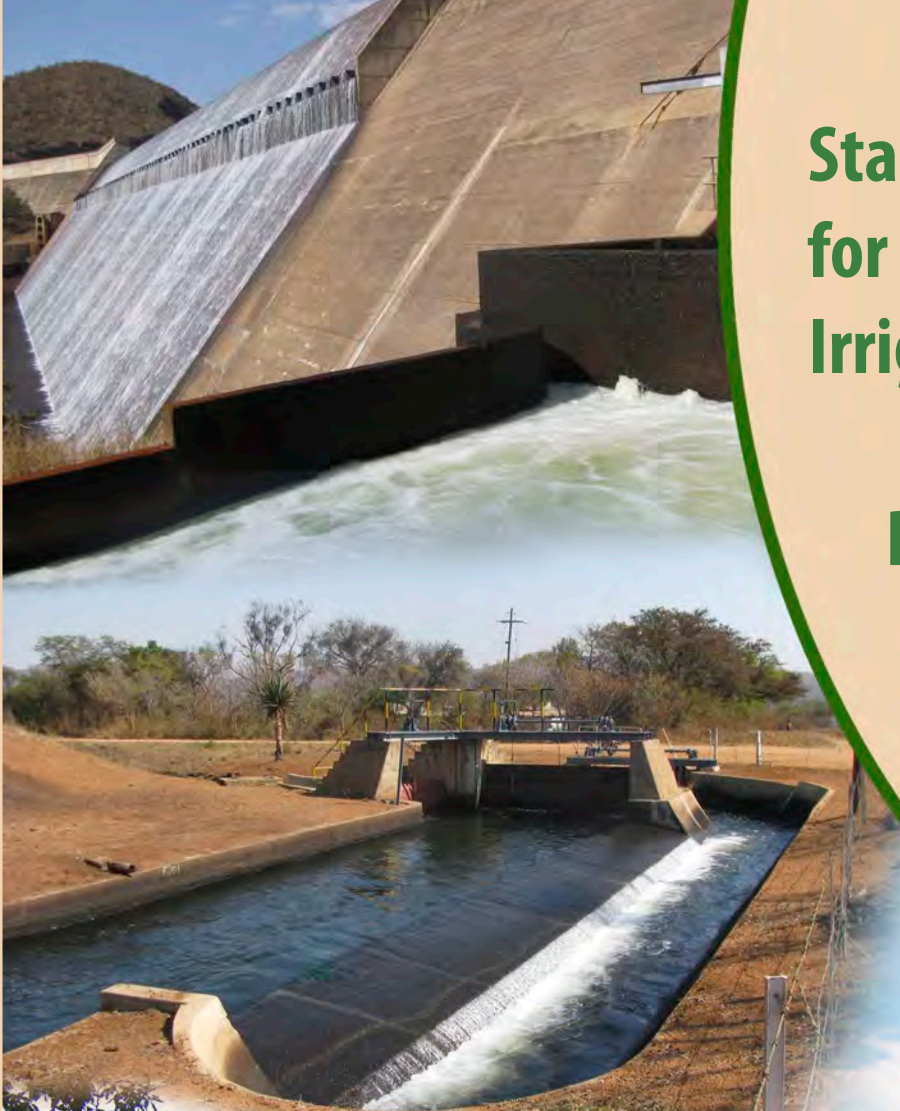

Standards and Guidelines for Improved Efficiency of Irrigation Water Use from Dam Wall Release to Root Zone Application:

MAIN REPORT

FB Reinders
(Project Leader)

WATER RESEARCH COMMISSION

TT 465/10

Standards and Guidelines for Improved Efficiency of Irrigation Water Use from Dam Wall Release to Root Zone Application

VOLUME 1 OF 3

MAIN REPORT

Report to the

Water Research Commission

by the

Agricultural Research Council

ARC-Institute for Agricultural Engineering

Project Leader: F B Reinders

WRC Report No. TT 465/10

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This report forms part of a series of 3 reports. The other reports in the series are:

Standards and guidelines for improved efficiency of irrigation water use from dam wall release to root zone application: Guidelines (WRC Report TT 466/10), and

Standards and guidelines for improved efficiency of irrigation water use from dam wall release to root zone application: Supplementary Information (WRC Report TT 467/10).

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Dzindi, Limpopo

Gamtoos, Eastern Cape

Hartbeespoort, North West

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Executive summary

This report concludes the solicited WRC Project K5/1482/4 "Standards and guidelines for improved efficiency of irrigation water use from dam wall release to root zone application", which was undertaken during the period April 2004 to March 2010.

The WRC recognised with considerable foresight in 2003 already that the efficient use of water by the irrigation sector will become increasingly important in the future. Although influencing factors such as significant economic and population growth as well as variable climatic conditions could not have been predicted, the project was however perfectly timed to investigate the needs of the water users as well as the organisations that are responsible for water management at different levels. A call by the President of South Africa in 2009 that water losses in the agricultural should be halved by 2014, as well as a new effort by the Department of Water Affairs to finalise the Water Conservation and Water Demand Management (WC/WDM) regulations coincided with the final project report compilation process.

With the agricultural water use sector being the largest of all water use sectors in South Africa, there have been increased expectations from government that the sector should increase efficiency and reduce consumption in order to increase the amount of water available for other uses, and in particular for human domestic consumption. Great emphasis has been placed on how an increase in efficiency will lead to reduced consumption by agricultural users and thereby "release" some of the annual water yield for use by the domestic sector.

The expectation was that the performance of all irrigation systems should be assessed in terms of one or more performance indicators which should be compared with benchmarks, and improved until the benchmark is achieved.

In the light of these expectations, the original WRC project proposal called for activities to be undertaken to evaluate appropriate measurement tools, propose best management practices, and formulate guidelines to improve conveyance, distribution, on-farm surface storage, field application, soil storage and return flow efficiencies of irrigation water use.

The project team was to address this main aim through the following project phases:

- Standardise the terminology, definitions and formulae for distribution, surface storage, application, soil storage and return flow efficiencies;
- Develop locally relevant tools and criteria to measure efficiency and practically achieve benchmarks;
- Apply the tools at selected locations to determine current efficiency levels, propose best management practices for improvement and develop site specific scenarios for water management, and
- Compile guidelines for improving water use efficiency.

The solicited project commenced in April 2004, having been preceded by an industry workshop organised by the WRC in 2003 to obtain inputs for the project terms of reference, and being concluded in 2010 with the writing of the final report.

The project activities included field work at scheme and farm level at irrigation schemes across the country:

- Breede River, Western Cape
- Canal Irrigation Scheme, KwaZulu-Natal
- Dzindi, Limpopo
- Gamtoos, Eastern Cape
- Hartbeespoort, North West
- Hex River Valley, Western Cape
- Loskop, Mpumalanga/Limpopo
- Orange-Riet, Free State/Northern Cape
- Steenkoppies, North West
- Vaalharts, North West/Northern Cape
- Worcester East, Western Cape

The main output of the project was the compilation of guidelines for improved irrigation water management from dam wall release to root zone application. The guidelines are aimed at assisting both water users and authorities to obtain a better understanding of how irrigation water management can be improved, thereby building human capacity so that targeted investments can be made with fewer social and environmental costs. Using lessons learnt during the WRC project, best practices and technologies are introduced and illustrated.

The Guidelines (Volume 2 – WRC Report No. TT 466/10) consist of four modules. Each module is a stand alone unit with its own table of contents, introduction and conclusion. Module 1 provides an introduction to the fundamental concepts and should be used in conjunction with any of the other modules to introduce the fundamental concepts.

Module 1: Fundamental concepts

This module introduces the concept of optimised water use, irrigation system performance and the water balance. It also touches on lawfulness of water use, demand management and appropriate technologies.

Module 2: In-field irrigation systems

This module addresses the water balance approach at field level, and describes how each decision made during the planning, design and management of irrigation systems influences the amount of water required to irrigate the crop successfully. The most efficient in-field irrigation system will be one that:

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

Module 3: On-farm conveyance systems

This module addresses the water balance approach at farm level, and describes how the on-farm water distribution system should be planned, designed and managed to optimise water and energy requirements. The most efficient on-farm conveyance system will be one that:

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

Module 4: Irrigation schemes

This module introduces the water balance approach at irrigation scheme level, and describes how technologies such as the Water Administration System (WAS), SAPWAT, iScheme and water measuring devices can be used to ensure greater reliability of supply to all water users on a scheme. For an irrigation scheme, good water management means meeting the water demands of its customers as efficiently as possible, with minimum waste or loss. Good water management is, therefore, fundamentally important to good overall scheme management.

In the last volume (Volume 3 – WRC Report No. TT 467/10) the **Supplementary information** is provided. It includes the scheme and on-farm data on when the research was carried out and the evaluation of the water balance framework.

A large volume of data has been collected and knowledge generated in the course of the project. It is recommended that the project output, i.e. the guidelines for management advice on improved efficiency of irrigation water use, should be developed into a user-friendly computer-based model, packaged with supporting training material aimed at helping water users, irrigation organisations, the irrigation industry and policy makers, achieve an equal understanding of the potential and realities of efficient irrigation water use across all levels of water management, and encouraging the adoption of the water balance approach.

Table of Contents

This report forms part of a set of reports.

Volume 1: Main report

Volume 2: Guidelines

Volume 3: Supplementary information

Each volume is a stand-alone with its own table of contents.

Main report

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List of Acronyms and Abbreviations

AGEP	Groundwater Exploitation Potential ()
ARC	Agricultural Research Council
BC	Beneficial consumption
CI	Confidence Interval
CMA	Catchment Management Agency
CV	Coefficient of variation
DWEA	Department of Water and Environment Affairs
ECA	Environment Conservation Act (Act 73 of 1989),
ECSA	Engineering Council of South Africa
FWACS	Fractional water allocations and capacity sharing/water banking
GWCA	Ground Water Control Area
IB	Irrigation Board
ICID	International Commission on Irrigation and Drainage
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
NBC	Non-beneficial consumption
NEMA	National Environmental Management Act
NRF	Non-recoverable fraction
NWA	National Water Act (Act No.36 of 1998)
NWCDMS	National Water Conservation and Demand Management Strategy
NWRS	National Water Resources Strategy
PEL	Potential economic loss
PLL	Potential loss of life

RF	Recoverable fraction
SAAFWUA	South African Association for Water User Associations
SABI	South African Irrigation Institute
SC	Storage change
WAS	Water Administration System
WC/WDM	Water conservation and water demand management
WMP	Water Management Plan
WUE	Water Use Efficiency
WUA	Water Users Association

1 Introduction

This report concludes the solicited WRC Project K5/1482/4 "Standards and guidelines for improved efficiency of irrigation water use from dam wall release to root zone application".

The WRC recognised with considerable foresight in 2003 already that the efficient use of water by the irrigation sector will become increasingly important in the future. Although influencing factors such as significant economic and population growth, as well as variable climatic conditions could not have been predicted, the project was however perfectly timed to investigate the needs of the water users as well as the organisations that are responsible for water management at different levels.

1.1 Project background

The water requirements of irrigated agriculture in South Africa are estimated at 56% of the total annual water requirements of 22 045 million m^3 surface and groundwater. Although the contribution of irrigation to total agricultural production varies according to crop type, most of this water is used for commercial food production. With increasing water demand from the domestic, mining and industrial sectors due to urbanisation and higher standards of living, more pressure is being placed on agricultural water users to give up their share (Backeberg, 2007).

With the agricultural water use sector being the largest of all water use sectors in South Africa, there have been increased expectations from government that the sector should improve efficiency and reduce consumption, in order to increase the amount of water available for, in particular, human domestic consumption. Great emphasis has been placed on the expectation that an increase in efficiency will lead to reduced consumption by agricultural users and thereby "release" some of the annual water yield for use by the domestic sector. The expectation was that all irrigation systems' water use efficiency should be assessed in terms of one or more performance indicators which should be compared with benchmarks, and efficiency improved until the benchmark is achieved.

The project team addressed this need through the following project phases:

- Standardise the terminology, definitions and formulae for distribution, surface storage, application, soil storage and return flow efficiencies;
- Develop locally relevant tools and criteria to measure efficiency and practically achieve benchmarks;
- Apply the tools at selected locations to determine current efficiency levels, propose best management practices for improvement and develop site specific scenarios for water management, and
- Compile guidelines for improving water use efficiency (WUE).

The project commenced in April 2004, having been preceded by an industry workshop organised by the WRC in 2003 to obtain inputs for the project terms of reference, and being concluded in 2010 with the writing of the final report.

1.2 Project aims

The following aims were stated in the project proposal to be addressed by the project activities:

1.2.1 General

To evaluate appropriate measurement tools, propose best management practices and formulate guidelines to improve conveyance, distribution, on-farm surface storage, field application, soil storage and return flow efficiencies of irrigation water use.

1.2.2 Specific

- Collate and formulate consistent and standardised water use efficiency terminology (biological, technical and economic) based on local and international theory, concepts and practice defining conveyance, distribution, surface storage, application, soil storage and return flow efficiencies
- Identify efficient variables or factors for quantifying conveyance, distribution, surface storage, application, soil storage and return flow efficiencies
- Obtain stakeholder support for proposed terminology and variables or factors and propose tools for measurement thereof
- Evaluate and test appropriate tools for measurement of conveyance, distribution, surface storage, application, soil storage and return flow efficiencies on selected irrigation schemes
- Implement tools to quantify (directly and /or indirectly) conveyance, distribution, surface storage, application, soil storage and return flow variables and factors on selected irrigation schemes
- Establish typical or representative current efficiency levels from dam wall release to root zone application on selected irrigation schemes
- Propose best management practices, which are practically achievable, based on potential efficiency levels/ standards/benchmarks on selected irrigation schemes
- Evaluate technical, economic and environmental feasibility of changing from current to best management practices based on beneficial and non-beneficial use of water on selected irrigation schemes
- Identify and evaluate possible scenarios for water management from dam wall release to root zone application on selected irrigation schemes.

- Formulate guidelines for management advice to improve conveyance, distribution, surface storage, application, soil storage and return flow efficiencies on selected irrigation schemes

1.3 Project deliverables

The aims of the project were addressed over the 6 year period through hundreds of hours of field work, analyses and report writing that were presented to the WRC as the following deliverable reports:

- Review of international and local literature
- Interim report on standardised terminology and essential variables or factors
- Interim report on interaction with stakeholders to document support for draft terminology and variables or factors
- Interim report on desktop study to identify and select appropriate tools
- Interim report on scoping study to propose schemes and obtain agreement on proposed schemes
- Interim report(s) on field testing and evaluation of appropriate tools (pilot sites)
- Interim report on progress with installation and effective operation of measuring equipment (where appropriate)
- Interim report(s) on field testing and evaluation of appropriate tools (additional sites)
- Interim report on results of appropriate direct and indirect measurement
- Interim overview report on current efficiency levels
- Interim report(s) on best management practice for conveyance, distribution, surface storage, application, soil storage and return-flow of irrigation water
- Interim report(s) on best management practice for conveyance, distribution, surface storage, application, soil storage and return-flow of irrigation water
- Interim report on evaluation of technical, economic, and environmental feasibility of changing from current to recommended best management practices
- Interim report on possible site specific scenarios for water management from dam release to root zone application
- Interim report on guidelines for management advice and training programmes to improve conveyance, distribution, surface storage, application, soil storage and return flow efficiencies
- Popular articles on research findings

- Annual progress reports (4) to the WRC
- Final project report to the WRC.

The raw data and deliverable reports are archived at the Agricultural Research Council's Institute for Agricultural Engineering, at 141 Cresswell Road, Weavind Park, Pretoria.

1.4 Project outcomes

Table 1 presents an overview of the project activities and outcomes, and their possible application. The table shows that the project activities were undertaken, and the outcomes implemented, in four phases:

- Baseline study phase

  During this phase, deliverables 1 to 9 were submitted. The various performance indicators previously available were reviewed, and irrigation systems evaluated to obtain information on the current status of irrigation schemes and systems. The outcome of this phase was a decision to introduce the water balance approach in which the framework components have to be defined and quantified for the boundary conditions selected, using standardised measurements), rather than the performance indicator approach.

- Assessment phase

  During this phase, existing best management practices, as compiled in deliverable 10, were used to assess the current status of irrigation schemes and systems, and identify to which components of the water balance framework improvements can be made. This may be at WMA, scheme or farm level where different sources of information are available for assessment.

- Scenario development phase

  During this phase, when deliverables 11 and 12 were submitted, alternative scenarios were developed for the components requiring change, and the feasibility of implementing the changes was assessed from technical, environmental and economic perspectives. Models were used for feasibility assessment, making use of available computer programs and data sets.

- Implementation phase

  In deliverable 13, recommendations were made for implementing feasible changes, and guidelines were developed. These guidelines should be promoted amongst all levels of stakeholders (WMA, scheme and farm), as a means of influencing the way in which water use efficiency is reported at the different management levels, for example in water use efficiency accounting reports, water management plans and water conservation plans.

Table 1: Overview of project activities and applications

Project phase:		Baseline study	Assessment	Scenario development	Implementation
Project deliverables:		Nr 1 to 9 (performance indicators investigated and system evaluations done)	Nr 10 (Best Management Practices considered)	Nr 11 & 12 (possible scenarios developed and feasibility of changing assessed)	Nr 13 (guidelines developed to implement project outcomes)
Outcome (process/es to be implemented, identified or developed in the deliverables above):		Quantify water balance system components for the current situation	Assess the current situation and identify system components to change	Assess feasibility of changing (Technical, environmental, economic)	Implement changes, using proven and recognised methodologies
Requirements (tools or inputs needed to apply the proposed process/es above):		Water balance framework and measurements	Benchmarks for comparison/assessment	Information on options available (captured into suitable models)	Guidelines (modules 1-4)
		Technology transfer/training to create skilled implementing agents			
Typical requirements at different levels:	**WMA**	Lawful water use Environmental impact	Water use planning Water quality guidelines	DWA hydrological models Water quality monitoring	WUE accounting report WC&WDM regulations
	Scheme	Conveyance system Distribution system Surface storage system Drainage/Return flows	Design norms Service delivery standards Water balance	WAS Groundwater models River hydrology models	Water Management Plan
	Farm	Surface storage system Distribution (on-farm) system Application system Soil water storage Drainage/Return flows	Design norms Farm water balance System Efficiency Soil water balance	Irricost SWB SAPWAT	Water Conservation Plan

The main envisaged outcome of the project was achieved: guidelines have been developed for improving irrigation water use efficiency. The structure and content of the guidelines are based on the lessons learnt locally and internationally during the course of the project. Hence, a set of performance indicators with benchmarks was moved away from and a water balance approach is instead being promoted as a more meaningful and sustainable approach to improving water use efficiency.

1.5 Products

The final report covers both the activities undertaken by the project team at the different schemes, as well as the guidelines that were compiled, which comprise the main product of the project. The description and results of the project team field work activities are attached in a separate document entitled "Supplementary Information", while Modules 1 to 4 of the guidelines complement this main report.

1.5.1 Guidelines for improved irrigation water management from dam wall release to root zone application

The guidelines are aimed assisting both water users and authorities to achieve a better understanding of how irrigation water management can be improved, thereby building human capacity, allowing targeted investments to be made with fewer social and environmental costs. Using lessons learnt during the WRC project, best practices and technologies are introduced and illustrated.

The guidelines, consisting of four modules, form part of this report and are briefly introduced here:

Module 1: Fundamental concepts: This module introduces the concepts of optimised water use, irrigation system performance and the water balance. It also touches on lawfulness of water use, demand management and appropriate technologies.

Module 2: In-field irrigation systems: This module addresses the water balance approach at field level, and describes how each decision made during the planning, design and management of irrigation systems influences the amount of water required to irrigate the crop successfully.

Module 3: On-farm conveyance systems: This module addresses the water balance approach at farm level, and describes how the on-farm water distribution system should be planned, designed and managed to optimise water and energy requirements.

Module 4: Irrigation schemes: This module introduces the water balance approach at irrigation scheme level, and describes how technologies such as the WAS, iScheme and water measuring devices can be used to ensure greater reliability of supply to all water users on a scheme.

Each module is a stand alone unit with its own table of contents, introduction and conclusion. Module 1 should be used as an introduction to any of the other modules to introduce the fundamental concepts. Before the guidelines can be used for training, some repackaging, improved illustrations and development of assessment activities will be necessary.

1.5.2 Report on project activities

The report section entitled "Supplementary Information" covers an overview of the project activities, undertaken during the field work by the project team members, at the Breede River, Dzindi, Gamtoos, Hartbeespoort, Hex River, KwaZulu-Natal, Loskop, Orange-Riet, Steenkoppies, Vaalharts and Worcester East irrigation areas. Work undertaken at each of the sites had specific objectives, and was reported on by different team members.

Although the sections therefore differ largely in structure and content, they contain a large amount of valuable data that complements the guidelines, and which will form the basis of case study material for training purposes when the outcomes of the project are promoted in future.

1.6 Policy implications

The Department of Water Affairs (DWA) is in the process of developing "Proposed regulations relating to limiting the purpose, manner or extent of water use by water conservation measures and the monitoring, measurement and recording of raw water consumption and the disposal of water containing waste". The proposed regulations are directly related to the outcomes of this research project by means of the "water conservation measures" that will be required.

In South Africa, our reliance on irrigation is greater than this global average due to the arid and semi-arid climate in large parts of the country. Although the NWA (1998) does not make provision for water conservation and water demand management (WC/WDM), as part of the implementation of the National Water Resources Strategy (NWRS) various interventions are considered to reconcile demand with supply (Backeberg, 2007). These include the following:

- Demand management – implementing cost recovery through consumer tariffs and user charges to influence the behaviour of water users and to install technologies which reduce waste and losses of water such as undetected leakages.
- Resource management – regulation of streamflow through storage; control of abstractions and releases; and assessment of the groundwater resource at specific localities.
- Re-use of water – recycling of return flows and treatment of water.

- Control of alien invasive vegetation – clearing of invading alien vegetation and controlling the spread of such vegetation to increase surface runoff.
- Re-allocation of water – enable gradual transfers between use sectors with differential benefits through compulsory licensing, supported by water demand management and trading of water use authorizations.

The WC/WDM strategy for agriculture provides a framework for "regulatory support and incentives designed to improve irrigation efficiency …. in order to increase productivity and contribute to reducing income inequalities among people supported by farming activities". A plan of action is envisaged which must present the following strategic outputs:

- appropriate measures that reduce wastage of water
- progressive modernization of water conveyance, distribution and application infrastructure, equipment and methods
- preventative maintenance programmes
- water allocation processes that promote equitable and optimal utilization of water
- generation of sufficient irrigation information which is accessible to all stakeholders
- implementation of water audits from the water source to the end user.

In the case of five of these action points, conditions and regulations for WC/WDM for water use sector authorization have been published and are currently being reviewed (Backeberg, 2007). For irrigation and agricultural water use the emphasis is on five categories: (1) measuring devices and information systems; (2) water audits, accounting and reporting to the responsible authority; (3) water management planning and WC/WDM measures; (4) management of return flows; and (5) education and awareness rising.

The Minister of Water and Environmental Affairs is mandated to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other things, the promotion of efficient, sustainable and beneficial use of water in the public interests. One means of achieving this is when making regulations in terms of the National Water Act (NWA) (Act No. 36 of 1998), the Minister must take into account the conservation of water resources. Research has indicated that water users who exceed 150 000 cubic meters, with a particular focus on users above 1 000 000 cubic meters of water per annum need to specifically be regulated. These categories of water users account for most water use in South Africa. Limiting and controlling their use through the implementation of water conservation measures, will result in a saving of the nation's scarce water resources. This is also in alignment with the Minister's Constitutional mandate. The project team has informed the relevant DWA Directorate and their consultants of the outcomes of this WRC project, and it is hoped that they will be incorporated into the new DWA regulations.

2 Project methodology: Adopting the water balance approach

2.1 The irrigation efficiency framework

At the beginning of the project (in 2005), the project team set out to develop an efficiency framework consisting of performance indicators that aimed to include or make provision for all possible levels of water management and possible scenarios that can be found in irrigated agriculture.

However, the standardisation of components within the large range of water supply and management systems was found to be problematic. The wide variety of performance indicators that were identified made the assessment process cumbersome. Interpretation of the performance indicators without benchmarks was nearly impossible, and the number of benchmarks required would have been too great to handle within the research project, and impractical to implement on the ground. Furthermore, the draft framework included the concept of efficiency expressed both in terms of flows of water, as well as money (or produce) which could not be reconciled in an acceptable way by the project team.

2.2 The water balance framework

Since 2005, two significant international research developments have taken place which have changed the way the irrigation (and water in general) community look at water use efficiency.

Firstly, the concepts of *water footprints* and *virtual water* became more widely recognised (Hoekstra & Hung, 2002), and secondly there was a move away from efficiency indicators towards a water balance approach (Perry, 2007).

The water footprint of an individual, business or nation is defined as the total volume of fresh water that is used to produce the goods and services consumed by the individual, business or nation. In order to give a complete picture of water use, the water footprint includes both the water withdrawn from surface and groundwater and the use of soil water (in agricultural production). The water footprint concept was first introduced by Hoekstra in 2002 in order to have a consumption-based indicator of water use that could provide useful information in addition to the traditional production-sector-based indicators of water use.

The water footprint concept is closely linked to the virtual water concept. Virtual water is defined as the volume of water required to produce a commodity or service. The concept was introduced by Allan in the early 1990s (Allan, 1993, 1994) when studying the option of importing virtual water (as opposed to real water) as a partial solution to problems of water scarcity in the Middle East. Allan elaborated on the idea of using virtual water import (coming along with food imports, for example) as a tool to release the pressure on scarce domestic water resources. Virtual water import thus becomes an alternative water source, next to endogenous water sources. Imported virtual water has therefore also been called 'exogenous water' (Haddadin, 2003).

These concepts provide the link between water use and production (money) that was previously hard to define, and they can of course also be applied equally well at farm, WUA or WMA level.

An article by Perry (2007) presented the newly developed framework for irrigation efficiency as approved by the International Commission on Irrigation and Drainage (ICID). In the paper, the author describes in detail the history and subsequent confusion surrounding the calculation and interpretation of so-called irrigation or water use "efficiency" indicators. The framework and proposed terminology is scientifically sound, being based on the principle of continuity of mass, and promotes the analysis of irrigation water use situations or scenarios in order to expose underlying issues that can be addressed to improve water management, rather than simply the calculation of input-output ratios as done in the past.

The basis of the framework is that any water withdrawn from a catchment for irrigation use contributes either to storage change, to the consumed fraction, or to the non-consumed fraction at a point downstream of the point of abstraction. The water that is consumed will either be to the benefit of the intended purpose (beneficial consumption) or not (non-beneficial consumption). Water that is not consumed but remains in the system will either be recoverable (for re-use) or non-recoverable (lost to further use).

To improve water availability in the catchment, the relevant authority needs to focus its attention on reducing non-beneficial consumption and non-recoverable fractions: the activities undertaken to achieve this result can be called the best management practices.

The ICID water balance framework, based on Perry's model, is shown schematically in Figure 1.

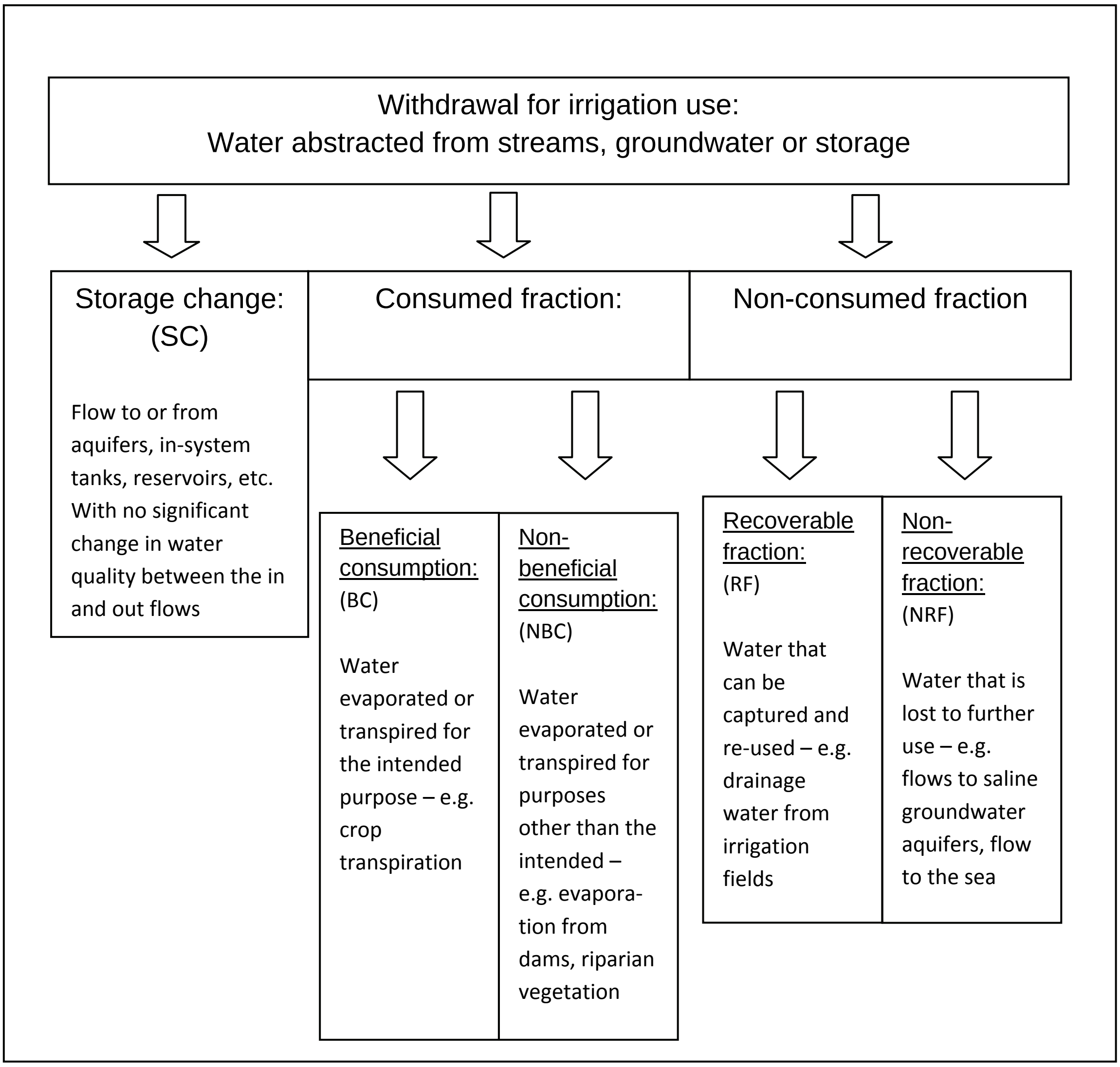

Figure 1: ICID water balance framework for irrigation water management (after Perry, 2007)

In order to apply this framework to irrigation areas, typical water infrastructure system components are defined wherein different scenarios may occur. In South Africa, most irrigation areas consist of a dam or weir in a river from which water is released for the users to abstract, either directly from the river or in some cases via a canal. Water users can also abstract water directly from a shared source, such as a river or dam/reservoir, or the scheme-level water source could be a groundwater aquifer. Once the water enters the farm, it can either contribute to storage change (in farm dams), enter an on-farm water distribution system or be directly applied to the crop with a specific type of irrigation system.

The South African framework presented here covers four levels of water management infrastructure, (as shown in Table 2): i.e. the water source, the bulk conveyance system, the irrigation scheme and the irrigation farm, and the relevant water management infrastructure.

Table 2: Four levels of water management infrastructure

Water management level	Infrastructure system component		
Water Source	Dam/Reservoir		Aquifer
Bulk conveyance system	River	Canal	
Irrigation scheme	On-scheme dam		
	On-scheme canal		
	On-scheme pipe		
Irrigation farm	On-farm dam		
	On-farm pipe/canal		
	In-field irrigation system		

The different water balance framework system components and their classification according to the ICID framework, for whichever water management infrastructure may be encountered in the field, are shown in Table 3. Although care has been taken to include all possible system components and water destinations, practitioners are encouraged to customise the framework for their specific circumstances. The abbreviations used to classify the framework components are declared in Figure 1.

In order to improve water use efficiency in the irrigation sector, actions should be taken to reduce the non-beneficial consumption (NBC) and non-recoverable fraction (NRF). Desired ranges for the NBC and NRF components have been included in Table 3 to help the practitioner evaluate the results obtained when first constructing a water balance.

The values shown here are based on actual results obtained during the course of the project, (as documented in Part B of this report), and can be adjusted if more accurate, locally relevant data is available in a particular area. However, as circumstances differ greatly from one irrigation area to the next, it is recommended that water managers at all levels assess a specific system component's performance against the same component's previous years' data in order to achieve continuous improvement, rather than against other (seemingly similar) system components from different areas.

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

Finally, it is recommended that the water user's lawful allocation is assessed at the farm edge, in order to encourage on-farm efficiency. At scheme level, conveyance, distribution and surface storage losses need to be monitored by the WUA or responsible organisation, acceptable ranges set, and agreement obtained with the DWA where in the system provision should be made to cover the losses.

Table 3: Water balance framework allocation of typical irrigation system components

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

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

2.3 *Application of the water balance approach*

The field work undertaken in the course of the project consisted of various approaches and strategies applied by the different project team members at each of the irrigation schemes, in order to try and quantify some of the water use components mentioned above. As the application of water balance approach was an outcome of the project rather than a planned solution at the outset, the field work was not initially designed to produce results to which the water balance approach could be readily applied. However, at many of the schemes where field work was undertaken, at least some of the system components could be assessed using the water balance approach.

Table 4 shows the irrigation schemes where field work was undertaken, together with the system components that were assessed at each scheme. The methodologies followed and the outcomes achieved are documented in a separate part of this report, entitled "Supplementary Information".

Table 4 Irrigation schemes where field work took place and system components were assessed

Irrigation Scheme	Bulk Conveyance	On-scheme distribution	On-scheme return flow	Irrigation system (application)	Irrigation management (Soil storage)
Breede River	X	X	X	X	
Dzindi	X			X	
Gamtoos	X			X	X
Hartbeespoort	X			X	
Hex River				X	
KZN scheme	X	X		X	X
Loskop	X			X	
Nkwalini	X			X	
ORWUA	X	X	X	X	X
Steenkoppies					X
Vaalharts	X		X	X	
Worcester East				X	

The cross reference of the water balance framework and the sites where related field work was undertaken is included in the introduction of the Supplementary Information.

3 Conclusion and recommendations

The activities undertaken during the course of the project have contributed to local knowledge on issues regarding irrigation water use efficiency. The outcomes deviate from the original envisaged outcomes, in that:

- efficiency refers to the state of a water balance for a defined spatial and temporal area rather than to the value of a performance indicator, and
- improved efficiency is achieved through a process of assessment and targeted actions, rather than general practices.

The resulting approach that has been documented in the final report therefore still complies with the original proposed improvement process of "measure; assess; improve; evaluate", but it promotes an investigative approach to improving efficiency, rather than relying only on water accounting.

The main outcome of the project was the compilation of guidelines for improved irrigation water management from dam wall release to root zone application. The guidelines are aimed at assisting both water users and authorities to achieve a better understanding of how irrigation water management can be improved, thereby building human capacity, allowing targeted investments to be made with fewer social and environmental costs. Using lessons learnt during the WRC project, best practices and technologies were introduced and illustrated.

3.1 Contribution to new knowledge in South Africa

The guidelines developed as part of this project contain information on the following aspects of irrigation water use efficiency that is either new or deviates from previously available information:

3.1.1 New proposed irrigation system efficiency values

The ICID framework was applied by the project team to re-assess the system efficiency indicators typically used by irrigation designers when making provision for losses in a system and converting net to gross irrigation requirement. A new set of system efficiency (SE) values for design purposes is proposed. These values are illustrated in Table 5 and are considerably more stringent than the present system design norms.

System efficiency defines the ratio between net and gross irrigation requirements (NIR and GIR). NIR is therefore the amount of water that should be available to the crop as a result of the planned irrigation system and GIR is the amount of water supplied to the irrigation system that will be subject to the envisaged in-field losses.

The present application efficiency values are shown in the "Norms" column of Table 5, while the different water use components at the point of application with a specific irrigation system has each been allocated a column under “Losses”. The approach makes provision for the occurrence of non-beneficial spray evaporation and wind drift, in-field conveyance, filter and other minor losses. The sum of all these losses makes up the value in the column ‘Total losses”. The new proposed default system efficiency values in the last column were obtained by subtracting the total losses from 100%.

When an irrigation system is evaluated, the system efficiency value can be compared with these default values, and possible significant water loss components identified as areas for improvement. The approach is therefore more flexible and easier to apply than the original efficiency framework where definitions limited the applications.

Table 5: Comparison between the present design norms and the proposed default system efficiency values

	Norms	Losses				Proposed default system efficiency (net to gross ratio) (%)
Irrigation system	Present application efficiency value (%)	Non-beneficial spray evaporation and wind drift (%)	In-field conveyance losses (%)	Filter and minor losses (%)	Total Losses (%)	
Drip (surface and subsurface)	90	0	0	5	5	95
Microspray	80	10	0	5	15	85
Centre Pivot, Linear move	80	8	0	2	10	90
Centre Pivot LEPA		0	0	2	2	98
Flood: Piped supply	80	0	0	2	2	98
Flood: Lined canal supplied	60	0	5	2	7	93
Flood: Earth canal supplied		0	12	2	14	86
Sprinkler permanent	75	8	0	2	10	90
Sprinkler movable	70	10	5	2	17	83
Traveling gun	75	15	5	2	22	78

It should always be kept in mind that a system’s water application efficiency will vary from irrigation event to irrigation event, as the climatic, soil and other influencing conditions are never exactly the same. Care should therefore be taken when applying the SE indicator as a benchmark.

It is recommended that system efficiency be assessed in terms of the losses that occur in the field. This can be determined as the ratio between the volume of water lost to non-beneficial spray evaporation and wind drift, in-field conveyance, filter and other minor losses, and the volume of water entering the irrigation system, for a specific period of time. The losses can also be expressed as a depth of water per unit area, rather than a volume.

3.1.2 Improved understanding of distribution uniformity

Irrigation uniformity is a characteristic of the type of irrigation system used, together with the standard to which a given system has been designed, is operated and is maintained. It can also be affected by soil infiltration characteristics and by land preparation.

The traditional approach to accounting for the distribution uniformity of the lower quarter (DU_{lq}) has likely resulted in the default irrigation efficiencies customarily referred to, e.g. that furrow irrigation is assumed to be 65% efficient and centre pivot irrigation is assumed to be 85% efficient.

Unfortunately, the rationale for these assumed efficiencies, i.e. the typical or assumed non-uniformity, is seldom considered, and water is often thought to just 'disappear' with the assumed low efficiencies. However, once the water balance approach is applied, it is realised that the water does not 'disappear' but contributes to increased deep percolation which may eventually appear as return flow further along the drainage system.

The bottom line is that assuring high irrigation uniformity is of primary importance, and should be the goal of good design and maintenance procedures. It is very unlikely that low crop yields caused by non-uniform irrigation water applications will be improved by assuming low irrigation efficiencies and increasing the water applications accordingly.

If poor uniformity results in low crop yields, the uniformity needs to be corrected in order to improve system performance. Simply applying more water to compensate for the part of the field that is being under-irrigated is unlikely to result in improved crop yields – large parts of the field will now suffer from over-irrigation, and the risk of long term problems developing due to a raised water table will increase.

The preferred recommendation in this case would be to deal specifically with the problem of poor uniformity. For planning purposes, the GIR at the field edge should therefore be calculated as the product of the NIR and system efficiency (see 3.1.1), and when using the SAPWAT programme for planning purposes, the DU_{lq} value should be set to 100%.

3.1.3 Improved system evaluation forms

During the baseline study phase of the project, 75 irrigation systems across the country were evaluated using the standard evaluation forms and procedures as published in ARC-Institute for Agricultural Engineering's *Manual for the Evaluation of Irrigation systems*.

As a result of the intensive use of the templates and procedures, the evaluation forms were adjusted and improved, and improved software for the capturing and analysis of the data was developed. The software development was financed separately by the ARC and Department of Agriculture.

3.1.4 Improved understanding of energy costs and the effects of cost increases

Energy costs influences the selection, design and operation of an irrigation system. As part of an MSc research project undertaken at the University of KwaZulu-Natal (Jumman, 2009), the effect of making various decisions regarding irrigation system design and operation was investigated and reported on. The effects of system lay-out, emitter selection, standing times and ESKOM tariff structures on the capital and operational cost of an irrigation system were documented, and various calculation tools were developed.

3.1.5 A Crop Water Use module for the WAS programme

The Water Administration System (WAS) was designed as a management tool for irrigation schemes and water management officers wanting to manage their water accounts and water supply to users through canal networks, pipelines and rivers. WAS is developed and maintained by NB Systems cc. Financial contributions for the development of WAS were made by the WRC and DWA. The WAS program is currently in use at all the major irrigation schemes and a number of smaller irrigation boards throughout South Africa.

During the early stages of the project, a Crop Water Use module was developed for the WAS to calculate the water usage per crop between two specified dates for all the planted crops on a scheme based on the plant date, the area planted and the crop water use curve. The crop yield (ton/ha) can be captured at the end of a growing season and used to calculate the total yield (ton) and the yield in (g/m^3).

A summary of water used for a specified period can easily be generated per crop type. All the crop water use information can easily be linked to a geographic information system (GIS).

3.1.6 iScheme information system

The iScheme information system for irrigation schemes was developed as part of this project and subsequently adapted and adopted by DWA to develop "water use efficiency accounting reports" (WUEA reports) at irrigation schemes, replacing the previously used disposal reports.

It was recognised that it is a simple and effective way to keep track of water losses on a scheme or part of a scheme should be used. It is important to keep the reporting of water losses simple; past experience has shown that complicated reports such as the previous disposal report from the DWA were either incorrectly used, or not used at all. The calculation of water losses on a scheme should add value to water distribution management, providing a tool to help minimise water losses.

iScheme is an information system for irrigation schemes that contains a list of all irrigation schemes throughout South Africa. Every irrigation scheme is linked to a specific Water Management Area (WMA) and a region. This feature makes it possible to filter the information in the database according to scheme, WMA, region and nationally. One of the uses of iScheme is to archive WUEA reports for all schemes on a national basis. The iScheme database is ideally suited to import, manage and report on WUEA reports on a scheme, WMA, region and national levels.

3.2 Recommendations and way forward

A large volume of data has been collected and much knowledge has been accumulated in the course of the project. It is recommended that the project output, i.e. the guidelines for management advice on improved efficiency of irrigation water use, should be packaged into training material aimed at water users, irrigation organisations, the irrigation industry and policy makers in order to create an equal understanding of the potential and realities of efficient irrigation water use across all levels of water management.

The following specific actions are recommended as part of the technology transfer of the project outcomes:

3.2.1 The water balance approach

In order to ensure that the water balance approach is not only understood but also adopted by as wide an audience as possible, a simple, practical, technical guide to the implementation of the water balance approach needs to be developed, supported by user-friendly computer based software in which framework components can be selected, values for each component entered, and the water balance calculated.

The software should include references or links to the tools that can be used to quantify the framework components (for example models such as SAPWAT, or measuring devices that can be used), default values or acceptable ranges for component values, and even simple calculators (for example, to calculate evaporation losses from a farm dam).

A user manual needs to be developed for training purposes, with the technical guide included in the software as a help file.

3.2.2 Technology transfer to the water users

The project outcomes regarding in-field and on-farm irrigation systems are of great importance to irrigation water users. Technology transfer at this level should specifically be aimed at demonstrating to water users the effect of irrigation system management decisions, (including aspects such as irrigation amounts and timing (scheduling), and maintenance), on the efficiency and uniformity of the irrigation system, within the context of the water balance framework.

Training sessions should be arranged so that area-specific practices can be analysed using the water balance and the tools identified during the project, and opportunities for improvement in water management on the farm identified in collaboration with the water users. To provide further incentives for water users to adopt more efficient practices, the link to production inputs and yields should be made clear and any possible benefits highlighted. Partnering with farmer organisations such as AgriSA, cooperatives and study groups is recommended for the technology transfer process at farm level.

The WRC project output will make a valuable supporting contribution to the water conservation plans that are being proposed by the DWA as part of the WC&WDM regulations, to be implemented by water users with lawful allocations greater than 1 million m^3 of water per year.

3.2.3 Technology transfer to WUAs and Irrigation Boards

The water balance approach has great potential to change the way in which irrigation schemes are managed. The water balance framework may be the tool that can link the models used in practice to operate irrigation schemes to the legal requirements that have to be met by WUAs in terms of water management plans.

Technology transfer initiatives such as training on the water balance approach and workshops on irrigation scheme management should focus on specific types of schemes – groundwater, canals, river or pipeline – so that awareness can be created about specific tools and methods available to irrigation organisations. Partnering with the South African Association for Water User Associations (SAAFWUA) is recommended for the technology transfer process at irrigation scheme level.

3.2.4 Technology transfer at the WMA level (DWA and CMAs)

Although the solicited WRC project did not deal specifically with water management at the catchment level, stakeholders within DWA and the CMAs, where applicable, should be made fully aware of the outcomes of the research and the water balance approach. At this level, technical training on the use of the water balance framework may not be necessary but a good understanding of the approach and application thereof by the lower management levels is imperative. The framework can also be used to develop a better understanding of irrigation water use and understanding amongst policy makers. It is recommended that workshop material and presentations for DWA and CMA stakeholders be arranged in collaboration with the DWA, Directorate for Water use Efficiency.

3.2.5 Technology transfer to the irrigation industry

The suppliers of irrigation equipment and management services play an important role in water management at the farm and field level. These professionals need to be made aware of the outcomes of the WRC project, as some of the outcomes have an effect on current design and operational practices. Furthermore, trained professionals could also possibly play a role as independent auditors of water conservation plans as proposed in the WC&WDM regulations. It is recommended that technology transfer initiatives aimed at the irrigation industry, be arranged in collaboration with their representative organisation, the South African Irrigation Institute (SABI).

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