IMPROVED EFFICIENCY OF IRRIGATION WATER USE: A SOUTH AFRICAN FRAMEWORK

AMELIORATION DE L'EFFICIENCE D'UTILISATION DE L'EAU D'IRRIGATION : CADRE SUD AFRICAINE

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ABSTRACT

Irrigated agriculture plays a major role in the livelihoods of nations all over the world and in South Africa it is not different. With the agricultural water use sector being the largest of all water use sectors in South Africa, there have been increased expectations that the sector should increase efficiency and reduce consumption in order to increase the amount of water available for other uses.

In a recent study on irrigation efficiency, the approach is that irrigation efficiency should be assessed by applying a water balance to a specific situation rather than by calculating various performance indicators. The purpose of an irrigation system is to apply the desired amount of water, at the correct application rate and uniformly to the whole field, at the right time, with the least amount of non-beneficial water consumption (losses), and as economically as possible. The fraction of the water abstracted from the source that can be utilised by the plant, can be called the beneficial water use component and optimised irrigation water supply is therefore aimed at maximising this component. It implies that water must be delivered from the source to the field both efficiently (with the least volume for production along the supply system) and effectively (at the right time, in the right quantity and at the right quality). Optimising water use at farm level requires careful consideration of the implications of decisions made during both development (planning and design), and management (operation and maintenance), taking into account technical, economic and environmental issues.

The South African framework covers four levels of water management infrastructure: -the water source, bulk conveyance system, the irrigation scheme and the irrigation farm. The water balance approach can be applied at any level, within defined boundaries, or across all levels to assess performance within the whole Water Management Area.

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Key words: *Irrigation efficiency, Optimising Water Use, Water balance approach.*

RESUME ET CONCLUSIONS

L'agriculture irriguée joue un rôle majeur dans les moyens de subsistance des nations partout dans le monde et c'est aussi le cas en Afrique du Sud. L'utilisation de l'eau par le secteur agricole étant la plus importante de tous les autres secteurs de l'eau en Afrique du Sud, les attentes gouvernementales sont croissantes pour ce secteur qui doit accroître l'efficacité et réduire la consommation afin d'augmenter la quantité d'eau disponible pour d'autres usages, et en particulier pour la consommation domestique humaine. L'accent a été mis sur la façon dont une augmentation de l'efficacité pourra conduire à une réduction de la consommation par les utilisateurs agricoles et ainsi «libérer» une partie des productions d'eau annuelle pour une utilisation par le secteur domestique. Dans le cadre de L'Eau pour la Croissance et le Développement (ministère des Affaires des Eaux et Forêts, 2008), il est indiqué que l'utilisation inefficace de l'eau dans l'irrigation commerciale doit être traitée d'urgence. Les mesures recommandées comprennent la quantification de l'eau distribuée et utilisée à des moments précis, la préparation à une utilisation de l'eau efficace et des plans de gestion des risques, et une réduction de la quantité d'eau déjà utilisée pour l'irrigation par les agriculteurs existants grâce à l'investissement dans une technologie appropriée.

Dans une étude récemment complétée de la Commission de Recherche sur l'Eau sur le rendement de l'irrigation, l'efficacité d'irrigation est évaluée en appliquant un bilan hydrique à une situation spécifique plutôt que par le calcul de différents indicateurs de performance. Le but d'un système d'irrigation est d'appliquer la quantité désirée en eau, à des doses d'application correcte et uniformément à l'ensemble du champ, au bon moment, avec le minimum de consommation d'eau non-bénéfiques (pertes), et aussi économique que possible. Lors de l'utilisation d'eau pour produire des cultures, l'eau ne doit pas seulement être considérée comme une ressource rare et précieuse, mais aussi comme un des intrants agricoles à utiliser de façon optimale. Toute l'eau qui est prélevée à partir d'une source à des fins d'irrigation n'atteint pas la destination prévue où la plante peut en faire le meilleur usage - la zone racinaire. La fraction de l'eau prélevée à la source qui peut être utilisée par la plante, peut être appelée la composante d'utilisation bénéfique de l'eau. L'optimisation de l'alimentation par irrigation a donc pour but de maximiser cette composante et implique que l'eau doit être livrée à partir de la source vers le champ de manière efficiente (avec la quantité la plus faible pour le système d'approvisionnement) et efficace (au bon moment, en quantité suffisante et avec une bonne qualité). Optimiser l'utilisation de l'eau au niveau de la ferme exige un examen attentif des implications des décisions prises lors du développement (planification et conception) et de la gestion (exploitation et maintenance), en tenant compte des questions techniques, économiques et environnementales.

Depuis 2005, deux importants développements de la recherche internationale ont eu lieu et ont changé la façon dont la communauté de l'irrigation (et de l'eau en général) voit l'efficacité d'utilisation de l'eau. D'une part, les concepts d'empreinte hydrique et d'eau virtuelle sont devenus plus largement reconnus (Hoekstra & Hung, 2002), et d'autre part il y a eu un désintéressement des indicateurs d'efficacité au profit d'une approche par bilan hydrique (Perry, 2007).

Le cas sud-africain couvre quatre niveaux de gestion de l'eau des infrastructures : la ressource en eau, le système de transport en gros, le système d'irrigation et l'irrigation de la ferme. En Afrique du Sud, la plupart des zones irriguées sont composé d'un barrage ou un déversoir sur un cours d'eau depuis lequel l'eau est libérée pour les utilisateurs, soit directement de la rivière ou dans certains cas, par l'intermédiaire d'un canal. Les utilisateurs d'eau peuvent aussi extraire l'eau directement d'une source commune, comme une rivière ou un barrage / réservoir, ou alors la ressource en eau peut être un aquifère. Une fois que l'eau pénètre dans la ferme, elle peut soit à nouveau contribuer au stockage (fermes possédant des barrages), soit entrer dans le système de distribution d'eau de la ferme ou encore être directement appliqués sur la culture avec un type spécifique de système d'irrigation. La méthode du bilan hydrique peut être appliquée à n'importe quel niveau, dans des limites définies, ou à travers tous les niveaux pour évaluer la performance au sein d'une zone entière de gestion de l'eau.

La méthode du bilan hydrique a un grand potentiel de changer la façon dont les systèmes d'irrigation sont gérés et du matériel de formation sera élaboré à partir des résultats de recherches résultant de sessions de transfert de technologie. Le cadre du bilan hydrique peut être l'outil qui peut relier les modèles d'exploitation des systèmes d'irrigation utilisés en pratique, aux exigences juridiques qui doivent être remplies par les AUE en termes de plans de gestion de l'eau. L'utilisation de la technologie moderne peut aider davantage l'irrigant et les autorités afin d'optimiser la gestion de l'eau d'irrigation à tous les niveaux. Par la planification et la budgétisation de la mise en œuvre de ces technologies, des solutions abordables peuvent être trouvés dans la plupart des cas.

Mots clés : *Efficience d'irrigation, Optimisation de l'usage d'eau, approche de bilan hydrique.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Irrigated agriculture plays a major role in the livelihoods of nations all over the world and in South Africa it is not different. 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. In the framework on Water for Growth and Development (Department of Water Affairs and Forestry, (2008) it is stated that inefficient water use in commercial irrigation must be urgently addressed. Recommended actions include measurement of the quantity of water distributed and applied at specific times; preparation of water use efficiency and risk management plans; and a reduction of the quantity of water used for irrigation by existing farmers through investment in appropriate technology.

In a recently completed Water Research Commission research project (Reinders, 2010) on irrigation efficiency, the approach is that irrigation efficiency should be assessed by applying a water balance to a specific situation, rather than by calculating various performance indicators. The purpose of an irrigation system is to apply the desired amount of water, at the correct application rate and uniformly to the whole field, at the right time, with the least amount of non-beneficial water consumption (losses), and as economically as possible. When using water to produce crops, it should be considered both as a scarce and valuable resource and an agricultural input to be used optimally. Not all the water that is abstracted from a source for the purpose of irrigation, reaches the intended destination where the plant can make best use of it – the root zone. The fraction of the water abstracted from the source that can be utilised by the plant, can be called the beneficial water use component. Optimised irrigation water supply is therefore aimed at maximising this component and implies that water must be delivered from the source to the field both efficiently (with the least volume for production along the supply system) and effectively (at the right time, in the right quantity and at the right quality). Optimising water use at farm level requires careful consideration of the implications of decisions made during both development (planning and design), and management (operation and maintenance), taking into account technical, economic and environmental issues.

2. THE WATER BALANCE APPROACH

At the beginning of the research, the objective was 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. The objectives were formulated as follows: 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.

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 internationally and nationally 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 and impractical to implement on the ground.

Two significant international research developments have taken place since 2005 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 introduced 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 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 (through food imports) 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, production and financial returns that were previously hard to define. 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).

In order 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**.

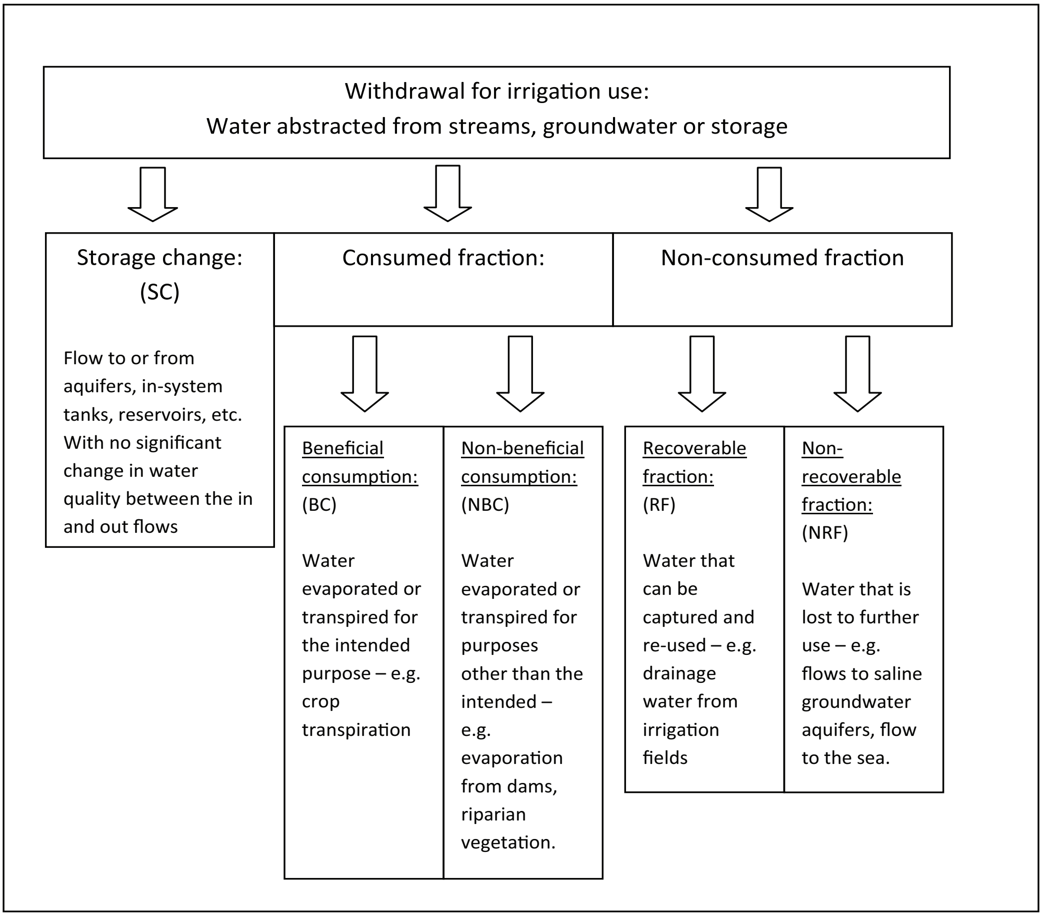

Figure 1: ICID water balance framework for irrigation water management (after Perry, 2007)
Figure 1: Cadre équilibre CIID l'eau pour la gestion de l'eau d'irrigation (après Perry, 2007)

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 1): i.e., the water source, the bulk conveyance system, the irrigation scheme and the irrigation farm, and the relevant water management infrastructure.

Table 1: Four levels of water management infrastructure (Reinders, 2010)
Tableau 1: Quatre niveaux de l'infrastructure de gestion de l'eau (Reinders, 2010)

<table>
<tr><th>Water management level</th><th colspan="3">Infrastructure system component</th></tr>
<tr><td>Water Source</td><td colspan="2">Dam/Reservoir</td><td rowspan="5">Aquifer</td></tr>
<tr><td>Bulk conveyance system</td><td>River</td><td>Canal</td></tr>
<tr><td rowspan="3">Irrigation scheme</td><td colspan="2">On-scheme dam</td></tr>
<tr><td colspan="2">On-scheme canal</td></tr>
<tr><td colspan="2">On-scheme pipe</td></tr>
<tr><td rowspan="3">Irrigation farm</td><td colspan="3">On-farm dam</td></tr>
<tr><td colspan="3">On-farm pipe / canal</td></tr>
<tr><td colspan="3">In-field irrigation system</td></tr>
</table>

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 2**. 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 2** 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 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 first measure or calculate the beneficial consumption and recoverable fraction in combination (transpiration, leaching requirement, drainage water, etc.) and then to determine or calculate the non-beneficial (NBC) or non-recoverable fractions (NRF) – by constructing the water balance.

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 2: Water balance framework allocation of typical irrigation system components (Reinders, 2010)Tableau 2: répartition cadre sur l'eau l'équilibre des composants typiques système d'irrigation(Reinders, 2010)

Water balance framework system component (based on infrastructure)	**Inflow of water into system component**	**Possible water destinations within the system component**	**Frame-work classi-fication**	**Desired Range, % of inflow**
Dam / reservoir	Total amount of water released from storage	Increase flow in bulk conveyance system (river or canal) Operational losses at the point of release	SC 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 On-scheme distribution system Farm edge (on-farm surface storage, distribution system or irrigation system) Evaporation from water surface Seepage in river bed Transpiration by riparian vegetation Unlawful abstractions Operational losses (unavoidable)	BC BC BC NBC NRF NBC NBC NRF	<5 <10 <5 0 <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 On-scheme distribution system Farm edge (on-farm surface storage, distribution system or irrigation system) Evaporation from canal Seepage in canal Unlawful abstractions Operational losses (unavoidable, eg filling canal, tailends) Operational losses (inaccurate releases, spills, breaks,etc.)	BC BC BC NBC NRF NRF RF NRF	<1 <5 0 <10 0
On-scheme surface storage	Total amount of water entering a scheme dam	Increase volume of water stored On-scheme distribution system (release from dam) Farm edge (on-farm surface storage, distribution system or irrigation system) Evaporation from dam Seepage from dam Operational losses (spills)	SC BC BC NBC NRF NRF	<1 <1 <1
Shared (scheme-level) groundwater aquifer compartment	Total aquifer recharge	Increase groundwater storage Farm edge (on-farm surface storage, distribution system or irrigation system)	SC 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) Evaporation from canal Seepage in canal Unlawful abstractions Operational losses (unavoidable, eg. filling canal, tailends) Operational losses (inaccurate releases, spills, breaks,etc.)	BC NBC NRF NRF RF NRF	 <1 <5 0 <10 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) Operational losses (unavoidable) Leaks	BC RF NRF	 <5 0
On-farm surface storage	Total amount of water entering a farm dam	Increase volume of water stored On-farm distribution system (release from dam) Irrigation system (abstraction from dam) Evaporation from dam Seepage from dam Operational losses (spills, leaks)	SC BC BC NBC NRF NRF	 <1 <1 <1
On-farm distribution system	Total amount of water entering the on-farm pipelines or canals	Irrigation system On-farm distribution system leaks Operational losses (unavoidable)	BC NRF RF	 0 <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 Transpiration by crop In-field evaporation (beneficial) Frost protection irrigation water Leaching (intended, beneficial but non-recoverable) Interception (unavoidable) In-field evaporation (non-beneficial, excessive) In-field deep percolation (non-intended, non-recoverable) In-field run-off (uncontrolled) Drainage water (surface & subsurface, recoverable) Operational losses (unavoidable)	SC BC BC BC BC NBC NBC NRF NRF RF NRF	 <1 0 0 0 <5

3. APPLICATION OF THE WATER BALANCE APPROACH

The field work undertaken in the course of the project consisted of various approaches and strategies applied at each of the irrigation schemes, in order to try and quantify some of the water use components mentioned. As the application of water balance approach was an outcome of the research 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 3 shows the irrigation schemes where field work was undertaken, together with the system components that were assessed at each scheme.

Table 3: Irrigation schemes where field work took place and system components were assessed Tableau 3: Les programmes d'irrigation où les travaux de terrain ont eu lieu et les composants du système ont été évalués

Irrigation Scheme	Bulk Conveyance	On-scheme distribution	On-scheme return flow	Irrigation system (application)	Irrigation manage-ment (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	

4. RESEARCH OUTCOMES

The research activities undertaken and the outcomes implemented were done in four phases:

- Baseline study phase

  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 were used to assess the current status of irrigation schemes and systems and to identify which components of the water balance framework improvements can be made. This may be at Water Management Area (WMA) scheme or farm level where different sources of information are available for assessment.

- Scenario development phase

  During this phase, 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 this phase, 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.

With this the main outcome has been developed: Guidelines 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.

The "Guidelines for improved irrigation water management from dam wall release to root zone application" 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.

The guidelines consist of four modules:

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.

In South Africa, reliance on irrigation water for food production is important due to the arid and semi-arid climate in large parts of the country. Although the National Water Act (NWA) (Act 3 of 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 raising awareness.

5. CONTRIBUTIONS TO NEW KNOWLEDGE IN SOUTH AFRICA

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

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 4 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 4**, 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 4: Comparison between the present design norms and the proposed default system efficiency values Tableau 4: Comparaison entre les normes de conception actuelles et les valeurs proposées par défaut du système d'efficacité

Irrigation system	Norms	Losses				New default system efficiency (net to gross ratio) (%)
	Present application efficiency value (%)	Non-beneficial spray evaporation and wind drift (%)	In-field con-veyance 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	85	3	0	2	5	95
Flood: Piped supply	80	0	3	2	5	95
Flood: Lined canal supplied	60	0	5	2	7	93
Flood: Earth canal supplied	50	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

Adapted from Reinders, 2010

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, as it does not make provision for irrigation management practices.

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.

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.

Improved understanding of energy costs and the effects of cost increases

Energy costs influences the selection, design and operation of an irrigation system. 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.

6. 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).

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 so called 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.

7. CONCLUSIONS 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 of “measure; assess; improve; evaluate”, but it promotes an investigative approach to improving efficiency, rather than relying only on water accounting.

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 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.

It is recommended that the research output, i.e. the guidelines for management advice on improved efficiency of irrigation water use, should be further developed into a user-friendly package with supporting training material targeting farmers, service providers and policy advisors. This will contribute to better understanding of the realities and potential for efficient irrigation water use across all levels of water management, and encourage the adoption of the water balance approach.

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