

Similarly to the flow rate, the higher the pressure (H) required to operate the irrigation system, the higher the energy requirement of the system. The pressure requirement of the system is influenced by the operating pressure of the selected irrigation system, the topography of the farm, the pipe sizing strategy used to design the distribution system, the length of the pipes distributing water on the farm, and friction loss through the other system components such as valves, filters, etc. The greater any of these factors are on a farm, the greater the pressure requirement will be and therefore the higher the operating cost will be. Design norms are determined by SABI and should be adhered to in order to design efficient systems.

3.1.3 Energy demand

The total power requirement of the pump station supplying water to the conveyance system can be calculated as:

$$\boldsymbol{P_i = \frac{H \times Q}{0.036 \times \eta_p \times \eta_m}}$$

Where P_i = Input power required by the motor (kW)

H = Pressure head (m)

Q = Flow rate (m^3/h)

η_p = pump efficiency (fraction)

η_m = motor efficiency (fraction)

The higher the flow rate and the pressure required, the greater the amount of power needed to supply it, and therefore the higher the energy cost. In addition, each pump and motor in the system will operate at a certain energy efficiency, which is determined by the following two factors:

- The quality of the technology used as defined by the efficiency rating of the pump or motor)
- The duty point or load factor of the technology as defined by the design and selection process

The efficiencies are indirectly proportional to the power requirement and therefore a decrease in efficiency will lead to an increase in power requirement. Efficiencies are optimised by selecting high efficiency pumps and motors, operating them at the correct duties or loads, and by performing timely and effective maintenance.

The use of variable speed drives (VSDs) are becoming more widespread, making it possible to closer match water supply to the demand, thereby reducing unnecessary friction losses, resulting in lower operating costs. VSDs do not however always provide a benefit, and will also not compensate for poor design – every situation must be assessed to determine whether as VSD is viable option.

3.1.3.1 The total cost of pumping water

The cost of pumping water can be calculated as follows:

$$k_{\mathrm{p}} = \mathrm{P} \times \mathrm{t} \times k_e$$

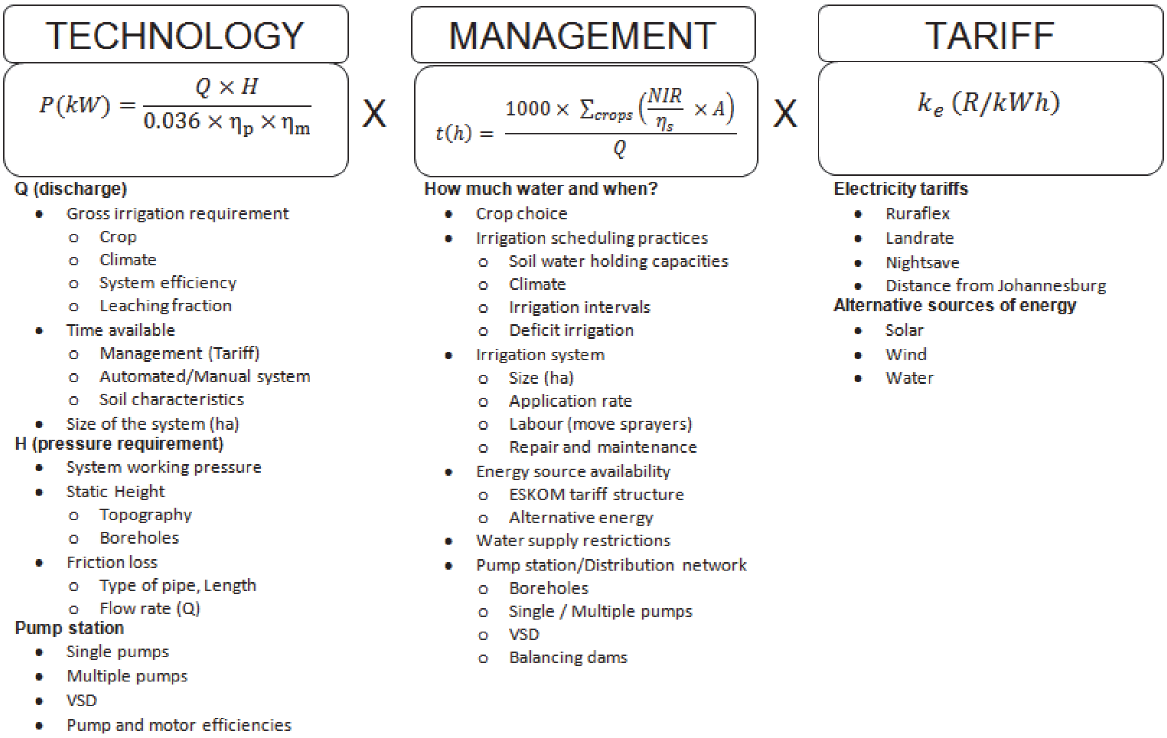
Where:

$\mathrm{P_i}$ = input power requirement of the electrical motor, kW

t = total number of hours the pump is operated for at $\mathrm{P_i}$, hours

$\mathrm{k_e}$ = energy tariff, Rand per kWh

If each of these inputs are considered individually it can clearly be seen that every decision made during the planning and design of the in-field and on-farm irrigation systems have an impact on the pumping cost:



TECHNOLOGY

$$P(kW) = \frac{Q \times H}{0.036 \times \eta_{\mathrm{p}} \times \eta_{\mathrm{m}}}$$

X

MANAGEMENT

$$t(h) = \frac{1000 \times \Sigma_{crops}\left(\frac{NIR}{\eta_s} \times A\right)}{Q}$$

X

TARIFF

$$k_e\ (R/kWh)$$

Q (discharge)
- Gross irrigation requirement
  - Crop
  - Climate
  - System efficiency
  - Leaching fraction
- Time available
  - Management (Tariff)
  - Automated/Manual system
  - Soil characteristics
- Size of the system (ha)

H (pressure requirement)
- System working pressure
- Static Height
  - Topography
  - Boreholes
- Friction loss
  - Type of pipe, Length
  - Flow rate (Q)

Pump station
- Single pumps
- Multiple pumps
- VSD
- Pump and motor efficiencies

How much water and when?
- Crop choice
- Irrigation scheduling practices
  - Soil water holding capacities
  - Climate
  - Irrigation intervals
  - Deficit irrigation
- Irrigation system
  - Size (ha)
  - Application rate
  - Labour (move sprayers)
  - Repair and maintenance
- Energy source availability
  - ESKOM tariff structure
  - Alternative energy
- Water supply restrictions
- Pump station/Distribution network
  - Boreholes
  - Single / Multiple pumps
  - VSD
  - Balancing dams

Electricity tariffs
- Ruraflex
- Landrate
- Nightsave
- Distance from Johannesburg

Alternative sources of energy
- Solar
- Wind
- Water

Figure 19 The total cost of pumping irrigation water

3.1.3.2 Electricity tariffs and supply

Irrigators do not have much influence over electricity prices or the reliability of supply. There is a trend for some electricity supply companies to tailor tariffs to suit irrigation, or to offer load management options, but these are not yet common.

Where cheaper night rate electricity options are available, there is a temptation to design irrigation systems to only operate within those hours, even during peak irrigation periods. For a ten-hour night rate period, irrigation systems have to be designed with over twice the capacity, compared to a system that is operated over a full day (24 hours). This means bigger pipes, pumps and system components, and a much higher cost system.

Given that irrigation systems only need to operate at their peak capacity for part of the season, it is usually much cheaper overall to design systems to operate over the whole day (24 hours), operate at night whenever possible, and extend irrigation into day time rates when demand requires it. A full economic analysis is recommended in the case of new systems, taking into account envisaged tariff increases from ESKOM.

Alternative energy sources such as hydro, wind or solar power can be considered for irrigation systems; however, these sources are relatively expensive and are usually only available for limited hours per day (Table 6).

Table 6 Alternative energy sources with cost (De Jager, 2015)

Technology	Cost to generate (c/kWh)
Large hydro	38
Small hydro	45
Biogas	49
DSM	64
Coal	70
Gas – closed cycle	80
Nuclear	84
Wind	86
Biomass	107
Gas – simple cycle	140
Solar – thermal	200
Solar – photovoltaics – ground surface mounted	250
Solar – photovoltaics – rooftop mounted	400

In order to ensure all electrical motors are operating correctly and efficiently, adequately sized electrical cable should be used to distribute electricity from the transformer to the motor. Cables should be designed to conform to SABS 0142-1981, Regulation 4.3.4. This regulation dictates that the maximum voltage drop under full-load conditions may not exceed 5%.

If the cable size is too small, the voltage [V] decreases excessively over the length of the cable and this causes the electric motor to draw a higher current. The motor may thus overheat and the energy loss will also increase. It is therefore very important not to use cables that are too small.

3.2 Management of on-farm systems

3.2.1 Operation

In order to make best use of the on-farm infrastructure, the irrigator should operate the system as intended by the designer. In the case of large commercial farms, the use of software programmes to optimise the scheduling of different irrigation blocks or systems will assist the irrigator to make the best decisions and keep record of water applied.

Irrigators can limit the cost of energy by employing energy-saving practices into their irrigation management strategies, such as:

- Reducing the pumping hours through accurate scheduling and improved in-field system efficiency
- Reducing the pump pressure by making changes to the irrigation infrastructure
- Switching to more efficient pumps and/or motors
- Changing to a different electricity tariff plan

3.2.2 Monitoring

Monitoring of flows and pressures at strategic locations in mainlines, at filter and pump stations is necessary not only for volumetric recordkeeping but also to detect performance problems within the system such as blockages or leakages. Modern technologies can be built into the switchgear to send out messages via GSM networks and thereby limit losses due to breakdowns. Water quality can be monitored in a similar manner.

The on-farm conveyance system can be monitored at the following locations:

- At the inlet to the pump station (water quality, flow rate, water depth, etc.)
- Pressure drop over the filter bank
- Quality of the backwash water of the filter (turbidity)
- Pressure at the inlet to the main line

A separate chapter in this material is dedicated to measurement.

3.2.3 Maintenance

Regular maintenance (preventative and corrective) will reduce operating costs and water losses in the on-farm conveyance system. Leaks in systems results in additional demands of flow from the water source, reducing efficiency. Timely fixing of leaks, checking of valves (especially hydraulic ones) and filters and maintenance of pumps and motors will ensure that water is supplied to the intended destination in the most energy (and therefore cost) efficient manner. Complete maintenance guidelines for different system components are available from the manufacturers and should be adhered to.

Figure 20 Water leaks increase flow requirements and reduce efficiency (Horn, 2014)

Basic preventative maintenance guidelines are shown in Table 7 can be used for centrifugal pumps:

Table 7 Typical maintenance schedule for conveyance systems

Monitor	Monthly	1 000 Operating hours	Bi-annually	Annually
Pipeline leakages – repair	x			
Air valves			x	
Build-up of sand in low points – flush scour valves				x
Deposits inside pipeline (bacteria / lime / iron) – clean mechanically / chemically				x
Check pump alignment / settings			X	
Replace oil for pump bearings			X	
Inspect bearings and clean		X		
Inspect all parts for wear and do hydraulic test (check pressure against flow)	X			
Inspect the gland packing leakage (it must leak slightly, because it is lubricated by water)	X			
Replace the gland packing				X
Inspect cables and electric equipment			X	

Guidelines for corrective maintenance of conveyance systems are provided in Table 8.

Table 8 Trouble shooting table for PVC pipes (Koegelenberg & Breedt, 2003)

Problems	Possible causes	Solutions
Pipe splits	Surge pressure exceeding the pressure class of the pipe	Replace pipe with a higher class Control the pressure
	Water hammer in system	Put in air valves Reduce flow velocity Change the operational sequence of the system
	Poor quality	Replace pipe
	Damaged pipe	Replace or repair damaged portion
Pipe bursts in a herringbone fracture along its entire length	Water hammer in the system, usually induced by the rapid relocation of air in the system	Investigate air entrapment in the system and install air relief valves
Pipe flattens causing stress cracking	Negative pressures in the line	Provide air valves to allow air into the system. Provide a non-return valve.
Joint leaks – seal pushed into the pipe	No lubrication during jointing	Use Gel lubricant
	No chamfer on the pipe spigot	Chamfer pipe to 15°
	Seal inserted the wrong way round	Insert seal correctly
Joint leaks – seal extruded out of the pipe	Air in the line trying to escape	Purge the line at low pressure during commissioning.
	Poor alignment of the joint	“Ease” the alignment horizontally and/or vertically
Joint leaks – constant dripping	Sand/grit behind the joint	Remove and clean properly
	Pipe spigot over-inserted into the socket not allowing movement	Ensure pipe is only inserted up to the depth of entry mark.
	Poor quality of housing	Cut out joint and repair
	Pipe diameter under size	Replace pipe
Solvent cement joint pulls out	Surface not prepared properly	Use sandpaper and a solvent cleaner.
	Solvent cement is “old” and does not “bite” into the surface	Use new pressure cement that has a strong smell and is not too thick
	Pipe too small or socket too big	Replace pipe or socket

Problems	Possible causes	Solutions
	Solvent cement not cured properly	Allow longer curing time, especially at low temperatures.
Pipe splits near a solvent weld joint	Too much solvent cement in the joint area, softens the pipe	Only use sufficient to just cover both surfaces.
Small hole appears in the pipe wall	Foreign particles in the raw material	Repair hole or replace pipe

3.2.4 Evaluation

Evaluation differs from monitoring in the sense that it is performed periodically rather than continuously. . Control valves should regulate pressure and flow correctly, filters should effectively remove impurities, and pump stations should supply water at the correct pressure and flow at the lowest possible power requirements.

There are standard evaluation procedures that have been developed by the ARC-IAE. A summary of some of the basic procedures applicable to the on-farm conveyance system is shown in Table 9.

Table 9 Proposed basic evaluation procedure of on-farm conveyance system components

Subject / Item	Measurement/Evaluation	Action if measurements / evaluation does not conform to the design specifications
Inlet pressure of block	Determine the inlet pressure of the blocks with a pressure gauge and compare with the required pressured as specified on the peak design form	Contact designer and adjust set-up schedule if necessary
Equipment: model and manufacturer	Compare the model/ manufacturer of the installed pump, electric motor, filter and emitters with the specifications as per design report.	Contact designer for replacement of faulty equipment
Pump suction side fittings	Examine if the measurements of the suction pipe is according to plan and if the shape of the reducer, bend and adapters are as correct.	Contact designer for replacement or re-installation of faulty equipment
Pump duty point	Determine the pump pressure by reading the pressure from the pressure gauge at the	Contact designer for fault detection

Subject / Item	Measurement/Evaluation	Action if measurements / evaluation does not conform to the design specifications
	delivery side of the pump and compare with the pump pressure height specified on the peak design form. Determine the pump delivery by comparing the reading on the flow meter and compare with the design flow rate.	
Pump cavitation	Determine whether the pump cavitates by listening and feeling for excess vibration	Contact designer for fault detection.
Schedule of blocks/ movable sprinklers in simultaneous operation	Compare the blocks / sprinklers that are in simultaneous operation, with the specification as suggested in design report.	Change the blocks / sprinklers that are in simultaneous operation, by either opening the correct taps or reprogramming the irrigation computer.
General installation	Examine if any leakages occur in the system	Repair leaks
Operation of equipment	Examine operation of filters (e.g. pressure loss and back flushing action), air and pressure control valves	Contact designer for fault detection
System capacity	Determine system flow rate by taking the reading from the flow meter/ measuring notch	If a flow rate deviation of more than 10% from the average occurs, as specified in the peak design form, contact the designer.

If a complete system evaluation is required, an irrigation consultant can be approached to execute the evaluation as described in *Manual for the evaluation of irrigation systems*. Approved system evaluators who are also SABI approved irrigation designers are listed on the SABI website www.sabi.co.za.

3.3 Summary

The following guidelines should be adhered to when planning, designing and managing on-farm conveyance systems:

- The system should be laid out and designed with capital as well as operational costs in mind
- The most efficient pumps and motors should be used as far as possible
- Infrastructure should be designed using SABI design norms
- Electrical cables should be correctly sized
- High quality equipment should be selected and correctly installed
- Flow rate, pressure, electrical current and water quality should be monitored regularly at strategic locations and assessed against the design values

For more information on on-farm conveyance systems, please refer to WRC Report number TT 466/10 Module 3.

Self-assessment questions:

- Name the 5 characteristics of an efficient on-farm conveyance system.
- Name 4 practices that irrigation water users can employ to reduce the energy demand of irrigation systems.

4 Irrigation schemes

In this chapter we will cover the following concepts:

- Water use models that can be applied at scheme level
- Scheme management tools
- Water measurement implementation

An irrigation scheme is defined as that part of the system where irrigation water users are grouped into an organisation that share a water source such as a canal, river or groundwater aquifer, with the management authority taking responsibility for managing demand and conserving water.

To the farmer, good water management means getting the right amount of water to the crops at the right time with minimum labour and expense. If this can be accomplished without creating other problems, such as a build-up of salt in the soil or losing water to spills and seepage, so much the better.

To the irrigation scheme, good water management means meeting the water needs of its customers as efficiently as possible, with minimum waste or loss. Good water management is, therefore, fundamentally important to good overall scheme management.

Therefore to manage irrigation schemes with water use efficiency in mind, it is necessary that:

- The water available to all the users on the scheme is known to both the scheme management and the water users, and the information is accessible,
- The water use on the scheme is planned on a weekly, monthly, seasonal or annual basis, as applicable, to match the expected crop water requirements but not exceed the supply available from the resource,
- The scheme has accurate and reliable measuring devices installed at the identified strategic points on the conveyance system,
- The scheme is operated and maintained according to the design specifications and sound operational rules, as captured in a regularly updated water management plan and supported by a water pricing policy that encourages efficiency, and
- The scheme management system is regularly evaluated to assess the level of performance and detect problems as early as possible.

To society, good water management means having adequate supplies of good quality water for all municipal, industrial, agricultural, recreational, and environmental needs. Those in charge of operating water supply and delivery systems bear the greatest burden of responsibility for promoting and achieving the good water management demanded by society.

4.1 Planning

Planning of water use – to predict expected abstractions by users from the shared water resource – is probably the most important aspect of water management. It is not enough to try and control or monitor water use after it has taken place without having an expected or predicted figure to compare it against.

The irrigation boards or WUAs in South Africa that have managed to implement practical and accurate planning functions into their management systems, have succeeded in establishing water management systems that are effective, useful and considered fair by all involved – an imperative factor if the water users are expected to respect and accept the system.

Good planning relies on an understanding of the supply of water from the source, as well as the behaviour of users abstracting water from the system. Understanding the hydraulics of a canal system, or the hydrology of a river, or the recharge of a groundwater aquifer are specialised fields of water management but there are South African models that help water managers to plan and predict the behaviour of the supply system they have to manage.

In the case of estimating end-users demand, software such as SAPWAT3 provides the capability to import regional crop data from an outside source and to estimate irrigation requirements of the imported crops as an automated function for a field, farm, WUA or even WMA. Year-on-year crop water and irrigation requirements are estimated, and the user can export average crop irrigation requirements with and with-out the effect of rain to a spread-sheet, if so required.

4.2 Management systems

Successful delivery of water to large numbers of users simultaneously demanding water from a shared source requires powerful tools and a thorough understanding of the system.

A major part of scheme water management is the administration thereof – keeping records of water users, their details, allocations, transfers and financial management. The Water Administration System (WAS) is designed to be a management tool for irrigation schemes and water management offices to manage water accounts and water supply to users through canal networks, pipelines and rivers (Benadé, 2011). WAS is developed and maintained by NB Systems cc. Financial contributions for the development of WAS were made by the WRC and the Department of Water Affairs (DWA).

WAS is an integrated database driven system with many water management capabilities. WAS can be implemented in a small water office that manages a few abstractions and measuring stations up to a CMA level that manages thousands of abstractions and measuring stations. WAS is used for the efficient administration of:

- Address information.
- Scheduled areas.
- Water quota allocations.

- Water delivered through pressure-regulated sluice gates, measuring structures and water meters.
- Water transfers between users (Automatic and manually).
- Water use calculations for planted areas based on crop water use data.
- Date and time related flow data collected from electronic loggers or mechanical chart recorders.
- Discharge tables (DT) to do conversions between water depth and flow rate for measuring structures or vice versa.
- List of rateable areas (LRA) information.
- Calculation of scheme water balances.
- Calculation of water releases for water distribution through canal networks, pipelines and rivers taking lag times, evaporation, transpiration and seepage into account.
- Billing system that links to the water usage information.
- Flexible tariff sets based on water usage, a flat rate or scheduled area.
- Images and photos that can be linked to different types of information in the database.
- Mail merge facility for sending letters to clients.

The WAS program is currently in use at all the major irrigation schemes and a number of smaller irrigation boards throughout South Africa, and is highly recommended as a management tool to improve on-scheme efficiency.

4.3 Water measurement

In order to perform a water balance on the whole or part of the canal scheme, flow measurements are needed. Wide-scale implementation can be expensive but a phased approach can help manage expenditure. At the very least, the flow into the canal system, and all outflows from the system (including deliveries to farms) should be measured to ensure fair and equitable distribution of water. Thereafter, more interim measuring locations can be identified and equipped to assist the WUA with on-scheme efficiency.

There are many measuring devices available, ranging in cost and capability. Devices should be suitable for the water quality and installation conditions under which they are expected to function. A separate chapter in this material is dedicated to flow measurement. While permanently installed devices with continuous data logging is the ideal, there are various portable or manually operated alternatives available to the WUA.

4.4 Summary

The following guidelines should be adhered to when planning, designing and managing irrigation schemes:

- All legal requirements as specified in the NWA should be met, especially regarding institutional arrangements and water use

- Software such as the SAPWAT3 program should be used when planning irrigation demands, adapted if necessary for local conditions
- The relevant modules of the WAS program should be used to operate irrigation schemes on a daily basis for record keeping
- Water abstraction and distribution should be measured at an appropriate level of accuracy with suitable measuring devices at strategic points on the irrigation scheme
- A water balance should be compiled for the scheme and used to monitor and evaluate irrigation scheme performance

For more information on irrigation schemes, please refer to WRC Report number TT 466/10 Module 4.

Self-assessment questions:

- Name the five areas of management that determines the efficiency of an irrigation scheme.

5 Measurements for data collection

In this chapter we will cover the following concepts:

- Measurements required to compile a water balance
- Importance of measurement accuracy
- Devices for pipe and canal flow measurements
- Flow measurement implementation process
- Additional measurements (environmental and evaluation)

The use of the water balance implies that a large number of measurements need to be made to quantify the different components. Measuring also makes business sense for management at any water use level.

5.1 Which measurements are required?

A summary of required measurements and available measuring methods to quantify the water balance framework components are shown in Table 10, with references where more information can be accessed.

Many suitable and proven technologies are available to collect the required data such as flow rates, pressure, soil water content, flow depth, climatic data as well as soil and water quality parameters, and most of the measurements can be managed remotely using modern communication technology such as modems and the internet, enabling real-time water management and more effective decision-making. Appropriate modern technologies should be used as far as possible to improve water management.

5.2 How accurate will the measurements have to be?

Measurement is at best an approximation and will always have a degree of error. In general, the more accurate the data, the more expensive the measurement device or method will be. Care should be taken to ensure that expensive, high accuracy measurement devices or methods are strategically used or positioned.

Once the water balance components have been identified and quantified, an estimate of the confidence interval (CI) for each value should be made (Burt, 1999). A CI of “6” indicates that one is 95% certain that the correct value lies between plus or minus 6% of the value stated in the water balance. Therefore the smaller the CI, the more accurate the water balance component. The CI is selected on the basis of experience, or through comparative measurements done in the field.

Table 10 Summary of measuring methods for water balance framework components

Water use component	Details	Recommended measuring method/s	Reference
Flow	In a river	• Measuring structure (flume or weir with water level measurement) • Area-velocity method o Mechanical o Ultrasonic	WRC Report no. TT248/05 Guidelines for the design of canals and related structures, Department of Water Affairs, 1980 ARC Irrigation Design Manual
	In a canal	• Measuring structure (flume or weir with water level measurement) • Area-velocity method o Mechanical o Ultrasonic	WRC Report no. TT248/05 Guidelines for the design of canals and related structures, Department of Water Affairs, 1980 ARC Irrigation Design Manual
	In a pipe	• Flow meter o Mechanical o Electromagnetic o Ultrasonic	WRC Report no. TT248/05
Surface storage	Dam volume	• Manual • Digital Terrain Model	ARC Irrigation Design Manual
	Canal volume	• Manual	Guidelines for the design of canals and related structures, Department of Water Affairs, 1980
Groundwater storage	Aquifer recharge	Specialist geohydrological methods	
Evaporation	From water surface	American Class A pan	ARC Irrigation Design Manual
	From soil surface	Evaporation coefficient (K_e method)	FAO Irrigation and Drainage Paper 56

Water use component	Details	Recommended measuring method/s	Reference
Transpiration	Crops	Penmann-Monteith equation	FAO Irrigation and Drainage Paper 56
	Riparian vegetation	Penmann-Monteith equation	FAO Irrigation and Drainage Paper 56
Frost protection		Dew point/wet bulb temperature method	FAO Env. and Nat. Resources Paper 10
Leaching requirement		EC threshold value method (Department of Agriculture Soil Conservation Manual)	ARC Irrigation Design Manual
Soil water content		• Neutron probe (calibrated) • Gravimetric method • Di-electric probe (calibrated)	WRC Report no. 1137/1/05 WRC Report no. TT 540/4/12 ARC Irrigation User's Manual
Seepage	From canal	Ponding test	Guidelines for the design of canals and related structures, Department of Water Affairs, 1980
Leakage	From canal	Ponding test	Guidelines for the design of canals and related structures, Department of Water Affairs, 1980
Drainage	Surface (run-off)	Measuring structure (flume or weir with water level measurement)	WRC Report no. TT 248/05 Guidelines for the design of canals and related structures, Department of Water Affairs, 1980 ARC Irrigation Design Manual
	Subsurface (percolation)	• Neutron probe (calibrated) • Di-electric probe (calibrated) • Piezometer	WRC Report no. 1137/1/05 WRC Report no. TT 540/4/12 ARC Irrigation User's Manual

The acceptable level of accuracy for a certain water balance component depends on the situation. In the field, measuring devices are more often than not subject to less-than-perfect conditions, resulting in accuracies lower than the stated laboratory values. Most of the irrigators interviewed during a survey indicated that they would be satisfied with ± 5% accuracy levels in the field.

The purpose of using CIs on figures and tables is to reinforce the fact that we rarely know many values with precision, even though discussions of those values often seem to assume that we do know them as absolute values. It is better to include all water components in the water balance, even if they have a large confidence interval rather than ignore them because they are perceived to be inaccurate.

The use of modern technology can assist the irrigator and authorities to collect data with a better CI. By planning and budgeting for the implementation of such technologies, appropriate yet affordable solutions can be found in most cases.

5.3 Flow measurement

In irrigation water measurement, water managers are usually interested in determining either the flow rate in a canal or pipe section, or the volume of water that has passed a certain point during a certain period. In South Africa, the common unit for measuring flow rate, Q, is cubic meters per hour (m^3/h) or per second (m^3/s), and if this is known, the volume of water, V, in m^3 passing a specific point in a specific period of time can be determined by multiplying the flow rate with the time period (t in hours (h), or t in seconds (s)).

The required flow rate can be determined if the flow velocity ("speed" of the water), v, in meters per second (m/s) is known. In some cases, especially in open channels the flow rate is derived from a measurement of head (pressure expressed as a water depth) h in meters, m. This method is actually just an indirect "measurement" of the velocity, since head is a proportional indication of the velocity.

It is therefore always either velocity or head that a measuring device actually measures at a specific location, and by combining this parameter with the cross sectional flow area (basically the flow depth and width in a canal, or the inside size of a pipe) at the same location (area, A, in square meters, m^2), the flow rate can be calculated. Many measuring devices contain built in mechanisms to convert the measured flow parameter to flow rate before it is displayed or transmitted. The relationship is shown schematically in Figure 21.

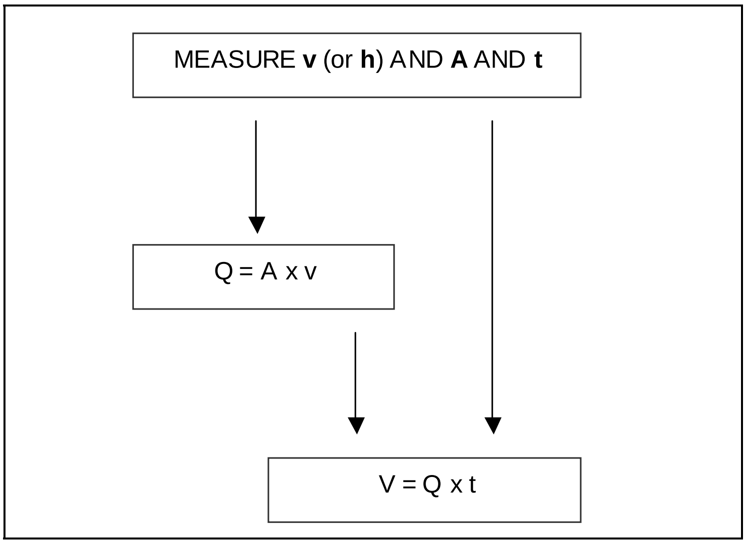


Figure 21 Relationship between volumetric and instantaneous flow measurement

Measuring devices typically used in South Africa are shown below in Table 11, with details in Table 12 and Table 13.

In the case of pipe flow measurement, it is highly recommended that either electromagnetic or acoustic flow meters are used rather than mechanical meters, because of the high load of physical impurities typically found in irrigation water, unless the water is filtered and measurement takes place after the filter. The instantaneous electric power meter, a device that was developed during a WRC funded project, also offers good value for money as it has no moving parts and also collect useful electricity use data to monitor power consumption.

In the case of canal flow measurement, the use of acoustic Doppler velocity meters are highly recommended as their installation are much simpler than measuring structures, they interfere very little with the flow of the water, and they can measure continuous data more accurately than hydraulic structures.

For irrigation schemes, it is recommended that a portable transit time meter be obtained (available for either canals or pipelines), which can be used to easily measure flow at nearly any location to calibrate other measuring devices or settle disputes.

Figure 22 Portable acoustic measuring devices for pipes (left) and canals (right)

For more information on flow measurement devices, please refer to WRC Report number TT 248/05.

Table 11 Typical measuring devices used in South Africa

The following open channel (canals & rivers) flow measurement devices are typically used in South Africa:	**The following closed conduit (pipes) flow measuring devices are typically used in South Africa:**
Hydraulic structures: **Flumes:** Parshall **Weirs:** Crump Sharp-crested (Rectangular, 90° V-notch, Cipoletti) **Orifices:** Pressure regulated sluice gate with long weir Piped orifice outlets with long weir	Flow meters: **Mechanical velocity meters:** Turbine type Impeller type (small paddle wheel) Propeller type Proportional type **Electromagnetic flow meters:** In-line type Insert type **Acoustic meters:** Transit time type (fixed or portable) (ultrasonic) Doppler type (fixed or portable)
Water level recording devices for hydraulic structures: Measuring plate in stilling basin Float and counterweight level sensors Submersible depth sensors Ultrasonic depth sensor (non contact)	Indirect flow meters: Instantaneous electrical power meter kilowatt-hour meters Differential pressure meters
Open channel velocity meters: Mechanical current meters Acoustic Doppler velocity meters Acoustic transit time velocity meters	Flow meter secondary units: Displays (Registers) Transmitters (Pulse outputs) Converters

Table 12 Summary of measurement devices for pipe flow

Method	Volumetric data output (standard)	Flow rate data output (standard)	Sensitivity to installation conditions (hydraulic)	Needs ext. electric power (standard)	Accuracy (relative)	Sensitivity to dirty water	Additional pressure loss in system	Continuous data recording possible	Typical cost of standard unit (including installation)
Turbine	Yes	No	High	No	Moderate	High	Low	Yes*	<R 10 000
Impeller	Yes	No	High	No	Moderate	Moderate	Low	Yes*	<R 10 000
Propeller	Yes	No	High	No	Moderate	High	Low	Yes*	<R 10 000
Bypass	Yes	No	High	No	Moderate/Low	High	Moderate	Yes*	<R 10 000
Electromagnetic (inline)	Yes	Yes	Moderate	Yes	High	Low	None/Low	Yes*	R 16 000- R 45 000
Electromagnetic (insert)	Yes	Yes	High	Yes	Moderate	Moderate/Low	None/Low	Yes*	R 8 000- R 18 000
Acoustic Doppler	Yes	Yes	High	Yes	High	Low	None	Yes**	R 25 000- R 75 000
Acoustic Transit Time	Yes	Yes	High	Yes	High	Low	None	Yes**	R 35 000- R 120 000
Electric power	Yes	Yes	Low	No	Moderate/High	Low	None	Yes*	<R 15 000
kiloWatt-hour	Yes	No	Low	No	Low	Low	None	No	<R 5 000
Hour meters	Yes	No	Low	No	Low	Low	None	No	<R 3 000

* Additional hardware always required

** Additional hardware sometimes required

Table 13 Summary of measurement devices for canal systems

Method	Volumetric data output (standard)	Flow rate data output (standard)	Sensitivity to installation conditions (hydraulic)	Needs ext. electric power (standard)	Accuracy (relative)	Sensitivity to dirty water	Additional pressure loss in system	Continuous data recording possible	Relative cost of standard unit (including installation)***
Weir	No	Yes	High	No	Moderate/High	High	High	Yes*	Moderate/Low
Flume	No	Yes	High	No	Moderate/High	Moderate	Moderate/High	Yes*	Moderate/High
Mechanical velocity	No	Yes	Moderate	No	Moderate	High	Low	Yes*	Moderate
Doppler velocity	No	Yes	Moderate/High	Yes	Moderate/High	Moderate/High	Low	Yes*	Moderate/High
Floats	No	Yes	Moderate/Low	No	Low	Low	None/Low	No	Low
Orifices (Pressure controlled sluice gate)	No	Yes	High	No	Moderate	Moderate	Low	No	Moderate
Acoustic Doppler	No	Yes	High	Yes	High	Low	None	Yes**	Low-high****
Acoustic Transit Time	No	Yes	High	Yes	High	Moderate/Low	None	Yes**	Low-high****

* Additional hardware always required

** Additional hardware sometimes required

*** Prices vary widely with size and therefore only relative.

**** Often “one size” device for all flow rates – expensive for small canals but affordable for big canals

5.3.1 Flow measurement implementation

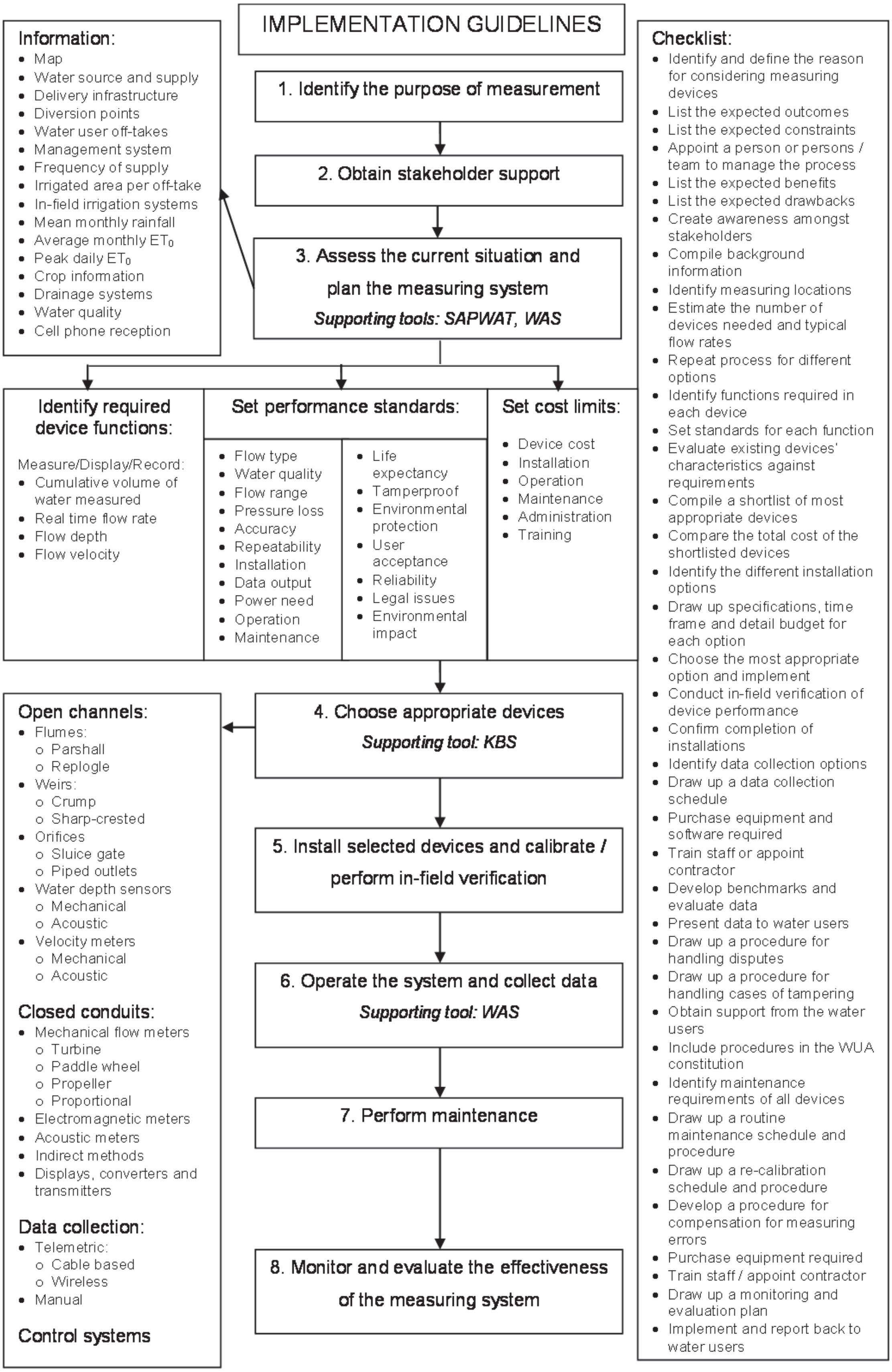
It is strongly advised that the process, outlined in Figure 23, is used to plan the implementation of measurement equipment, especially if a large number of measuring points are required.

The implementation plan should consist of the following sections, containing detailed information specified under the different headings:

- Measurement implementation planning.
    - Background to the implementation area.
    - Measurement trigger.
    - Purpose of the proposed system.
    - Locations for measurement.
    - Benefits of measurement.
    - Water user support and organisational arrangements.
- The measurement system.
    - Measuring device selection.
    - Installation.
    - Operation and maintenance.
    - Monitoring and evaluation.
- Implementing the plan.
    - Budget and funding.
    - Role-players and responsibilities.
    - Gantt chart.
    - Invitation for inputs.

The WRC has published reports and guidelines for the direct and indirect measurement of water use on irrigation schemes to meet the practical need to measure and manage water effectively and efficiently. However in most cases, the water management system in operation does not incentivise water measurement, and consequently measurement of water use and volumetric charging is not widely practiced. The application of the water balance framework encourages measurement and the WRC guidelines can therefore be applied here.

For more information on flow measurement implementation, please refer to WRC Report number TT 550/12.



IMPLEMENTATION GUIDELINES

Information:
- Map
- Water source and supply
- Delivery infrastructure
- Diversion points
- Water user off-takes
- Management system
- Frequency of supply
- Irrigated area per off-take
- In-field irrigation systems
- Mean monthly rainfall
- Average monthly ET_0
- Peak daily ET_0
- Crop information
- Drainage systems
- Water quality
- Cell phone reception

1. Identify the purpose of measurement

2. Obtain stakeholder support

3. Assess the current situation and plan the measuring system
Supporting tools: SAPWAT, WAS

Identify required device functions:

Measure/Display/Record:
- Cumulative volume of water measured
- Real time flow rate
- Flow depth
- Flow velocity

Set performance standards:
- Flow type
- Water quality
- Flow range
- Pressure loss
- Accuracy
- Repeatability
- Installation
- Data output
- Power need
- Operation
- Maintenance
- Life expectancy
- Tamperproof
- Environmental protection
- User acceptance
- Reliability
- Legal issues
- Environmental impact

Set cost limits:
- Device cost
- Installation
- Operation
- Maintenance
- Administration
- Training

4. Choose appropriate devices
Supporting tool: KBS

5. Install selected devices and calibrate / perform in-field verification

6. Operate the system and collect data
Supporting tool: WAS

7. Perform maintenance

8. Monitor and evaluate the effectiveness of the measuring system

Open channels:
- Flumes:
  - Parshall
  - Replogle
- Weirs:
  - Crump
  - Sharp-crested
- Orifices
  - Sluice gate
  - Piped outlets
- Water depth sensors
  - Mechanical
  - Acoustic
- Velocity meters
  - Mechanical
  - Acoustic

Closed conduits:
- Mechanical flow meters
  - Turbine
  - Paddle wheel
  - Propeller
  - Proportional
- Electromagnetic meters
- Acoustic meters
- Indirect methods
- Displays, converters and transmitters

Data collection:
- Telemetric:
  - Cable based
  - Wireless
- Manual

Control systems

Checklist:
- Identify and define the reason for considering measuring devices
- List the expected outcomes
- List the expected constraints
- Appoint a person or persons / team to manage the process
- List the expected benefits
- List the expected drawbacks
- Create awareness amongst stakeholders
- Compile background information
- Identify measuring locations
- Estimate the number of devices needed and typical flow rates
- Repeat process for different options
- Identify functions required in each device
- Set standards for each function
- Evaluate existing devices' characteristics against requirements
- Compile a shortlist of most appropriate devices
- Compare the total cost of the shortlisted devices
- Identify the different installation options
- Draw up specifications, time frame and detail budget for each option
- Choose the most appropriate option and implement
- Conduct in-field verification of device performance
- Confirm completion of installations
- Identify data collection options
- Draw up a data collection schedule
- Purchase equipment and software required
- Train staff or appoint contractor
- Develop benchmarks and evaluate data
- Present data to water users
- Draw up a procedure for handling disputes
- Draw up a procedure for handling cases of tampering
- Obtain support from the water users
- Include procedures in the WUA constitution
- Identify maintenance requirements of all devices
- Draw up a routine maintenance schedule and procedure
- Draw up a re-calibration schedule and procedure
- Develop a procedure for compensation for measuring errors
- Purchase equipment required
- Train staff / appoint contractor
- Draw up a monitoring and evaluation plan
- Implement and report back to water users

Figure 23 Water measurement implementation process

5.4 *Additional measurements*

In addition to the measurements required for water use monitoring, the water balance framework also requires that other types of measurements may be necessary to collect data. These measurements include:

- Environmental measurements:
    - Rainfall
    - Evaporation / Transpiration / Evapotranspiration
    - Soil water content
    - Drainage water
    - Seepage losses

It is recommended that every irrigation scheme and farm should have an automatic weather station to collect basic climatic data from which more accurate scheduling can be done in conjunction with soil water sensors (see Section 2.3.2).

Drainage water can be measured with similar types of devices used for flow measurement in canals (see Section 5.3 above), at points where the water flows in half-full pipes or open channels.

Seepage losses in canals can be determined by means of a ponding test, which entails that a section of the canal be isolated, filled with water and the water level monitored over a 3 days period. Seepage losses can then be estimated by subtracting evaporative losses from the total losses determined from water level readings taken during the three days.

Figure 24 Example of an automatic weather station for climatic data collection

- In-field irrigation measurements:
    - Surface run-off
    - Irrigation applications
    - Distribution uniformities

Surface run-off can be measured with similar types of devices used for flow measurement in canals (see Section 5.3 above).

Irrigation applications and distribution uniformities are usually measured during irrigation system evaluations (see Sections 2.4 and 3.2 above) which should be undertaken in accordance with the methods prescribed by the ARC-IAE in their Manual for the Evaluation of Irrigation Systems (Koegelenberg & Breedt, 2003).

Figure 25 Efficiencies and uniformities can be measured during a system evaluation

Most of additional measurement data can be collected through direct measurement but in some cases more cost effective solutions can be found by means of indirect measurements of estimation methods.

5.5 Summary

To successfully implement irrigation water measurements, especially when large a number of measuring devices are concerned, it is recommended that:

- A responsible person is appointed to facilitate the implementation process
- A number of different measuring devices be assessed on a trial basis before making a final decision
- The most appropriate (and not the cheapest) technologies be used
- The affected parties commit to a simple yet effective implementation plan

A series of pamphlets on irrigation and other measurements have been developed and is available for download on the project website www.waterbalance.org.za. The topics include the following:

- Implementing irrigation water measurement
- Measuring irrigation water flow in pipes
- Measuring irrigation water flow in canals
- Environmental measurements and the in-field water balance
- Irrigation system performance evaluations

6 The water balance

In this chapter we will cover the following concepts:

- The water balance (compilation, calculation and evaluation)

The concept of irrigation efficiency is frequently misunderstood, leading to the widespread belief that water just disappears with low irrigation efficiencies and re-appears with improvements. Such beliefs are an over-simplification. Often the actual amount of water consumed in irrigation, i.e. the evaporated component, hardly changes at various levels of "efficiency". It could even increase with systems which are perceived to be more efficient.

The "water accounting" or "water balance" approach has been recognised internationally as the way forward when assessing irrigation efficiency (Perry, 2007), and the South African framework presented in this material was developed on the same principles (Reinders, Van der Stoep & Backeberg, 2013).

The advantages of using a water balance approach are the following:

- It is a holistic approach and can be applied at all levels of water management and potentially to all water use sectors within a catchment
- It makes the destinations of the water fractions visible and therefore necessitates the management authority to develop an understanding of water movement within its area of jurisdiction through proper hydrological analysis
- It avoids the misuse of confusing performance indicator terminology

The implementation of the water balance is presented in 3 sections addressing the following and shown schematically in Figure 26 below:

- Preparation to implement the water balance framework
- Application of the water balance framework
- Evaluation and impact assessment

6.1 Preparation

6.1.1 Understanding the water balance principle and its terminology

Rather than thinking about irrigation efficiency as a percentage, irrigation system performance should be considered in terms of a water balance. A water balance is an accounting of all water volumes that enter and leave a 3-dimensional space over a specified period of time (Burt, 1999). Changes in internal water storage must also be considered.

Such a "space" could be an in-field irrigation system, an irrigation farm, an irrigation canal, or a whole irrigation scheme – the spatial boundaries that are set, determines the extent of the water balance.

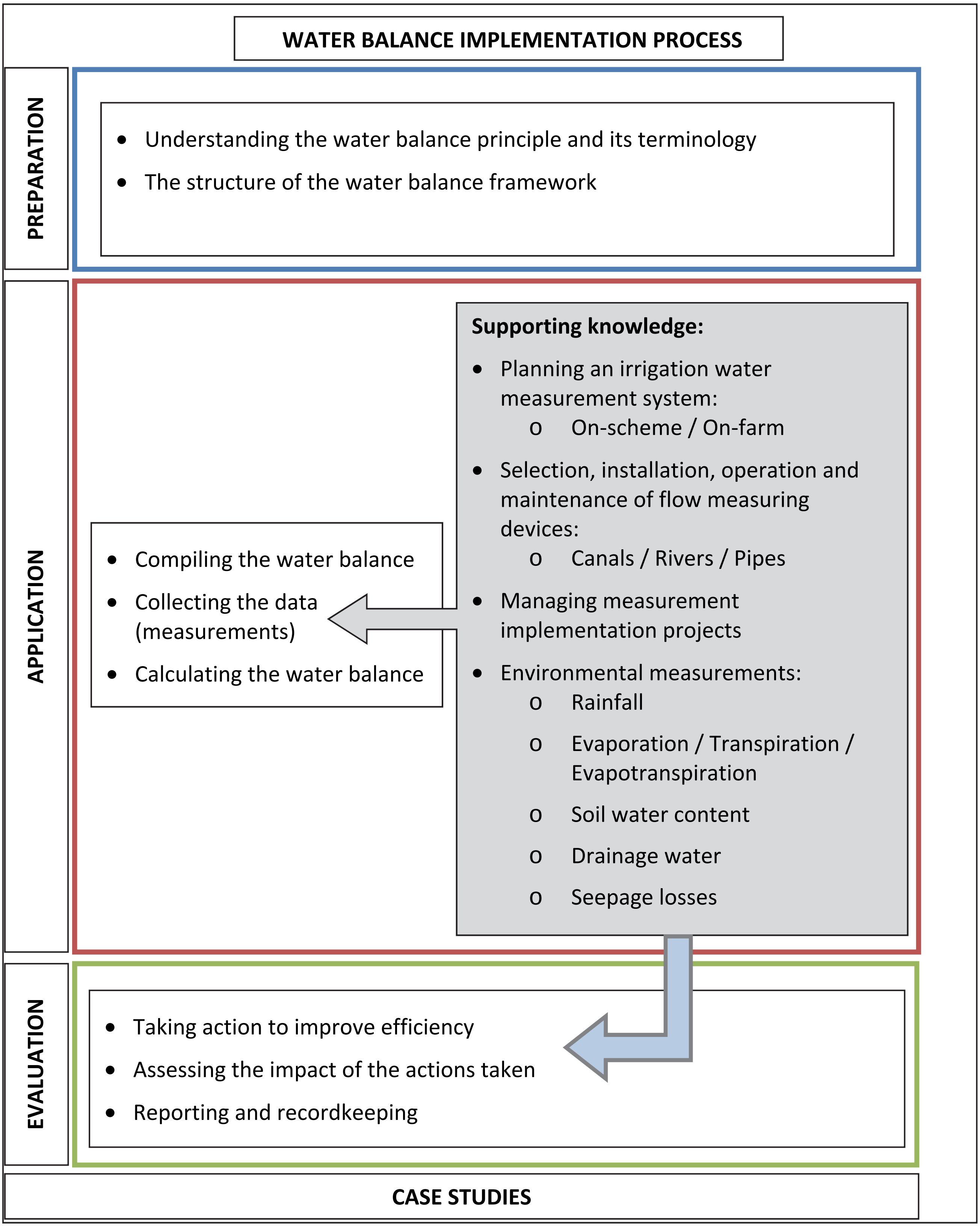


Figure 26 The water balance implementation process

The water balance is also compiled for a specific time frame – a day, a week, a month, a season or a year. The beginning and end of the time period is called the temporal boundaries of the water balance.

Both the spatial and temporal boundaries of a water balance must therefore be clearly defined in order to compute and to discuss a water balance. A complete water balance is not limited to only irrigation water or rainwater or groundwater, etc., but includes all water that enters and leaves the spatial boundaries.

6.1.2 Definition of terms:

A schematic representation of the ICID framework as described by Perry (2007) on which the water balance is based, is shown in Figure 27 and discussed further in this document.

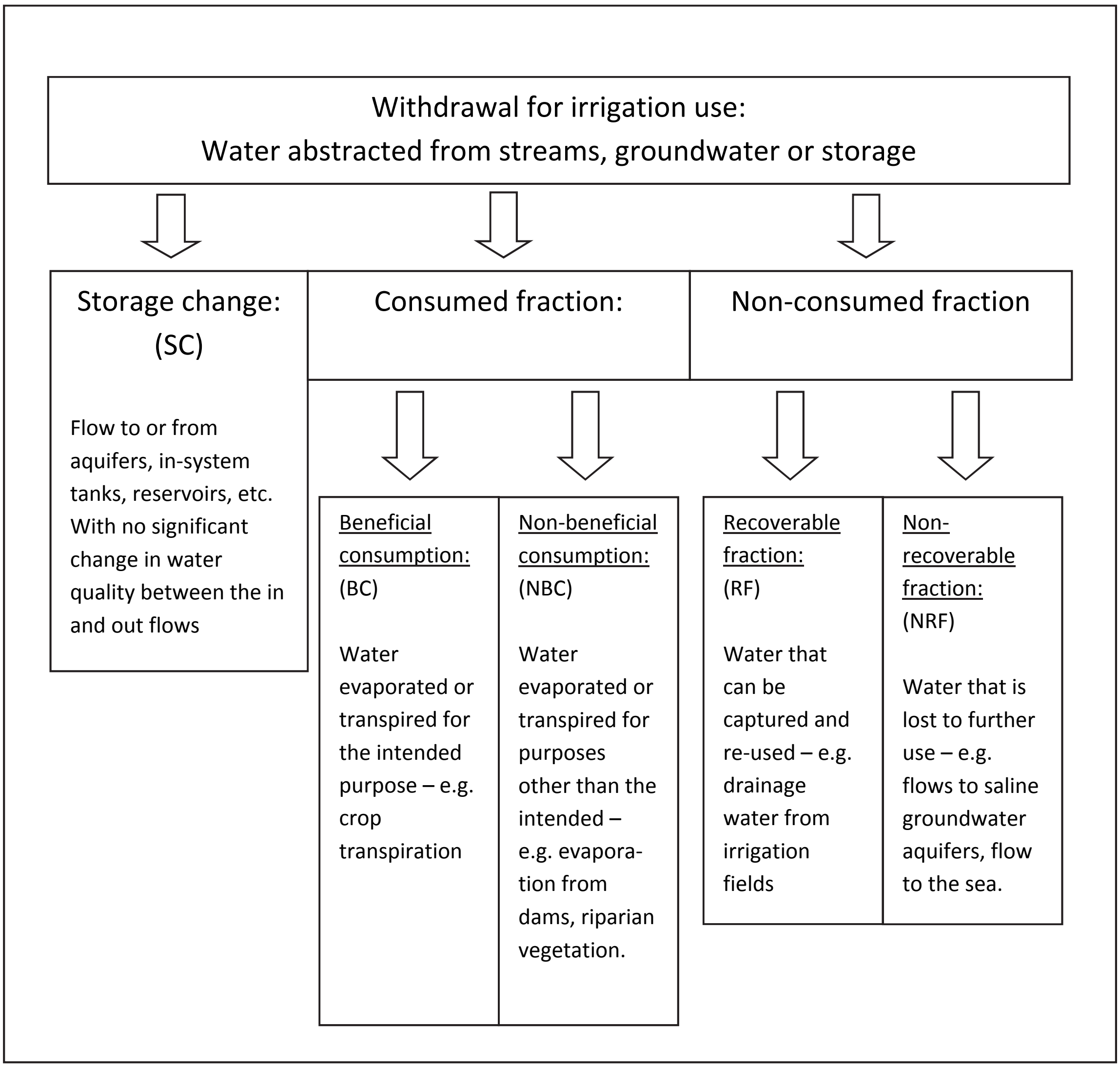


Figure 27 ICID Analytical framework for irrigation water management (After Perry, 2007)

The basis of the framework is that any water withdrawn from a catchment for irrigation use will contribute either to storage change, to the consumed fraction or to the non-consumed fraction at a point downstream of the point of abstraction. The water that is consumed, will either be to the benefit of the intended purpose (beneficial consumption) or not (non-beneficial consumption). Water that is not consumed, but remains in the system will either be recoverable (for re-use) or non-recoverable (lost to further use). To improve water availability in the catchment, the relevant authority will have to focus its attention on reducing non-beneficial consumption and the non-recoverable fraction.

It is important to take note of the following terms that will be used in this Chapter:

1. Water use: any deliberate application of water to a specified purpose. The term does not distinguish between uses that remove the water from further use (evaporation, transpiration, flows to sinks) and uses that have little quantitative impact on water availability (navigation, hydropower, most domestic uses).

2. Withdrawal: water abstracted from streams, groundwater or storage for any use – irrigation, domestic water supply, etc.

   a. Changes in storage (positive or negative) – changes in storage include any flows to or from aquifers, in-system tanks, reservoirs, etc. The key characteristic of storage is that the water entering and leaving is essentially of the same quality.

   b. Consumed fraction (evaporation and transpiration) comprising:

      i. Beneficial consumption: Water evaporated or transpired for the intended purpose – for example evaporation from a cooling tower, transpiration from an irrigated crop.

      ii. Non-beneficial consumption: Water evaporated or transpired for purposes other than the intended use – for example evaporation from water surfaces, riparian vegetation, waterlogged land.

   c. Non-consumed fraction, comprising:

      i. Recoverable fraction: water that can be captured and re-used – for example, flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems.

      ii. Non-recoverable fraction: water that is lost and does not become available for downstream use – for example, flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

6.1.3 The structure of the water balance framework

The water balance framework is presented in Table 14. The different levels of water management (scheme, farm and field), on the basis of infrastructure components, are presented in Column 1. Column 2 reports on the inflow, associated with boundaries for the water balance. The destinations of water fractions with their corresponding water balance classifications (storage change, consumed fraction, non-consumed fraction, etc.) and the associated desired ranges are shown in columns 3, 4 and 5, respectively.

Although care has been taken to include all possible system components and water destinations, practitioners are encouraged to customise the framework for their specific circumstances.

The water balance approach can be applied at one level only, within defined boundaries, or across all levels to assess performance within a complete WMA. When drawing up the water balance, all water entering the water management level as "Inflow" (second column in Table 14), should be allocated to a specific destination within or exiting the water management level boundaries (third column).

In column 5 of Table 14, desired ranges for the NBC and NRF components have been included to help the practitioner evaluate the results obtained when first constructing a water balance. The values shown here are based on actual results obtained in the course of the previous projects, as documented in the WRC report number TT 467/10, and can be adjusted if more accurate, locally relevant data is available in an area.

However, as circumstances differ greatly from one irrigation area to the next, it is recommended that water managers at all levels assess a specific system component's performance against the same component's previous years' data in order to achieve continuous improvement, rather than against other (seemingly similar) system components from different areas.

When trying to quantify the different components, one is faced with the dilemma of the lack of data available. It is possible to construct a water balance with limited data by presenting the results for combined water destinations. For example, at the irrigation system level, it is often easier to measure or calculate the combined beneficial consumptive and recoverable fractions (transpiration, leaching requirement, drainage water, etc.) than the non-beneficial or non-recoverable fractions – by constructing the water balance, the NBC and/or NRF can be calculated and then assessed.

The steps to compile and apply a water balance are discussed in the next sections.

Table 14 Framework allocation of typical irrigation system components

Water balance framework system component (based on infrastructure)	Inflow of water into system component	Possible water destinations within the system component	Framework classification	Desired Range, % of inflow
Dam / reservoir	Total amount of water released from storage	Increase flow in bulk conveyance system (river or canal)	SC	
		Operational losses at the point of release	NRF	<5
River bulk conveyance system (from on-river dam to scheme / farm edge) (if applicable)	Total amount of water entering the river	On-scheme surface storage	BC	
		On-scheme distribution system	BC	
		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	
		Evaporation from water surface	NBC	<5
		Seepage in river bed	NRF	<10
		Transpiration by riparian vegetation	NBC	<5
		Unlawful abstractions	NBC	0
		Operational losses (unavoidable)	NRF	<10
Canal bulk conveyance system (from on-river dam to scheme / farm edge) (if applicable)	Total amount of water entering the main canal	On-scheme surface storage	BC	
		On-scheme distribution system	BC	
		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	
		Evaporation from canal	NBC	<1
		Seepage in canal	NRF	<5
		Unlawful abstractions	NRF	0
		Operational losses (unavoidable, e.g. filling canal, tailends)	RF	<10
		Operational losses (inaccurate releases, spills, breaks, etc.)	NRF	0
On-scheme surface storage	Total amount of water entering a scheme dam	Increase volume of water stored	SC	
		On-scheme distribution system (release from dam)	BC	
		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	
		Evaporation from dam	NBC	<1
		Seepage from dam	NRF	<1
		Operational losses (spills)	NRF	<1
Shared (scheme-level) groundwater aquifer compartment	Total aquifer recharge	Increase groundwater storage	SC	
		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	

Water balance framework system component (based on infrastructure)	Inflow of water into system component	Possible water destinations within the system component	Framework classification	Desired Range, % of inflow
On-scheme canal distribution system (if applicable)	Total amount of water entering the on-scheme canal distribution system	Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	
		Evaporation from canal	NBC	<1
		Seepage in canal	NRF	<5
		Unlawful abstractions	NRF	0
		Operational losses (unavoidable, e.g. filling canal, tailends)	RF	<10
		Operational losses (inaccurate releases, spills, breaks, etc.)	NRF	0
On-scheme pipe distribution system (if applicable)	Total amount of water entering the on-scheme pipe distribution system	Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	
		Operational losses (unavoidable)	RF	<5
		Leaks	NRF	0
On-farm surface storage	Total amount of water entering a farm dam	Increase volume of water stored	SC	
		On-farm distribution system (release from dam)	BC	
		Irrigation system (abstraction from dam)	BC	
		Evaporation from dam	NBC	<1
		Seepage from dam	NRF	<1
		Operational losses (spills, leaks)	NRF	<1
On-farm distribution system	Total amount of water entering the on-farm pipelines or canals	Irrigation system	BC	
		On-farm distribution system leaks	NRF	0
		Operational losses (unavoidable)	RF	<5
Irrigation system (from field edge to root zone) *Intended destination of the water released.*	Total amount of water entering the irrigation system (Gross Irrigation Requirement, GIR)	Increase soil water content	SC	
		Transpiration by crop	BC	
		In-field evaporation (beneficial)	BC	
		Frost protection irrigation water	BC	
		Leaching (intended, beneficial but non-recoverable)	BC	
		Interception (unavoidable)	NBC	<1
		In-field evaporation (non-beneficial, excessive)	NBC	0
		In-field deep percolation (non-intended, non-recoverable)	NRF	0
		In-field run-off (uncontrolled)	NRF	0
		Drainage water (surface & subsurface, recoverable)	RF	
		Operational losses (unavoidable)	NRF	<5

BC: Beneficial consumption NBC: Non-beneficial consumption

RF: Recoverable fraction NRF: Non-recoverable fraction

SC: Storage change

6.2 Application of the water balance

6.2.1 Compiling the water balance

The water balance framework must be customized before it can be applied to a specific situation. This process involves the following:

- Clearly stating the reason why the water balance is being compiled (its purpose)
- Identifying the water management level at which the framework will be applied
- Identifying the water management infrastructure to be assessed
- Identifying the boundaries of the water balance framework
- Finalising the possible water destinations, and
- Setting the allowable range or threshold values.

A spreadsheet based tool has been developed to guide water managers at any level through the process of compiling a water balance. In this manual, the application of the tool will be illustrated by means of an example.

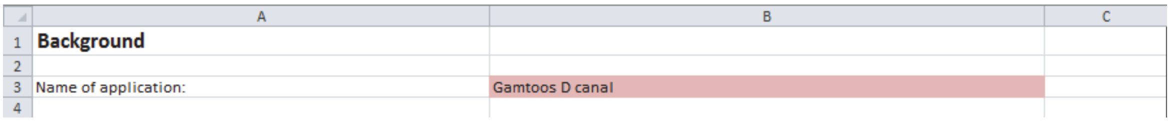
Example

The Gamtoos Irrigation Scheme is located in the Eastern Cape and has 7 431 ha of scheduled irrigation area. Water allocations are 8 000 m^3/ha and there are approximately 170 farmers on the scheme, receiving water from the Kouga Dam. Water is distributed with a canal network with automatic gates and water meters are used to measure water distributed through pipelines to the farmers from the canal network. Irrigation systems used include centre pivot, drag lines, micro, drip, and travelling guns to irrigate a range of crops but mostly citrus (30%), vegetables, pastures, coffee, tobacco, soya beans, and canola.

The Board is continuously upgrading the scheme and has in the last 9 years succeeded in improving the management of the main canal. There is an on-going process of repairs to siphons on the main canal in conjunction with DWAF, as the scheme is strategically important in its role as co-water provider for Port Elizabeth.

A section of a secondary canal, Canal D, was evaluated using the water balance method to determine total losses over a 3 month period.

The spreadsheet can be set up for this example by typing in the name of the canal in cell B3 of the worksheet marked "Inputs":



	A	B	C
1	**Background**		
2			
3	Name of application:	Gamtoos D canal	
4			

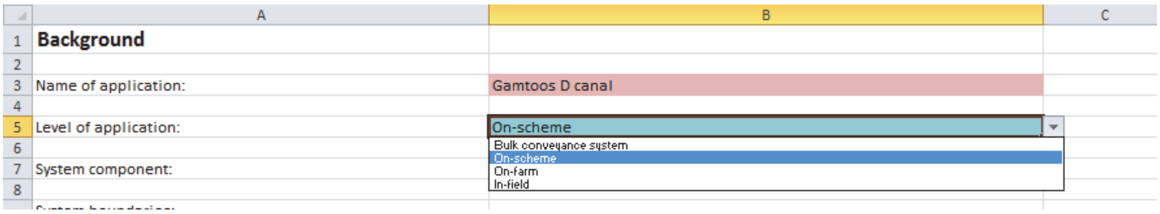
6.2.1.1 Identify the appropriate level of application

Agricultural water infrastructure usually includes the following components, applicable at different levels of water management.

- An in-field irrigation system to apply the water to the crop.
- An on-farm water conveyance system to convey the water to the field edge.
- An on-scheme water distribution system such as a canal or river, shared by a number of water users to convey the water to the farm edge

Example (continued)

The level of application can be specified by using the drop down menu in cell B5 of the spreadsheet:



Background

Name of application: Gamtoos D canal

Level of application: On-scheme

System component:

6.2.1.2 Identify the water management infrastructure

The framework categorises infrastructure at four levels of water management infrastructure (Table 15) – the water source and bulk conveyance system, the irrigation scheme, the irrigation farm and the irrigation field.

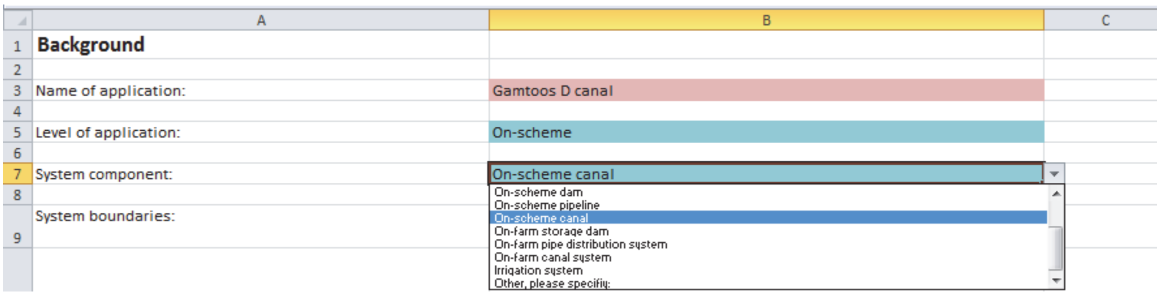
Table 15 Four levels of water management infrastructure

Water management level	Infrastructure system component		
Water source & Bulk conveyance system	Dam/Reservoir		Groundwater aquifer
	River	Canal	
Irrigation scheme	On-scheme dam		
	On-scheme canal		
	On-scheme pipe		
Irrigation farm	On-farm dam		
	On-farm pipe / canal		
Irrigation field	Irrigation system		

In order for the water balance framework to be implemented, the applicable infrastructure must be identified. Although a water balance can cover more than one infrastructure component, it is strongly recommended that a separate water balance is compiled for each component.

Example (continued)

The water management infrastructure can be specified by using the drop down menu in cell B7 of the spreadsheet:



Background

Name of application: Gamtoos D canal

Level of application: On-scheme

System component: On-scheme canal

System boundaries:

6.2.1.3 Identify the boundaries

When defining boundaries for water balance areas, it is necessary to define both spatial (related to area) and temporal (related to time) boundaries.

- **Spatial boundaries**

Water balances can be conducted for different geographical areas: a field, a farm, the area controlled by a water user association, a catchment, etc. The same concept applies to *all* areas but one must be absolutely clear about which boundaries apply to the areas under consideration.

Spatial boundaries should be set horizontally and vertically, to define at which points water enters or leaves the water balance area. Table 16 defines the suggested spatial boundaries for the different levels of water management in irrigation.

Table 16 Spatial boundaries of water balance areas

Area	Upper boundary	Lower boundary	Horizontal boundary
In-field application systems (from field edge to root zone)	Crop canopy	Bottom of root zone	Field edges
On-farm distribution system (from farm edge to field edge)	Water surface	Bottom of canal / pipe walls / drainage system	Farm edges
On- scheme conveyance system	Water surface	Bottom of canals / pipe walls	Scheme edges
River system (from on-river dam to scheme / farm edge)	Water surface	Bottom of river	All river inflows, outflows and sides

In Figure 28, an example of a river section for which a water balance must be compiled is shown. The spatial boundaries of this section as described in Table 16 can be identified.

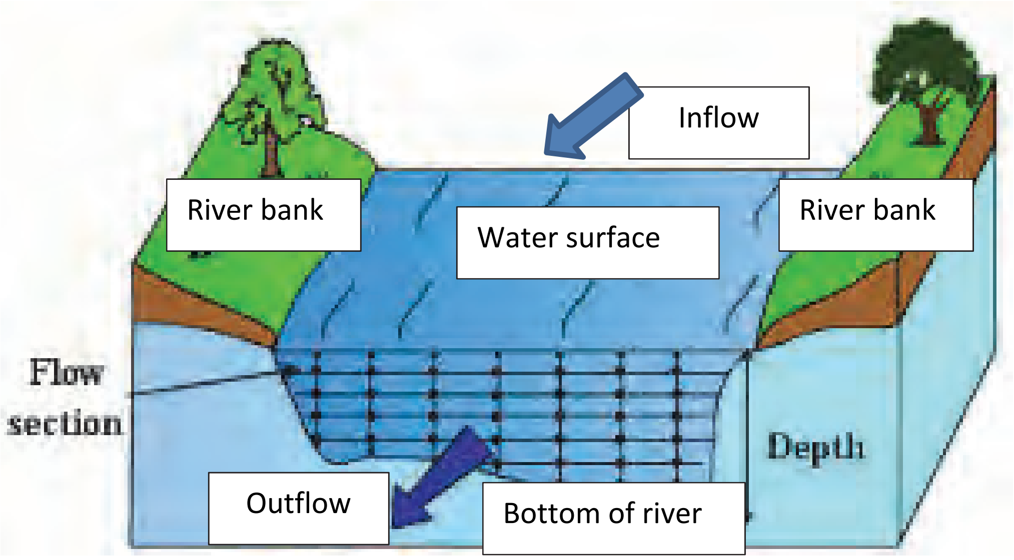
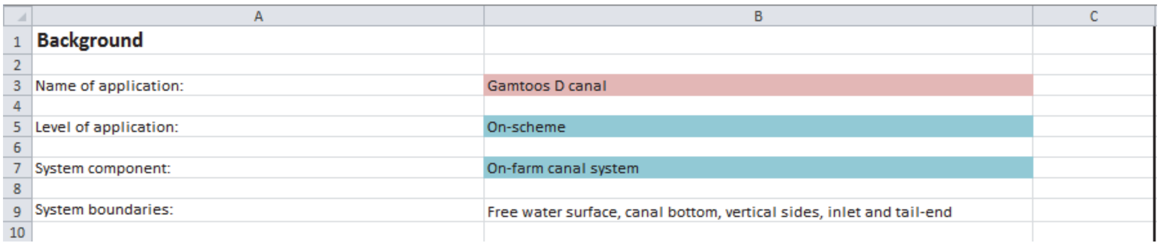


Figure 28 Example of a river section identified for a water balance

The efficiency of water delivery and consumption at different levels, are linked and interdependent. Improved management can often be achieved at one management level (e.g. on-farm) by improving infrastructure at another level (e.g. on-scheme); for example, by building on-scheme balancing dams, greater flexibility of supply to the farm edge can be ensured, leading to better timed on-farm irrigation applications, with an increased beneficial water use fraction in-field, due to reduced deep percolation.

Example (continued)

The default system boundaries for the selected system component selected in cell B5 of the spreadsheet will automatically be shown in cell C9:



	A	B	C
1	**Background**		
2			
3	Name of application:	Gamtoos D canal	
4			
5	Level of application:	On-scheme	
6			
7	System component:	On-farm canal system	
8			
9	System boundaries:	Free water surface, canal bottom, vertical sides, inlet and tail-end	
10			

- **Temporal boundaries**

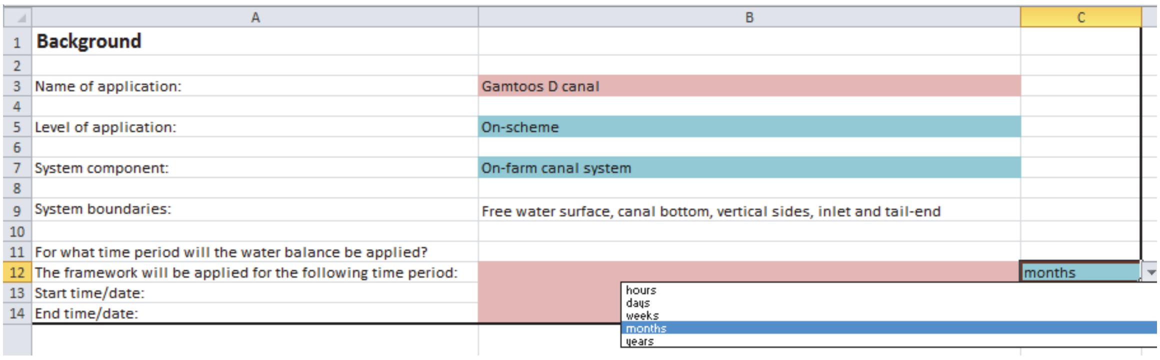
The temporal boundaries of the water balance will be determined by the purpose for which the balance is done.

As water is allocated for irrigation use on an annual basis, a one year period is generally recommended as a temporal boundary. However, all of the values of water balances change from one year to another, and it is advisable that water balances should be examined annually to obtain a better understanding of the effect of climatic changes from one year to another.

In some cases, such as at field level, the time scale may be reduced to the length of a season for a specific crop. A daily soil water balance can also be done for specific reasons such as irrigation scheduling, as an annual balance at this level will be useless.

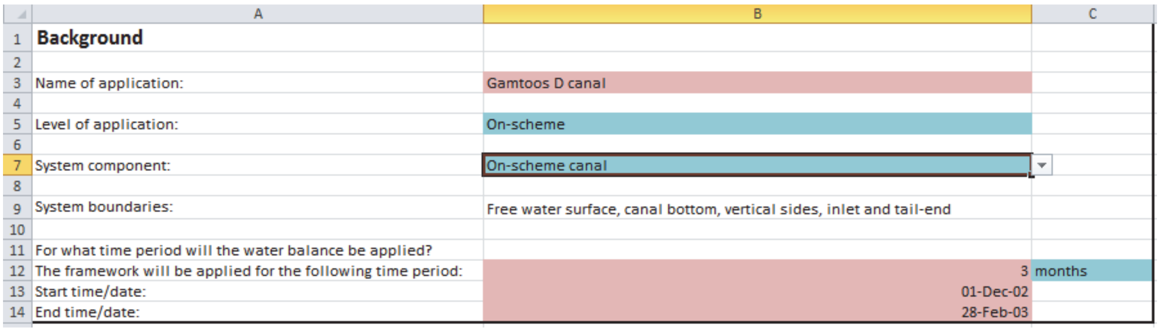
Example (continued)

The units for the time period over which the water balance is to be calculated must be selected first by using the drop down menu in cell C11 of the spreadsheet:



	A	B	C
1	**Background**		
2			
3	Name of application:	Gamtoos D canal	
4			
5	Level of application:	On-scheme	
6			
7	System component:	On-farm canal system	
8			
9	System boundaries:	Free water surface, canal bottom, vertical sides, inlet and tail-end	
10			
11	For what time period will the water balance be applied?		
12	The framework will be applied for the following time period:		months
13	Start time/date:		
14	End time/date:		

Then the details of the time period can be completed in cells B12, B13 and B14:



	A	B	C
1	**Background**		
2			
3	Name of application:	Gamtoos D canal	
4			
5	Level of application:	On-scheme	
6			
7	System component:	On-scheme canal	
8			
9	System boundaries:	Free water surface, canal bottom, vertical sides, inlet and tail-end	
10			
11	For what time period will the water balance be applied?		
12	The framework will be applied for the following time period:	3	months
13	Start time/date:	01-Dec-02	
14	End time/date:	28-Feb-03	

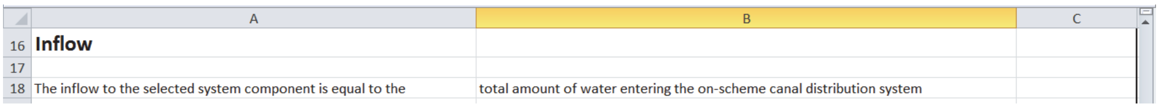
6.2.1.4 Define the inflow

The source of the water entering the system component must be specified, as this is usually the parameter which is being scrutinised by compiling the water balance. In order to compile a credible water balance, the flow volume or flow rate at the entry point of the system component must be measured or quantified. The more often this can be measured, the greater the accuracy and reliability of the data. Continuous measurement should be the aim of any measurement system.

A detailed review of flow measuring devices typically used in South Africa is presented in Section 5.3.

Example (continued)

The definition of the inflow for the selected system component will automatically appear in cell B18 of the spreadsheet:



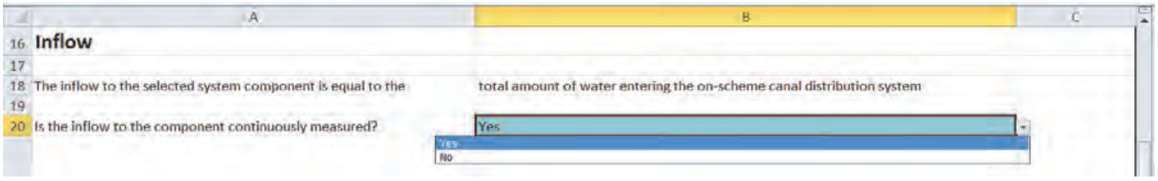
	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	

This must be similar to the condition found in the field for the situation being assessed:

Inlet to the D canal

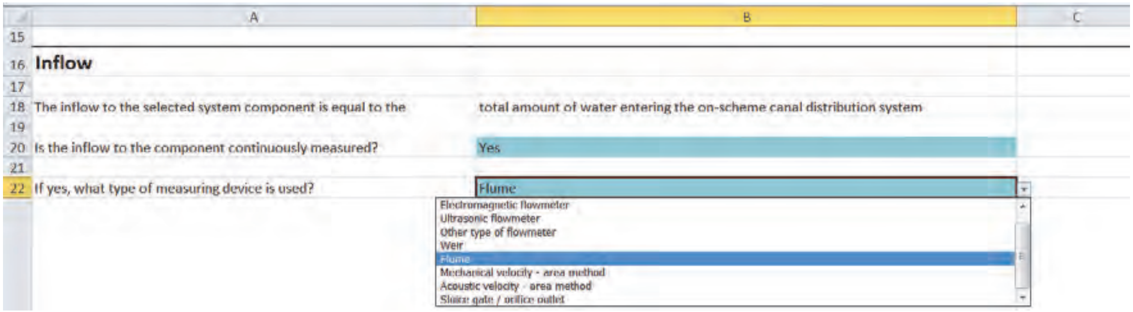
There is a Parshall flume installed at the inlet to the D canal, fitted with a water level sensor that continuously record the depth of the water flowing through the measuring structure.

The next step is to confirm whether the inflow is being measured continuously by selecting from the dropdown menu in cell B20:



	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	

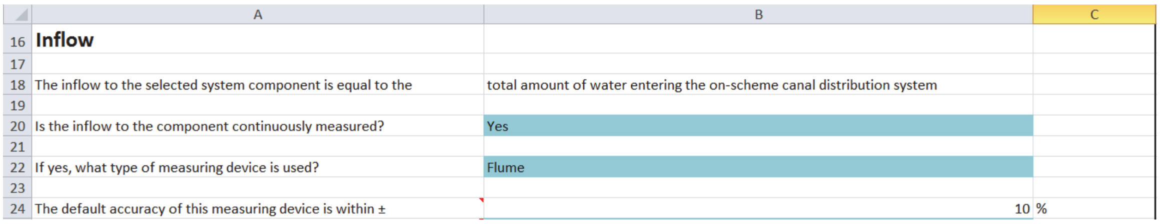
The type of measuring device can then be selected from the dropdown menu in cell B22



	A	B	C
15			
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	

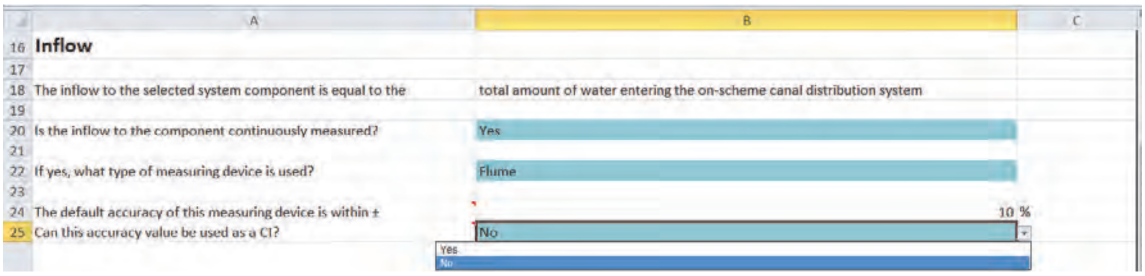
Example (continued)

The default accuracy of the measuring device will automatically appear in cell B24 when the device is selected:



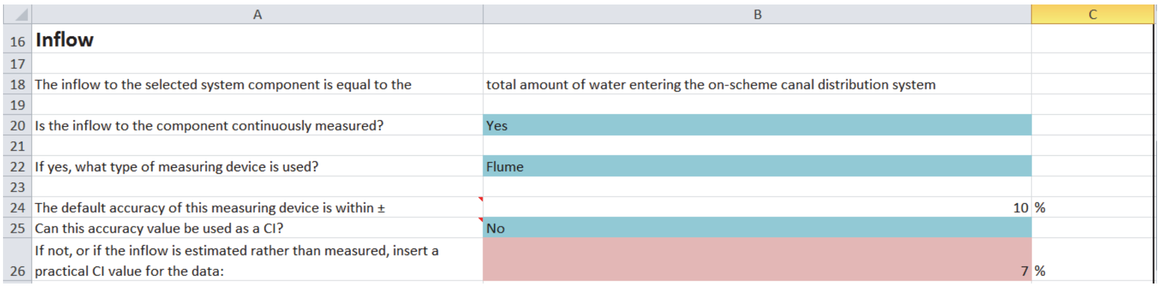
	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%

The default device accuracy will be used as the CI for the inflow, unless the spreadsheet user indicates in cell B25 that the default value is not acceptable by selecting No in the dropdown menu:



	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%
25	Can this accuracy value be used as a CI?	No	

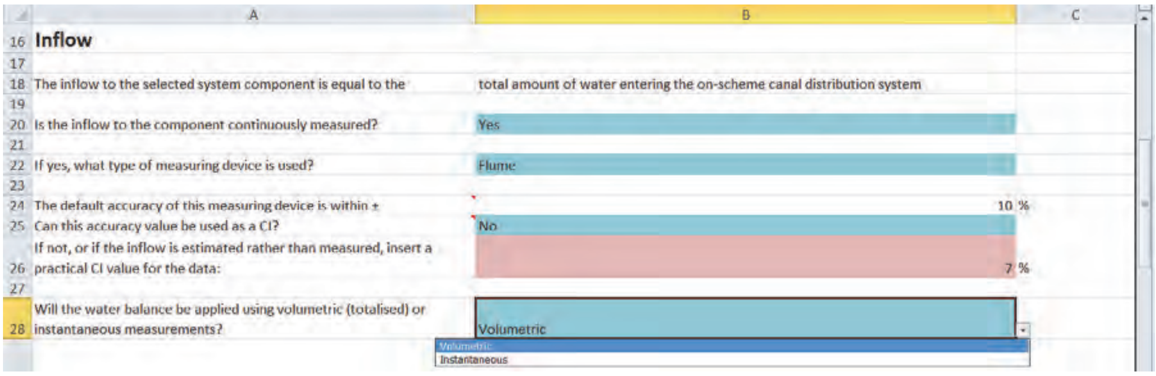
If No is selected in cell B25, a new CI value can be entered in cell B26:



	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%
25	Can this accuracy value be used as a CI?	No	
26	If not, or if the inflow is estimated rather than measured, insert a practical CI value for the data:	7	%

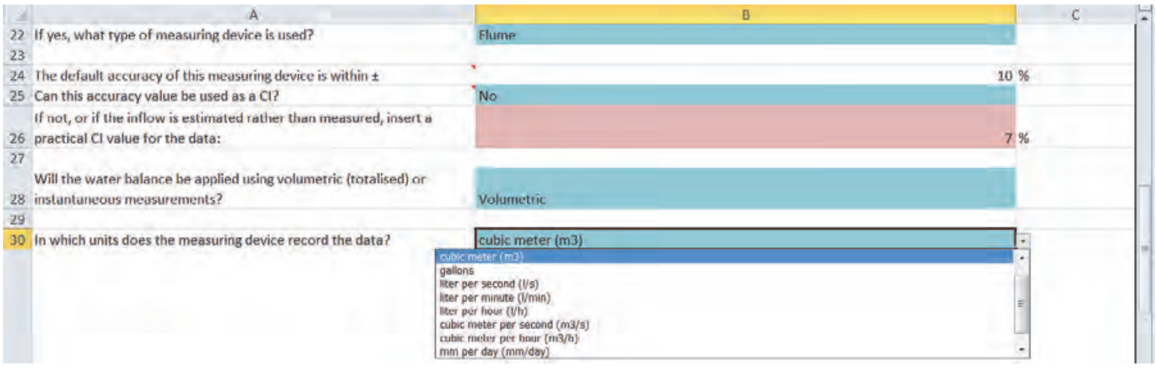
Example (continued)

In cell B28, the spreadsheet user can indicate whether the water balance will be applied using volumetric or instantaneous readings:



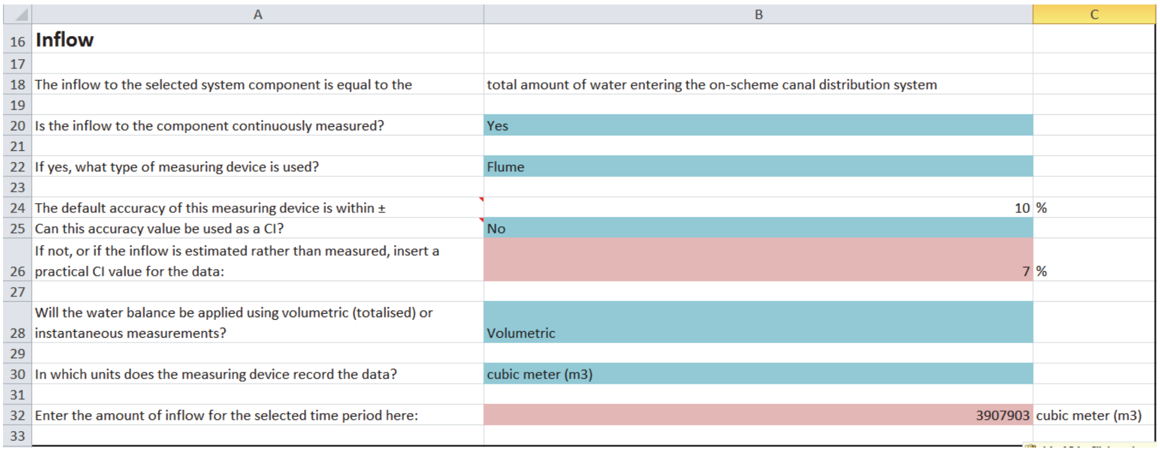
	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%
25	Can this accuracy value be used as a CI?	No	
26	If not, or if the inflow is estimated rather than measured, insert a practical CI value for the data:	7	%
27			
28	Will the water balance be applied using volumetric (totalised) or instantaneous measurements?	Volumetric	

The measurement units for the inflow can be selected from the dropdown menu in cell B30:



	A	B	C
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%
25	Can this accuracy value be used as a CI?	No	
26	If not, or if the inflow is estimated rather than measured, insert a practical CI value for the data:	7	%
27			
28	Will the water balance be applied using volumetric (totalised) or instantaneous measurements?	Volumetric	
29			
30	In which units does the measuring device record the data?	cubic meter (m3)	

Finally the value for the inflow for the whole water balance period can be entered into cell B32:



	A	B	C
16	**Inflow**		
17			
18	The inflow to the selected system component is equal to the	total amount of water entering the on-scheme canal distribution system	
19			
20	Is the inflow to the component continuously measured?	Yes	
21			
22	If yes, what type of measuring device is used?	Flume	
23			
24	The default accuracy of this measuring device is within ±	10	%
25	Can this accuracy value be used as a CI?	No	
26	If not, or if the inflow is estimated rather than measured, insert a practical CI value for the data:	7	%
27			
28	Will the water balance be applied using volumetric (totalised) or instantaneous measurements?	Volumetric	
29			
30	In which units does the measuring device record the data?	cubic meter (m3)	
31			
32	Enter the amount of inflow for the selected time period here:	3907903	cubic meter (m3)
33			

6.2.1.5 Finalise the list of possible water destinations

When drawing up the water balance, all water entering the water management level as “Inflow”, should be allocated to a specific destination within or exiting the water management level boundaries. If all the destinations are not known, or cannot be quantified, the water balance can use the known components to solve for the unknown, i.e. to estimate the water that is "lost" (going to unknown or non-beneficial uses).

Considering the example shown in Figure 28, the possible destinations of water leaving (crossing the boundaries of) the selected infrastructure component (the river section), will be as shown in Figure 29.

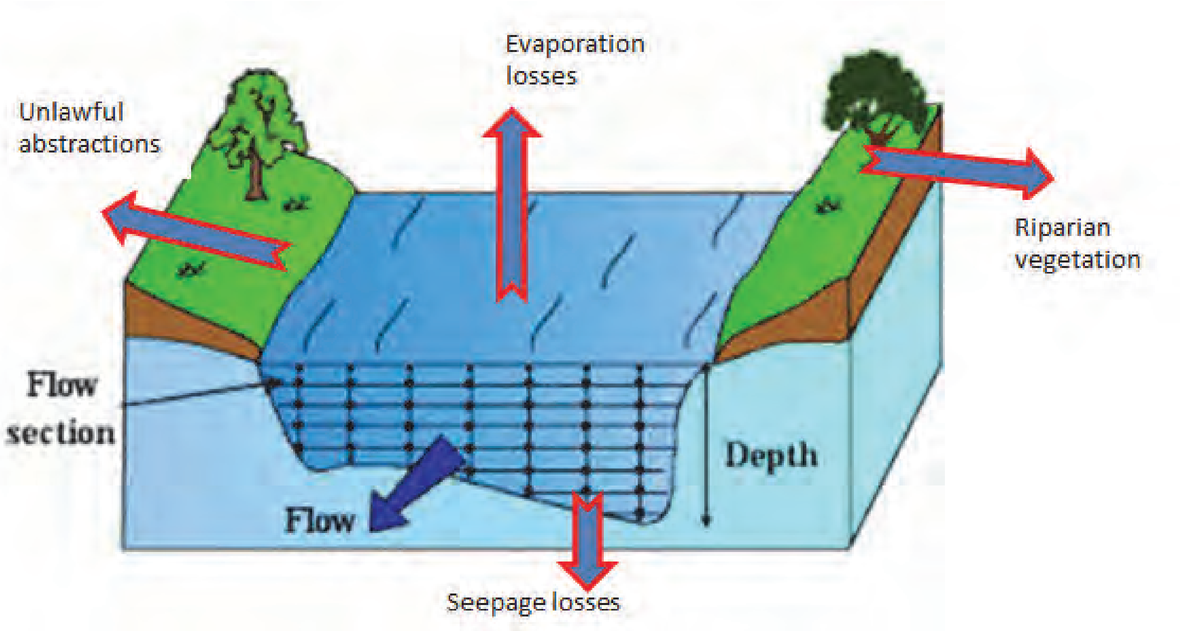


Figure 29 Example of possible water destinations in a river section

The water manager should inspect his or her specific situation for which the water balance is being compiled and identify all the possible water destinations (where water exits the water balance area by crossing over one of the boundaries.

Each destination is then also classified in terms of the water balance framework:

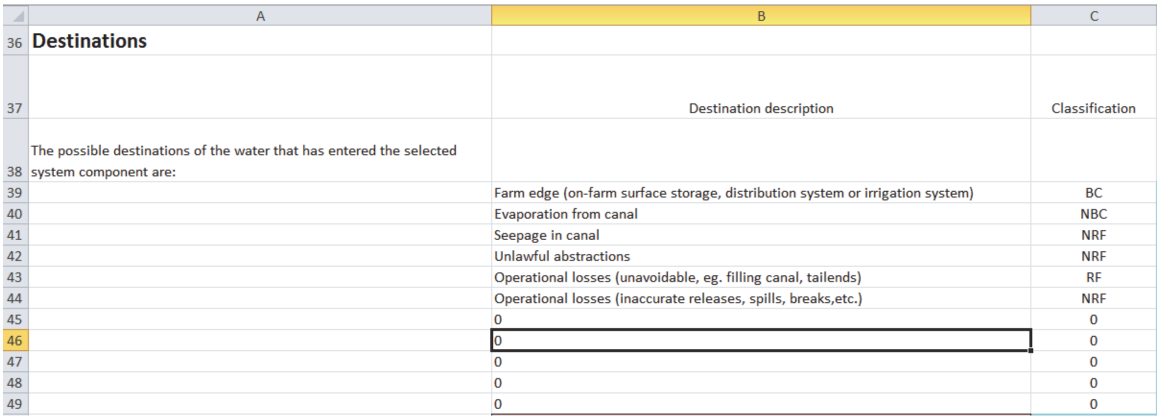
BC:	Beneficial consumption
NBC:	Non-beneficial consumption
RF:	Recoverable fraction
NRF:	Non-recoverable fraction
SC:	Storage change

The purpose of the classification is to help the water manager identify which water uses may need attention to increase the beneficial consumption of the system.

Example (continued)

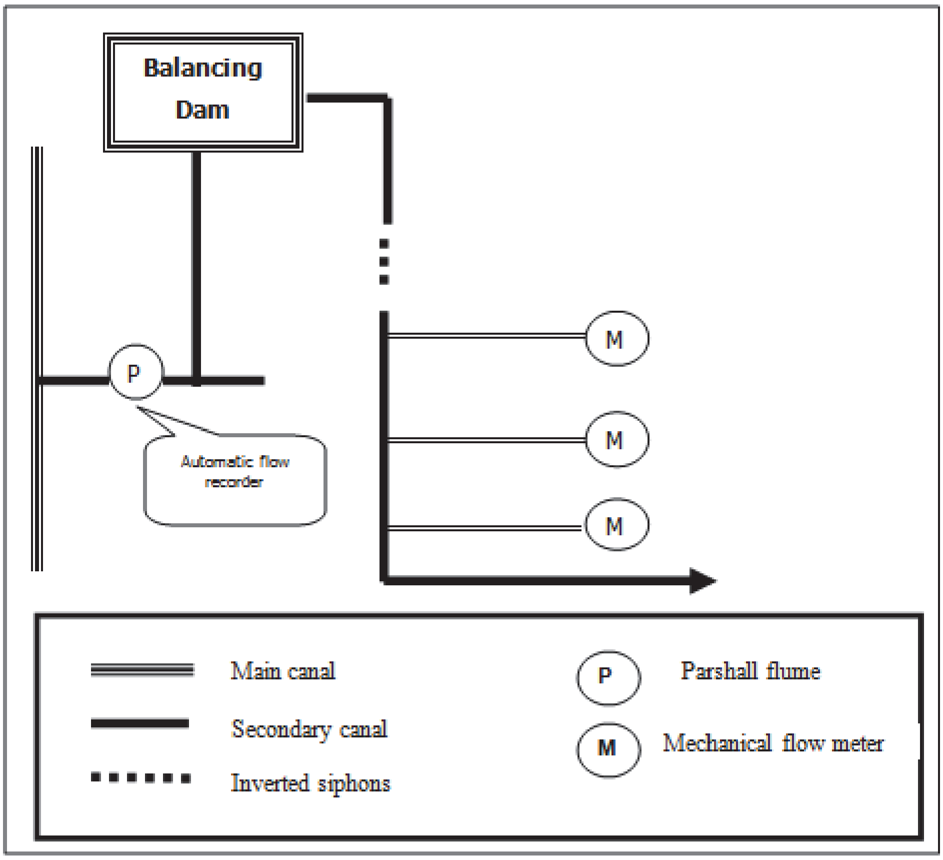
The default water destinations for the selected system component appears automatically in cells B39 to B49 when the system component is selected. As all the components do not have the same number of destinations, some of the cells may be filled by a zero.

The classification of each water destination according to the water balance framework is automatically indicated in cells C39 to C49.



	A	B	C
36	**Destinations**		
37		Destination description	Classification
38	The possible destinations of the water that has entered the selected system component are:		
39		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC
40		Evaporation from canal	NBC
41		Seepage in canal	NRF
42		Unlawful abstractions	NRF
43		Operational losses (unavoidable, eg. filling canal, tailends)	RF
44		Operational losses (inaccurate releases, spills, breaks,etc.)	NRF
45		0	0
46		0	0
47		0	0
48		0	0
49		0	0

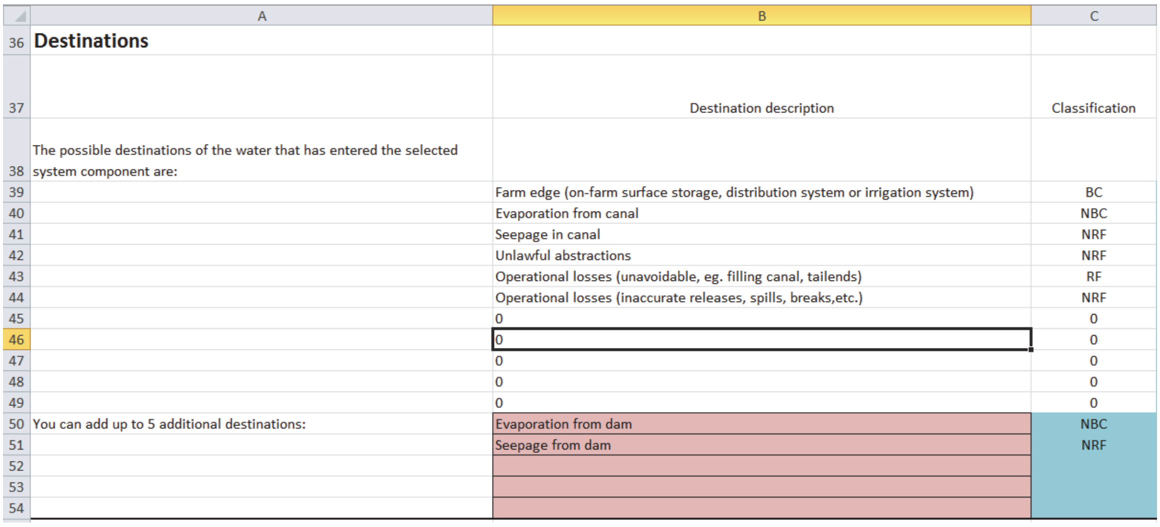
For the Gamtoos example, the situation was analysed by drawing a schematic diagram of the secondary canal and its components:



Water in the D canal flows from the main canal through the Parshall flume fitted with the automatic recorder to a balancing dam. From the balancing dam, the canal crosses a stream by means of an inverted siphon before reaching the part of the scheme where water is delivered to individual farmers through piped outlets fitted with mechanical flow meters.

Example (continued)

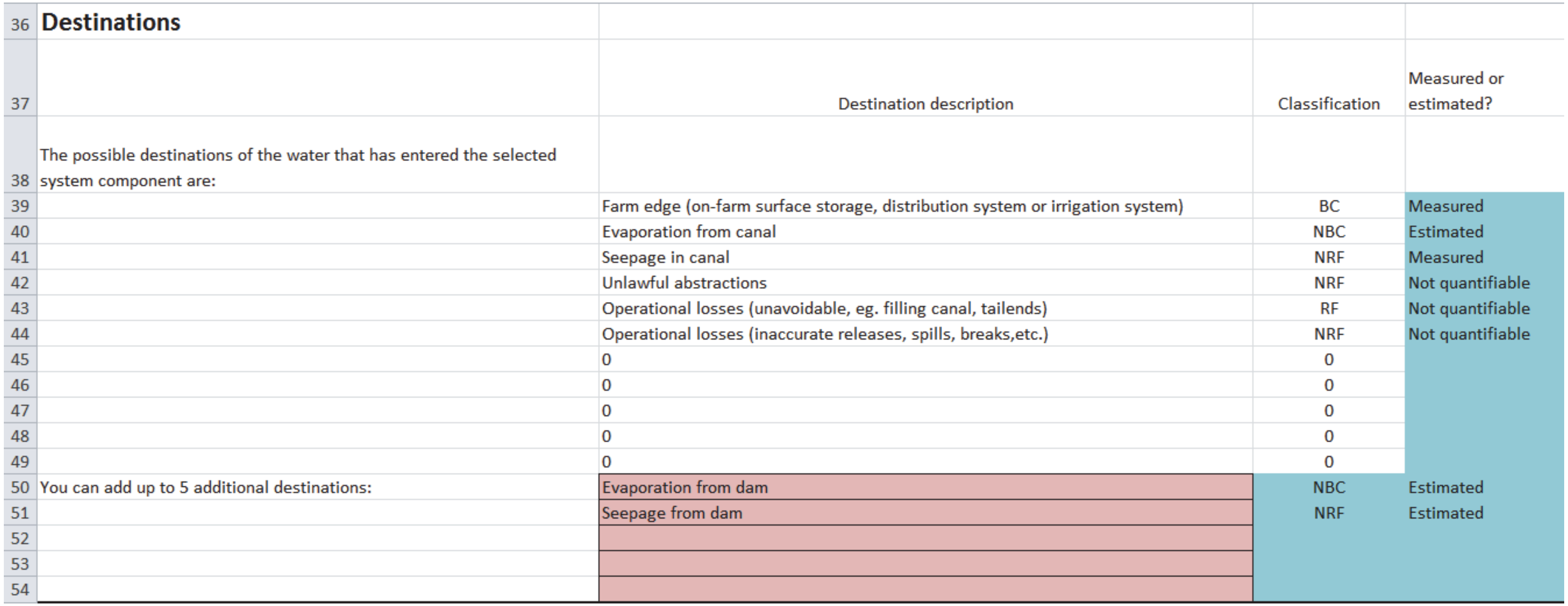
If additional water destinations must be added, the spreadsheet user can do so manually by typing in destination descriptions in cells B50 to B54, and selecting their corresponding classifications from the dropdown menus in cells C50 to C54:



	A	B	C
36	**Destinations**		
37		Destination description	Classification
38	The possible destinations of the water that has entered the selected system component are:		
39		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC
40		Evaporation from canal	NBC
41		Seepage in canal	NRF
42		Unlawful abstractions	NRF
43		Operational losses (unavoidable, eg. filling canal, tailends)	RF
44		Operational losses (inaccurate releases, spills, breaks,etc.)	NRF
45		0	0
46		0	0
47		0	0
48		0	0
49		0	0
50	You can add up to 5 additional destinations:	Evaporation from dam	NBC
51		Seepage from dam	NRF
52			
53			
54			

Up to 5 additional destinations can be added.

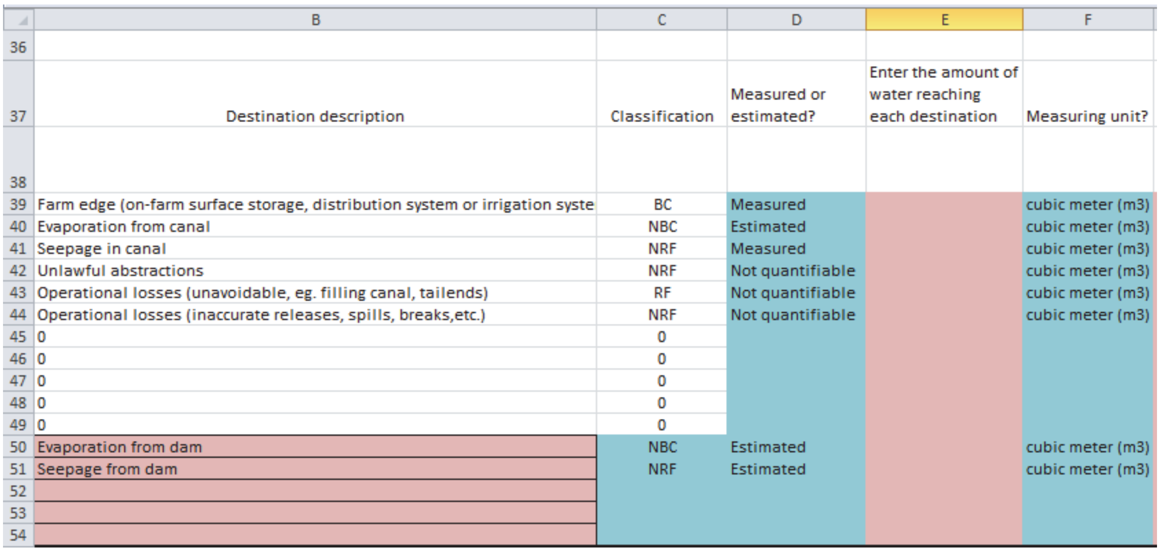
The next step is to indicate whether the amount of water assigned to a certain destination, is measured or estimated by selecting from the dropdown menus in cells D39 to D54.



36	**Destinations**			
37		Destination description	Classification	Measured or estimated?
38	The possible destinations of the water that has entered the selected system component are:			
39		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	Measured
40		Evaporation from canal	NBC	Estimated
41		Seepage in canal	NRF	Measured
42		Unlawful abstractions	NRF	Not quantifiable
43		Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable
44		Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable
45		0	0	
46		0	0	
47		0	0	
48		0	0	
49		0	0	
50	You can add up to 5 additional destinations:	Evaporation from dam	NBC	Estimated
51		Seepage from dam	NRF	Estimated
52				
53				
54				

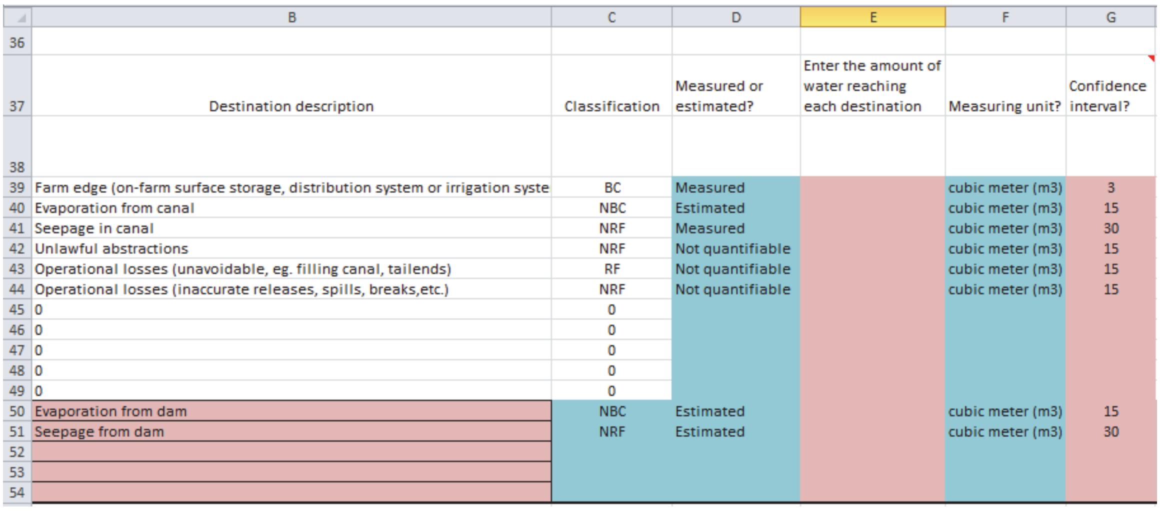
Example (continued)

Before entering the values for the water reaching the different destinations in cells E39 to E54, the measuring units must be selected from the drawdown menus in cells F39 to F54:



	B	C	D	E	F
36					
37	Destination description	Classification	Measured or estimated?	Enter the amount of water reaching each destination	Measuring unit?
38					
39	Farm edge (on-farm surface storage, distribution system or irrigation syste	BC	Measured		cubic meter (m3)
40	Evaporation from canal	NBC	Estimated		cubic meter (m3)
41	Seepage in canal	NRF	Measured		cubic meter (m3)
42	Unlawful abstractions	NRF	Not quantifiable		cubic meter (m3)
43	Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable		cubic meter (m3)
44	Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable		cubic meter (m3)
45	0	0			
46	0	0			
47	0	0			
48	0	0			
49	0	0			
50	Evaporation from dam	NBC	Estimated		cubic meter (m3)
51	Seepage from dam	NRF	Estimated		cubic meter (m3)
52					
53					
54					

And the CI values can be entered in cells G39 to G54:



	B	C	D	E	F	G
36						
37	Destination description	Classification	Measured or estimated?	Enter the amount of water reaching each destination	Measuring unit?	Confidence interval?
38						
39	Farm edge (on-farm surface storage, distribution system or irrigation syste	BC	Measured		cubic meter (m3)	3
40	Evaporation from canal	NBC	Estimated		cubic meter (m3)	15
41	Seepage in canal	NRF	Measured		cubic meter (m3)	30
42	Unlawful abstractions	NRF	Not quantifiable		cubic meter (m3)	15
43	Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable		cubic meter (m3)	15
44	Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable		cubic meter (m3)	15
45	0	0				
46	0	0				
47	0	0				
48	0	0				
49	0	0				
50	Evaporation from dam	NBC	Estimated		cubic meter (m3)	15
51	Seepage from dam	NRF	Estimated		cubic meter (m3)	30
52						
53						
54						

Finally the value for the inflow for the whole water balance period can be entered into cell B32:

6.2.1.6 Set the allowable range or threshold values

The allowable range or threshold values are the benchmarks according to which the water balance is assessed. By comparing the actual value entered for a specific water destination as a percentage of the inflow with the benchmark, decisions can be made as to whether action is required to reduce water reaching the destination. Setting these values are therefore of great importance.

In Table 14, desired ranges for the NBC and NRF components have been included to help the practitioner evaluate the results obtained when first constructing a water balance. The values shown in the table are based on actual results obtained from past case studies (WRC reports number TT 248/05, TT 465-467/10 and TT 550/12). The values in Table 14 can be adjusted if more accurate, locally relevant data is available in an area. However, as circumstances differ greatly from one irrigation area to the next, it is recommended that water managers at all levels assess a specific system component's performance against the same component's previous years' data in order to achieve continuous improvement, rather than against other (seemingly similar) system components from different areas.

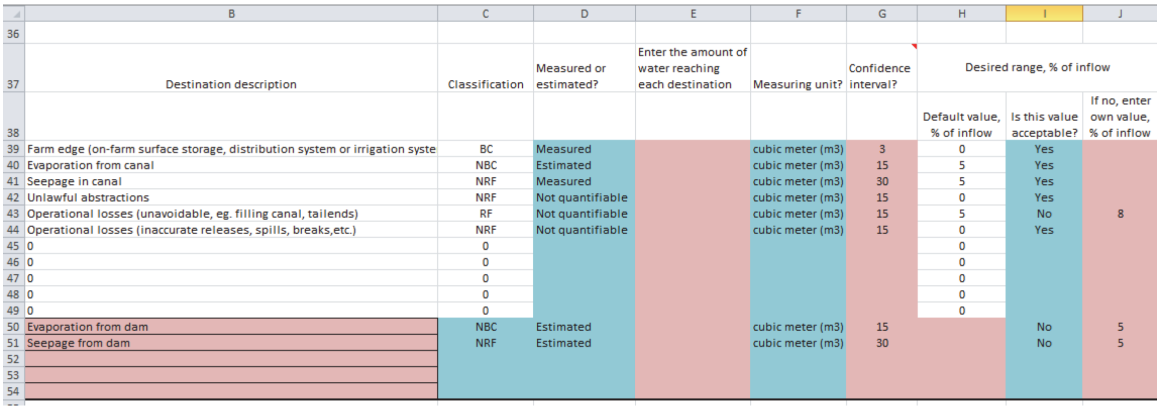
Example (continued)

In cells H39 to H54, default values for the desired range or threshold values will appear automatically for the default water destinations of the selected system component.

The spreadsheet user can indicate in cells I39 to I54 whether these values are acceptable or not by selecting Yes or No from the dropdown menus in each cell.

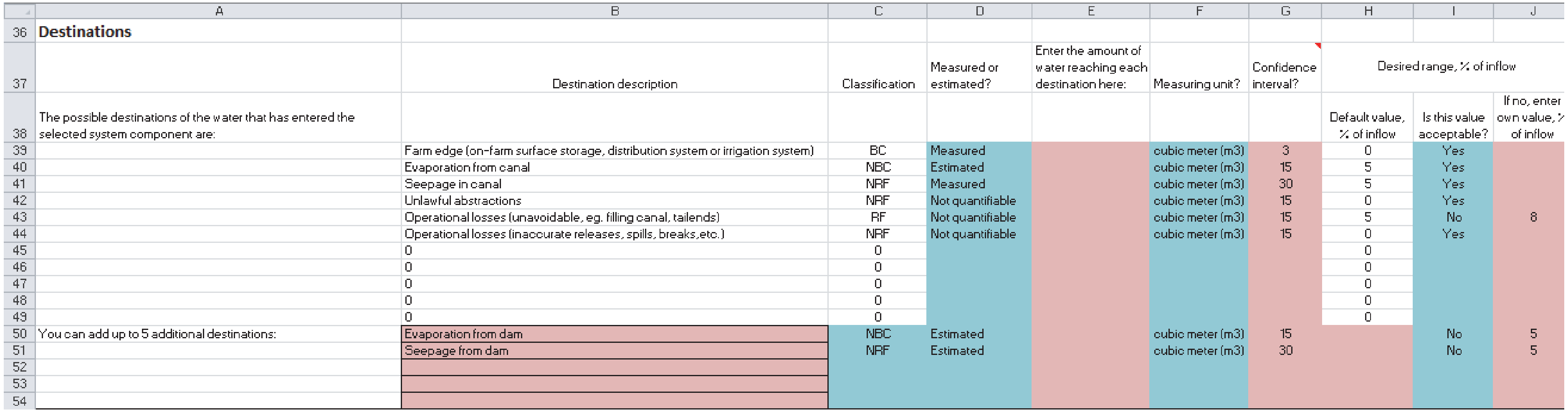
If No is selected, an alternative value can be entered in cells J39 to J54.

In the case of the additional destinations that were entered manually, an own value must be entered at all times.



	B	C	D	E	F	G	H	I	J
36									
37	Destination description	Classification	Measured or estimated?	Enter the amount of water reaching each destination	Measuring unit?	Confidence interval?	Desired range, % of inflow		
38							Default value, % of inflow	Is this value acceptable?	If no, enter own value, % of inflow
39	Farm edge (on-farm surface storage, distribution system or irrigation syste	BC	Measured		cubic meter (m3)	3	0	Yes	
40	Evaporation from canal	NBC	Estimated		cubic meter (m3)	15	5	Yes	
41	Seepage in canal	NRF	Measured		cubic meter (m3)	30	5	Yes	
42	Unlawful abstractions	NRF	Not quantifiable		cubic meter (m3)	15	0	Yes	
43	Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable		cubic meter (m3)	15	5	No	8
44	Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable		cubic meter (m3)	15	0	Yes	
45	0	0					0		
46	0	0					0		
47	0	0					0		
48	0	0					0		
49	0	0					0		
50	Evaporation from dam	NBC	Estimated		cubic meter (m3)	15		No	5
51	Seepage from dam	NRF	Estimated		cubic meter (m3)	30		No	5
52									
53									
54									

The complete Destination section is shown below. All that is needed now is to enter the measured or estimated amounts of water reaching each destination.



	A	B	C	D	E	F	G	H	I	J
36	**Destinations**									
37		Destination description	Classification	Measured or estimated?	Enter the amount of water reaching each destination here:	Measuring unit?	Confidence interval?	Desired range, % of inflow		
38	The possible destinations of the water that has entered the selected system component are:							Default value, % of inflow	Is this value acceptable?	If no, enter own value, % of inflow
39		Farm edge (on-farm surface storage, distribution system or irrigation system)	BC	Measured		cubic meter (m3)	3	0	Yes	
40		Evaporation from canal	NBC	Estimated		cubic meter (m3)	15	5	Yes	
41		Seepage in canal	NRF	Measured		cubic meter (m3)	30	5	Yes	
42		Unlawful abstractions	NRF	Not quantifiable		cubic meter (m3)	15	0	Yes	
43		Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable		cubic meter (m3)	15	5	No	8
44		Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable		cubic meter (m3)	15	0	Yes	
45		0	0					0		
46		0	0					0		
47		0	0					0		
48		0	0					0		
49		0	0					0		
50	You can add up to 5 additional destinations:	Evaporation from dam	NBC	Estimated		cubic meter (m3)	15		No	5
51		Seepage from dam	NRF	Estimated		cubic meter (m3)	30		No	5
52										
53										
54										

6.2.2 Collecting the data

Example (continued)

Seepage was calculated as 1.2 (ℓ/s)/1 000 m^2 of wetted canal lining (from literature review), average flow depths as recorded in the canal before for the periods under consideration and the basic canal shape as determined by the DWA technicians in their survey.

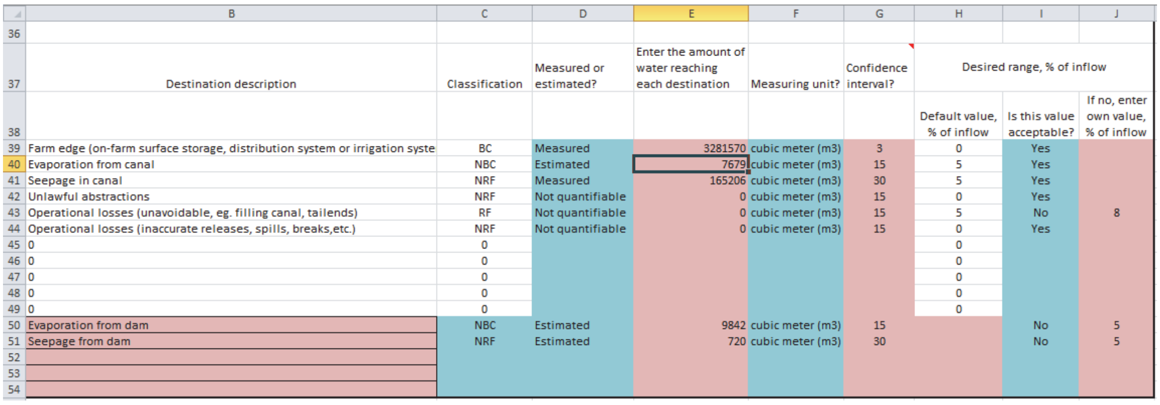
Evaporation was calculated on the bases of the actual measured daily pan evaporation figures recorded by the Irrigation Board.

Losses which were observed but cannot be quantified include canal spills, especially at the balancing dam, and unlawful use, mainly for domestic use of houses close to the canal.

The combined results of the measurements together with estimated confidence intervals for the various components are shown below.

	Dec (m^3)	**Jan (m^3)**	**Feb (m^3)**	**D+J+F (m^3)**	**% of Inflow (%)**	**CI (%)**	
						Min	**Max**
Inflow	1 261 844	1 487 872	1 158 187	3 907 903		-5	5
Usage	964 380	1 375 510	941 680	3 281 570	84.0%	-3	3
Gross losses	297 464	112 361	216 507	626 333	16.0%	-5	5
Gross losses detail:							
Evaporation (canal)	2 631	2 898	2 149	7 679	0.2%	-15	15
Seepage (canal)	53 120	58 686	53 399	165 206	4.0%	-30	30
Evaporation (dam)	3 502	3 493	2 846	9 842	0.3%	-15	15
Seepage (dam)	248	248	224	720	0.02%	-30	30

From the information collected at the scheme and shown above, the water destination values were entered in cells E39-E54:



	B	C	D	E	F	G	H	I	J
36									
37	Destination description	Classification	Measured or estimated?	Enter the amount of water reaching each destination	Measuring unit?	Confidence interval?	Desired range, % of inflow		
38							Default value, % of inflow	Is this value acceptable?	If no, enter own value, % of inflow
39	Farm edge (on-farm surface storage, distribution system or irrigation syste	BC	Measured	3281570	cubic meter (m3)	3	0	Yes	
40	Evaporation from canal	NBC	Estimated	7679	cubic meter (m3)	15	5	Yes	
41	Seepage in canal	NRF	Measured	165206	cubic meter (m3)	30	5	Yes	
42	Unlawful abstractions	NRF	Not quantifiable	0	cubic meter (m3)	15	0	Yes	
43	Operational losses (unavoidable, eg. filling canal, tailends)	RF	Not quantifiable	0	cubic meter (m3)	15	5	No	8
44	Operational losses (inaccurate releases, spills, breaks,etc.)	NRF	Not quantifiable	0	cubic meter (m3)	15	0	Yes	
45	0	0					0		
46	0	0					0		
47	0	0					0		
48	0	0					0		
49	0	0					0		
50	Evaporation from dam	NBC	Estimated	9842	cubic meter (m3)	15		No	5
51	Seepage from dam	NRF	Estimated	720	cubic meter (m3)	30		No	5
52									
53									
54									

6.2.3 Calculating the water balance

The final water balance is compiled by combining the inflow and water destination values as shown in Table 17. The measured inflow to the selected infrastructure (the secondary canal in this case) is shown on the left, while the possible water destinations are shown on the right.

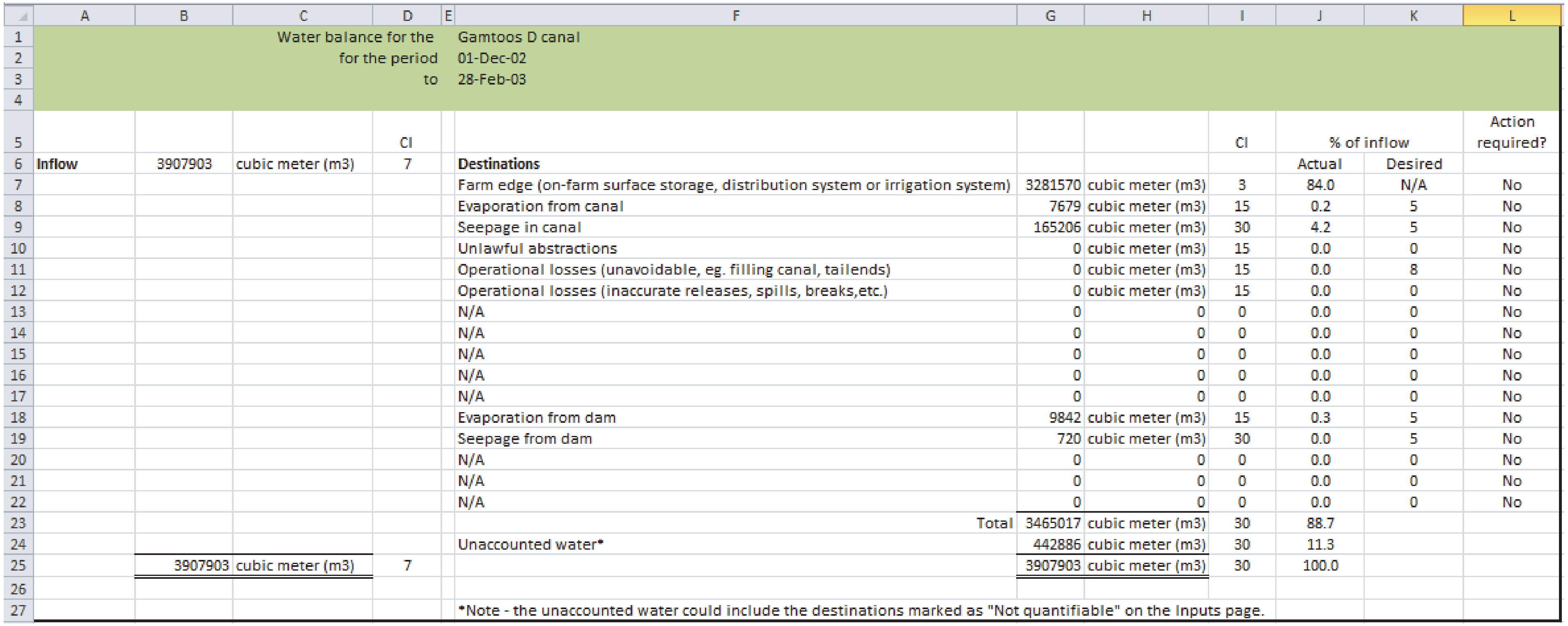
The overall confidence interval of each side of the water balance will be the highest (in other words, most uncertain) confidence interval noted for any of the data inputs.

The volumes of water reaching the possible destinations, as a percentage of the total inflow, are compared with the threshold values. Where threshold values are exceeded, action is required on the part of the responsible water management authority.

The example illustrates why it is better to estimate water balance components (even at a poor CI) rather than to leave them out – as water destined for "Unlawful abstractions" and "Operational losses" were not quantified, it weakens the water balance overall.

For more information on the water balance, please refer to WRC Report numbers TT 466/10 Module 1 and TT 467/10 Supplementary information.

Table 17 Example: Final water balance



	A	B	C	D	E	F	G	H	I	J	K	L
1			Water balance for the			Gamtoos D canal						
2			for the period			01-Dec-02						
3			to			28-Feb-03						
4												
5				CI					CI	% of inflow		Action required?
6	**Inflow**	3907903	cubic meter (m3)	7		**Destinations**				Actual	Desired	
7						Farm edge (on-farm surface storage, distribution system or irrigation system)	3281570	cubic meter (m3)	3	84.0	N/A	No
8						Evaporation from canal	7679	cubic meter (m3)	15	0.2	5	No
9						Seepage in canal	165206	cubic meter (m3)	30	4.2	5	No
10						Unlawful abstractions	0	cubic meter (m3)	15	0.0	0	No
11						Operational losses (unavoidable, eg. filling canal, tailends)	0	cubic meter (m3)	15	0.0	8	No
12						Operational losses (inaccurate releases, spills, breaks,etc.)	0	cubic meter (m3)	15	0.0	0	No
13						N/A	0	0	0	0.0	0	No
14						N/A	0	0	0	0.0	0	No
15						N/A	0	0	0	0.0	0	No
16						N/A	0	0	0	0.0	0	No
17						N/A	0	0	0	0.0	0	No
18						Evaporation from dam	9842	cubic meter (m3)	15	0.3	5	No
19						Seepage from dam	720	cubic meter (m3)	30	0.0	5	No
20						N/A	0	0	0	0.0	0	No
21						N/A	0	0	0	0.0	0	No
22						N/A	0	0	0	0.0	0	No
23						Total	3465017	cubic meter (m3)	30	88.7		
24						Unaccounted water*	442886	cubic meter (m3)	30	11.3		
25		3907903	cubic meter (m3)	7			3907903	cubic meter (m3)	30	100.0		
26												
27						*Note - the unaccounted water could include the destinations marked as "Not quantifiable" on the Inputs page.						

6.2.4 Other water balance tools

It should be noted that other tools to compile a water balance exists both locally and internationally. Other local models that can be used include:

- Soil Water Balance (SWB), University of Pretoria (SWB)
- Vinet, ARC – Nietvoorbij
- CaneSIM, SASRI
- BEWAB, University of the Free State
- Water Administration System (WAS), NB Systems
- iScheme, NB Systems

Internationally, Water Accounting Plus (WA+) is a water accounting procedure for complex river basins based on satellite measurements, developed by Wim Bastiaansen and colleagues at the Delft University of Technology.

6.3 Evaluation of the water balance results

6.3.1 Making decisions and taking action

The purpose of the water balance approach is to make users more aware of the destination of various fractions of water, especially the losses.

In order to improve water use efficiency in the irrigation sector, actions should then be taken to reduce losses – the non-beneficial consumptive (NBC) and non-recoverable fractions (NRF) – at all levels of water management, from the source to the crop. All water users and water user organisations should strive to use state of the art technology to help them manage their water as effectively as possible.

The process of assessing the water balance and taking action consists of the following steps:

- Identifying and prioritising the system components that need attention
- Identifying possible solutions and alternatives
- Identifying incentives for change and quantifying the benefits, and
- Making investment decisions

6.3.1.1 Identify and prioritise the system components that need attention

After the water balance has been drawn up, the next very important step is to assess the results and determine whether any action needs to be taken in order to optimise the water use of the selected system component.

The more accurately the elements of the water balance can be quantified, the greater the confidence with which recommendations can be made. The responsible authority should therefore always strive to improve the accuracy of data collected to populate the water balance.

Computer-based decision support systems are available for both on-farm and on-scheme applications, to improve the delivery of water and to assist with early detection of possible system problems.

Many suitable and proven technologies are also available to collect the information necessary as input for the decision support programmes, such as soil water content, flow rates, pressure, flow depth, as well as soil and water quality parameters, and most of the measurements can be managed remotely using modern communication technology such as modems and the internet, enabling real-time water management and more effective decision-making.

In some cases there may be more than one element of a system component that needs attention. It is therefore necessary to consider possible solutions to the problem, obtain cost estimates and on the basis of the envisaged benefit, prioritise the elements that need to be addressed.

6.3.1.2 Identify possible solutions and alternatives

Depending on the water management level for which the water balance was compiled (field, farm or scheme level), different solutions may be considered to improve water use efficiency. The use of suitable, quality equipment result in more durable systems with longer life cycles, less leakages and lower energy requirements. Applying maintenance practices recommended by the manufacturers will further prolong the working life of any part of the infrastructure.

For more information on the planning, design, operation, maintenance and evaluation practices that should be applied to improve system performance and irrigation efficiency, refer back to Chapters 2 to 4.

6.3.1.3 Identify the incentives and quantify the potential benefits

Informed decisions regarding irrigation system selection and design as well as improved irrigation management at farm and field level can also result in reduced costs of other production inputs such as electricity, labour, fertilisers and even pesticides. Reduced costs and increased yields lead to greater profitability. These are some of the incentives that can be pointed out to water users.

In the context of this document, an incentive is motivational factor, such as the expectation of a benefit or reward (e.g. improved profit) that encourages action, or motivates effort towards the optimisation of the beneficial water use component. The threat of a negative effect (e.g. penalties for excess water use) may also be seen as an incentive.

According to Backeberg (2007), water users must understand the economic value of water as a scarce resource; and respond to incentives to use less water which could then reduce the demand from a source. Sustained reduced consumption of water, in turn, can lead to postponement of new capital infrastructure and delay increases in the cost of water supply. At scheme level, demand management can improve the financial independence of organizations such as water user associations (WUA) by balancing the budget through increased revenue collection and reduced unaccounted water and non-payment by users or consumers.

The annual operating cost of the different irrigation systems should be considered and compared during system selection. The capital cost of the system cannot be considered in isolation and life cycle costing principles should be applied – the lower operating cost of a system with a higher capital cost but better performance can be an incentive for the water user to invest into the system.

Decisions made during the selection and design of irrigation systems will influence the flow rate and operating pressure of the system, which directly influences the power requirements and therefore the energy cost. Computer programs such as the IRRICOST program (Meiring, Oosthuizen, Botha & Crous, 2002) can be used to estimate both the annual fixed and variable costs for different scenarios.

Furthermore, a properly designed system consisting of high quality irrigation equipment will ensure uniformly applied water, and fertiliser if applicable, affecting crop yield. Appropriate irrigation system operation and maintenance practices will also limit water and energy requirements, ensuring irrigation is scheduled and applied as intended, creating the best possible conditions for crop production in terms of productive use of water and plant health.

Higher yields, greater water productivity and reduced input costs are incentives that water users should be made aware of, together with the added benefits of good irrigation management practices.

Example (continued)

The combined results of the measurements together with estimated confidence intervals for the various components are shown in Table 17.

After allocating portions of the losses to evaporation and seepage in the dam and canal, there is still an estimated 11.33% (442 885 m^3) unaccounted for, which may be due to unquantifiable destinations such as:

- *Change in the dam level between the beginning and end of the water balance period*
- *Dam and/or canal spills*
- *Unlawful abstractions*

The Irrigation Board took the investigations further by conducting ponding tests in the canal. This lead to the discovery of extreme losses taking place in the inverted siphon. This helped them to make an informed decision of how funds should be spent to upgrade the scheme infrastructure, based on the amount of water that was lost in the leaking inverted siphon. Other benefits of fixing the leaks were improved service delivery to water users downstream of the inverted syphon and lowering the risk of a complete canal failure should the leak soften and wash away the soil surrounding the pipe.

6.3.1.4 Making investment decisions

Once potential alternative solutions to optimise the water use within a specific system component have been identified, economic tools can be applied to assess the feasibility of implementation.

A decision-making tool used by Backeberg (1981), to evaluate capital investment on irrigation drainage is benefit cost analysis which includes:

- Internal Rate of Return (IRR),
- Net Present Value (NPV), and
- Benefit Cost Ratio (B/C ratio)

The Net Present Value (NPV) is the difference between the present value of income and present value of the capital and other expenditure. The Benefit Cost Ratio (B/C Ratio) is obtained by dividing the present value of the income by the present value of capital and other expenditure. The Internal Rate of Return (IRR) is the breakeven discount rate at which the B/C ratio equals 1, or alternatively where the NPV equals zero.

6.3.2 Assessing the impact of actions taken

In order to assess the impact of changes made to a system component, it is recommended that the water balance be applied regularly to the specific system component in the same manner as it was applied originally. This will make it possible to assess progress or improvement and thereby create motivation for further changes or upgrades.

At most water management levels within irrigation, annual impact assessment will be the most logical step to be taken. However, at field and farm level, it may be possible to do the assessment at more regular intervals, such as per irrigation event. For example, if the operating pressure of a system is corrected, the effect thereof can be assessed immediately during the first irrigation event following the correction.

In general, the larger the flow rates involved at the point of applying a water balance, greater accuracy of the data will be obtained by extending the data collection period (and therefore the impact assessment period).

6.3.3 Reporting and recordkeeping

It is recommended that both electronic and hard copies of the water balance results are kept by the water user or management authority.

The benefit to the water users includes proactively aligning with the planned regulations for monitoring the taking of water. The NWA provides two bases upon which measurement can be given effect:

a) According to Section 26 (b) the Minister may make regulations requiring that the use of water from a water resource be monitored, measured and recorded.

b) Section 29 (b)(ii) states that a responsible authority may attach conditions to every general authorisation or license relating to water management by requiring the monitoring and analysis of and reporting on every water use and imposing a duty to measure and record aspects of water use, specifying measuring and recording devices to be used.

DWS is in the process of developing regulations with regard to measurement of water in the irrigation sector which will address some of the constraints identified during the project. Entitled "Proposed regulations requiring the taking of water from a water resource for irrigation purposes be limited, monitored, measured and recorded", the latest version of the document puts forward a process to monitor water use by irrigation farmers using remote sensing applications as a starting point, with direct measurement of water only recommended as a final solution in the case of confirmed transgressors. The regulations are still under development, with an extended stakeholder engagement process still to take place before being introduced into practice.

6.4 Summary

With respect to the typical infrastructure encountered in practice, the management responsibilities for the different water use components can be described as follows:

> The **water management authorities** are responsible for managing water supply infrastructure used for conveying water from the dam wall in a canal, river or pipe to the user. Alternatively an authority may also be responsible for managing a groundwater aquifer from which different users abstract water individually. In open channel systems, surface storage such as balancing dams may also be found. **The on-scheme infrastructure should be developed and managed in such a way that the users receive the right amount of water at the right time, with as little unaccounted-for (non-beneficial and non-consumed) water as possible.**
>
> The **water user** is responsible for managing the water from the point where he/she receives it from the management authority up to the point where it infiltrates the root zone (and possibly beyond). The water user may first store the water on-farm before distributing it to different irrigation blocks, with or without adding additional energy through pumping the water, and finally applying the water with a specific type of irrigation system. **The on-farm infrastructure should be developed and managed in such a way that the right amount of water is applied to the crop at the right time so that energy is used as efficiently as possible, production is optimized, and as little water as possible is lost to non-beneficial consumption and the non-recoverable fraction, while the recoverable fraction is utilized or minimised.**

The water balance is a useful tool that incorporates both detail investigations with flexibility to be applied at any level for responsible water managers at any level to improve system performance.

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