TRADE AND INDUSTRY CHAMBER

FUND FOR RESEARCH INTO INDUSTRIAL DEVELOPMENT, GROWTH AND EQUITY (FRIDGE)

STAKEHOLDER ACCORD ON WATER CONSERVATION

Guideline for Establishing Baseline Water Use and Water Conservation Targets in the Irrigation Sector SAWC G1

AUGUST 2009

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WfA10_2010

DOCUMENT INDEX

This is the fourth document in the following series of guidelines for the determination of Baseline Water Use and Targets for various economic sectors:

SAWC G1	**Irrigated Agriculture Sector**
SAWC G2	Commercial Sector
SAWC G3	Manufacturing Sector
SAWC G4	Mining Sector

ACKNOWLEDGEMENTS

The authors acknowledge the invaluable input and guidance from the Counter Part Group, which initiated the Stakeholder Accord on Water Conservation Project, to this guide.

APPROVAL

This document has been approved by the Counter Part Group for use in support of the Stakeholder Accord on Water Conservation.

This document should be cited as:

The Stakeholder Accord on Water Conservation, 2009: Guideline for Baseline Water Use Determination and Target Setting in the Irrigation Sector

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ABBREVIATIONS

BMP	Best Management Practice
DWA	Department of Water Affairs
ET	Evapo-Transpiration
IB	Irrigation Board
KPIs	Key Performance Indicators
RDI	Regulated Deficit Irrigation
USBR	United States Bureau of Reclamation
WUA	Water User Association
WUE	Water Use Efficiency

GLOSSARY OF TERMS

Application efficiency The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent.

Conduit: Any open or closed channel intended for the conveyance of water.

Conservation: Increasing the efficiency of energy use, water use, production, or distribution.

Consumptive use (evapo-transpiration) Combined amounts of water needed for transpiration by vegetation and for evaporation from adjacent soil, snow, or intercepted precipitation. Also called: Crop requirement, crop irrigation requirement, and consumptive use requirement.

Conveyance loss: Loss of water from a channel or pipe during conveyance, including losses due to seepage, leakage, evaporation and transpiration by plants growing in or near the channel.

Conveyance system efficiency: The ratio of the volume of water delivered to irrigators in proportion to the volume of water introduced into the conveyance system.

Cropping pattern: The acreage distribution of different crops in any one year in a given farm area such as a catchment, water agency, or farm. Thus, a change in a cropping pattern from one year to the next can occur by changing the relative acreage of existing crops, and/or by introducing new crops, and/or by cropping existing crops.

Crop water requirement: Crop consumptive use plus the water required to provide the leaching requirements.

Crop irrigation requirement: Quantity of water, exclusive of effective precipitation, that is needed for crop production.

Crop root zone: The soil depth from which a mature crop extracts most of the water needed for evapo-transpiration. The crop root zone is equal to effective rooting depth and is expressed as a depth in mm or m. This soil depth may be considered as the rooting depth of a subsequent crop, when accounting for soil moisture storage in efficiency calculations.

Deep percolation: The movement of water by gravity downward through the soil profile beyond the root zone; this water is not used by plants.

Demand scheduling: Method of irrigation scheduling whereby water is delivered to users as needed and which may vary in flow rate, frequency, and duration. Considered a flexible form of scheduling.

Distribution efficiency: Measure of the uniformity of irrigation water distribution over a field.

Distribution loss: See conveyance loss.

Distribution system: System of ditches, or conduits and their appurtenances, which conveys irrigation water from the main canal to the farm units.

Diversion (water): Removal of water from its natural channels for human use.

Diversion (structure): Channel constructed across the slope for the purpose of intercepting surface runoff; changing the accustomed course of all or part of a stream.

Drainage: Process of removing surface or subsurface water from a soil or area.

Drainage system: Collection of surface and/or subsurface drains, together with structures and pumps, used to remove surface or groundwater.

Drip (trickle) irrigation: An irrigation method in which water is delivered to, or near, each plant in small-diameter plastic tubing. The water is then discharged at a rate less than the soil infiltration capacity through pores, perforations, or small emitters on the tubing. The tubing may be laid on the soil surface, be shallowly buried, or be supported above the surface (as on grape trellises).

Drought: Climatic condition in which there is insufficient soil moisture available for normal vegetative growth.

Evaporation: Water vapour losses from water surfaces, sprinkler irrigation, and other related factors.

Evapo-transpiration: The quantity of water transpired by plants or evaporated from adjacent soil surfaces in a specific time period. Usually expressed in depth of water per unit area.

Farm consumptive use: Water consumptively used by an entire farm, excluding domestic use. See irrigation requirement, consumptive use, evapo-transpiration.

Farm distribution system: Ditches, pipelines and appurtenant structures which constitute the means of conveying irrigation water from a farm turnout to the fields to be irrigated.

Farm loss (water): Water delivered to a farm which is not made available to the crop to be irrigated.

Flood irrigation: Method of irrigating where water is applied from field ditches onto land which has no guide preparation such as furrows, borders, or corrugations.

Groundwater: (1) Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper level of the saturated zone is called the water table. (2) Water stored underground in rock crevices and in the pores of geologic materials that make up the earth's crust. That part of the subsurface water which is in the zone of saturation; phreatic water.

Groundwater recharge: The flow to groundwater storage from precipitation, infiltration from streams, and other sources of water.

Groundwater table: The upper boundary of groundwater where water pressure is equal to atmospheric pressure, i.e., water level in a bore hole after equilibrium when groundwater can freely enter the hole from the sides and bottom.

Growing season: The period during which the climate is such that crops can be produced.

Irrigation efficiency: The ratio of the average depth of irrigation water that is beneficially used to the average depth of irrigation water applied, expressed as a percent. Beneficial uses include satisfying the soil water deficit and any leaching requirement to remove salts from the root zone.

Irrigation: Application of water to lands for agricultural purposes.

Irrigation frequency: Time interval between irrigations.

Irrigation requirement: Quantity of water, exclusive of effective precipitation, that is required for crop production.

Leaching: Removal of soluble material from soil or other permeable material by the passage of water through it.

Lining: Protective covering over the perimeter of a conduit, reservoir, or channel to prevent seepage losses, to withstand pressure, or to resist erosion.

On-farm: Activities (especially growing crops and applying irrigation water) that occur within the legal boundaries of private property.

On-farm irrigation efficiency: The ratio of the volume of water used for consumptive use and leaching requirements in cropped areas to the volume of water delivered to a farm (applied water).

Operational losses: Losses of water resulting from evaporation, seepage, and spills.

Operational waste: Water that is lost or otherwise discarded from an irrigation system after having been diverted into it as part of normal operations.

Pan evaporation: Evaporative water losses from a standardized pan. Pan evaporation is sometimes used to estimate crop evapo-transpiration and assist in irrigation scheduling.

Parshall flume: A calibrated device, based on the principle of critical flow, used to measure the flow of water in open conduits. Formerly termed the Improved Venturi Flume.

Percolation: Downward movement of water through the soil profile or other porous media.

Reservoir: Body of water, such as a natural or constructed lake, in which water is collected and stored for use.

Return flow: That portion of the water diverted from a stream which finds its way back to the stream channel, either as surface or underground flow.

Return-flow system: A system of pipelines or ditches to collect and convey surface or subsurface runoff from an irrigated field for reuse. Sometimes called a "reuse system.

Seepage: The movement of water into and through the soil from unlined canals, ditches, and water storage facilities.

Seepage loss: Water loss by capillary action and slow percolation.

Sprinkler irrigation: A method of irrigation in which the water is sprayed, or sprinkled, through the air to the ground surface.

Sprinkler systems: **1. Boom type**: An elevated, cantilevered sprinkler(s) mounted on a central stand. The sprinkler boom rotates about a central pivot.

2. Farm system: System which will properly distribute the required amount of water to an entire farm.

3. Field system: That part of a farm system which covers one field or area for which it is designed.

4. Hand move: Method of moving the sprinkler system by uncoupling and picking up the pipes manually, requiring no special tools. This includes systems in which lateral pipes are loaded and unloaded manually from racks or trailers used to move the pipes from one lateral setting to another.

5. Mechanized: System which is moved either by engine power, tractor power, water power, or hand power on wheels or skids. Generally considered as any type of system that can be moved without carrying manually.

6. Permanent: System consisting of permanent underground piping with either permanent risers for sprinklers, or quick coupling valves, in such a manner that sprinklers may be attached.

7. Self-propelled system: Portable system which moves continuously when in operation. May rotate about a pivot in the centre of field, or move laterally across the field in a predetermined direction.

8. Semi-portable: Systems designed with permanent pumping units and mains, but with portable sprinkler laterals.

9. Side-roll system: System, mounted on wheels, usually employing the lateral pipe line as an axle, where the lateral is moved at right angles to the mainline by rotating the pipeline either by hand or by engine power.

10. Solid set: System, either permanent or portable, which covers the complete field with pipes and sprinklers in such a manner that all the field can be irrigated without moving any of the system.

11. Towed system: System where lateral lines are mounted on wheels, casters, sleds, or skids, and are pulled or towed in the field to be irrigated in a direction approximately parallel to the lateral.

Tailwater Applied irrigation water that runs off the lower end of a field. Tailwater is measured as the average depth of runoff water, expressed in mm or cm.

Tensiometer: Instrument, consisting of a porous cup filled with water and connected to a manometer or vacuum gauge, used for measuring the soil-water metric potential.

Water budget: An analytical tool whereby the sum of the system inflows equals the sum of the system outflows.

Water conveyance efficiency: Ratio of the volume of irrigation water delivered by a distribution system to the water introduced into the system.

Water delivery system: Reservoirs, canals, ditches, pumps, and other facilities to move water.

LIST OF MEASUREMENTS

Quantity	**Unit**	**Symbol**
Length	metre millimetre kilometre micrometre	m mm km μm
Mass	kilogram milligram gram tonne	kg mg g t
Time	second minute hour day	s min h d
Area	square metre hectare	m^2 ha
Volume ***Fluid*** ***Solid***	 litre Megalitre cubic metre	 L ML m^3
Flow Rates	Megalitre per day litre per second	ML/d L/s
Concentration/Density ***Fluid*** ***Solid***	 milligram per litre kilogram per cubic metre	 mg/L kg/m^3
Velocity	metre per second	m/s
Acidity/Alkalinity	pH unit	pH
Grade	nil	Vertical : Horizontal
Seepage	cubic metres per square metre per day	m3/m2/day

1 INTRODUCTION

1.1 Overview

In recent years, as community demand for water has increased, the availability of this valuable natural resource has decreased. This makes it more important than ever to employ water conservation measures.

This guideline draws together the best available published water efficiency information relevant to irrigation agriculture. Other guidelines have been developed on the same basis as the irrigation agriculture sector, and therefore is one of a series of guidelines for outlining the steps to follow at site-level for the:

i. Determination of baseline water use levels and;
ii. The setting of water use targets, within the context of a water use efficiency improvement programme.

In particular, the guideline supports the objectives of the Stakeholder Accord on Water Conservation, and the chosen water use performance indicators are aligned to those required for reporting as agreed by Accord stakeholders.

This guideline refers to the irrigation agriculture sector, which comprises irrigation schemes, conveyance infrastructure, distribution infrastructure to the field edge and the irrigation infrastructure used on-farm.

1.2 Intent and objectives of the guideline

The objectives of these guidelines are to ensure that participants in the Stakeholder Accord on Water Conservation within the irrigation agriculture sector receive guidance on:

- How to categorise the key water-using processes for their individual sites;
- How to determine baseline water use and establish routine water use monitoring systems;
- Understand water use efficiency (WUE) requirements
- What the water use and water use efficiency measures appropriate to the irrigation agriculture sector are in terms of the requirements of the Stakeholder Accord on Water Conservation;
- How to identify opportunities for water use efficiency improvement and;
- How to translate identified opportunities into short and long-term water use efficiency targets.

1.3 When to use this guidelines

This guideline has been developed with specific reference to the Stakeholder Accord on Water Conservation. It is however also of use in the following general circumstances:

- When developing a water conservation management plan to identify what can be done to improve water efficiency;
- As input to planning and budgeting processes

1.4 Definition of the irrigation sector

The irrigation sector is defined in the guideline document to include all the irrigators as well as the Water User Associations (WUA) and/or Irrigation Boards who are have the responsibility of operating and maintaining the related infrastructure for delivering the water to the farmers

1.5 Who should be using this guideline

This guideline is meant to be used by irrigators who are either part of an irrigation scheme or individual irrigators, the managers and staff of water user associations (WUA), government agency involved in irrigation agriculture, and others to improve water management at the farm and the scheme and /or water use association (WUA) level. Throughout this guideline the term "you" refers to WUA and farm management and staff members or others responsible for water management of irrigation water.

1.6 Structure of the guideline document

This guideline document has four features for auditing of an irrigation scheme from source to on-farm water use namely:

- A process guide for collecting information to be used in the development of a water use baseline for an irrigation scheme. This forms the basis of establishing whether there is scope in setting water use efficiency targets when comparing the baseline with the Best Management Practices (BMP) in the irrigation agriculture supply chain
- The process guide for determining the water use baseline and establishing the level of water use efficiency based on key performance indicators (KPIs). The KPIs recommended for use are discussed in detail in this guiding document.
- The identification of the scope for improving water use efficiency levels for irrigation agriculture including reducing water losses in the conveyance and distribution infrastructure.
- A process guide to setting of water conservation targets for the irrigation agriculture sector.

The following steps are recommended for developing the baseline water use and establishing irrigation water use targets:

1. Step 1: Process mapping of the delivery of irrigation water to the farm
2. Step 2: Determining the Key Performance Indicators (KPIs) to measure irrigation water use efficiency
3. Step 3: Determining the baseline irrigation water use
4. Step 4: Identification of opportunities for improving irrigation water use

5. Step 5: Determining overall and specific irrigation water uses targets for the scheme and the irrigators
6. Step 6: Annual Reporting of Irrigation water use performance

2 WATER SUPPLY CHAIN AND WATER USE FOR IRRIGATION AGRICULTURE

2.1 Overview

The determination of water use baseline and setting of water use efficiency targets for the irrigation sector cannot only be done at the site level which is commonly known as the on-farm water use. This is because of the inter-linkages between the methods used to supply and deliver the water to the irrigator and the on-farm water use management practices by the irrigator. Furthermore, because the water applied on the fields is not all lost through evapo-transpiration but is returned back to the system, the volume of water returned though drainage systems needs to be understood in order to complete the water budget for irrigation agriculture.

Therefore in developing an irrigation water use baseline and water use efficiency performance targets this guideline document has considered the two main organisational and administrative levels of irrigation, the irrigation scheme level managed by the WUA or Irrigation Board (IB) responsible for delivering the water to the field edge and the farmer level where the irrigator uses the water delivered on -farm.

This chapter discusses the general delivery process common in irrigation sector. This will aid in developing guidelines to ensure the different levels of “water use” in the irrigation supply chain are included in the target setting process.

2.2 Understanding water use in irrigation agriculture

2.2.1 Overview

The first important thing to understand is how water is delivered from the source which can be a dam, run-of-river or a borehole to the field edge and who is responsible for the management of this section of the irrigation supply chain. The movement of water through an irrigation system, from the water source (river, lake, reservoir, etc.) to the crop, can be considered to go through the following four stages:

- ***Water mobilisation*** – This first component is to do with the physical headworks, which consists of tapping water resources (i.e. catchment, diversion weir, boreholes), sometimes storing it (dam, reservoir), and managing it (releasing it to meet irrigation user’s needs in a given water allocation framework).
- ***Conveyance***. This is the second component, corresponding to the physical main system (or primary system) which consists of conveying water from the headworks to the distribution (main canal, natural river or pipeline) and the accompanying equipment such as flow measurement and management rules.
- ***Distribution***. This third consists of delivering water to irrigators through secondary and tertiary channels (sometimes called laterals) in accordance with existing water rights, quotas or other allocation arrangements.

- ***On-farm water management*** The fourth component consists of on-farm irrigation water application defined as the irrigation equipment directly owned and managed by the farmer for watering crops (for example, furrows, sprinklers, drip) together with the associated water management practices (for example, irrigation intervals, scheduling, etc)***.***

Figure 2.1 below provides a process map of this movement of water use in irrigation agriculture.

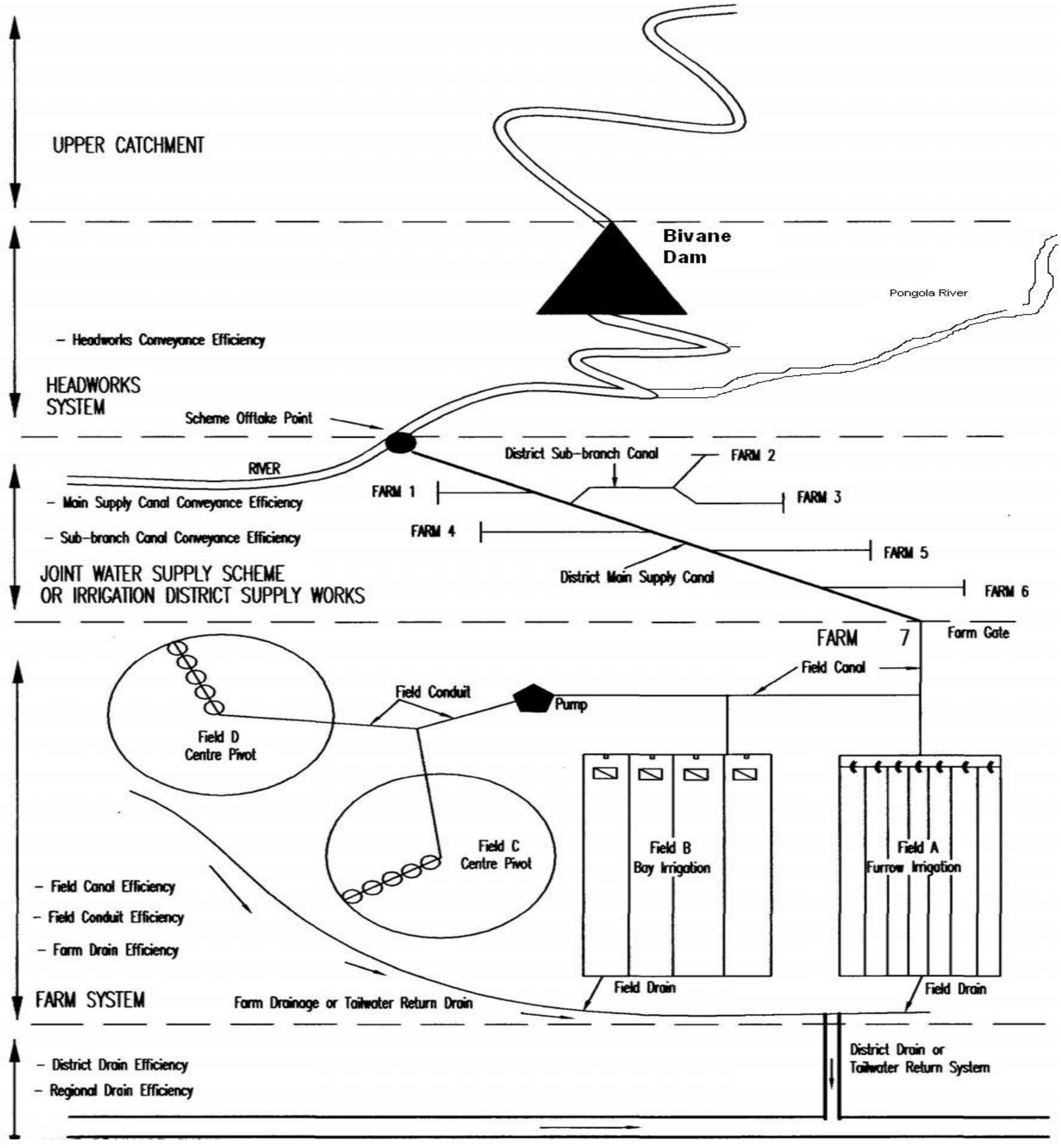

Figure 2:1: Example of an irrigation scheme layout

When irrigation is applied on the field some of it will evaporate from the soils, while some of the water is lost through evapo-transpiration, and some will be lost through deep percolation into the groundwater. However some of the water drains back into the river system for use by other users downstream in the case of inland systems. What is presented above for irrigation water use similarly applies to drainage of the water away from the scheme in reverse order, from the farm to large drainage canals (see **Figure 2.1** above), sometimes complemented by pumping plants.

2.2.2 Conveyance infrastructure

Water used for irrigating crops is normally stored in dams, rivers and lakes or as groundwater. In order to deliver the water to the irrigators, it is normally transported through some conduit which is the conveyance infrastructure. This can be either the river itself or other conveyance infrastructure such as lined or unlined canals or pipelines. The conveyance infrastructure is important because it is the means by which the irrigation water can be delivered to the edge of the farms for its use for crop irrigation to improve crop productivity.

In cases where water is not discharged into the river, different conveyance infrastructures are used to transport water to the farms. They include irrigation canals (see **Figure 2.2**) which can be either lined or unlined canals, and in a few cases pipelines.

Figure 2:2: Transvaal Irrigation Canal (Impala Scheme)

The operation and maintenance of the main conveyance infrastructure is normally undertaken by the Water User Association (WUA) which is the body representing the irrigators in the irrigation scheme or an Irrigation Board (IB). Therefore the water use efficiency in the delivery of water is the responsibility of the WUA. This guideline document is therefore very relevant to the WUA as well as the irrigators.

In conveying irrigation there are losses that take place in the conveyance infrastructure. These range from leakage that takes place in canals depending on the condition of the infrastructure and the maintenance taking place on the infrastructure. Other conveyance losses include seepage particularly on unlined canals; evaporation on canal surfaces and operational losses that can take place due to the ordering of the water by the irrigators. For an irrigation scheme and for irrigators in that scheme it is important to know how much water is being lost and not reaching the irrigators so that intervention measures can be put in place based on water use performance targets that can be set for the conveyance infrastructure.

2.2.3 Distribution infrastructure

From the main conveyance infrastructure there are branch canals or delivery system to either a group of irrigators or single irrigators (see **Figure 2.1** above). These branch canals deliver water to the field edge for application by the irrigator on the crops. The distribution infrastructure to get the water to the field edge is normally secondary or branch canal systems which are operated and maintained by the WUA. Besides canals, pipelines can be used for distribution of the irrigation water to the field edge. For canals, they can be either lined with concrete lining to reduce seepage and water losses as illustrated by **Figure 2.2**.

2.2.4 On-farm water use

Once the water is delivered at the farm gate, the responsibility for distributing the water to the fields and on-farm application of the water to the crops becomes the responsibility of the individual irrigator. The irrigator can only receive his/her authorised water use entitlement for each water year which normally starts on the 1st of April each year.

The on-farm water use varies with irrigators but most irrigators will have storage facilities (i.e. farm dams) to store the ordered water. From the farm dams, water is either pumped through pipes (for example quick coupling pipes) to the irrigation system such as centre pivots, sprinklers, etc. or it is distributed using normally unlined canal. The water use efficiency after the farm gate resorts to the irrigator and not the WUA as long as the irrigator does not exceed the water use entitlement.

2.2.5 Drainage of excess water

When the water is applied to the field, there is excess water which is drained from the field, or farms back into the river system (see **Figure 2.1** above). Measurement of how much water drains back to the river system and is not used consumptively for irrigation is important in conducting the water audit and establishing the irrigation water use efficiency including downstream recycling.

2.3 What does it help to understand how irrigation water is delivered and used?

The above information provides the WUA and the irrigator with the areas of their responsibilities. But what is important is how then a baseline irrigation water use can be established given that the organisational and administration of water use in irrigation agriculture. This is discussed in the following chapter of this guideline.

3 GATHERING OF RELEVANT BASIC INFORMATION TO DETERMINE IRRIGATION WATER USE BASELINE

3.1 Overview

It is important to first understand the water delivered for the irrigation and the water used by the irrigator. This information helps you determine what potential savings can be achieved and where in the irrigation supply chain the savings can be realised. This can the used to then set the water use efficiency targets by the WUA or the irrigator in the timeframe identified.

For the target setting process to be successful it needs to be based on accurate and comprehensive information. It needs to incorporate all aspects of the ordering, delivering and field application of the irrigation water on the crops. If only one part of the irrigation process is looked at in isolation any changes made may affect other parts of the process. For example – if you manage to conserve water by reducing water losses in irrigation conveyance infrastructure, this will make more water available to irrigators and if the additional water is not applied efficiently this may cause water logging resulting in salinity build up in the soils. This will consequently impact on crop yields and quality.

The first step that is essential is collecting as much information as necessary to undertake the mapping of the delivery of water to the field edge as well as the application of irrigation water to the fields.

One thing to consider while gathering the background information is incorporating the collection of the relevant data in the normal operating procedures. To be an efficient monitoring tool the data needs to be collected and analysed routinely as part of the operation of the irrigation scheme or at farm level. **Table 3.1** below illustrates the kind of water abstraction and water use data that should be collated routinely as part of the operation of an irrigation scheme and the information that an irrigator should be collecting as part of his/her irrigation management and scheduling process. This information is necessary for determining the baseline irrigation water use.

Table 3:1: Data requirements at different scales of the irrigation agriculture

Scale	Variable	Attribute	Dimension	Comment
Catchment	Dam releases	Weekly to monthly	Volume (Ml)	Volumetric information recorded on weekly and monthly based on flow measurements of dam releases into conveyance infrastructure. The data for the volume of water at conveyance, distribution and irrigation drainage conveyance infrastructure can be measured using various instruments ranging from flow meters, to measuring weirs, to estimating/calculating the volumetric flows
	Tributary inflows			
Catchment /Scheme	Conveyance diversions	Weekly to monthly	Volume (Ml)	
	Distribution diversion			
	Tailwater return flow (irrigation drainage)			
Scheme / Farm	Conveyance diversions	Weekly to monthly	Volume (Ml)	The data for the volume of water at conveyance, distribution and irrigation drainage conveyance infrastructure can be measured using various instruments ranging from flow meters, to measuring weirs, to estimating/calculating the volumetric flows
	Distribution diversion			
	Farm gate flow measurement			
	Tailwater return flow (irrigation drainage)			
Farm / Field	Evaporation	Daily to annual	Depth (mm)	
	Evapo-transpiration			
	Rainfall			

3.2 Water use information

The most important information that an irrigation scheme should collect is the water use information. The following information needs to be collected:

- The daily, weekly and monthly volume of water delivered to the scheme – The data for the volume of water delivered can be obtained from the Water Bailiff if it is supplied from a dam, or a weir.
- The volume of water delivered to each irrigator in the scheme - In the case of irrigators who are not in an irrigation scheme or abstract water from boreholes, the volume of water delivered to the field
- Maps, schematics of the irrigation scheme water infrastructure such as the conveyance and distribution infrastructure.
- The types of the irrigation systems used for field application.
- Capacities of storage and groundwater abstraction on the individual farms,
- Any paperwork (owner's manuals) related to irrigation systems equipment, etc.

3.3 Crop production information

The use of irrigation water is linked to the level of production for the volume of water available for irrigation. Therefore besides collecting information on the volume of water supplied /delivered, the application and return flows, it is important to understand the information on the crop production for the irrigation scheme where you want to determine the water use targets. The amount of water used at any farm is driven by the timing, capacity of the irrigation scheme to deliver the water and the level of production.

The first step is to collect the daily, weekly and monthly water use information at different points in the delivery cycle of the irrigation scheme as well as the application of water to the crops (irrigation scheduling). The crop production information which is available from the irrigator is also very useful information for the target setting process. However it is important that the different crop production data and the crop mix at a farm are identified. The format in which the crop production information is collected is very important. For example for sugar cane the amount of cane produced in tonnes must be collected.

The data collected on the volume of water delivered and applied on-farm and the crop yield or production must be done for the same timeframe.

With the above information collected, the WUA and irrigators are now in a position to start with the process of establishing their irrigation baseline water use.

4 KEY PERFORMANCE INDICATORS FOR IRRIGATION WATER USE

4.1 Why Key Performance Indicators are necessary?

Water use is directly related to the irrigation agriculture activities. Key Performance indicators (KPIs) are necessary because they can be used for analyzing the performance of various aspects of irrigation systems from a water use efficiency perspective. The KPIs can then be used to compare with other irrigation systems with the same characteristics (i.e. soil types, climatic conditions, crop type, cropping pattern, irrigation scheduling methods, etc.) and determine whether there is scope for improving the irrigation water performance based on the best management practices (BMP). Based on the scope for improving irrigation water use performance, water conservation and water use efficiency options to achieve the identified areas for improvement can be identified and evaluated. These options can be used to then set realistic water use efficiency targets by the WUA or IB at scheme level and by the irrigator at farm or field level.

The KPIs are water use indicators. The water use indicator is a measure of activity that takes into account core business operations specific to the scheme – for example how much water is used per tonne of sugar cane production on an irrigation scheme or how much water is used per tonne of sugar cane production at a farm level. It is important to consider how variables such as conveyance and distribution efficiency, field application efficiency, crop production, affect water use when determining water-saving targets.

There are two key metrics used to determine how effectively the water is delivered to the irrigators and how efficiently it is applied on the field crops. The two key metrics used is the water delivered per ha of the irrigated area and the water use efficiency.

4.1.1 Water delivered per ha – Irrigation water requirements

Why this measure?

This measure is important for the irrigation scheme and to the irrigator as it indicates how much water was delivered to the field edge for irrigating the crop(s). Together with the irrigated area the WUA will be able to determine whether the water delivered is in line with the irrigation requirements. There are two of these measures to be used. The first is to determine the gross water delivered including the tailwater return flow. The second measure is the water delivered less the return flow which is effectively the irrigation water requirement.

The calculation of the gross water delivered per ha and the net water delivered per ha to the field edge using **Figure 5.1** in the next chapter are as follows:

Equation 1:

Gross water delivered to field edge = (Raw water delivered from scheme + scheme rainfall + groundwater from farm + raw water from farm dams + farm rainfall) / total irrigated area (ha)

The net water delivered per ha is calculated as follows:

Equation 2:

Net water delivered to field edge = (Raw water delivered from scheme + scheme rainfall + groundwater from farm + raw water from farm dams + farm rainfall) - (tailwater return flow) / total irrigated area (ha)

What decisions can be made from this KPI?

Using too much irrigation water on crops can reduce the crop yield or production and increase salinity levels. It can also be a money drain where fertilizers is supplied to the crop through the application of the water which will result in washing away some of the fertiliser. This is one of the most expensive components of irrigation agriculture.

4.1.2 Percentage Water use efficiency

Why this measure?

This information indicates the effectiveness of the entire distribution system as well as the effectiveness of the irrigation water application. It is an indicator of how well various uses of the system (conveyance, distribution and on-farm application) are tracked and managed.

The water use efficiency KPI records the extent to which the level of watering exceeds the optimal crop requirement, i.e. it is a measure of how much water will travel beyond the root zone of the relevant crop, is lost to evaporation, leakage in conveyance and distribution or runs off at the bottom end of the farm. This measure takes account of the particular requirements of different crops, at different stages of growth and soil conditions.

The water use efficiency measure is necessary for the determination of the efficiency of conveyance or distribution infrastructure to convey to a group of farms or field edge without significantly losing the water supplied from the source.

There are three (3) different water use efficiencies that should be measured. These are the conveyance water use efficiency; the distribution water use efficiency and the field application efficiency. The first two are determined at scheme level by either a Water User Association (WUA) or Irrigation Board (IB). The last one is the measure of the efficiency of application of the water to the irrigated field which should be determined by the irrigator. The percentage water use efficiencies are calculated based on the following equation:

Equation 3:

Conveyance Water use efficiency (%) = (Water received to the inlet block of fields)* 100 / water released at the reservoir)

Equation 4:

Distribution Water use efficiency (%) = (Water received at field inlet)* 100 / water received at block of fields)

Equation 5:

Field application efficiency (%) = (Water available to the crop)* 100 / water received at field inlet)

The above KPIs are recommended by the Food and Agricultural Organisation (FAO) and have been defined in Table 4.1 below as well. Based on the determination of the irrigation efficiency, the irrigation water losses can be determined. By definition the conveyance losses for example are:

Conveyance losses (%) = 100% – Conveyance efficiency.

The same applies for the distribution water losses and field application water losses.

What decisions can be made off the data collected?

Lost water can be a monetary drain on a utility if it is not properly tracked and the appropriate corrections are not instituted. This information will indicate increases in lost revenue which can suggest improper contractor use, etc. It can also indicate breaks in the system and the need for renewal and rehabilitation of the conveyance infrastructure to the distribution system.

The irrigation water use performance indicators can be used to compare the performance of the same irrigation type between Irrigation Schemes and the irrigators in the same scheme. The exception being the crop production water use indicator which is expressed as tonnes or kg or trays or boxes of crop produce per m^3 of water supplied to the farm gate.

4.2 Applicable key performance indicators for irrigation water use

Figure 4.1 and Table 4.1 provide the main key performance indicators (KPIs) that are recommended for use in the assessment of the volume of water required for irrigation of a hectare of irrigated area and for the assessment of the water use efficiency at the different points in the supply chain in irrigation agriculture.

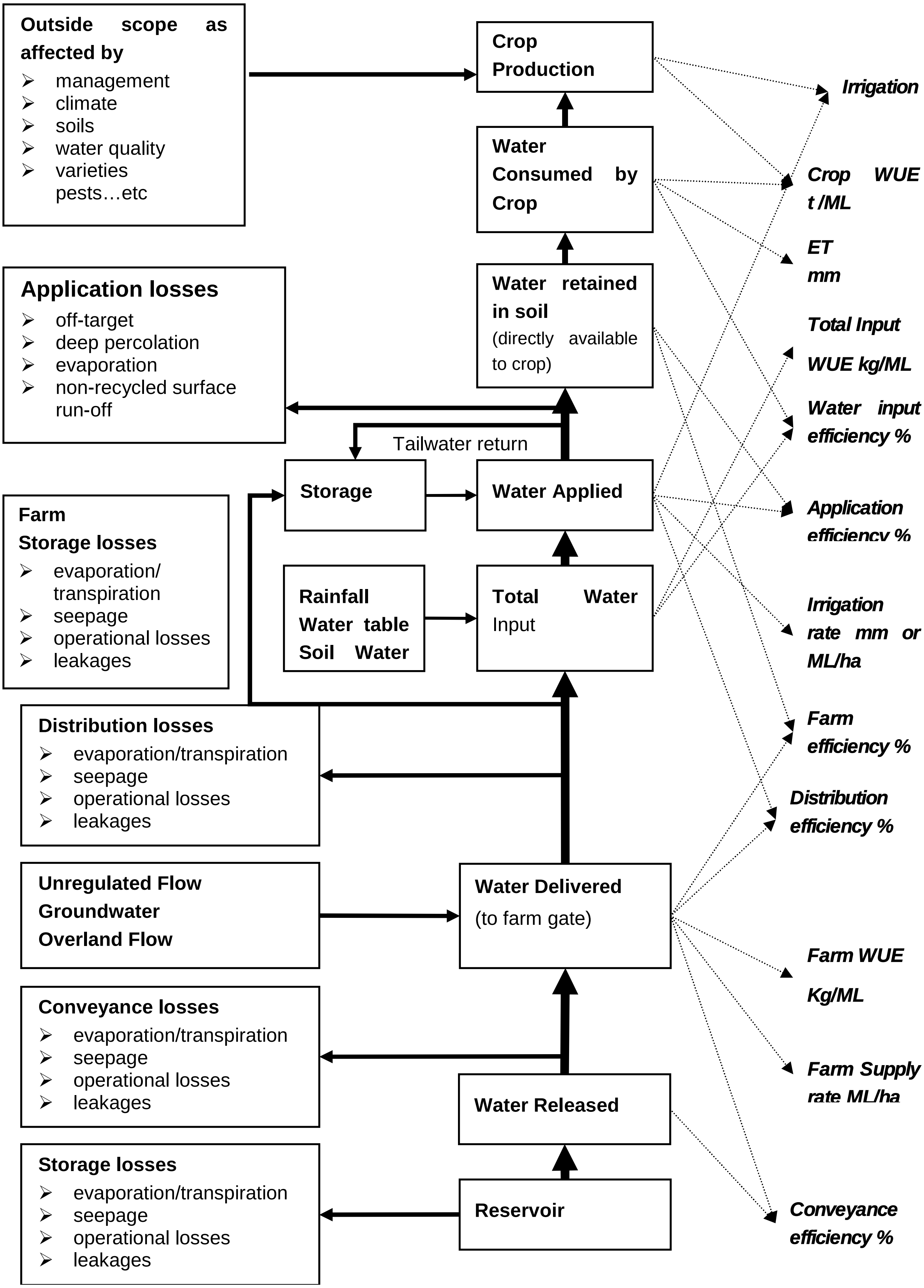

Figure 4:1: Framework for Water Use Efficiency Indicators

Table 4:1: Key performance indicators recommended for use in irrigation water use target setting

Performance Indicator	Description*
Overall Scheme Water Use Indicator	$\frac{\text{Water made available to crop } (m^3)}{\text{Water released at headworks } (m^3)}$
Conveyance Efficiency (E_c)	$\frac{\text{Water received at inlet to block of fields } (m^3)}{\text{Water released at headworks } (m^3)}$
Distribution Efficiency (E_d)	Field canal efficiency: $\frac{\text{Water received at field inlet } (m^3)}{\text{Water received at inlet of block of fields } (m^3)}$
Field Application Efficiency (E_a)	$\frac{\text{Water directly available to crop } (m^3)}{\text{Water received at field inlet } (m^3)}$
Farm irrigation crop production water use indicator	$\frac{\text{Quantity of produce generated from a particular irrigated crop (kg)}}{\text{Irrigation water supplied to the farm gate } (m^3)}$
Irrigation water requirements	$\frac{\text{Volume of water supplied to the farm gate for a specific crop}}{\text{Hectares of irrigated area}}$

Source: Food and Agricultural Organisation

There are five KPIs that are relevant for determining the irrigation water use performance in an irrigation scheme as well as at farm gate. These are discussed in the following section and examples are provided on how to calculate the five KPIs.

4.3 Irrigation key performance indicators

4.3.1 Performance indicators for conveyance efficiency

Conveyance losses are generally a concern for the irrigation district. The KPI to measure the efficiency of the conveyance infrastructure to transport water from the source to the distribution infrastructure in an irrigation scheme is important. The conveyance efficiency (Ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals.

In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined and actively maintained; only very little water is lost. If canals are not lined and are in poor soils and badly maintained, bund breaks are not repaired properly and roots grow on the embankments, a lot of water is lost. Therefore it is important to know how much water is being lost and not reaching the irrigators. The example below shows how a WUA or IB can calculate the conveyance efficiency.

Example 1:

An irrigation scheme releases water from a dam into a lined irrigation canal for distribution to an irrigation scheme. The volume of water released for the week is 575 000 m^3 measured at the dam, while the total volume of water delivered at the irrigation scheme was measured at a partial flume to be 459 575 m^3 for that week. The total area irrigated in the scheme is 65 ha.

Between the headworks and the irrigation scheme there are tributary inflows which were measured to be 110 275 m^3. Determine the gross water available per hectare to the field edge of the farms. Determine the conveyance losses and calculate the conveyance water use efficiency for the irrigation scheme.

Answer:

Gross water available	***= 575 000 m^3 + 110 275 m^3***	
	= 685 275 m^3	
Irrigation water requirement	***= 685 275 / 65***	***= 10 500 m^3/ha***
Conveyance losses	***= (575 000 m^3 + 110 275 m^3) – (459 575 m^3)***	
	=225 700 m^3	
Conveyance efficiency (Ec)	***= 459 575 m^3 *100 / (575 000 m^3 +110 275 m3)***	
	= 67%	
Conveyance losses (%)	***= 100% – 67% = 33%.***	

4.3.2 Performance indicators for distribution efficiency

The distribution efficiency (E_d) is a similar KPI to the conveyance efficiency. This represents the efficiency of distributing water from the block of irrigated fields to the farm. The distribution infrastructure can be lined or unlined canals, low pressure pipelines or ditches.

The conveyance efficiency and distribution efficiency calculated in the example above can then be used to benchmark against another conveyance system on another irrigation scheme which is considered to have the BMP in terms of conveyance and distribution of irrigation water to the field edges. This can then be used to determine whether there are opportunities to improve the conveyance and distribution efficiencies of the scheme.

4.3.3 Performance indicators for on-farm water use efficiency

The KPI to measure the performance of on-farm water use is the field application efficiency (Ea) which is driven by the type of irrigation technology used such as centre pivots, micro-irrigation, sprinklers, etc. and the irrigation scheduling method used. In order to determine the field application efficiency two measurements are required:

- The water supplied to the farm gate – this amount can be measured at the farm turnouts. There should be flow measurements such as weirs, or ultrasonic flow meters (these tend to be expensive, but are the most accurate). Daily, weekly and monthly flow measurements should be taken. In most cases the WUA will be recording the water supplied to each farm.
- The crop water requirements – this is the amount of water used by the crop. It is measured by determining the evapo-transpiration of the crop by irrigated. The crop water requirements can be determined using the SAPWAT model (Heerden & Crosby, 2002). This is available from the different institutions such as the Cane Growers Association, Citrus Board, etc. depending on your type(s) of crops you are irrigating.

With the two measurements the field application efficiency can be determined by dividing the water supplied to the farm gate and the crop water requirements.

Example 2:

An irrigator irrigating sugar cane, using centre pivots in the Impala irrigation area has 10 ha of sugar cane. He irrigates from March to December each year and applies 12 500 m^3 for each hectare. The irrigator measures the return flow at the farm drainage canal system and finds that for the same period approximately 25 000 m3. For his 10 ha he received 150 000 m^3 for the same period at the field edge from the Impala Water User Association. The field application efficiency (taking irrigation only and not including effective rainfall) would be calculated as follows:

Field application efficiency (Ea) = {Crop water requirements for 10 ha (12 500*10) - return flow (25 000) } / Water supplied at the farm gate (150 000)

(125 000 -2500)*100% / 150 000

66.67%

The field application efficiency calculated in the example above can then be used to benchmark against a sugar cane irrigator using centre pivots in similar soils and climatic conditions. This can then be used to determine whether there are opportunities to improve the field application efficiency. These opportunities are discussed in detailed in the following sections of this guideline.

The above three water use efficiency indicators, E_c, E_d, and E_a can be used to calculate the overall irrigation scheme water use indicator (or efficiency). This is provided by the following equation.

Overall Scheme Efficiency = Conveyance Efficiency (Ec) x Distribution Efficiency (Ed) x Mean ∑ Field Application Efficiency (Ea)

Example 3 below illustrates how the overall scheme efficiency should be calculated. As can be seen from the example, although the distribution efficiency is high, because the condition of the conveyance infrastructure is low and the application efficiency is low, the overall scheme efficiency is very low. By improving the conveyance and the application of the irrigation water on the fields, this will lead to improving the overall scheme efficiency. The focus would then be to identify what opportunities exist to reducing water losses in the conveyance and the irrigation equipment in the field. The guiding principles in identification and assessment of these opportunities are discussed in Chapter 6 of this guiding document for the irrigation sector.

Similarly, the product of Conveyance Efficiency and Field Canal/Conduit Efficiency is called **Distribution Efficiency (Ed)**

Ec x Eb = Ed and;

the product of the Field Canal/Conduit Efficiency and Application Efficiency is called **Farm Efficiency (Ef)**

Eb x Ea = Ef.

Example 3:

An irrigation scheme comprising of lined canals to convey irrigation water to a block of fields, determined that the conveyance efficiency is 67%. The water is then distributed to the field edges. The distribution network comprises of pipelines. The distribution efficiency (Ed) was calculated by the WUA to be 85%. The water is applied to the field crops and the mean of the irrigation application efficiency of the different farms is the scheme was found to be 66.7%. Determine the overall scheme efficiency.

Answer

Overall Scheme Efficiency = Conveyance efficiency (Ec) (0.67)*Distribution Efficiency (Ed) (0.85)*Application Efficiency (Ef) (0.667)

38%

The water use efficiency KPIs for a one time period alone is not very useful. What is important is to establish a trend of how the irrigation scheme and/or the irrigators are performing over a period of time. This requires that annual water delivery per ha are recorded and measured over a period of time and water use efficiency are calculated from the recorded information with a view to determining the irrigation water use efficiencies which can be benchmarked against the Best Management Practices (BMP).

It is important to calculate the year on year water use efficiency particularly after setting irrigation water use efficiency targets. The year on year water use can be calculated as illustrated in example 4 below. As illustrated the annual conveyance efficiency is 78%. When it is compared with the target conveyance efficiency for the year, it was low although there are months when the target was achieved. The scheme can then investigate why other months the target was not achieved.

Table 4:2: Monthly flow records for an irrigation scheme (Ml)

Year	Releases into canals	Scheme rainfall	Total release into canal	Water delivered to scheme	Conveyance efficiency	Target
Aug-98	14,500.00	-	14,500.00	10,875.00	75%	85%
Sep-98	17,500.00	2,000.00	19,500.00	14,040.00	72%	85%
Oct-98	18,235.00	1,750.00	19,985.00	13,589.80	68%	85%
Nov-98	13,765.00		13,765.00	10,736.70	78%	85%
Dec-98	5,750.00	5,750.00	11,500.00	8,050.00	70%	85%
Jan-99	8,750.00	5,765.00	14,515.00	11,612.00	80%	85%
Feb-99	9,750.00	5,450.00	15,200.00	12,464.00	82%	85%
Mar-99	12,890.00	2,750.00	15,640.00	12,355.60	79%	85%
Apr-99	13,765.00	3,506.00	17,271.00	14,162.22	82%	85%
May-99	16,540.00	575.00	17,115.00	14,547.75	85%	85%
Jun-99	13,950.00		13,950.00	11,578.50	83%	85%
Jul-99	13,950.00		13,950.00	11,439.00	82%	85%
Seasonal Total	159,345.00	27,546.00	186,891.00	145,450.57	78%	85%

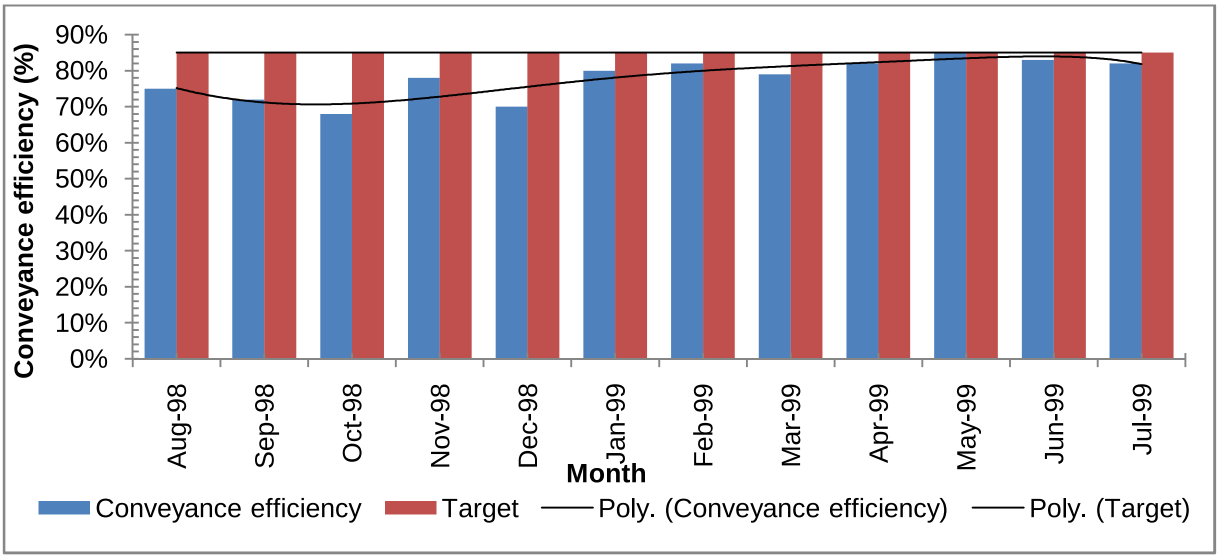

Figure 4:2: Example of the conveyance efficiency trend of an irrigation scheme

In order to calculate the KPIs, the volume of water required, and water supplied, must be measured over the same time frame; usually either the growing season of the crop or 12 calendar months, whichever is the shorter. This can be used to develop an irrigation water budget from which the irrigation water use targets based on the above KPIs can be established for an irrigation scheme. The determination of the water budget provides the baseline irrigation water use / requirement which is discussed in the following chapter.

5 DETERMINATION OF BASELINE IRRIGATION WATER USE

5.1 Overview

The determination of an irrigation water budget is the fundamental tool for assessing water use efficiency at scheme level or at the farm. The uncertainty associated with the measurement of each of the elements of the water balance varies within and across these scales.

Figure 5.1 below provides the framework for determining the baseline irrigation water use. It is important to note that the baseline water use cannot only be done at the farm gate level. It needs to be done from the source to the irrigated fields. The responsibility for determining the baseline irrigation water use should be done at two levels. The first is for the irrigation scheme which shall be undertaken by the Water User Association (WUA or the Irrigation Board (IB). The second shall be undertaken by the irrigator which is the application of water to the irrigated crops.

But before discussing how to determine the baseline irrigation water use for different types of crops, the first important aspect is to determine what measurement of the irrigation water that is abstracted, conveyed and used in an irrigation scheme up to the farm gate is necessary to complete a baseline irrigation water use (or water budget).

This process has a significant bearing on determining the level of water use efficiency and what targets can be set up at different components of the irrigation supply chain.

5.2 The need for flow measurement

Setting irrigation water use targets requires knowing how much water the crop has used since the last irrigation period and operating the irrigation system to apply the required amount of water. Flow measurements particularly flow meters provide the information necessary to determine the level of water use efficiency in delivering and applying it on the crops.

In most irrigation schemes there is very limited or no flow measurement. Effective water measurement and accounting is necessary for developing realistic water use targets at either scheme level or at farm level. The scheme must have sufficient flow measurements to measure and should be capable of tracking the amount of water abstracted from the source into the main canals, the amount of delivered at the secondary or branch canal and the amount of water delivered at the farm gate for use by the individual water user in the scheme. Furthermore, which is the case in most irrigation schemes; there are no flow measurements to measure the return flow from the drainage system. In some cases even the drainage system is not constructed. It is important that there are drainage systems installed with flow measurement to enable the water returning back to the river to be recorded. This will complete the water balance assessment required.

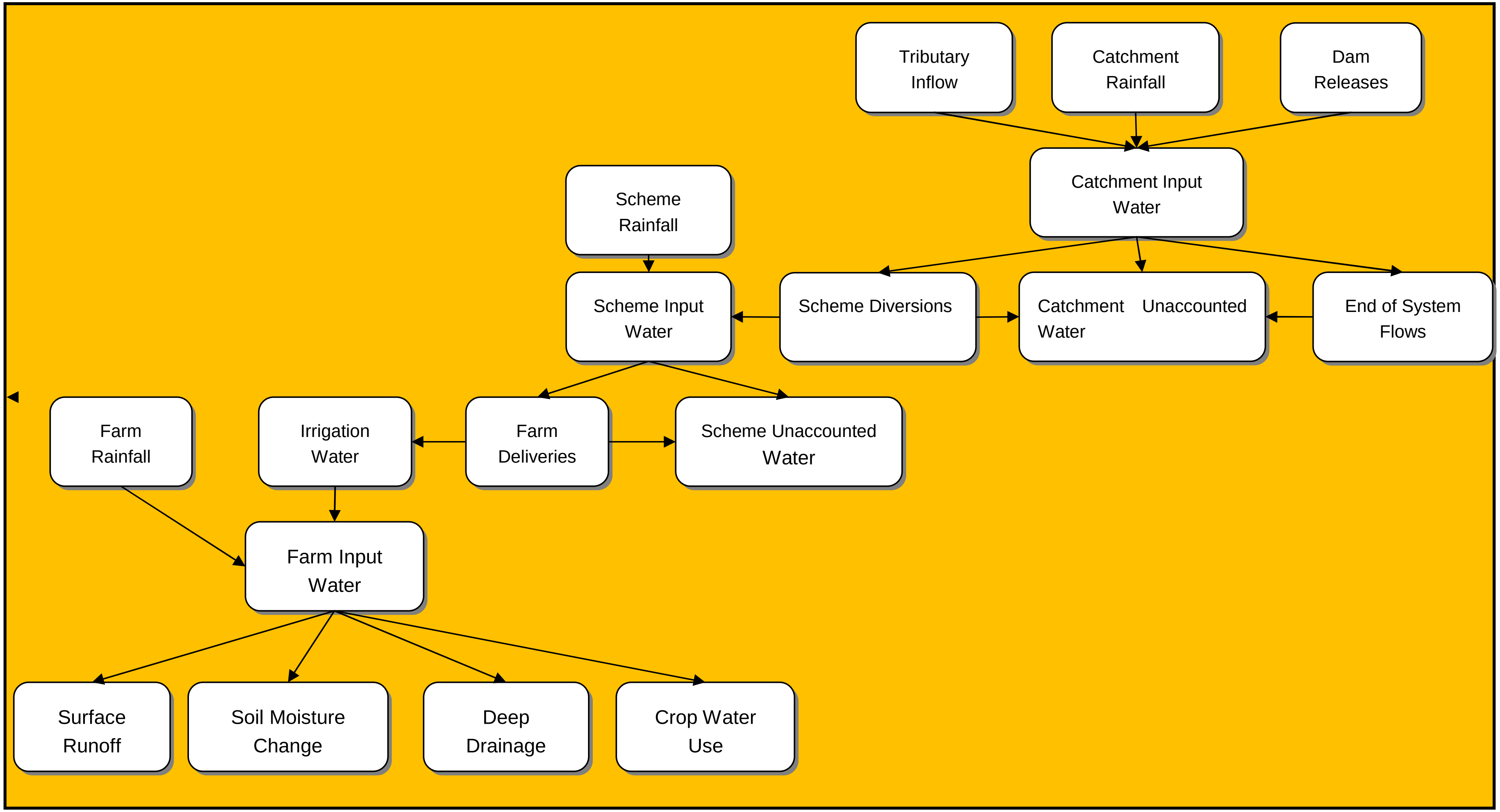

Figure 5:1: Framework for determining the irrigation baseline water use

Figure 5.2 below provides the extent of flow measurement that is ideal for conducting an irrigation scheme water budget. The availability of flow measurements helps inform both the water user and the WUA about the quantity, timing, and location of water use and therefore be able to conduct a water budget for scheme.

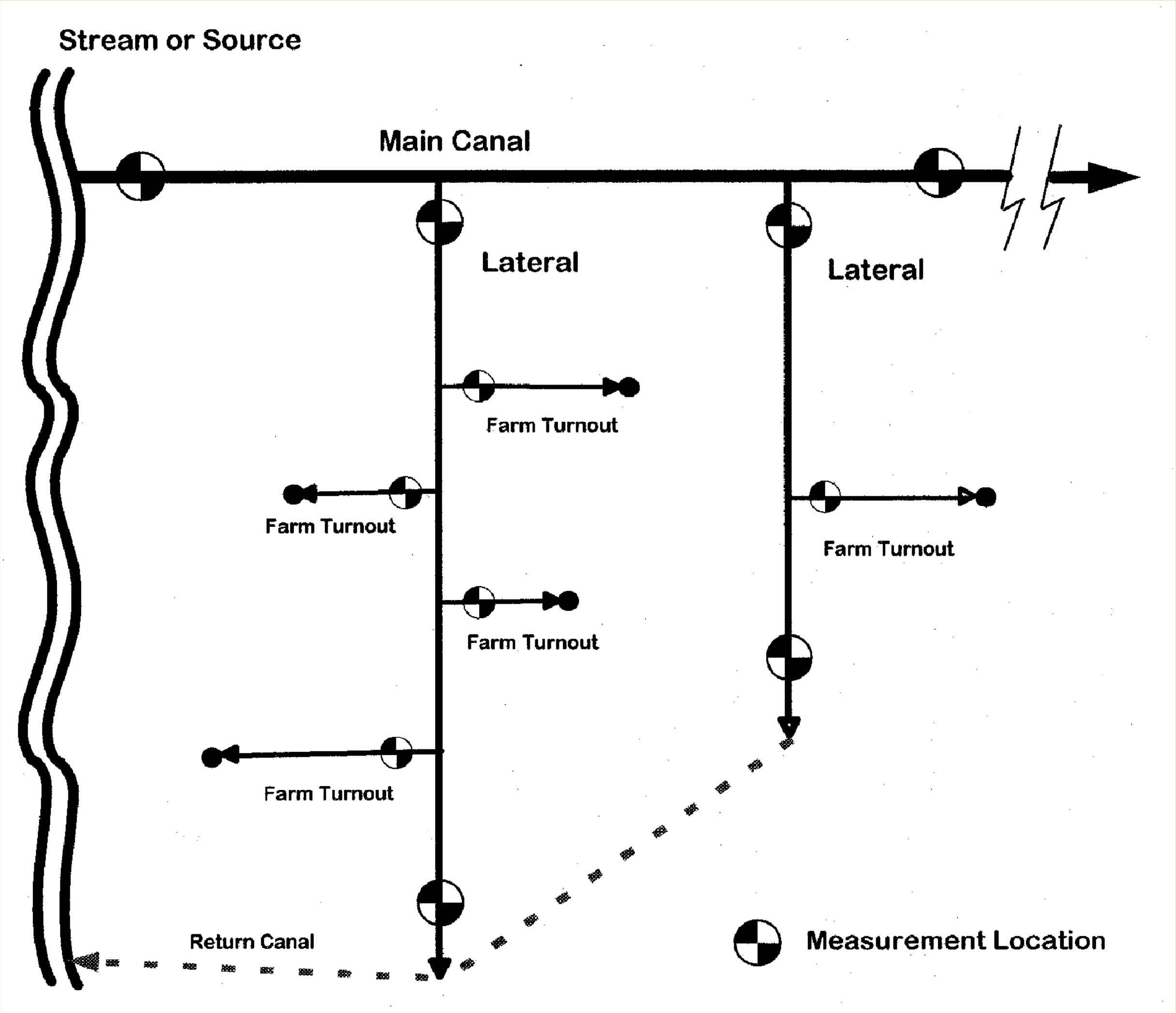

Figure 5:2: Irrigation Scheme with ideal water measurement system

Source: Bureau of Reclamation

From the scheme perspective, water measurement will help with:

- Assembling information needed for a detailed water budget
- Establishing water use efficiency targets to benchmark against other schemes
- Identifying areas where water use efficiency improvement can be achieved
- Implementing a billing system based on deliveries

At the farm level, water measurement will help with application of the proper amount of water to meet crop requirements and therefore may help to:

- Reduce erosion
- Improve crop yield and quality for the same amount of water
- Set on-farm water use application rates to compare with other irrigators irrigating similar crop having considered the climatic, irrigation systems, soil type and their water holding capacity.
- Identify management options to improve on-farm water use efficiency, and
- Reduce drainage problems

There are different types of flow measurements that a WUA or IB can use. These are discussed in the following section.

5.3 How to measure irrigation water use

Table 5.1 below provides a list of commonly used flow measurements in irrigation agriculture.

Table 5:1: Commonly use flow measurements

Direct measurements for closed channels and pipelines	Propeller or impeller meters
	Orifice, venturi, or differential pressure meters
	Magnetic flux meters (both insertion and flange mount)
	Ultrasonic meters (travel-time method)
Direct measurements for open channels	Weirs and flumes
	Stage discharge rating tables
	Area/point velocity measurements
	Ultrasonic (doppler and travel time methods)
Indirect measurements	Energy used by a pumping plant
	Elevation change of water level in a storage reservoir
	Timing and estimated flow rate

Source: Texas Water Development Board

5.3.1 Flow measurement – conveyance and distribution infrastructure

At the source, because irrigation water for most irrigation schemes is released from dams into either canals or into the river as a conduit, there are flow measurements provided at the outlets of most dams into the canals. These are mainly flow meters. The flow records can be obtained from the water operator of the dam which can be the Department of Water Affairs (DWA) or the WUA or a private company if the dam is owned and operated by a company such as Exxaro Resources Limited which operates the Mokolo Dam.

The measurements used in recording the flows from the main canals are measuring weirs, Parshall flumes or water meters. Magnetic and Ultrasonic flow meters are sometimes installed but these tend to be very expensive and difficult to maintain for most WUA except at the main source such as a dam.

At the outset there should be recognition of the need to balance science and rigour against what is measured and used by irrigators and water supply authorities in their normal activities with the cost of installing flow measurement. While there is scope to increase and improve what is currently measured at present the most likely data available would be:

- volume of water delivered from the scheme headworks from DWA flow meters
- some volume measurements at major sub-district off-takes from the primary conveyance canals into the distribution canals (see **Figure 5.2** above)
- water volume delivered at the farm gate from the distribution (or secondary) canals from measuring weirs.
- In the case of water delivered using the river as a conduit, water pumped at the river pumping station or at the farm borehole or well should have a flow meter. This can also be estimated by using a bucket and stopwatch to determine the flow rate and together with the pumping hours determine the volume per period.
- area of crop grown
- crop yield (tonnes, bales, litres milked, etc.)
- rainfall
- some soil water measurement (irrigation scheduling)
- some crop water use data from irrigation scheduling

5.4 Determining the water delivered to field edge

In order to determine the volume of water delivered at each farm gate, there are three points where the measurement of the water is required. The first is the volume released from the storages which can be either a dam or a weir or a borehole into the conveyance infrastructure. This water is released into the primary or main canal system as indicated in **Figure 5.2**. The operator of the dam or storage from which the water is released which can be the DWA if it is a multi-purpose dam.

The second measurement required is the flow rate and the total volume delivered at the block of fields. Where a WUA has canal infrastructure or conveyance through streams and rivers, it is likely that the flow measurements will be available in the form of weirs. The **weir discharge measurement** consists of measuring depth or **head** relative to the crest at the proper upstream location in the weir pool, and then using a table (see Table 5.2 below) or equation for the specific kind and size of weir to determine discharge. **Figure 5.3** below provides the general configuration of weir use for irrigation flow measurements. Commonly, a **staff gauge**, having a graduated scale with the zero placed at the same elevation as the weir crest, measures head (H). Putting staff gauges in stilling wells dampens wave disturbances when reading head. Using vernier hook point gauges in stilling wells produces much greater accuracy than staff gages. These staff gauges must be zero referenced to the weir crest elevation.

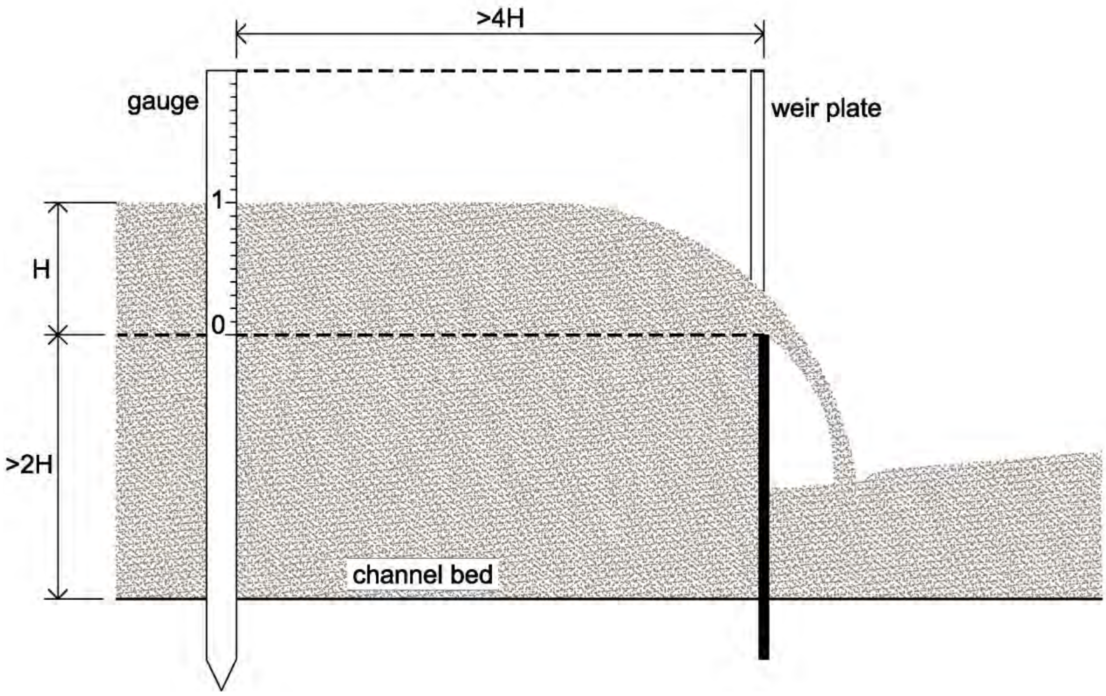

Figure 5:4: Configuration of the weir use for irrigation measurement

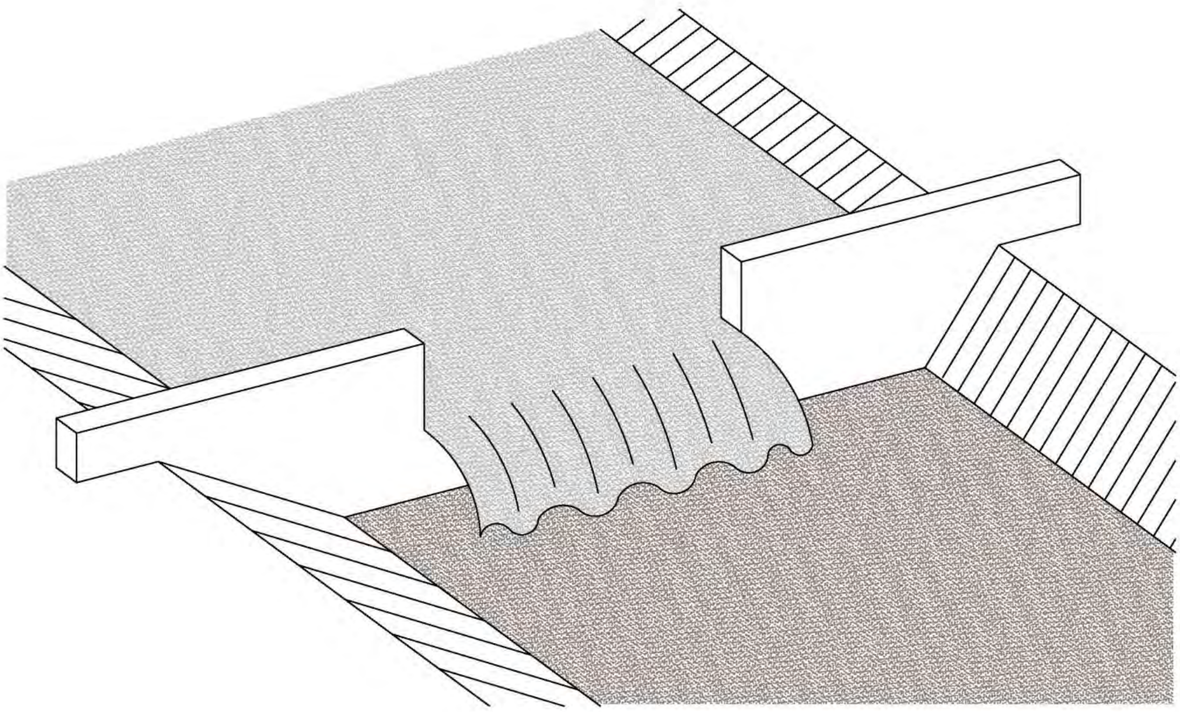

Figure 5:3: The rectangular weir: A sharp crested weir for discharge measurement

The flow measurement using a V-notch weir can be calculated using the following equation

Equation 6: $Q\ (l/s) = 0.0146 \times (H^{2.5})$

Where

H is in cm,

The other approach is based on the calibration of height and discharge as illustrated in **Table 5.2** below.

Table 5:2: Tabular rough calculation for a V-notch weir

Height	Discharge	Height	Discharge	Height	Discharge	Height	Discharge
(cm)	(l/s)	(cm)	(l/s)	(cm)	(l/s)	(cm)	(l/s)
5	0,803	14	10,167	23	35,039	32	80,057
6	1,257	15	12,066	24	38,973	33	86,459
7	1,836	16	14,169	25	43,160	34	93,175
8	2,551	17	16,477	26	47,606	35	100,19
9	3,409	18	19,001	27	52,317	36	107,52
10	4,420	19	21,748	28	57,306	37	115,17
11	5,592	20	24,719	29	62,560	38	123,13
12	6,935	21	27,921	30	68,106		
13	8,458	22	31,359	31	73,963		

Therefore based on the flow measurement records, the daily, weekly, monthly, or annual volume of water transmitted to the field edge can be determined by determining the number of hours per day the irrigation water was released from the source into the conveyance and distribution infrastructure as illustrated in the example 5 below.

Example 5:

The depth of flow for a V-notch weir constructed across the canal was measured to be 20 cm. Determine the flow rate to the irrigation scheme. The release from the dam into the canal on that day was for 20 hours. What is the volume of water released on the day?

Answer:

Based on equation 6: Q (l/s) = 0.0146 * 20^2.5 =

= 26.11 l/s

From Table 5.2 Q (l/s) = 24.7 l/s (there is a 5% difference which is acceptable).

Volume of water delivered on the day

Vol (Q) m = 26.11*60*60*20/1000 (m3/day)

= 1 879.92 m^3 or 1.88 Ml

5.4.1 Water delivered to the block of fields

The amount of water delivered to the block of fields would be the difference between the source flow record and the flow at the lateral as illustrated in **Figure 5.2**. This would provide the baseline irrigation water which is transported by the conveyance infrastructure. It is important to record the flows to the block of fields on a weekly, monthly and seasonal basis.

Table 5.3 below provides the baseline monthly flows from the source to the block of fields. This information can be used to determine the conveyance losses as described in the previous chapter.

Table 5:3: Baseline irrigation conveyance monthly flow to the scheme (m^3)

Year	Releases into canals	Scheme rainfall	Total release into canal	Water delivered to scheme
Aug-98	14,500.00	-	14,500.00	10,875.00
Sep-98	17,500.00	2,000.00	19,500.00	14,040.00
Oct-98	18,235.00	1,750.00	19,985.00	13,589.80
Nov-98	13,765.00		13,765.00	10,736.70
Dec-98	5,750.00	5,750.00	11,500.00	8,050.00
Jan-99	8,750.00	5,765.00	14,515.00	11,612.00
Feb-99	9,750.00	5,450.00	15,200.00	12,464.00

Year	Releases into canals	Scheme rainfall	Total release into canal	Water delivered to scheme
Mar-99	12,890.00	2,750.00	15,640.00	12,355.60
Apr-99	13,765.00	3,506.00	17,271.00	14,162.22
May-99	16,540.00	575.00	17,115.00	14,547.75
Jun-99	13,950.00		13,950.00	11,578.50
Jul-99	13,950.00		13,950.00	11,439.00
Seasonal Total	159,345.00	27,546.00	186,891.00	145,450.57

5.5 Estimating Water Requirements for different Crop types

Now that the weekly, monthly or annual flow records for the conveyance and distribution of the irrigation water to the field edge can be provided from the flow measurements discussed in the previous section, the irrigation water used by the different crops should be determined. The crop water requirements for different crop types must be estimated in order to complete the irrigation water budget. The two most common approaches are the:

1. Crop Factor Approach which is based on crop factors, pan evaporation data and pan site adjustment factors.
2. Crop Coefficient Approach which is based on crop coefficient and climatic data.

Both of these approaches enable crop water use to be calculated retrospectively, which is essential when reporting against daily, weekly and monthly historical data.

5.5.1 The crop factor approach

The crop factor approach is the most widely accepted method of calculating crop water use across the irrigation industry. The approach relates crop water use to measured evaporation (normally from a USBR Class A Pan), using the following equation:

$$ET_c \text{ (mm/day)} = K_f * E_{pan} \text{ (mm/day)} * K_a$$

where: ET_c = Calculated crop water use

K_f = Crop Factor (refer to Table 5.4 below)

E_{pan} = The measured evaporation from a USBR Class A Pan

K_a = Pan Site Adjustment. This factor takes into account the positioning of the pan in the landscape. This factor is unique to each pan and site.

E_{pan} provides a measure of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. As the evaporation results from USBR Class

A Pans are affected by the physical placement of the pan in the landscape (e.g. cleared areas, atmospheric humidity, etc.), a Pan Site Adjustment Factor (Ka) needs to be calculated to offset the effect of the positioning of the pan.

There are a number of Class A Pan sites in the country. These sites are generally associated with Weather Bureau weather stations.

Table 5:4: Example of the crop factors used to determine crop water requirement

Crop		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Annual Pasture		0	0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0	0
Perennial Pasture		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Vines	Min	0.25	0.3	0.25	0.1	0	0	0	0	0	0.1	0.25	0.25
	Max	0.5	0.6	0.55	0.4	0	0	0	0	0.21	0.21	0.35	0.5
Peaches (Feb Harvest)		0.8	1	0.4	0.2	0	0	0	0	0.2	0.4	0.6	0.6
Peaches (March Harvest)		0.8	1	1	0.4	0	0	0	0	0.2	0.4	0.6	0.6
Peaches (RDI Feb Harvest)(1)		0.8	1	0.4	0.2	0	0	0	0	0.2	0.4	0.3	0.3
Peaches (RDI March Harvest)(1)		0.55	1	1	0.4	0	0	0	0	0.2	0.4	0.3	0.3
Pears		1	1	0.4	0.4	0	0	0	0	0.2	0.5	0.6	0.8
Pears (RDI)(1)		1	1	0.4	0.4	0	0	0	0	0.2	0.5	0.2	0.5
Apples		0.8	0.8	0.8	0.4	0	0	0	0	0.2	0.5	0.6	0.6

Source: Food and Agricultural Organisation

Table 5:5: Crop coefficients for perennial crops and pastures in the summer rainfall areas

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Subtropical	0.80	0.80	0.80	0.80	0.80	0.80	0.65	0.65	0.65	0.65	0.70	0.70
Deciduous	0.85	0.78	0.64	0.50	0.27	0.27	0.27	0.27	0.55	0.85	0.85	0.85
Grape	0.73	0.63	0.45	0.35	0.20	0.20	0.15	0.15	0.15	0.21	0.31	0.53
Grape	0.70	0.70	0.55	0.35	0.31	0.31	0.31	0.31	0.31	0.35	0.60	0.67
Pasture	0.80	0.80	0.80	0.80	0.80	0.10	0.10	0.10	0.80	0.80	0.80	0.80
Lucerne (Frost)	0.80	0.80	0.80	0.80	0.80	0.10	0.10	0.10	0.80	0.80	0.80	0.80
Coffee	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Tea	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Olive	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sugarcane	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Date	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Pineapple	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35

Source: Hassan et all 2003

5.5.2 The crop coefficient approach

The crop coefficient approach is based on calculating reference crop evapo-transpiration using the Penman-Monteith equation or other formula, which draws on climatic data as inputs. Using the crop coefficient approach, crop water use is calculated based on the following equation:

$$ET_c\ (mm/day) = ET_o\ (mm/day) * K_c$$

where: ET_c = Calculated crop water use

ET_o = The evapo-transpiration rate from a reference crop that is not short of water

K_c = Coefficient relating ET_o calculated via the Penman-Monteith equation to ET_c.

The Penman-Monteith equation is primarily used by researchers because it is considered to be the most accurate formula for calculating plant water use from climatic data. Climate data used in the Penman-Monteith equation is can be obtained from Weather Station

There are a number of weather stations throughout the country. The climatic data required to quantify the Penman-Monteith equation are:

- air temperature
- wet bulb temperature and dry bulb temperature (or Relative Humidity)
- radiation
- wind speed.

There is however still considerable uncertainty associated with the accuracy and consistency of the climatic data (e.g. radiation data), and a lack of crop coefficients for key irrigated agricultural crops.

Based on the above factors, and the historic wide-ranging use of the crop factor approach, the application of the crop coefficient method is currently not considered to be the preferred approach to calculate crop water use for WUE performance reporting purposes.

Although the above two approaches can be used to determine the crop water requirements it is recommended to use the SAPWAT model which is available on the Water Research Commission (WRC) website.

5.6 Volume of return flow

Besides measurements of the flow of water conveyed, distributed and used by the crop as described above, in order to complete the irrigation water budget, there should be measurement of drainage water which is return back to the water supply system. Similar flow measurements as for open conduits can be used to measure the volume and flow rate of the return flow.

5.7 Determination of an irrigation water balance of an irrigation scheme

To determine the irrigation baseline water use, the flow measurements of the diversion works into the conveyance infrastructure, the precipitation during this period, any groundwater pumping by the individual irrigators should be provided. This will provide the Total inflow into an irrigation scheme. On the other side of the equation is what happens to all the water brought to the irrigation scheme. Some of the water will be lost in the conveyance and distribution infrastructure, spills because of operation, while the crops will use the water through evaporation and transpiration. Because not all the water applied to the crop is used as the soil-moisture level reaches a saturation point at which point the rest of the water goes into groundwater as deep percolation or returned back into the river or streams. The water balance equation can be written as follows:

Total inflow = Direct diversion volume + Storage releases+ supplemental groundwater + precipitation in the scheme area

Total outflow = Crop ET + Evaporation /Seepage in conveyance + Drainage + Operational spills

The water balance is therefore given as:

Total inflow = Total outflow.

The irrigation water balance is an accounting of all water volumes that enter and leave an irrigation scheme over a specified period of time. There are sub-categories of water balances which should be determined in an irrigation scheme. These include conveyance water balances, and on farm irrigation water balances. Therefore water balances can be conducted for a field, for a farm, for an irrigation district or scheme or for the catchment in which the irrigation is taking place. **Table 5.6** below provides an irrigation water balance undertaken for an irrigation scheme for a calendar year. The total inflow is all from measured and recorded information. The ET is determined as previously discussed above. The difference between the total inflow and the crop ET and return flow is the unaccounted for water (UAW).

For the water conservation stakeholder accord, it is important to then disaggregate the UAW to determine where the water losses are taking place. This can be used to determine why there are losses and whether there are opportunities for savings if some intervention measures are implemented.

A typical water balance assessment can be represented by the process flow chart illustrated in **Figure 5.5** below.

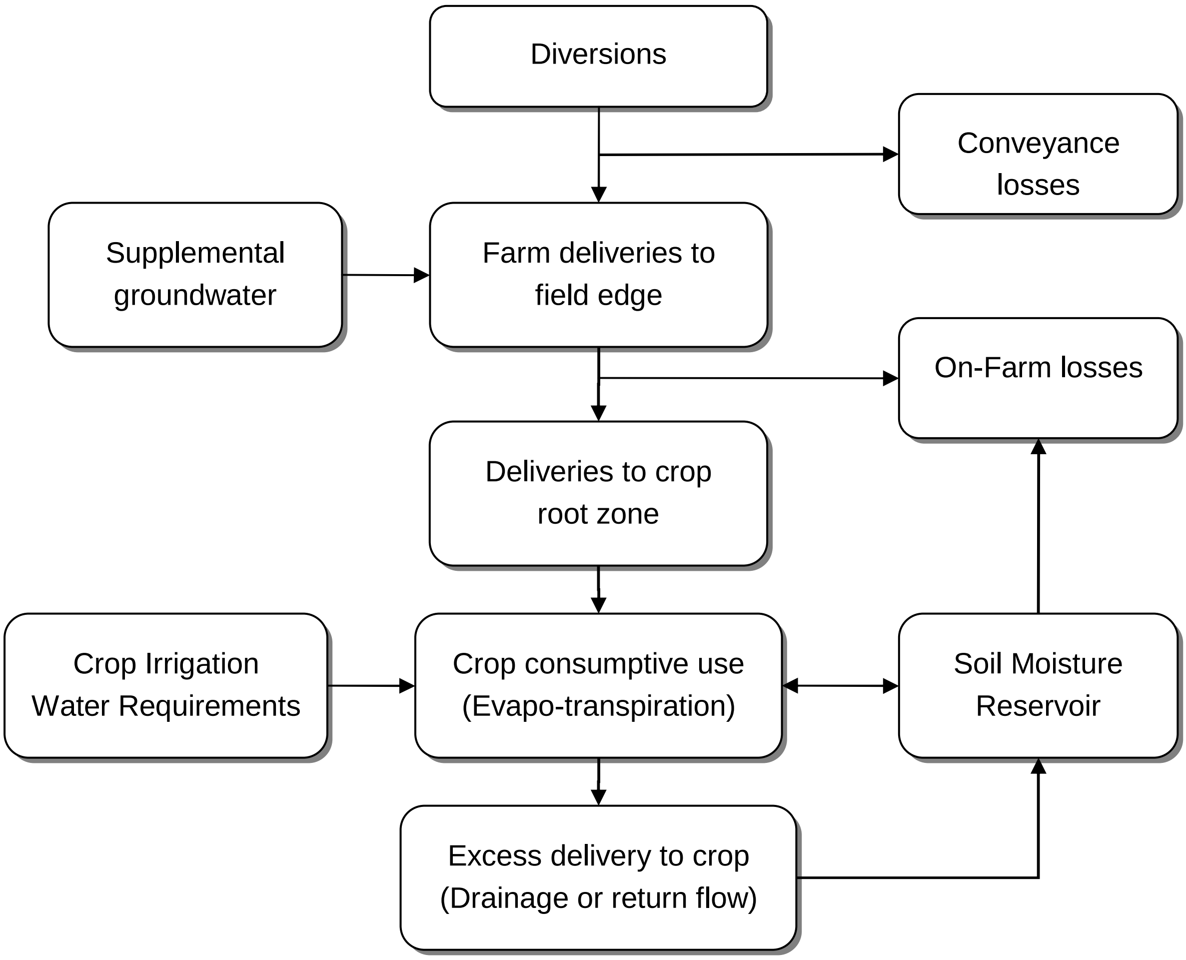

Figure 5:5: Typical irrigation water balance process flow chart

Table 5:6: Example of an irrigation water budget

	INFLOWS					OUTFLOWS				
Month	Direct Diversion	Storage Release	Ground Water Pumping	Precipitation	Total Inflows	Operational Spills	Drainage	Evap. & Seepage	Crop ET	Total Outflow
Jan	0	0	0	1,200	1,200	0	720	480	0	1,200
Feb	0	0	0	1,500	1,500	0	900	600	0	1,500
Mar	0	0	0	2,250	2,250	0	1,350	900	0	2,250
Apr	3,581	0	0	2,700	6,281	105	527	1,053	3,648	6,281
May	8,723	0	0	2,550	11,273	1,491	1,491	1,988	6,302	11,273
Jun	9,318	0	0	750	10,068	705	1,411	1,411	6,541	10,068
July	9,692	4,395	550	450	15,024	1,053	2,107	2,107	9,757	15,024
Aug	5,777	7,770	400	300	14,247	1,208	2,416	2,416	8,207	14,247
Sep	2,889	4,101	0	600	7,589	611	1,221	1,221	4,536	7,589
Oct	654	978	0	750	2,382	195	389	389	1,409	2,382
Nov	0	0	0	750	750	0	450	300	0	750
Dec	0	0	0	1,050	1,050	0	630	420	0	1,050
Total	**40,634**	**17,244**	**950**	**14,100**	**73,614**	**5,368**	**13,612**	**13,285**	**40,400**	**73,614**

6 IDENTIFICATION OF OPPORTUNITIES TO IMPROVE IRRIGATION WATER USE EFFICIENCY

6.1 Why it is important to identify opportunities for improving water use efficiency

In order to set meaningful water use targets, the amount of water that can potentially be saved through implementation of water conservation and demand management measures should be determined first. Each opportunity can then be evaluated in terms of its viability, and those found to be viable can be planned for implementation. Implementation timelines will determine when the savings expected from planned conservation interventions can be built into targets. The identification of the opportunities for improving irrigation water use efficiency is fundamental to establishing realistic targets for the scheme and for the individual irrigator.

6.2 Assessment of conveyance and distribution losses

6.2.1 Conveyance water losses determination

An assessment of the conveyance and distribution losses is the first starting point in an irrigation system.

The determination of the conveyance losses is calculated using the following equation:

Conveyance losses, Ec = $(V_c + V_l) - (V_d + V_2)$

Where

E_c = conveyance losses (m^3)

V_c = volume of water at canal headworks (m^3)

V_l = inflow, if any, from other sources (m^3)

V_d = volume of water delivered to the farmer (m^3)

V_2 = non-irrigation deliveries from the conveyance system (m^3)

The conveyance losses can be expressed as a percentage as follows:

Conveyance efficiency (%) = $(V_d + V_2) / (V_c + V_l) * 100$

Example: 7: The volume of irrigation water released from the source (a dam) was measured for the month to be 150 000 m^3. Between the dam and the irrigation scheme, tributary inflows for the same were estimated to be 25 000 m^3. The volume of water delivered to the block of farms was measured for the same period to be 105 500 m^3. There were no inflows from other sources. Calculate the conveyance losses and determine what the irrigation conveyance efficiency was for the same period.

Answer:

Conveyance losses = (150 000 + 25 000) – (105 500)

= 69 500 m^3

Conveyance efficiency = 105 500 / (150 000 + 25 000) * 100

= 60.2%

The conveyance efficiency can then be benchmarked against the best management practices for conveyance of the irrigation water using similar conveyance infrastructure. Based on the benchmarking, the opportunities for improving irrigation water conveyance efficiency can be determined.

6.2.2 Opportunities for improving conveyance and distribution efficiency

Now that the conveyance or distribution losses have been determined for the conveyance and distribution system and having benchmarked against BMP, potential savings have been determined, the next step is to answer the question is "***where and how is the water being lost in the conveyance?***"

Conveyance losses take the following forms:

- **Leakage.** Leakage through channel banks and structures is counted as a conveyance loss. A proportion of leakage is a 'real' loss of water to the catchment. However, some leakage flows into drainage schemes to be re-used downstream, or into on-farm delivery systems where it is used for irrigation;
- **Seepage.** Seepage is the movement of water through the beds of irrigation channels. Seepage losses are 'real' losses when seepage flows to saline groundwater and becomes unusable. However, in some situations, such as in areas with low groundwater salinity, seepage may:
  - beneficially recharge rivers, or
  - form a lens of fresher groundwater near the surface that is either pumped from the ground for crop irrigation or intercepted by the roots of crops;
- **Evaporation.** Evaporation losses occur in channels and storages. Evaporation losses are a 'real' loss of water resource, in the sense that there is no economic value in water vapour. However, in situations where water ponded in storages provides recreational opportunities or amenity values, the loss of water through evaporation could be considered to be a cost associated with a beneficial use of the resource;

- **Metering inaccuracy**. With increased demands for shorter irrigation cycles and the increasing practice of operating channels at full volumes and outside calibration limits, the flow measurements may under-record the volume of water flowing through the flow measurement. The understatement of water actually used on farms for irrigation leads to an equivalent overstatement of the conveyance loss;
- **Unrecorded usage.** Not all water usage is measured. Water received through unmeasured outlets is recorded as a conveyance loss;
- **Outfalls or water flowing out of the downstream end of delivery systems**. In some areas, outfalls flow back into rivers and are available to downstream users and/or for environmental flows. This means that there are ‘good’ return flows on the other side of the coin to ‘bad losses’. The benefits and costs of reducing these losses are more complex than they appear at first sight; and
- **System filling.** Water used in the filling and draining of channels, pipes etc

The WUA should undertake a condition and performance assessment of the conveyance and distribution infrastructure by inspecting the conveyance system. Operation and maintenance records if they are available of the conveyance infrastructure can be a very good source of information of the opportunities available to reduce conveyance water losses. For example if there have been breakdowns on the conveyance infrastructure and the frequency of the breakdowns can give a good indication whether there are leakage problems.

6.3 Assessment of on-farm water use

6.3.1 Assessment of on-farm water use efficiency

There are three types of irrigation systems namely surface irrigation, sprinkler irrigation and micro-irrigation systems. In each of the three categories various irrigation types are available with different application efficiency as illustrated in **Table 6.1** below.

Based on the Department of Agriculture irrigation system efficiency varies from area to area. In general irrigation efficiency is related to the percentage of water delivered to the field that is used beneficially. The irrigation efficiency in South Africa is dependent on the following factors:

- How well the irrigation system is designed and managed, i.e. irrigation management
- Climatic conditions
- Reliability of water supply, so that water can be used when it is need rather than when it is available

Table 6:1: Types of irrigation system

System	Method	Description
Surface (Gravity)	Flood	Water is diverted from ditches to fields or pastures
	Furrow	Water is channelled down furrows for row crops or fruit trees
	Border	Water is applied to sloping strips of fields bordered by ridges
	Surge	Valves control delivery of water to fields in intermittent surges
Sprinkler (Pressurized)	Pivot & linear systems	High pressure
		Medium pressure
		Low pressure
	Side rolls	Mobile pipelines deliver water across fields using sprinklers
	Solid set	Pipes placed on fields deliver water from raised sprinkler heads
Micro-irrigation (Pressurized)	Surface	Emitters along pipes or hoses deliver water directly to the soil surface
	Sub-surface	Emitters along pipes or hoses deliver water below the soil surface
	Micro-sprinklers	Emitters on short risers or suspended by drop tubes sprinkle or spray water above the soil surface

The assessment of on-farm water use efficiency can be determined by measuring the volume of water delivered to the field edge and the volume of water returned to the river system. Example 8 provides how the on-farm irrigation application efficiency should be calculated where flow measurements are available.

Example 8:

The volume of water delivered to field edge of a block of farms of 10 000 ha was 175 000 000 m^3 for the year. The measurement of the return flow indicated that 30 000 000 m^3 returned back to the system The type of irrigation system is sprinkler centre pivots. Determine the irrigation water use per ha and Calculate the on-farm application efficiency for the scheme.

Irrigation water use per ha = (175 000 000 – 30 000 000)/10 000

= 14 500 m^3/ha

On farm irrigation application efficiency (EFF) (Volume of water delivered – Volume returned) / Volume delivered to field edge

= 145 000 000 / 175 000 000

= 82.8%

It is important that on farm irrigation efficiencies for a number of years as well as on a monthly basis are determined. This is because of the seasonal variation of effective rainfall over time.

6.3.2 Opportunities for improving on-farm application efficiency

There are a number of opportunities to improve on-farm irrigation efficiency. These include but are not limited to the following:

Changing the irrigation system

Depending on the crop types, an irrigator can consider where it is technically feasible or financial viable to change from one type of irrigation system (for example sprinkler) to a more efficient system (for example micro-irrigation).

In identifying the opportunities for changing the irrigation system the irrigator must consider the following aspects:

- The potential savings to be made from changing the irrigation system
- The capital costs and operating costs of the new infrastructure
- The benefit cost ratio based on the net present value of implementing the changing of the irrigation system.

The above considerations apply to all opportunities identified for improving irrigation water use efficiency. In the case of irrigators it is also important to determine who will benefit from implementing the water use efficiency improvements, and whether they can trade the water saved in the case of situations where the irrigator cannot expand his or her irrigation area.

Leaks on on-farm conduits and or pipes

As is the case with conveyance and distribution infrastructure, the on-farm irrigation has pipes and conduits to apply the irrigation water. The irrigator must check the condition of this infrastructure to determine whether the condition of the infrastructure is poor and whether there are opportunities to undertake repairs or refurbish the equipment.

Irrigation scheduling

Irrigation scheduling concerns the farmer's decision process concerning, 'when' to irrigate and 'how much' water to apply in order to maximize profit. This requires knowledge on crop water requirements and yield responses to water, the constraints specific to each irrigation method and irrigation equipment, the limitations relative to the water supply system and the financial and economic implications of the irrigation practice. Thus, the consideration of all these aspects makes irrigation scheduling a very complex decision making process, one which only very few farmers can understand and therefore adopt.

It is recognized, however, that the adoption of appropriate irrigation scheduling practices could lead to significant water savings while increasing crop yields and greater profit for farmers, reduced environmental impact of irrigation and improved sustainability of irrigated agriculture.

Consequently, there is a need to better identify the factors that could enhance the adoption of appropriate irrigation scheduling practices, favour the transfer of technology from research to practice, and give new orientation to researchers. These aspects are particularly important in that they concern the inter-relationship between on-farm irrigation systems and irrigation scheduling, and involve two related disciplines: irrigation engineering and agronomy. This aspect is beyond the scope of the Water Conservation Accord.

Water savings have been proven through irrigation scheduling. Losses can be greatly reduced, more water would be stored in the root zone, yields would increase and irrigators would get a return on capital required to implement irrigation scheduling techniques.

Farm irrigation scheduling depends upon the delivery schedule, e.g., rate, duration and frequency of irrigation are dictated by the system's operational policies (Goussard, 1996).

Reducing Evapo-transpiration

Evapo-transpiration is amount of water that evaporates from the soil and transpires from the plant. Irrigators can reduce evapo-transpiration by reducing unproductive evaporation from the soil surface, eliminating weed evapo-transpiration, shifting crops to plants that need less water.

Regulated Deficit Irrigation

Some growers use regulated deficit irrigation (RDI) to stress trees or vines at specific developmental stages to improve crop quality, decrease disease or pest infestation, reduce production costs, while maintaining or increasing profits. Conventional irrigation management strategy has been to avoid crop water stress.

RDI has been primarily used as a production management practice and the extent of its application in South Africa has not been quantified. Before RDI can be applied to other crops, information on its costs, risks, long-term impacts, and potential benefits including water savings must be determined. Once that is done, practical guidelines for growers on how to initiate, operate, and maintain RDI should be developed and disseminated.

6.3.3 Scheme irrigation efficiency

With the conveyance, distribution and on-farm irrigation water use efficiencies determined, the scheme irrigation efficiency can be calculated. The equation for the scheme irrigation efficiency is given as follow:

Conveyance Efficiency (E_c) x Field Canal/Conduit Efficiency (E_b) x Field Application Efficiency (E_a) = **Overall Scheme (E_s)**

This can be done for the monthly and annual irrigation efficiencies as illustrated in the following example.

Example 9:

The monthly conveyance and distribution efficiencies for the irrigation scheme were calculated to be 60% and 72% respectively while the average on-farm application efficiency was determined to be 80%. Determine the over scheme irrigation efficiency.

Answer

Overall scheme efficiency (Es) = Ec * Eb * Ea

= 0.6 * 0.72 * 0.80

= 0.35 or 35%.

The low overall scheme efficiency can be attributed to the low conveyance efficiency which indicates that of the volume of water released at the headworks, 35% of the water does not reach the scheme. Therefore the overall scheme efficiency can help determine where more effort should be put in identification of opportunities for improving irrigation water use efficiency.

7 BENCHMARKING OF IRRIGATION WATER USE EFFICIENCY AND SETTING OF IRRIGATION WATER USE TARGETS

7.1 Why it is essential to undertaken irrigation water use performance benchmark

The overall aim of benchmarking is to improve the performance of an organisation as measured against its mission and objectives. Benchmarking implies comparison – either internally with previous performance and desired future targets, or externally against similar organisations, or organisations performing similar functions. Benchmarking is a management tool already in use in both the public and private sector organisations.

Therefore in order to set realistic irrigation water use targets, it is important that an irrigation scheme is benchmarked against Best Management Practices (BMPs) for conveyance, distribution and on-farm application of the irrigation water. Benchmarking is about change, moving from one position to a better position. It is important that:

- those responsible within the organisation for the benchmarking programme have the authority to bring about change;
- the change process is fully integrated within the organisation's management processes and procedures

7.2 Setting timelines for water use targets

Water use targets should be reviewed at least annually, with a target determined for each year over a five year time horizon. Hence at any one time an organisation should have an overall target for the five years and five targets, one for each of the next five years. In any given year, the target for the next year may be viewed as a short term target and the target in five years time as a long-term target. Repeating the process each year allows for current approaches in water conservation as well as current business strategy, or in the case of the public sector, stakeholder priorities, to be incorporated into the process.

Continuous improvement is one of the drivers of target setting and performance monitoring, and hence the target for each year should demonstrate a progressive planned reduction in water intensity i.e. a progressive improvement in water use efficiency. These planned improvements should be based on opportunities that have been evaluated as described above. Over time however, it does become more and more difficult to continue to improve without significant capital investment. This is the law of diminishing returns as applied to water conservation.

7.3 Benchmarking of conveyance and distribution efficiency

When the baseline conveyance and distribution efficiency levels have been determined and opportunities for improving conveyance efficiency identified, the next step is to compare the conveyance efficiency of other schemes using similar infrastructure (e.g. concrete lined or unlined canals) factoring in the climatic conditions, etc and determine whether conveyance efficiency is lower than an irrigation scheme considered to be conducting Best Management Practices (BMP) as far as conveyance of irrigation water is concerned.

It is important that for the Water Conservation Stakeholder Accord, a database of the Best Management Practices and benchmarks for different types of conveyance and distribution infrastructure, i.e. lined and unlined canals, river transmission, pipelines, etc. are provided for different conditions and states. The DWA should consider undertaking the benchmarking study.

Assuming the conveyance of irrigation water by Scheme B is the most efficient compared to scheme A, the potential savings to achieve the same efficiency as the scheme considered to be operating under BMP for conveyance of irrigation water is calculated as follows:

Potential savings = Conveyance losses of scheme A * (E_c of scheme B – E_c of scheme A).

Example 10:

The conveyance efficiency of an irrigation scheme, A, which comprises of concrete lined canals was calculated as 60.2% (see example 7). The conveyance losses were 69 500 m^3 per month. This was compared with an irrigation scheme B, also with a concrete lined canal system. The conveyance efficiency was found to be 75%. The two schemes were found to be in similar climatic and geological conditions. Determine the potential savings that can be by Scheme A to improve its conveyance efficiency to 75% as is the case with Scheme B.

Answer:

Potential savings = 69 500 * (75 – 60.2) %

= 10 286 m^3 per month

This means that by implementing certain water loss control measures on the conveyance infrastructure, there is potential to save 10 286 m^3 per month. The issue now is over what timeframe this potential saving can be achieved. The overall target would be to save the full amount over say 5 year on an incremental basis as shown in **Table 7.2** below.

7.4 Benchmarking of on-farm irrigation water use

The next step once the on-farm irrigation efficiencies have been determined for the different block of farms in the scheme, the application efficiencies can be benchmarked against application efficiencies for different irrigation systems. **Table 7.1** below provides a range of attainable on-farm application efficiencies for various irrigation systems.

The calculated on-farm application efficiency can be benchmarked against the range of efficiencies provided in the table.

The low efficiency for flood irrigation is seen to be partly due to a high rate of deep percolation or leaching below the rooting zone, rendering the water unavailable for crop growth. Much of the deep percolation from flood irrigation is assumed to return to the system as return flow.

Table 7:1: Range of attainable[1] application efficiencies for various irrigation systems

System Type	Application efficiency Range * (%)	Hassan (%)
Surface Irrigation[2]		
Flood Basin	55 - 75	25 - 75
Flood Furrow (	50 -75	25 - 75
Sprinkler Irrigation		
Travelling Boom	60 -70	65
Centre Pivot and lateral move	75 -85	75
Dragline	70 -75	70
Hop along	75 -85	70
Micro-irrigation		
Drip	80 -85	85
Micro spray	90-95	80
Micro sprinkler	85 -95	80

[1]Attainable application efficiency does not consider management, only efficiency through design and installation

[2] Application efficiencies for surface irrigation not given since this varies with soil hydraulic properties and is site specific

Source: Hassan, et al, 2002

Table 7:2: Target setting for improving irrigation conveyance efficiency and expected savings from implementing WC intervention measures (ML)

Month	Volume released	Volume received at block of field	Conveyance losses	Conveyance efficiency	Target 5 Year Conveyance efficiency	Total savings	Expected annual savings Year 1	Expected annual savings Year 2	Expected annual savings Year 3	Expected annual savings Year 4	Expected annual savings Year 5
Jan	975.00	750.00	225.00	77%	90%	127.50	46.75	29.75	29.75	12.25	9.00-
Feb	2,350.00	1,700.00	650.00	72%	90%	415.00	152.17	96.83	96.83	49.17	20.00
Mar	2,560.00	1,875.00	685.00	73%	90%	429.00	157.30	100.10	100.10	50.00	21.50
Apr	3,581.00	2,542.00	1,039.00	71%	90%	680.90	249.66	158.88	158.88	73.48	40.00
May	8,723.00	6,850.00	1,873.00	79%	90%	1,000.70	366.92	233.50	233.50	100.38	66.40
Jun	9,318.00	7,575.00	1,743.00	81%	90%	811.20	297.44	189.28	189.28	95.00	40.20
July	9,692.00	7,650.00	2,042.00	79%	90%	1,072.80	393.36	250.32	250.32	100.30	78.50
Aug	5,777.00	4,650.00	1,127.00	80%	90%	549.30	201.41	128.17	128.17	70.00	21.55
Sep	2,889.00	2,350.00	539.00	81%	90%	250.10	91.70	58.36	58.36	31.00	10.68
Oct	4,560.00	2,750.00	1,810.00	60%	90%	1,354.00	496.47	315.93	315.93	125.60	100.07
Nov	3,500.00	2,005.00	1,495.00	57%	90%	1,145.00	419.83	267.17	267.17	110.00	80.83
Dec	1,250.00	868.00	382.00	69%	90%	257.00	94.23	59.97	59.97	30.00	12.83
Total	**55,175.00**	**41,565.00**	**13,610.00**	**75%**	**90%**	**8,092.50**	**2,967.25**	**1,888.25**	**1,888.25**	**847.18**	**492.56**

Table 7:3: Target setting for improving irrigation distribution efficiency and expected savings from implementing WC intervention measures (ML)

Month	Volume released	Total Volume received at field edge	Distribution Losses	Distribution efficiency	Target 5 Year conveyance efficiency	Total savings	Expected annual savings Year 1	Expected annual savings Year 2	Expected annual savings Year 3	Expected annual savings Year 4	Expected annual savings Year 5
Jan	750.00	650.00	100.00	87%	92%	40.00	14.67	9.33	9.33	6.67	-
Feb	1,700.00	1,350.00	350.00	79%	92%	214.00	78.47	49.93	49.93	35.67	
Mar	1,875.00	1,375.00	500.00	73%	92%	350.00	128.33	81.67	81.67	58.33	

Apr	2,542.00	2,015.00	527.00	79%	92%	323.64	118.67	75.52	75.52	53.94	
May	6,850.00	5,350.00	1,500.00	78%	92%	952.00	349.07	222.13	222.13	158.67	
Jun	7,575.00	6,105.00	1,470.00	81%	92%	864.00	316.80	201.60	201.60	144.00	
July	7,650.00	6,200.00	1,450.00	81%	92%	838.00	307.27	195.53	195.53	139.67	
Aug	4,650.00	3,215.00	1,435.00	69%	92%	1,063.00	389.77	248.03	248.03	177.17	
Sep	2,350.00	1,465.00	885.00	62%	92%	697.00	255.57	162.63	162.63	116.17	
Oct	2,750.00	2,050.00	700.00	75%	92%	480.00	176.00	112.00	112.00	80.00	
Nov	2,005.00	1,500.00	505.00	75%	92%	344.60	126.35	80.41	80.41	57.43	
Dec	868.00	620.00	248.00	71%	92%	178.56	65.47	41.66	41.66	29.76	
Total	**41,565.00**	**31,895.00**	**9,670.00**	**77%**	**92%**	**6,344.80**	**2,326.43**	**1,480.45**	**1,480.45**	**1,057.47**	

Table 7:4: Target setting for improving on-farm irrigation water use efficiency and expected savings from implementing WC intervention measures (ML)

Month	Volume released	Tailwater volume	Distribution Losses	Distribution efficiency	Target 5 Year conveyance efficiency	Total savings	Expected annual savings Year 1	Expected annual savings Year 2	Expected annual savings Year 3	Expected annual savings Year 4	Expected annual savings Year 5
Jan	650.00	445.00	205.00	68%	79%	68.50	13.70	13.70	13.70	13.70	13.70
Feb	1,350.00	895.00	455.00	66%	79%	171.50	34.30	34.30	34.30	34.30	34.30
Mar	1,375.00	950.00	425.00	69%	79%	136.25	27.25	27.25	27.25	27.25	27.25
Apr	2,015.00	1,350.00	665.00	67%	79%	241.85	48.37	48.37	48.37	48.37	48.37
May	5,350.00	3,650.00	1,700.00	68%	79%	576.50	115.30	115.30	115.30	115.30	115.30
Jun	6,105.00	4,000.00	2,105.00	66%	79%	822.95	164.59	164.59	164.59	164.59	164.59
July	6,200.00	4,020.00	2,180.00	65%	79%	878.00	175.60	175.60	175.60	175.60	175.60
Aug	3,215.00	1,965.00	1,250.00	61%	79%	574.85	114.97	114.97	114.97	114.97	114.97
Sep	1,465.00	1,005.00	460.00	69%	79%	152.35	30.47	30.47	30.47	30.47	30.47
Oct	2,050.00	1,375.00	675.00	67%	79%	244.50	48.90	48.90	48.90	48.90	48.90
Nov	1,500.00	1,100.00	400.00	73%	79%	85.00	17.00	17.00	17.00	17.00	17.00
Dec	620.00	410.00	210.00	66%	79%	79.80	15.96	15.96	15.96	15.96	15.96
Total	**31,895.00**	**21,165.00**	**10,730.00**	**66%**	**79%**	**4,032.05**	**806.41**	**806.41**	**806.41**	**806.41**	**806.41**

Table 7.2 above provides an illustration of how the water conservation target for the conveyance infrastructure can be established for the irrigation scheme. The baseline water abstraction from the headworks of 55 175 Ml (or 55.175 million m^3) is being released and 41.565 million m^3 reaches a block of fields at the irrigation. Based on the monthly flow volumes it was determined that the annual conveyance efficiency was 75%. The type of conveyance infrastructure comprises of concrete lined canal system. However an assessment of the condition of the canal lined was found to be in a poor condition. It was estimated that water is being lost through leakage because of the poor concrete lining. Furthermore the climatic conditions are such that irrigation water is also being lost through evaporation from the surface. The ordering was also found to present problems in that it results in spillages as was the case in July. Based on the assessment, the WUA concluded that there were opportunities to increase the irrigation conveyance efficiency, by undertaking the following:

- Changing and improving the ordering system through improved irrigation scheduling
- Refurbishing the lining of the irrigation canal
- Construction of spillways to guide excess water safely to the drainage system

The potential savings from implementing the above measures was estimated to be 8.092 million m^3 (**see Table 7.2** above) which is 14.67% of the water released at the headworks. The target for improving irrigation water conveyance was therefore set at 90% over the next 5 years. The expected monthly and annual savings were then estimated based on the implementation plan of the water conservation measures.

The annual water release target is illustrated in **Table 7.5** below.

Table 7:5: Annual conveyance water use targets for the scheme

Year	Volume released	Conveyance efficiency
Baseline	55,175.00	75%
Year 1	52,207.75	80%
Year 2	50,319.50	83%
Year 3	48,431.25	86%
Year 4	47,584.07	87%
Year 5	47,082.51	88%

As illustrated in Table 7.5, although the target conveyance efficiency will improve from 75% to 88% by the end of year 5. However the target conveyance efficiency of 90% was not achieved. A review of the operations of the conveyance infrastructure can be undertaken to determine whether there are areas that can still be improved without significant capital investment such as converting the irrigation canal into a low pressure pipeline.

The same approach can be done for the distribution efficiency as illustrated in **Table 7.3** above.

In the case of the on-farm application efficiency, the same approach for target setting can be followed. However in the irrigation scheme there can be different irrigation systems being used for on-farm irrigation water application. Therefore the attainable irrigation efficiency is the weighted average of the various irrigation systems being used in the irrigation scheme.

For example there is 200 ha under micro-irrigation, drip irrigation, 120 ha under centre pivots and 180 ha under flood. From Table 7.1 above the weighted application efficiency can be calculated as follows:

Weighted on-farm application= {(200/500)*0.85} +{(120/500)*0.75} + {(180/500)*0.55}

= 0.34 +0.18 +0.2

= 0.72 or 72%.

Therefore based on the calculated on-farm application of 66% (see Table 7.4) and compared to the attainable irrigation application of 72%, indications are that the current irrigation management can be improved. This can be done by for example implementing irrigation scheduling methods to improve the current on-farm application from 66% to 70% if the irrigation systems are maintained.

However because 36% of the area being irrigated is under flood irrigation, this can be improved by changing from flood irrigation to centre pivots for example. This will increase the on- farm for the areas under flood from 55% to 75%.The target weighted on-farm application will be as follows:

Target weighted on-farm application = {(200/500)*0.85} +{(120/500)*0.75} + {(180/500)*0.75}

= 0.34 +0.18 +0.27

= 0.79 or 79%.

Based on **Table 7.5**, the potential savings that can be made over the next 5 years is 4.052 million m^3 per annum. The changing from flood irrigation to centre pivots can be done over the next 5 years while the irrigation scheduling is conducted from year 1 onwards.

To achieve these targets, it is important that the cost of implementation and the financing of the measures is mainstreamed into the management of the irrigation scheme where the WUA engages with the irrigators and agrees on the water conservation management plan.

8 CONCLUSION

8.1 Overview

One of the best ways to communicate whether you are achieving your irrigation water use targets through your water use efficiency (WUE) efforts is through the annual performance report. Your report must include information about how much water is released at the headworks, how much water is lost in the distribution system, and what progress has been made toward achieving your water savings goals for the year.

Figure 8.1 provides an example of the reporting of progress made for irrigation scheme where besides the 5 year irrigation efficiency target is set, the annual targets have also been set and are monitored.

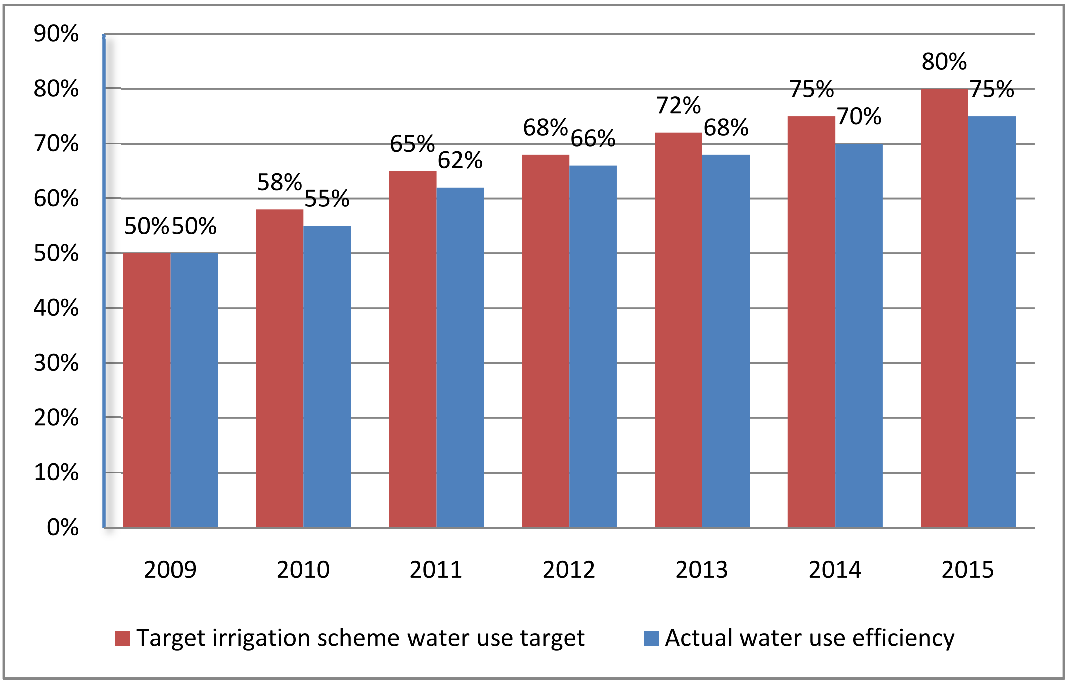

Figure 8:1: Reporting on scheme irrigation water use performance

This guideline represents a point of departure for baseline determination and water use target-setting in the commercial sector. Over time, it is expected that this guideline be improved, possibly incorporating details on specific sub-sectors within the irrigation sector. In its current format, it can however be applied to any sub-sector within the irrigation sector, provided that the principles illustrated here are adapted to account for any unique sub-sector characteristics.

As a final point, this guideline is for the benefit of users, and its ongoing improvement and development is welcome. Comments and suggestions for improvement of this guideline should be communicated to your sector representative.