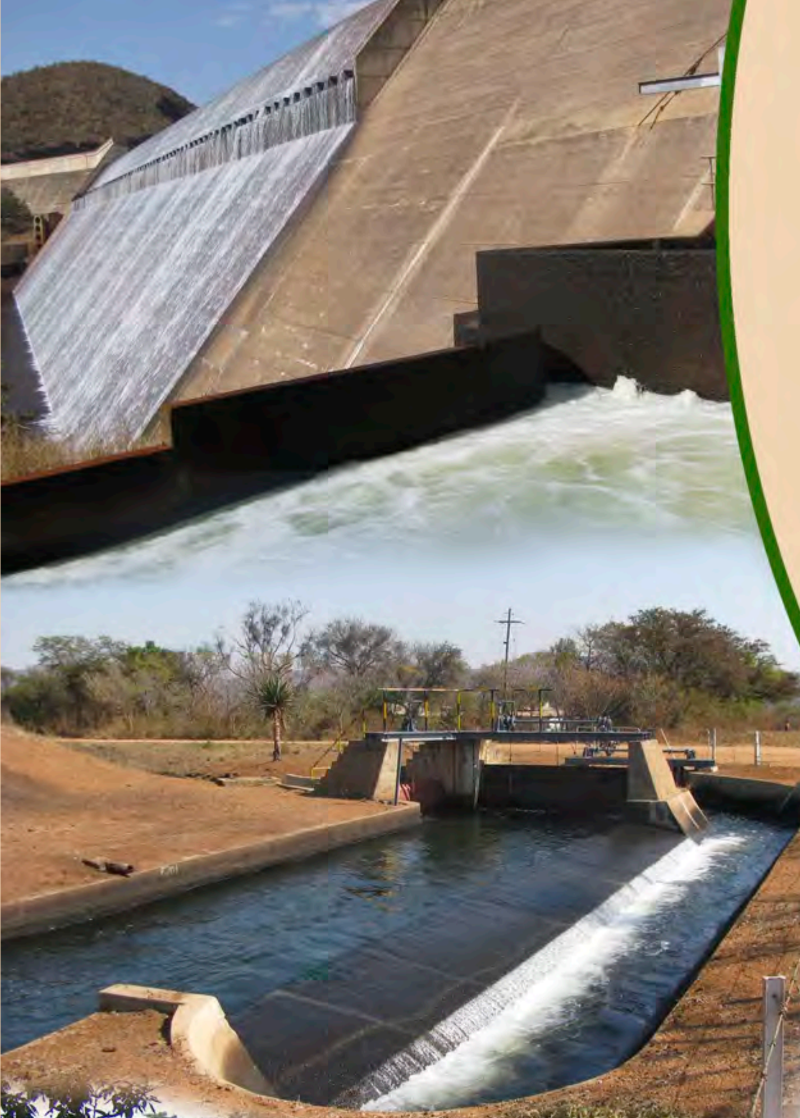

Standards and Guidelines for Improved Efficiency of Irrigation Water Use from Dam Wall Release to Root Zone Application: SUPPLEMENTARY INFORMATION

FB Reinders
(Project Leader)

WATER RESEARCH COMMISSION

TT 467/10

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

VOLUME 3 OF 3

SUPPLEMENTARY INFORMATION

Report to the

Water Research Commission

by the

Agricultural Research Council

ARC-Institute for Agricultural Engineering

Project Leader: F B Reinders

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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: Main Report (WRC Report TT 465/10), and

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

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List of Acronyms and Abbreviations

AGEP	Groundwater Exploitation Potential
ANCID	Australian National Committee of Irrigation and Drainage
ARC	Agricultural Research Council
ARC-IAE	ARC-Institute for Agricultural Engineering
ASF	Automatic Short Furrow
BC	Beneficial consumption
BMP	Best Management Practice
CI	Confidence Interval
CMA	Catchment Management Agency
CV	Coefficient of variation
DUL	Drained Upper Limit
DWA	Department of Water Affairs (formerly DWAF)
DWEA	Department of Water and Environment Affairs
ECA	Environment Conservation Act (Act 73 of 1989),
ECSA	Engineering Council of South Africa
FAO	Food and Agriculture Organisation
FWACS	Fractional water allocations and capacity sharing/water banking
GIS	Geographic Information system
GPRS	
GWCA	Ground Water Control Area
IB	Irrigation Board
ICID	International Commission on Irrigation and Drainage
IAEA	International Atomic Energy Agency

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
ORWUA	Orange River Water User Association
PEL	Potential economic loss
PLL	Potential loss of life
PSA	Potatoes South Africa
PT	Pressure Transducer
RF	Recoverable fraction
RWS	Relative Water Supply
SABI	South African Irrigation Institute
SAMA	Steenkoppies Aquatic Management Association
SAPWAT	South African Procedure on Water Requirements
SASRI	South African Sugar Cane Research Institute
SC	Storage change
SWB	Soil Water Balance
TAW	Total Available Water
TBRG	Tipping Bucket Rain Gauge
TDR	Time Domain Reflectometers

TDS	Total Dissolved Salts
WAS	Water Administration System
WC/WDM	Water conservation and water demand management
WCO	Water Control Officer
WDCR	Water Delivery Capacity Ratio
WMP	Water Management Plan
WRC	Water Research Commission
WUA	Water Users Association
WWTW	Waste Water Treatment Works

1 Introduction

1.1 Background to research project

This report forms part of the set of final reports that conclude the solicited Water Research Commission 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 (DWA) 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 has been increased expectations from government that the sector should increase efficiency and reduce consumption in order to increase the amount of water available for, in particular, human domestic consumption. A lot of expectation has been pinned 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 all irrigation systems' performance should be assessed in terms of one or more performance indicators which should be compared with benchmarks, and performance 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, being preceded by an industry workshop organised by the WRC in 2003 to obtain inputs for the project terms of reference, and 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 and this section of the final report documents the activities undertaken, results and conclusions.

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 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.

1.2 Scheme selection

A scoping study was undertaken to select suitable schemes where the selected performance indicators can be applied and evaluated. A number of schemes were available that could have been suitable to be used in the field trials for this research project. However, only a limited number of schemes could be selected due to limited resources such as time, budget and human resources constraints.

The following scheme selection criteria were used to evaluate and compare the list of possible schemes which can be used for the study.

1.2.1 Distribution system

Irrigation schemes were selected with different sources and supply systems which include:

- Canal
- Pipeline
- River
- Aquifer (Groundwater)

Schemes with more than one supply system (e.g. canal and pipe) were also included.

1.2.2 Geographic location

The geographic location of the selected schemes was to cover different regions where possible. Different geographic locations should also ensure variability in the soils and the climate of the different schemes.

1.2.3 Irrigation systems

Schemes were to be selected where there are a number of different irrigation systems in use. This is important to ensure that suitable research could be done on different irrigation systems.

1.2.4 Crops

The selected schemes were to have a variety of crops available for the research. The availability of a combination of permanent and cash crops was also considered as an advantage for a scheme to be selected.

1.2.5 GIS

A number of schemes in South Africa have detailed GIS information available and some were in the process of compiling detailed GIS maps as part of other WRC projects (such as Project K5/1481/4). It was suggested that the schemes should be selected, where possible, from the list of schemes which have GIS information available. The GIS information could help with the setup of some of the models such as SWB and WAS.

1.2.6 Resources

To be selected, the scheme management should have had a positive attitude towards the research project and a willingness to participate. This was important for the project to have a positive outcome. A specific scheme was expected to be prepared to make human resources available where possible and supply the necessary support during the execution of the project where needed. Participating schemes should also have had the necessary computers available to run any of the models on. Suitable personnel should have been available to receive training on the relevant models.

1.2.7 Data

Availability of suitable data (current and historical) was considered important for the successful execution of the research project. Schemes with reliable historical data and that had working measuring stations in place were considered as better candidates for the research project.

Long term and real time weather data would have been needed to run some of the software models. Access and availability of such data was therefore also considered during scheme selection.

1.2.8 HDI's (Historically Disadvantaged Individuals) and emerging farmer schemes

The importance of including HDI's and emerging farmer schemes in the research was kept in mind and taken into account when selecting schemes for participation.

1.2.9 Application of tools

The practical application of appropriate tools was considered when schemes were considered for selection. The following software models were identified in deliverable 4 as possible tools for quantifying water use and modeling scenarios:

- WAS
- SWB
- SAPWAT
- FARMS
- ACRU
- MIKE Basin
- ZIMSched

1.3 Farm selection

At each scheme, farms had to be selected where the on-farm and in-field work could be done. The following farm selection criteria were used to evaluate and compare the list of possible farms within the selected schemes which can be used for the study.

1.3.1 Location

The location of the farms within the selected schemes should have been spread all over the scheme and it should not have been concentrated in a single area. The locations of the farms were also to ensure variability in the soils and the climate of the specific schemes.

1.3.2 Distribution systems

On-farm distribution systems were taken into account which includes storage dams, pipelines, furrows and canals. On-farm pump station characteristics have an influence on the efficiency of distributions systems and were therefore also be considered during the selection process.

1.3.3 Irrigation systems

The selected farms were to include a variety of different irrigation systems.

1.3.4 Crops

The selected farms were to include a variety of crops that are representative of the specific scheme. The farms selected could include permanent and cash crops.

1.3.5 Resources

Farms were to be selected where the farmer had a positive attitude towards the research project and a willingness to participate. This was important for the successful completion of the research project. Irrigation board members were consulted in this regard.

1.3.6 Good and poor performers

The farm selection were to include farms with good management practices, irrigation and distribution systems which are in good condition and where previous crop yields were excellent. On the other hand farms with bad management practices, irrigation and distribution systems which are not in a good condition and where previous crop yields proved to be poor, should also be included. These criteria were applied in such a way to not offend any of the farmers.

1.4 Location map

The irrigation areas or schemes finally selected for field work at scheme and farm level were the following, as shown in the location map in Figure 1:

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

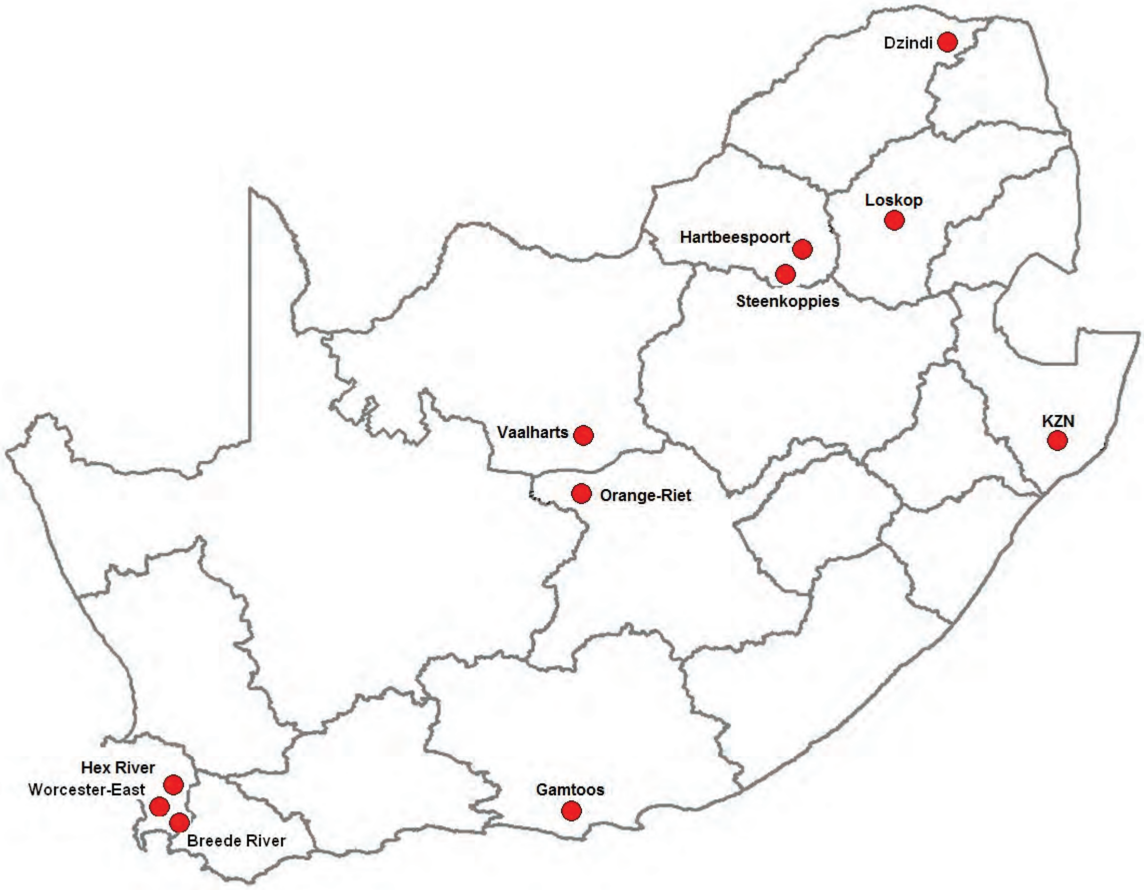

Figure 1: Location map of irrigation areas where field work took place

1.5 Water balance 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. Such a wide variety of performance indicators were also identified which made the whole 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. Furthermore, the draft framework included both flows of water as well as money (or produce) which could not be reconciled in an acceptable way by the project team.

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 regarding 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, will either contribute to storage change, the consumed fraction or the non-consumed fraction at a point downstream of the point of abstraction. The water that is consumed, will either do so to the benefit of the intended purpose (beneficial consumption) or not (non-beneficial consumption). Water that is not consumed but remains in the system will either be recoverable (for re-use) or non-recoverable (lost to further use).

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

The ICID water balance model, (after Perry) is shown schematically in Figure 2**.**

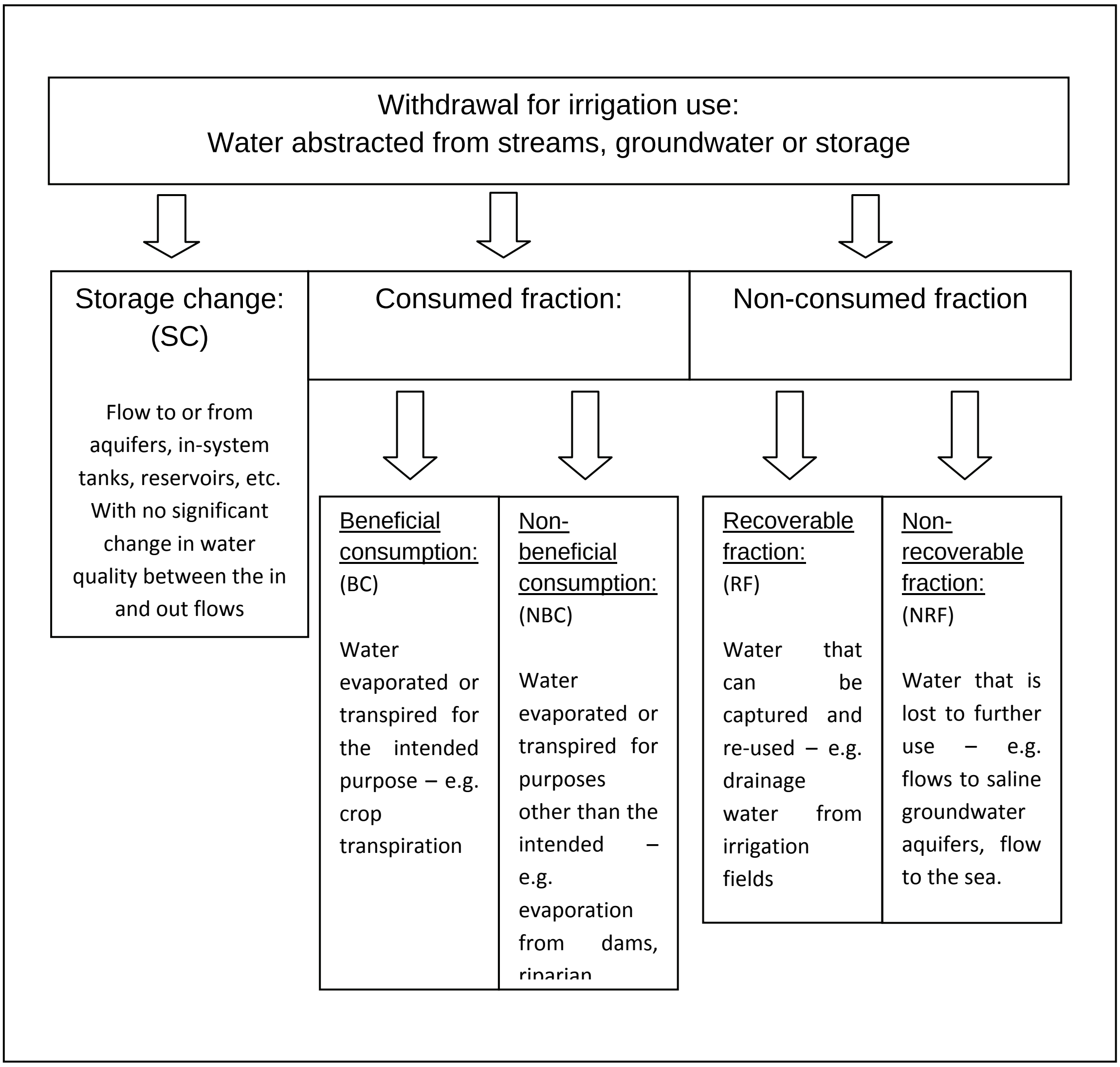

Figure 2: ICID water balance model for water management (after Perry, 2007)

In order to apply this framework to irrigation areas, one has to define typical water infrastructure system components wherein different scenarios may occur. In South Africa, most of the 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 again 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 (Table 1) water balance – the water source, bulk conveyance system, the irrigation scheme and the irrigation farm – and the relevant water management infrastructure.

Table 1: Four levels of water management infrastructure

<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>

For the possible water management infrastructure that may be encountered in the field, the different water balance framework system components and their classification according to the ICID framework, 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 2.

In order to improve water use efficiency in the irrigation sector, actions should be taken to reduce the non-beneficial consumptive (NBC) and non-recoverable (NRF) fractions.

In Table 2 desired ranges for the NBC and NRF components have been included to help the practitioner evaluate the results obtained when first constructing a water balance. The values shown here are based on actual results obtained in the course of the project, as documented in Part B of this report, and can be adjusted if more accurate, locally relevant data is available in an area. However, as circumstances differ greatly from one irrigation area to the next, it is recommended that water managers at all levels assess a specific system component's performance against the same component's previous years' data in order to achieve continuous improvement, rather than against other (seemingly similar) system components from different areas.

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

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: 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

1.6 Application of the water balance approach at the study schemes

Table 3 presents a cross-reference between results achieved at the different schemes and the water balance framework components. The water balance could not be applied at 3 of the 11 schemes due to a lack of data but at two of these three schemes, useful data was nonetheless collected and is included in the report.

Table 3: Cross-reference between study schemes and the water balance components

Scheme name	Water balance?	Infrastructure component analysed	Value	Paragraph nr in report
Breede	No	Conveyance system – combined river and canals	25% conveyance losses	2.2
		Crop irrigation requirements	Various – for table grapes, wine grapes and peaches	2.3.3
Dzindi	Yes	Conveyance system – lined canal	15% conveyance losses	3.2.2
		Crop irrigation requirements	Various – for vegetables	3.2.3
Gamtoos	Yes	Conveyance system – combined canal and pipelines	16% conveyance losses	4.2
Hartbeespoort	Yes	Conveyance system – lined canal	57% conveyance losses	5.2.2
		Sprinkler irrigation	38% System efficiency	5.3.2
Hex Valley	No			
KZN scheme	Yes	Conveyance system – lined canal	11.4% conveyance losses	7.2.3
		Crop irrigation requirements	Sugarcane	7.3.2
		Sprinkler irrigation	10% in-field losses	7.4.2.2
		Scheduling strategies	Various yield vs. irrigation requirement values	7.4.4.1
Loskop	Yes	Conveyance system – lined canal	20% conveyance losses	8.2.3
Vaalharts	Yes	Conveyance system – lined canal	28.4% of inflow unaccountable	9.2.1
		Centre pivot irrigation System	67% system efficiency	9.3

Orange-Riet	Yes	Conveyance system – combined lined canal and river	12.7% of inflow unaccountable	9.2.2
		Centre pivot irrigation system	77% system efficiency	9.3
		Whole scheme water balance	21.8% non-beneficial consumption	9.2.2
Steenkoppies (groundwater)	No	Crop irrigation requirements	Various vegetables	10.3.4
Worcester-East	Yes	Conveyance system – pipeline	4.3% conveyance losses	11.2
		Lawful water use	93% of lawful allocations actually used	11.3.4

The results summarised above represents only a fraction of the data collected and analysed by the project team, and the reader is invited to study the contents of the report for more detailed information.

2 Breede River

2.1 Scheme background

The Breede River Conservation Board was the owner of the original Lake Marais or Brandvlei Dam. In 1974, control of the dam and water supply was taken over by DWAF. The Board oversees a number of boards in the Robertson and Bonnievale areas which all get water from the Brandvlei Scheme. It covers the area from the Brandvlei Dam (off channel) near Worcester to Goudmyn near Robertson, a distance of 55 km.

The name of the Board has since been changed to the Central Breede River Water User Association. The CEO of the scheme is Mr Louis Bruwer, a civil engineering consultant in Robertson.

The districts served by the Association can be summarised as follows:

Angora Irrigation Board	1751,8 ha
Robertson (Breede River) Irrigation Board	2748,9 ha
Le Chasseur and Goree Irrigation Board	4195,8 ha
Zanddrift Irrigation Board	3283,5 ha
Diverse River Pump Areas	1064,5 ha
	13044,5 ha

The total scheduled area of the scheme is approximately 15 500 ha. The mentioned districts include farms that abstract water directly from the Breede River by means of private pump stations. There are approximately 150 private pumps on the Breede River between the Greater Brandvlei Dam and the Zanddrift weir, with typical capacities of between 0,01 m^3/s and 0,139 m^3/s. A number of farmers scheduled under the irrigation boards receive water from a series of four canals which are fed from diversion weirs along the Breede River.

2.2 Conveyance system

Brandvlei Dam was constructed in 1949 to a full supply level (FSL) of 207,1 m. It is an off-channel dam next to the Breede River. In 1972, it was raised by 3,4 m and extended by the construction of Kwaggaskloof Dam to form the Greater Brandvlei Dam. It is surrounded by low hills and is situated two valleys to the south of the Breede River near the town of Worcester.

Greater Brandvlei Dam is filled mainly during the winter months with water from the Smalblaar River (i.e. the lower reaches of the Molenaars River) and the Holsloot River. Diversion structures on these streams are situated downstream of Rawsonville. Under gravity the diversion canal can fill the dam to a capacity of 342 million m^3. A further 133 million m^3 of storage is available up to the full supply level of 210,1 m. Water can be pumped into this storage zone from the Breede River at the Papenkuils Pump Station. This pump station is in working condition, but is not frequently used due to the cost of pumping energy. The pump station has a capacity of 5 m^3/s, and provision has been made to increase the pumping capacity to 20 m^3/s. Water can only be pumped when flows in the Breede River exceed about 5 m^3/s.

The historical firm yield of Greater Brandvlei Dam is estimated as 127 million m^3/a. Stochastic analyses have shown that his yield is associated with a risk of failure of less than one in two hundred years.

During the summer irrigation period, water is released from the dam into the Breede River to supplement river flows for use by a number of irrigation boards with canals and pump schemes abstracting water from the river. Some of this water is diverted into the Le Chasseur Irrigation Canal, immediately downstream of the dam outlet. Water can also be fed directly into the Le Chasseur Canal from the Kwaggaskloof Dam outlet. The Bossieveld Pump Scheme withdraws water directly from Kwaggaskloof Dam.

Since 1981, water for downstream users has been released from Greater Brandvlei Dam through the tunnel outlet of the Papenkuils Pump Station. There are four canal systems and five pump schemes, as well as a number of private pumps that abstract water from the river between Greater Brandvlei Dam and the confluence of the Breede and Riviersonderend Rivers. The canal schemes are operated by the Le Chasseur and Goree, Breede River (Robertson), Angora, and Zanddrift Irrigation Boards. Pumping schemes are operated by the Agterkliphoogte, Uitnood, Klaasvoogds, Cogmanskloof and Worcester East Irrigation Boards.

The water quota for pump and canal schemes in the Breede River is 7 450 m^3/ha. If this is applied to the 13 045 ha controlled by the Breede River Conservation Board, then the total annual demand amounts to 97,2 million m3/a. If 25% loss is allowed for, 121,5 million m^3/a must be released from the Greater Brandvlei Dam. (Actually the Board has a preferential right to 94,4 million m^3/a, which is based on the yield of the original Brandvlei Dam).

2.2.1 Water Delivery Operating System

System operation mainly revolves around the water balance in the river, i.e. the releases of water from the Brandvlei Dam to satisfy the needs of the water users. With existing knowledge of the using patterns (fairly accurate on a monthly basis) the manager can plan releases from the dam. He then monitors the affect thereof (how it satisfies the withdrawal rat of the users) by reading river levels daily at several positions along the river, and then to adjust the discharge from the dam accordingly.

During the irrigation season the flow in the river entering the region is approximately zero for most of the time. However, if occasionally there is flow as a result of rain in the Tulbach/Ceres area (or in the catchments of other tributaries), the manager tries to cut down on the discharge from the Brandvlei dam as soon as possible. This “free” water is regarded very important in the water balance of the scheme.

Effective management of the scheme is judged by the volume of water flowing out of the system, downstream of Goudmyn. The closer this figure is to zero, the more effective the management.

The manager normally reads all water meters weekly, although he can access any meter at any other time via modem. If a farmer approaches his quota for the year, the manager will inform him about it, and agreement is reached on withdrawals for the rest of the season.

During the severe 2004/2005 drought in the Western Cape the scheme management had to apply strict water restrictions (approximately 60%). They then realised the difficulties to enforce these restrictions without metering (without the exceptions of a few farmers, none of the abstractions were metered). During the following season all water users installed water meters and the WUA paid for the expense of cell phone communication with each meter. The management of future water restrictions will be much more effective.

The CEO of the BRWUA provided bulk measurements of the scheme for the past three years. The data relates to a total area of 24 500 ha. All volumes shown were not measured, e.g. withdrawals from canals, and inflows into and outflows from the system are also not accounted for. The volume of return flows is also not measured, and the total water balance may be significantly affected by this. The bulk water measurements appear in Table 4.

Table 4: Historic water supply figures by the Breede River Water User Association.

MONTH	YEAR											
	2004/05				2005/06				2006/07			
	Rate	Period	Volume	Month	Rate	Period	Volume	Month	Rate	Period	Volume	Month
	(m^3/sec)	days	(m^3/sec)	Total m^3	(m^3/sec)		(m^3/sec)	Total m^3	(m^3/sec)		(m^3)	Total m^3
Oct	0.0	31	0		0.0	26	0		0.00	23	0	
			0		0.5	1	43,200		2.00	3	518,400	
			0		3.0	4	1,036,800		5.00	5	2,160,000	
				0				1,080,000				2,678,400
Nov	0.0	2	0		3.0	2	518,400		0.00	1	0	
	3.0	1	259,200		0.5	1	43,200		3.00	1	259,200	
	4.0	1	345,600		0.0	3	0		0.00	13	0	
	5.0	5	2,160,000		2.5	2	432,000		1.00	3	259,200	
	5.5	1	475,200		4.0	1	345,600		2.50	4	864,000	
	6.0	1	518,400		4.5	3	1,166,400		3.50	1	302,400	
	6.5	5	2,808,000		4.0	1	345,600		4.50	1	388,800	
	7.0	4	2,419,200		2.0	2	345,600		6.50	4	2,246,400	
	7.5	8	5,184,000		3.5	2	604,800		7.50	1	648,000	
	9.5	2	1,641,600		6.5	4	2,246,400		8.50	1	734,400	
			0		7.5	1	648,000				0	
			0		8.5	4	2,937,600				0	
			0		9.5	4	3,283,200				0	

MONTH	YEAR											
	2004/05				2005/06				2006/07			
	Rate	Period	Volume	Month	Rate	Period	Volume	Month	Rate	Period	Volume	Month
	(m^3/sec)	days	(m^3/sec)	Total m^3	(m^3/sec)		(m^3/sec)	Total m^3	(m^3/sec)		(m^3)	Total m^3
				15,811,200				12,916,800				5,702,400
Des	11.1	1	959,040		9.5	1	820,800		8.50	1	734,400	
	10.1	1	872,640		10.5	1	907,200		9.50	7	5,745,600	
	9.6	1	829,440		11.5	1	993,600		10.50	11	9,979,200	
	10.6	1	915,840		10.5	14	12,700,800		11.00	12	11,404,800	
	10.1	3	2,617,920		11.5	2	1,987,200				0	
	9.6	5	4,147,200		10.5	2	1,814,400				0	
	11.6	2	2,004,480		11.0	8	7,603,200				0	
	11.1	1	959,040		11.5	1	993,600				0	
	10.8	2	1,866,240		11.0	1	950,400				0	
	11.6	4	4,008,960				0				0	
	6.6	3	1,710,720				0				0	
	9.1	5	3,931,200				0				0	
	11.1	2	1,918,080				0				0	
				26,740,800				28,771,200				27,864,000
Jan	11.1	17	16,303,680		11.0	4	3,801,600		11.00	12	11,404,800	
	9.6	5	4,147,200		12.0	2	2,073,600		12.50	2	2,160,000	
	9.1	1	786,240		11.0	3	2,851,200		12.00	17	17,625,600	
	8.6	4	2,972,160		11.5	8	7,948,800				0	
	6.6	2	1,140,480		11.0	7	6,652,800				0	
	7.1	1	613,440		11.5	4	3,974,400				0	
	7.6	1	656,640		11.0	3	2,851,200				0	

MONTH	YEAR											
	2004/05				2005/06				2006/07			
	Rate	Period	Volume	Month	Rate	Period	Volume	Month	Rate	Period	Volume	Month
	(m^3/sec)	days	(m^3/sec)	Total m^3	(m^3/sec)		(m^3/sec)	Total m^3	(m^3/sec)		(m^3)	Total m^3
				26,619,840				30,153,600				31,190,400
Feb	7.6	4	2,626,560		11.0	2	1,900,800		12.00	14	14,515,200	
	8.1	6	4,199,040		12.0	1	1,036,800		11.50	5	4,968,000	
	9.1	4	3,144,960		11.0	13	12,355,200		11.00	9	8,553,600	
	8.6	7	5,201,280		11.5	3	2,980,800				0	
	8.1	2	1,399,680		11.0	8	7,603,200				0	
	7.6	5	3,283,200		10.0	1	864,000				0	
				19,854,720				26,740,800				28,036,800
Mar	7.6	6	3,939,840		10.0	4	3,456,000		11.00	6	5,702,400	
	7.1	3	1,840,320		9.0	1	777,600		10.50	2	1,814,400	
	7.6	2	1,313,280		8.5	1	734,400		10.00	7	6,048,000	
	7.1	4	2,453,760		9.5	1	820,800		9.75	4	3,369,600	
	6.6	16	9,123,840		8.5	5	3,672,000		8.75	3	2,268,000	
			0		9.0	9	6,998,400		9.25	3	2,397,600	
			0		8.5	1	734,400		8.75	2	1,512,000	
			0		8.0	9	6,220,800		8.25	4	2,851,200	
				18,671,040				23,414,400				25,963,200
Apr	5.6	3	1,451,520		8.0	4	2,764,800		8.25	10	7,128,000	
	4.6	2	794,880		7.0	5	3,024,000		7.75	5	3,348,000	
	3.8	6	1,944,000		6.5	1	561,600		6.75	3	1,749,600	
	0.8	1	64,800		6.0	13	6,739,200		6.25	8	4,320,000	
	2.8	1	237,600		1.0	2	172,800		0.00	4	0	

MONTH	YEAR											
	2004/05				2005/06				2006/07			
	Rate	Period	Volume	Month	Rate	Period	Volume	Month	Rate	Period	Volume	Month
	(m^3/sec)	days	(m^3/sec)	Total m^3	(m^3/sec)		(m^3/sec)	Total m^3	(m^3/sec)		(m^3)	Total m^3
	4.8	3	1,231,200		0.0	1	0				0	
	2.8	1	237,600		4.0	1	345,600				0	
	0.8	1	64,800		2.0	3	518,400				0	
	0.0	12	0									
				6,026,400				14,126,400				16,545,600
May	0.0	2	0		2.0	4	691,200		0.00	3	0	
	1.0	3	259,200		0.0	27	0		1.50	1	129,600	
	0.0	26	0				0		3.50	3	907,200	
									3.00	6	1,555,200	
				259,200				691,200				2,592,000
Total		243	113,983,200	113,983,200		243	137,894,400	137,894,400		225	140,572,800	140,572,800
										DWAF	139,009,418	

Table 5 shows the operating rules of the WUA with regards to water release patterns. Depending on the climatic condition of a particular year there will be deviations from these rules.

Table 5: Average water release patterns from Greater Brandvlei Dam

DATES OF WATER RELEASES			"NORMAL" SUPPLY PATTERN PER HA		
Year	**Open dam**	**Close dam**			
2006	16-Nov		01 Oct tot 15 Oct	2/3 x 0,472 x 15 days	408,2 m³
2005	28-Oct	05-May			
2004	03-Nov	06-May	15 Oct tot 15 Nov	2/3 x 0,472 x 31 days	843,7 m³
2003	04-Nov				
2002	28-Oct		15 Nov tot 28 Feb	1/1 x 0,472 x 105 days	4309,2 m³
2001	11-Nov	30-Apr			
2000	20-Oct	05-May	28 Feb tot 31 Mar	2/3 x 0,472 x 31 days	843,7 m³
1999	10-Oct	28-May			
1998	09-Oct	23-May	31 Mar tot 15 May	1/2 x 0,472 x 45 days	917,6 m³
1997	04-Oct	07-May			
1996	12-Dec			Total	7322,4 m³
1995	15-Nov	13-May			
1994	17-Oct	21-May			
AVERAGE SEASON				0,742 x 3.6 x 24 x 30.5 x 6	7450 (m³/ha)
15 Oct to 15 May = 7 months					

The enlisted areas in the BRWUA scheme are shown in Table 6. In certain sub-regions preferential water use rights are applicable and therefore there are differences in water allocation per ha. The tables also show the bulk water supply rates for different supply patterns.

Table 6: BRWUA enlistments and bulk water supply rates

Sub Region	Enlisted Areas (ha)				Supply Rate @ 0.472(l/s)/ha (m³/sec)				
	Preferential River	Preferential Canals	Additional River	Total	1.00	2/3	1/2	1/3	1/4
1A Private Pumps	481.90		2,126.26	2,608.16	1.23	0.82	0.62	0.41	0.31
1B Private Pumps	144.20		2,038.90	2,183.10	1.03	0.69	0.52	0.34	0.26
1C Private Pumps	428.50		1,436.44	1,864.94	0.88	0.59	0.44	0.29	0.22
Private Pumps				**6,656.20**	**3.14**	**2.09**	**1.57**	**1.05**	**0.79**
2A Le Chasseur & Goree		1,186.00	24.40	1,210.40	0.57	0.38	0.29	0.19	0.14
2B Le Chasseur & Goree		1,127.40		1,127.40	0.53	0.35	0.27	0.18	0.13
2C Le Chasseur & Goree		1,093.90		1,093.90	0.52	0.34	0.26	0.17	0.13
2D Le Chasseur & Goree		788.50		788.50	0.37	0.25	0.19	0.12	0.09
2E Le Chasseur & Goree	25.00		185.00	210.00	0.10	0.07	0.05	0.03	0.02
Le Chasseur & Goree				**4,430.20**	**2.09**	**1.39**	**1.05**	**0.70**	**0.52**
3 Robertson		2,868.90	8.60	**2,877.50**	**1.36**	**0.91**	**0.68**	**0.45**	**0.34**
4 Angora		1,139.40	622.40	**1,761.80**	**0.83**	**0.55**	**0.42**	**0.28**	**0.21**
Central Breede WUA	**1,079.60**	**8,204.10**	**6,442.00**	**15,725.70**	**7.42**	**4.95**	**3.71**	**2.47**	**1.86**
5 Agterkliphoogte 2			120.00	120.00	0.06	0.04	0.03	0.02	0.01
6 Noree 2			235.70	235.70	0.11	0.07	0.06	0.04	0.03
7 Uitnood			149.00	149.00	0.07	0.05	0.04	0.02	0.02
8 Klaasvoogds			300.13	300.13	0.14	0.09	0.07	0.05	0.04
9 Cogmanskloof			2,217.44	2,217.44	1.05	0.70	0.52	0.35	0.26
10 Worcester-East			1,797.71	1,797.71	0.85	0.57	0.42	0.28	0.21
11 Zanddrift		3,058.00	851.57	3,909.57	1.85	1.23	0.92	0.62	0.46

Sub Region	Enlisted Areas (ha)				Supply Rate @ 0.472(l/s)/ha (m³/sec)				
	Preferential River	**Preferential Canals**	**Additional River**	**Total**	**1.00**	**2/3**	**1/2**	**1/3**	**1/4**
				8,729.55	**4.12**	**2.75**	**2.06**	**1.37**	**1.03**
Total	**1,079.60**	**11,262.10**	**12,113.55**	**24,455.25**	**11.54**	**7.70**	**5.77**	**3.85**	**2.89**
	Normal water releases with no river flow				12.00	10.00	8.00	5.00	4.00
		Brandvlei			10.00	8.00	5.50	3.50	3.00
		Kwaggasklo of			1.60	1.60	1.60	1.60	0.75
	Indicators in river								
	Reading at Alfies				25	21	17		12
	Reading at Le Chasseur				7.8	6	4.5		3

The total water quotas for the different sub-region of the BRWUA are shown in Table 7.

Table 7: BRWUA enlistments and quotas

Sub Region	Total enlistment (ha)	Preferential River		Preferential Canals		Additional River		Total Quota (m³/yr)
		Area (ha)	Quota (m³/ha)	Area (ha)	Quota (m³/ha)	Area (ha)	Quota (m³/ha)	
1A Private Pumps	2,608.2	481.9	10000	0	0	2,126.3	7450	20,659,637
1B Private Pumps	2,183.1	144.2	10000	0	0	2,038.9	7450	16,631,805
1C Private Pumps	1,864.9	428.5	10000	0	0	1,436.4	7450	14,986,478
Private Pumps	**6,656.2**							
2A Le Chasseur & Goree	1,210.4	0	0	1,186.0	10000	24.4	7450	12,041,780
2B Le Chasseur & Goree	1,127.4	0	0	1,127.4	10000	0	0	11,274,000
2C Le Chasseur & Goree	1,093.9	0	0	1,093.9	10000	0	0	10,939,000
2D Le Chasseur & Goree	788.5	0	0	788.5	10000	0	0	7,885,000
2E Le Chasseur & Goree	210.0	25.0	10000			185.0	7450	1,628,250
Le Chasseur & Goree	**4,430.2**							
3 Robertson	**2,877.5**	0	0	2,868.9	10000	8.6	7450	28,753,070
4 Angora	**1,761.8**	0	0	1,139.4	10000	622.4	7450	16,030,880
Central Breede WUA	**15,725.7**							
	156.0	0	0	0	0	156.0	6770	1,056,120
5 Agterkliphoogte 2	**235.7**	0	0	0	0	235.7	7450	1,755,965
6 Noree 2	**149.0**	0	0	0	0	149.0	8920	1,329,080
7 Uitnood	**559.0**	0	0	0	0	559.0	4000	2,236,000
8 Klaasvoogds	**1,056.0**	0	0	0	0	1,056.0	7450	7,867,200
9 Cogmanskloof	**1,236.1**	0	0	0	0	1,236.1	7000	8,652,700
10 Worcester-East	**1,797.7**	0	0	0	0	1,797.7	7450	13,392,940
11 Zanddrift	**3,909.6**	0	0	3,058.00	10000	851.6	7450	36,924,174
Total	**24,824.8**	**1,079.6**		**11,262.1**		**12,483.1**		**214,044,079**

2.3 Irrigation systems

2.3.1 System evaluation results

The results for the Robertson area are shown in Table 8 to Table 11.

Table 8: General information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
R1	Drip PC	Grapes	12	NA	2,7
R2	Micro sprayer	Grapes	12	NA	6,7

Table 9 General information of pump

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
R1	Not measured	510	55	Yes	Yes	Good condition
R2	Not measured	510	55	Yes	Yes	Good condition

2.3.2 Micro irrigation systems

Table 10: General information

Test site code	Type of micro system	Filter type	Emitter spacing (m)	Operating pressure measured(kPa)		Emitter discharge (ℓ/h)	
				Average measured (block)	Hydrant	Average measured (block)	Design
R1	Drip PC	Sand / Disc	2,4 x 0,6	80	Not measured	3,9	4
R2	Micro sprayer	Sand / Disc	2,4 x 2	91	160	32,0	32

Table 11: Test results

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s(%)		EU(%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
R1	80	90,75	85	88,8	20	125	0,4	0,5
R2		90,8		88		55		NA

2.3.3 Crop water requirements

Micro climates and differences in annual weather patterns can play a significant role in the irrigation demand of a crop. To illustrate this, the nett irrigation demand for three crops was determined for three consecutive years for 15 automatic weather stations in the Breede River Valley. The locations of these stations are shown in Figure 3.

Figure 3: Locality of automatic weather stations in the Breede River Valley

The total distance over which these are distributed is less than 100 km.

Table 12 shows the nett irrigation requirement for each of the crops, sites and years, whilst the results are shown graphically in Figure 4.

Table 12: Nett irrigation requirement comparison of various crops in the Breede River Valley

Weather station	Nett Irrigation Requirement Comparison(mm/ha)								
	Table Grapes			Wine Grapes			Peaches		
	2004/2005	2005/2006	2006/2007	2004/2005	2005/2006	2006/2007	2004/2005	2005/2006	2006/2007
Zandvliet	822	766	787	715	668	686	1111	1032	1036
Robertson	548	686	738	469	594	651	766	923	964
Bo-Klaasvoogds	607	688	718	520	596	631	848	928	944
Goree	718	787	774	627	683	678	962	1057	1024
Goudmyn	760	809	783	662	704	681	1027	1081	1044
Le Chasseur	771	783	795	665	674	698	1057	1069	1050
Vinkrivier	796	842	848	692	731	742	1079	1124	1118
Nuy	793	701	793	693	608	693	1062	937	1052
Eendrag	756	691	735	659	607	634	1021	884	992
Goedemoed	653	756	726	563	656	634	895	1012	962
Hexvallei	675	766	714	588	664	622	908	1030	960
Die Straat	649	533	407	559	462	354	890	728	545
Meulplaas	770	778	773	670	674	670	1040	1043	1032
Wakkerstroom	549	618	667	472	557	595	762	837	861
Boesmansrivier	442	510	621	359	442	543	637	687	816

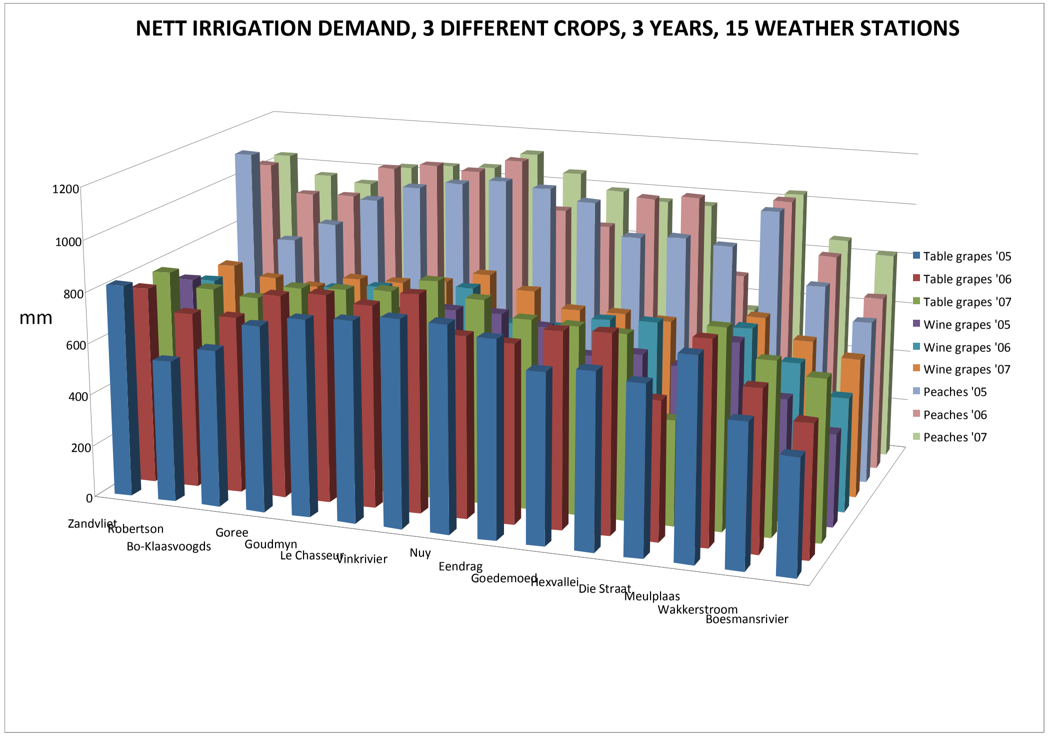

Figure 4: Nett irrigation demand, 3 different crops, 3 years, 15 weather stations

2.4 *Conclusion*

2.4.1 Conveyance system

Considerable losses occur in the river between the Greater Brandvlei Dam and the irrigated areas, and these have to be provided for. Strictly speaking, river and canal losses should be separated, but little information in this regard is available, with the result that a combined figure of 25% is often accepted. This may seem low, but the following should be taken into account:

- Various tributaries contribute to the flow in the Breede below the Papenkuils outlet from the Greater Brandvlei Dam.
- Substantial quantities of water are released for freshening purposes. This water dilutes salt concentrations in the Breede River, but also helps to compensate for losses.
- As flow in the Breede River becomes more constant as result of releases from Brandvlei, the quantity lost due to river losses is reduced percentage wise.

2.4.2 Irrigation systems

The data shown in

Figure 4 highlight the following:

- There can be fairly big variations between seasons in the irrigation requirement for a specific crop at a specific location. In this analysis these annual differences can be as high as 50% (based over a period of only three seasons).
- Micro climates can cause big variations in irrigation requirement for a specific crop over relative small distances. In this analysis this difference amounts to up to 50% increase in the requirement by moving approximately 15 km (Robertson to Zandvliet) in a particular year.

The analysis results stress the fact that monitoring of climate and in particular soil moisture is of utmost importance when it comes to irrigation planning and system management. General figures for a region are not good enough, and will lead to inefficient water use.

3 Dzindi irrigation Scheme

3.1 Scheme background

Following the completion of a study on "Losses in the distribution system of Dzindi Irrigation scheme" that formed part of a research initiative partially funded by the WRC through project K5/1464, and of which the results were presented as a poster at the 32nd Conference of the SA Society for Agricultural Extentionists in May 2003, recommendations were made by the project steering committee that the water distribution system at the scheme should be further evaluated.

A proposal was drawn up to obtain additional funding for the investigation, which was to broadly consist of the installation of measurement devices at selected locations on the canal, monitoring the performance of the devices over a period of time, periodic data collection and analysis, development of a water accounting report for the canal, and calculating benchmarks and performance indicators.

The following activities were undertaken to reach the objectives:

- Inspect the water distribution infrastructure at Dzindi Irrigation Scheme
- Identify suitable performance indicators for evaluating the water distribution and use situation
- Define the spatial and temporal boundaries of the water balance and its components, as well as the required level of accuracy
- Identify the available and required measuring infrastructure
- Install or repair and commission the necessary measuring devices
- Monitor the measuring process and collect flow data for the specified period
- Collect crop data (growth stage, planted areas and scheduling practices) for the specified period
- Conduct an evaluation of typical in-field irrigation practices (once-off)
- Perform data analysis
- Evaluate the results using the chosen performance indicators
- Compile the report

The project comprised of these activities that were undertaken to quantify the various components of the water balance, as set out under Methodology below.

The water balance assisted in evaluating the efficiency of the water supply and distribution system at scheme level (in other words, up to the field edge). A request by the project leader of project K5/1464 was also made to investigate the in-field irrigation practices at the scheme, in this case short furrow irrigation system. This was done at one site, which was chosen to be representative of typical practices, lay-out and soil type at the scheme.

Once the water balance had been drawn up and the in-field evaluation conducted, data was analised with various indicators typically used for irrigation water use benchmarking (Burt & Styles, 2004). In this case external indicators, which are defined as expressions of various forms of efficiency are applicable. The expressions used in external indicators are related to budgets, water and crop yields, which are important in the provision of key values that assist in problem areas identification and provide guidance for improvement. The actions that may be needed to remedy situations can be identified through examining internal indicators, but that is outside the scope of this project, although recommendations in this regard are made.

3.2 Conveyance system

The scheme was laid out in the typical manner of flood irrigation schemes in the former homeland areas, and the infrastructure consists of a weir in the river from where water is diverted in into a parabolic concrete canal which runs parallel to the river downstream of the weir for a distance of about 14 km. The irrigation block receive their water from secondary concrete canals that branch off the main canal at various locations, conveying water to leveled areas with irrigable soils.

At the canal inlet at the weir, the control gate (sluice) had been removed, resulting in too much water entering the canal. This causes water to spill over the sides of the canal, especially in the section between the weir and the beginning of block 4, which leads to the supporting material being washed away, exposing the concrete and leading to breakages. In some lower sections of the scheme the canals are also not in good condition due to these breakages.

All the major diversion points on the canal system were originally fitted with measuring devices (cipoletti and v-notch weirs). Most of these devices are still in place but the control mechanisms have mostly been removed or are broken. Since no regular control is exercised at the canal inlet, a large volume of water that is diverted is not utilised for irrigation and simply flows back to the river from the bottom ends of the canals.

3.2.1 Canal flows

The flow data was collected at locations M1 to M5 (Table 13) for a period of 45 days (15 October to 30 November 2004) at 30 minute intervals. A graph of the data collected at the canal inlet at the weir is shown in Figure 5 as flow rate (m^3/s) over the monitoring period.

The results showed that water is diverted into the canal continuously and confirmed that no adjustments were ever made to the inlet sluice (which had been removed) to regulate the flow rate according to demand. The average inlet flow rate was 0.36 m^3/s (or 1 296 m^3/h) and the variations on the graph was probably caused by fluctuations in the flow depth upstream or downstream of the measuring structure, disturbances in the stilling basin (waves) or blockages at the canal inlet (plastic bags, etc.)

The total volume of water diverted into the canal for the 45 day period was 1 408 213 m^3 (or 1.408 million m^3) and it was conveyed by the distribution system at the scheme as shown in Figure 6**.**

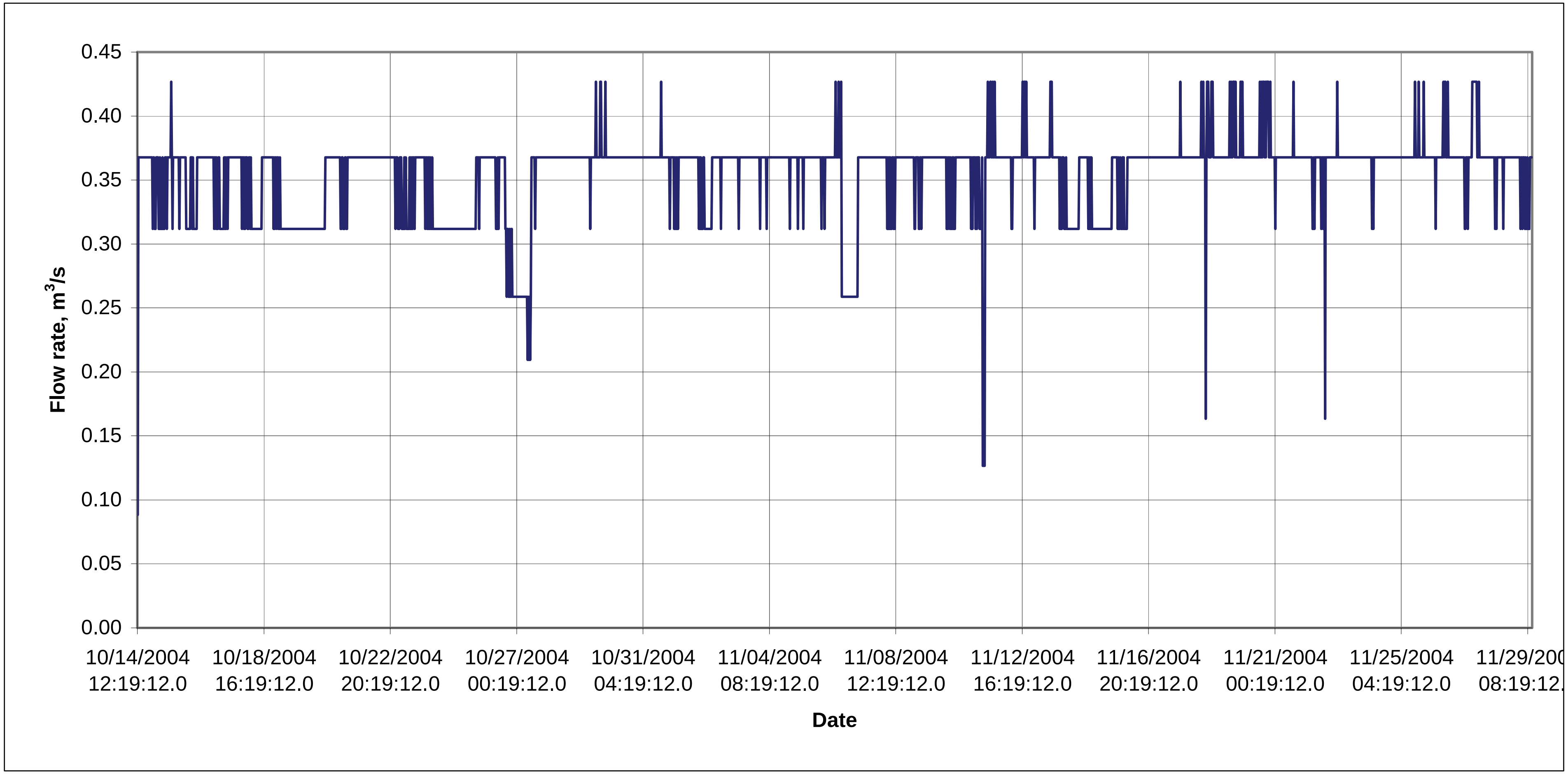

Figure 5: Flow Rate of Water into the Canal at the Weir over the Monitoring Period

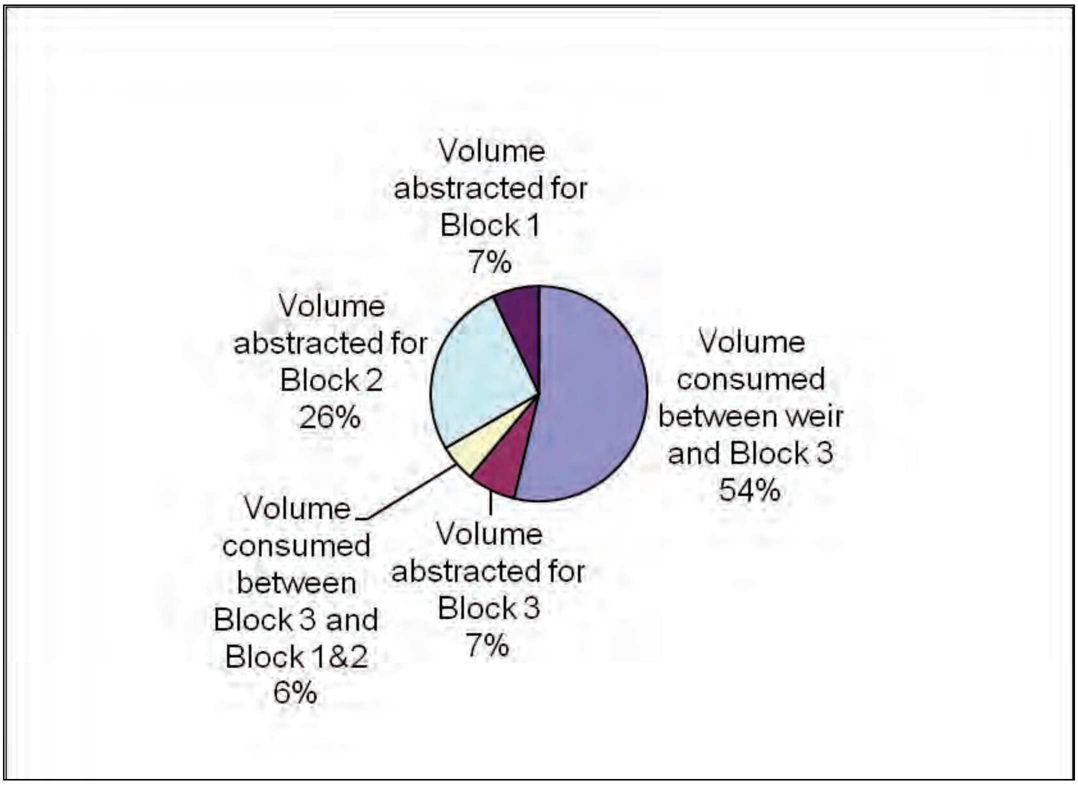

Figure 6: Distribution of the Total Inflow during the Monitoring Period

Figure 6 shows that most of the water diverted into the canal at the weir was consumed between the weir and the off-take to block 3. This consumption would have consisted of the water diverted into the secondary canals of block 4 (which were not measured), as well as evaporation, seepage and spills along the canal sections (discussed below).

The graph also shows that only 7% of the total volume was to divert to blocks 3 and 1 each but that 26% of the total volume was diverted to block 2. In order to assess the importance of these figures, one could compare it with the block areas as shown in Table 13**.**

Table 13: Water allocation of recorded flows for 45 day period to system components

Description	Inflow (m^3)	Outflow (m^3)	Outflow (%)	Area (ha)	Area (%)
Total volume abstracted at weir	1 408 213				
Volume consumed between weir and block 3		756 667	54%	42.24	31%
Volume abstracted for block 3		102 878	7%	16.64	12%
Volume consumed between block 3 and block 2		78747	6%		
Volume abstracted for block 2		371 096	26%	44.8	33%
Volume abstracted for block 1		98 826	7%	32	24%
	1 408 213	1 408 213	100%	135.68	100%

If one considers the block areas, it seems as if only block 2 (which represents 33% of the total scheme area) received close to its rightful volume of water (26%) and that block 3 and especially block 1 should have experienced considerable water shortages. However, one should keep in mind that provision should be made for losses that occur in the distribution system and that all the water that is diverted at the weir will not reach the irrigation fields.

The main canal contributes considerably to the losses that occur. The estimated lengths of different sections are shown in Table 14. The measurements that were made indicates that 78 747 m³ of water was consumed in section 3, between the off-takes of block 3 and block 2. In this section, there are no secondary canal off-takes and therefore all the water was lost in seepage, evaporation and spills, as well as possibly unlawful abstractions.

Table 14: Sections and lengths of the main canal

Section No.	Description	Length (m)
1	Weir to Block 4 (First off-take)	3 100
2	Block 4 to Block 3	2 300
3	Block 3 to Block 2	600

To put it another way, the volume of water lost in section 3 converts to a loss of 2 m³ of water per meter of canal per day. For a crop water requirement of 5 mm per day, 1 m³ of water can irrigate 200 m² of land, excluding system efficiency factors.

Estimations of the losses in the different sections are shown in Table 15, where it can be seen that seepage makes a big contribution to the total losses (5.74%).

However, if one compares the total estimated losses in section 3 (4 167 m³) with the recorded losses of 78 747 m³, it would seem that either the estimations are far too low, or that there is a major leakage or diversion in the system between block 3 and block 2.

Table 15: Estimated evaporation and seepage losses in the main canal

	Evaporation (m³)	Seepage (m³)	Total (m³)
Sections 1	628	47 631	48 259
Section 2	419	29 051	29 470
Section 3	87	4 088	4 176
Total	**1 134**	**80 770**	**81 904**
Total as percentage of inflow	0.08%	5.74%	5.82%

The loss estimations shown here were already done for worst than normal situations. Evaporation was calculated on maximum free water surface areas (in other words as if the canal was always flowing as full as possible) while seepage losses were based on a seepage rate of 2.2ℓ/s per 1 000 m² of wetted canal lining, which was also based on maximum flow depth at all times.

Since the seepage rate does not make provision for major leakages, it is recommended that a ponding test be conducted on a section of the canal to determine the seepage rate more accurately. Section 3 of the canal could also be investigated in more detail for possible leakages that occur underground.

Analysis of the water balance should furthermore also take into account that the areas shown in Table 16 are command areas and not the actual irrigated areas. In order to investigate further whether any serious water shortages could have been experienced in any of blocks for the actual situation, the water demand of the crops planted in the different blocks were determined and are discussed in the next paragraph.

3.2.2 Water required for irrigation

The crop water requirements for the actual planted crops and areas were determined using the results of a field survey completed by the student in the SAPWAT computer program. This exercise was done for blocks 1 to 3 only, since the inflow to the fields in block 4 were not recorded. However, when the data was analised, the figures for block 4 were estimated, based on field observations and discussions with the extension officer, so that the whole situation could be assessed. The actual irrigated (planted) areas per block are shown in Figure 7**.**

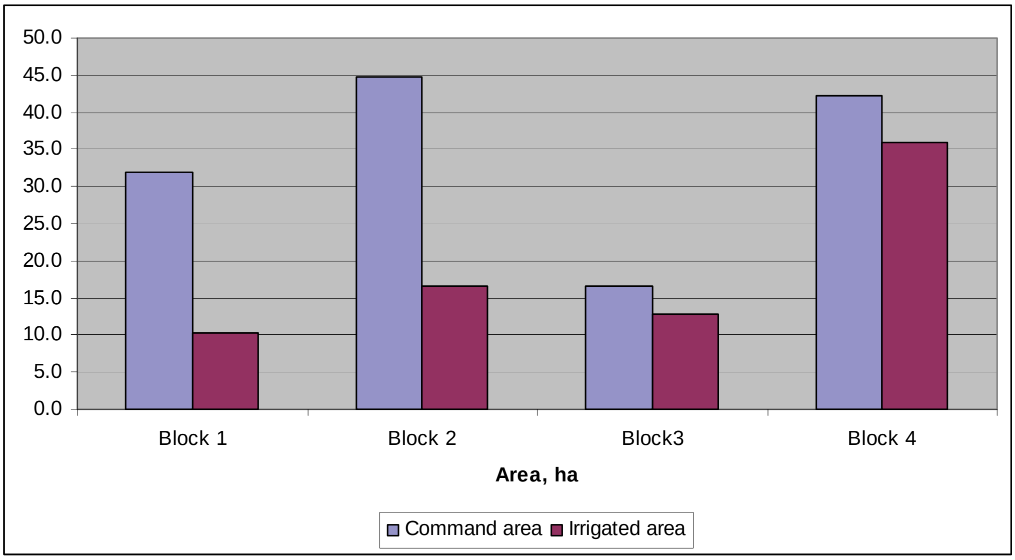

Figure 7: Command and actual irrigated areas during the monitoring period

The best land use of the surveyed blocks occurred in block 3, where 77% of the plots were planted during the monitoring period. Although the value for block 4 is higher, this value was estimated as described above. It is, however, clear that block 1 was used least intensively during this season.

Table 16: Command and actual irrigated areas during the study period

Area Balance	Command Area (ha)	Irrigated Area (ha)	Ratio
Block 1	32.0	10.3	0.32
Block 2	44.8	16.5	0.37
Block 3	16.6	12.7	0.77
Block 4	42.2	*35.9	*0.85
Total	**135.7**	**75.5**	**0.56**

* Estimated

The results of the crop surveys are shown in Table 17. A variety of crops were irrigated but the majority was maize, planted on various dates from 1 August to 3 November. Crops were grouped together according to type and planting date and the growth modeled using SAPWAT. The settings that were used in the program made provision for the following:

- Canopy cover at full growth of 70% for vegetables and 80% for maize
- Wetted area of 60% (short furrow method)
- One irrigation event per week
- Application efficiency of 70% (based on field trials – see paragraph 3.3)
- Distribution uniformity of 66% (based on field trials – see paragraph 3.3)

Table 17: Actual crops and planted areas during the study period

Block 1	**(32 ha)**							**Block 2**	**(44.8 ha)**					
Crop	Planting date	Irrigated area	ETo	ETc	NIR	GIR		Crop	Planting date	Irrig. Area	ETo	ETc	NIR	GIR
		ha	mm	mm	m^3	m^3				ha	mm	mm	m^3	m^3
carrots	21-Sep	0.07	216.8	113.5	81.72	177.33		Beans	1-Aug	0.06	0	0	0.00	0.00
groundnuts	1-Oct	0.29	216.8	99.5	286.56	621.84		beans	08-Sep	0.06	156	118.2	71.49	155.13
maize	27-Aug	2.16	216.8	210.8	4553.28	9880.62		Cabbage	20-Jun	0.31	0	0	0.00	0.00
maize	14-Sep	0.50	216.8	169.9	856.30	1858.16		Cabbage	20-Jul	0.72	13.8	11	79.12	171.70
maize	22-Sep	1.01	216.8	146.6	1477.73	3206.67		Cabbage	01-Aug	0.80	217	165.7	1333.22	2893.09
maize	28-Sep	0.50	216.8	121.7	613.37	1331.01		Cabbage	30-Aug	0.53	221	152.7	804.29	1745.30
maize	5-Oct	1.30	216.8	114.1	1478.74	3208.86		Cabbage	06-Sep	0.11	161	121.7	132.09	286.64
maize	11-Oct	1.58	216.8	97.7	1547.57	3358.22		Cabbage	14-Sep	0.51	198	145	737.04	1599.37
maize	20-Oct	0.65	189.2	71.1	460.73	999.78		groundnuts	01-Sep	0.17	217	166.7	287.81	624.54
maize	26-Oct	1.15	161.6	54.3	625.54	1357.41		maize	01-Aug	1.31	217	218	2846.47	6176.84
maize	3-Nov	0.58	124.8	36.9	212.54	461.22		maize	06-Aug	0.70	217	217.9	1530.31	3320.78
onion	25-Aug	0.14	216.8	87.1	125.42	272.17		maize	15-Aug	0.71	217	217.9	1546.68	3356.29
spinach	25-Aug	0.07	216.8	124.1	89.35	193.89		maize	19-Aug	1.43	217	217.3	3097.12	6720.76
sweet potato	1-Oct	0.29	216.8	137.6	396.29	859.94		maize	28-Aug	3.70	217	210.8	7805.82	16938.63
		10.30		113.21	12805.13	27787.13		maize	05-Sep	1.06	217	194.9	2066.91	4485.20
								maize	08-Sep	0.81	217	187.6	1524.17	3307.46
Block 3	**(16.6 ha)**							maize	12-Sep	1.47	217	169.9	2505.46	5436.86
Crop	Planting date	Irrigated area	ETo	ETc	NIR	GIR		maize	20-Sep	0.78	217	146.6	1146.37	2487.62
		ha	mm	mm	m^3	m^3		maize	27-Sep	0.41	217	121.7	497.21	1078.94
beans	07-Aug	0.40	0	0	0.00	0.00		maize	06-Oct	0.53	217	114.1	607.74	1318.80
cabbage	21-Sep	0.35	216.8	151.9	530.80	1151.83		onions	01-Aug	0.13	217	137.4	175.10	379.97

groundnuts	1-Oct	1.96	216.8	99.5	1953.70	4239.53		onions	28-Aug	0.02	217	87.1	13.94	30.24
maize	27-Aug	3.66	216.8	210.8	7716.97	16745.82		spinach	20-Jul	0.07	217	148.8	101.18	219.57
maize	14-Sep	3.49	216.8	169.9	5936.99	12883.26		tomatoes	15-Aug	0.12	217	176	213.84	464.03
maize	28-Sep	2.16	216.8	121.7	2632.61	5712.77				16.52		158.5143	29123.38	63197.75
maize	5-Oct	0.37	216.8	114.1	417.70	906.40								
sweet potato	1-Oct	0.35	216.8	137.6	480.83	1043.40								
		12.75		143.64	19669.59	42683.02								

Rainfall and temperature data was obtained from the SA Weather Service for their weather station at Thohoyandou. According to their records, (Table 18) only 13.4 mm fell during the monitoring period and this was so little that it was disregarded for the purposes of the water balance.

Table 18: Rainfall data from Thohoyandou weather station (Weather SA)

Month	Date	mm
October	25	1.5
November	8	1.6
November	23	3.5
November	30	6.7
Total		**13.3**

The net irrigation requirement (NIR) expressed as a volume of water was therefore calculated as the product of the irrigated area and the crop evapotranspiration, since provision for the reduced wetted areas were already made in SAPWAT.

The gross irrigation requirement (GIR) per crop expressed as a volume of water was calculated by dividing the NIR with the product of the average application efficiency and the average distribution uniformity.

The sum of all the GIR for the different crops per block is considered to give an indication of the actual water requirements for the monitoring period. When compared to the measured volumes of water diverted to each block (or estimated, in the case of block 4), the ratio of water required to water diverted to the blocks is rather poor, as shown in Table 19**.**

Table 19: Water use at block level

Block Number	Volume Diverted (to Blocks) (m^3)	Volume Required (SAPWAT) (m^3)	Ratio
Block 1	98 826	27 787	0.28
Block 2	371 096	63 198	0.17
Block 3	102 878	42 683	0.41
Block 4	*628 890	*115 309	0.18
Total	**1 201 690**	**248 977**	**0.21**
As %age of total inflow	85%	18%	

* Estimated

However, the volumes of water diverted to the blocks are not totally consumed by irrigation since the bottom ends of the secondary canals return all excess water to the river as return flows. The amount of return flows were not measured during the study since it would have required each secondary canal end to be fitted with a measuring structure and data logger, but from observations it would seem that this could be a considerable amount of water.

Although this water is not consumed it may return to the river at a poorer quality that what it was when originally diverted at the weir. Most of the canal bottom ends are very overgrown and it is likely that the return flows seeps back into the river as groundwater, and during this percolation process its salt content may increase.

The flow measurement results at the block off-takes, as shown in Figure 8 for block 1 and 2, also confirmed that water was continuously being diverted to the secondary canals and that little management was taking place.

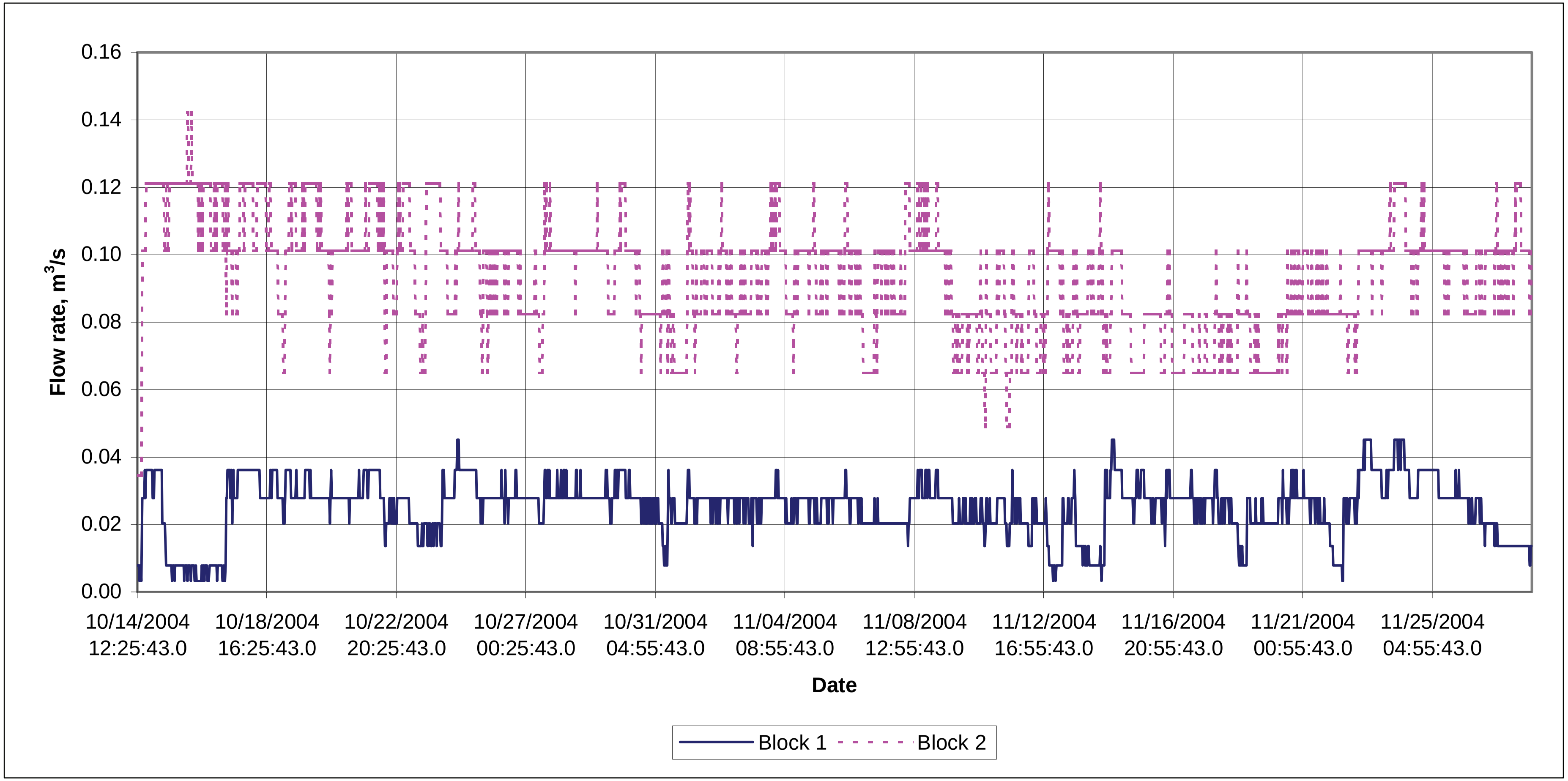

Figure 8: Flow diverted to blocks 1 and 2 during the monitoring period

A few significant conclusions can be drawn from the results of the system evaluation:

- Only about 56% of the command (scheme) area was planted with crops requiring irrigation during the monitoring period.
- Only 18% of the water diverted at the weir was required at field level by the actual planted crops based on climatic requirements.
- Approximately 85% of the water diverted at the weir reached the secondary canals leading to the irrigated areas (therefore the losses were 15% of the inflow).
- Of the 15% losses, only 5.8% can be directly linked to evaporation and seepage losses in the main canal up to the diversion to block 2, leaving 9.2% unaccounted for.
- The amount of water lost in section 3 of the main canal seems unrealistically high but if analised it works out to 14.3% of the total volume of water that passed through the section and is therefore in line with the 15% calculated for the whole main canal.
- Although return flows were not measured, it is estimated that between 40 and 60% of the water that reached the secondary canals, is return flow and not used for irrigation.

The 18% of inflow that is required by the crops for evapotranspiration does not take in-field irrigation system efficiencies into account. The short furrow evaluation made it possible to quantify these values and this is discussed in the next paragraph.

3.2.3 Water balance

The final water balance, based on the field measurements, modeling results and 40% return flow, is presented in Table 20.

Table 20: Water balance for Dzindi Irrigation Scheme

		Scheme				CI	Block 1	Block 2	Block 3	Block 4
		%	%	m^3	m^3	%	m^3	m^3	m^3	m^3
Gross inflow		100		1408213		10				
Consumptive uses and outflows						25				
Main canal losses						10				
Seepage & evaporation		5.8		81904		10				
Unaccounted		9.2		129556		5				
	Delivered to blocks		85.3		1201364	10	98826	371096	102878	628890
Secondary canal losses (15%)		12.8		180205		10	14824	55664	15432	94334
Return flows (40%)		34.1		480546		25	39530	148439	41151	251556
	Delivered to fields		38.4		540614	25	44472	166993	46295	283001
In-field distribution losses (30%)		11.5		161644		10	13297	49931	13842	84617
	Delivered to soil surface	26.9		378970		25	31175	117062	32453	198383
	m^3/ha			5019			3028	7086	2546	5525.39
	mm/day on irrigated area			11.2			6.7	15.7	5.7	12.3

The following assumptions were made:

- Conveyance losses in the concrete canals are 15% of the volume of water that flowed during the monitoring period. This is definitely valid for the main canal but the figure may be considerably higher for the secondary canals (it was not measured at this level).
- 40% of the water diverted to the blocks are not utilised for irrigation and are considered outflows
- The in-field application efficiency of the short furrow system is 70% and therefore 30% losses occur in-field
- CI = Confidence interval, an indication of probable variation of the parameter (lower CI is better), reflecting mainly the accuracy of the different measuring methods. The combined CI of a number of parameters can only be as good as the worst CI of all the parameters under consideration.

According to this scenario the volume of water delivered to field (540 614 m³) is much higher than the theoretical requirement of 248 977 m³ calculated in Table 19. If this value is used in the water balance, the return flows (i.e. the real variable), increase to 64.3% of the volume delivered to the blocks, or 54.8% of the gross inflow to the scheme, as shown in Table 21.

Table 21: Water balance with return flows at 64.3% of the water delivered to the blocks

		Scheme			
		%	%	m³	m³
Gross inflow		100		1408213	
Consumptive uses and outflows					
Main canal losses					
Seepage & evaporation		5.8		81904	
Unaccounted		9.2		129556	
	Delivered to blocks		85.3		1201364
Secondary canal losses (15%)		12.8		180205	
Return flows (64.3%)		54.8		772237	
	Delivered to fields		17.7		248923
In-field distribution losses (29.9%)		5.3		74428	
	Delivered to soil surface	12.4		174495	
Nett application:	m³/ha			2311	
	mm/day on irrigated area			5.1	

However, this may still differ from the real situation if all farmers apply water in a similar way as the farmer of the short furrow evaluation plot, who gave an average application of 18.9 mm per week. If a scenario is considered where all the planted areas received 20 mm nett irrigation per week during the monitoring period, the water balance shows that 73.5% of the water diverted to the blocks would be lost as return flows, as shown in Table 22**.**

Table 22: Water balance with return flows at 73.5% of the water diverted to the blocks

		Scheme			
		%	**%**	**m³**	**m³**
Gross inflow		100		1408213	
Consumptive uses and outflows					
Main canal losses					
Seepage & evaporation		5.8		81904	
Unaccounted		9.2		129556	
	Delivered to blocks		85.3		1201364
Secondary canal losses (15%)		12.8		180205	
Return flows (73.5%)		62.7		882642	
	Delivered to fields		9.8		138517
In-field distribution losses (29.9%)		2.9		41417	
	Delivered to soil surface	6.9		97101	
Actual nett application:	Delivered to soil surface:			97071	m^3
Based on:	20 mm per week			1285.71	m^3/ha
	on 75.5 ha			2.9	mm/day

Although 73.5% seems high, it must be kept in mind that water is diverted into the main canal 24 hours per day, and therefore approximately 44% flows through the scheme during the night (based on estimated daylight hours). Although the extension staff reported that some night time irrigation does take place it is probably considerably less than the day time irrigation. If, argument's sake, 4% of the total inflow is used during the night, this still leaves 40% of the water to be lost during the night. Furthermore, during the day not every drop of water is used for irrigation, and if the return flow during the day is 15%, the total return flows could easily be 55%.

The losses in the secondary canals can also be higher than the 15% used, especially if one considers the work done by Cadet et al. (2003) in Van Averbeke et al. (2004) that reported on the poor state of in-field infrastructure. If leakages in these canals are excessive it can also to some extent be considered return flows (through percolation) but in practice it cannot be used for irrigation until the canals are repaired.

3.3 Irrigation systems

The results for the Dzindi area are shown in Table 23. All the systems are short furrow irrigation systems and no pumps are used.

The efficiency of the systems can be assessed by evaluating the results in the last two columns. Sites Z1 and Z7 had high losses, which mostly occurred in the supply furrow, and were caused by the low inflow rate to the plot. The sites where a better inflow of 25 m^3/h was used had less loss as the water could reach its destination faster. At all sites the DU_{lq} was poor. Interestingly enough, the site with the highest DU_{lq} was one of the sites with the highest losses.

Table 23: General information

Test site code	Plot width (m)	Plot length (m)	Supply furrow length (m)	Nr of beds	Inflow rate (m^3/h)	Total time (min)	Total volume used for irrigation	Total volume applied in beds (m^3/h)	Average depth applied (mm)	DU_{lq} (%)	Losses (%)
Z1	4,3	92	85	10	10,5	54,5	9,5	6,2	17,7	71,2	35,0
Z2	4	81	70	10	25,3	200,5	84,5	72,7	234,0	50,8	14,0
Z3	7,3	93	72	8	25,3	81	34,2	30,8	55,2	31,0	9,7
Z4	Not measured										
Z5	7,8	82	72	9	25,3	119,3	50,3	41,3	62,0	49,9	17,9
Z6	5	83	74	9	25,3	70	29,5	24,2	62,2	60,2	17,9
Z7	4,5	78	60,5	7	10,5	146,3	25,6	14,8	40,1	58,6	42,1

3.4 Conclusion

A few significant conclusions can be drawn from the results of the conveyance system evaluation:

- Only about 56% of the command (scheme) area was planted with crops requiring irrigation during the monitoring period.
- Only 18% of the water diverted at the weir was required at field level by the actual planted crops based on climatic requirements.
- Approximately 85% of the water diverted at the weir reached the secondary canals leading to the irrigated areas (therefore the losses were 15% of the inflow).
- Of the 15% losses, only 5.8% can be directly linked to evaporation and seepage losses in the main canal up to the diversion to block 2, leaving 9.2% unaccounted for.
- The amount of water lost in section 3 of the main canal seems unrealistically high but if analised it works out to 14.3% of the total volume of water that passed through the section and is therefore in line with the 15% calculated for the whole main canal.
- Although return flows were not measured, it is estimated that between 40 and 60% of the water that reached the secondary canals, is return flow and not used for irrigation.

The 18% of inflow that is required by the crops for evapotranspiration does not take in-field irrigation system efficiencies into account. The short furrow evaluation made it possible to quantify these values.

The scenarios presented here are only three possibilities. The return flows and the actual in-field water use for the whole scheme are the two unknown parameters: it would have been interesting to try to determine them more accurately, but the cost of trying to quantify these parameters through flow measurements at all the diversion points on the scheme would be high.

4 Gamtoos Irrigation Scheme

4.1 Scheme background

The Gamtoos Irrigation Scheme is located in the Eastern Cape and has 7 431 ha of scheduled irrigation area. Water allocations are 8 000 m^3/ha and there are approximately 170 farmers on the scheme, receiving water from the Kouga Dam. Water is distributed with a canal network with automatic gates and water meters are used to measure water distributed through pipelines to the farmers from the canal network. Irrigation systems used include centre pivot, drag lines, micro, drip, and travelling guns to irrigate a range of crops but mostly citrus (30%), vegetables, pastures, coffee, tobacco, soya beans, and canola. Potatoes form an important crop on the scheme, and Potatoes South Africa (PSA) is also interested in supporting its producers to improve water use efficiency (particularly system and irrigation management efficiency) on the scheme. PSA, therefore, also contributed financially to the project.

The irrigation board is very forward thinking and has put the whole scheme on a GIS, while they also use the WAS and SAPWAT programmes. Water abstraction data is available on the WAS program. All abstractions are captured as meter readings in WAS. Water release and tail end records are available (measured with OTT chart recorders).

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

4.2 Conveyance system

Results from a previous WRC study were available to assess conveyance efficiency at the scheme. A section of a secondary canal was evaluated to determine total losses. It did not make it possible for us to say where exactly the losses occur. In order to perform a successful water balance it is necessary to include all the components of the system, even if there is no or little data available. Including these components in the balance will show where possible losses may occur, and also how important it may be to obtain the data.

To do this, Burt (1999) advises that estimates of the confidence interval (CI) for each component should be made. A confidence interval of “10” indicates that one is 95% certain that the correct value lies between plus or minus 10% of the stated value. The purpose is to reinforce the fact that we rarely know many values with precision, although we may argue about them as if they are precise!

It is therefore better to include all the components even though their quantities are relatively unknown, rather than to ignore them. In view of this, the balance shown in section

3 of this report makes provision for seepage and evaporation losses although it could not be given at a great accuracy.

Seepage was calculated as 1.2 (ℓ/s)/1 000 m² of wetted canal lining based on a literature review for the value, average flow depths as recorded in the canal before for the periods under consideration and the basic canal shape as determined by the DWAF technicians in their survey.

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

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

The combined results of the measurements together with estimated confidence intervals for the various components are shown in Table 24.

The accuracy with which the possible causes of the losses can be determined is, however, considerably less as shown in the confidence intervals. After allocating portions of the losses to evaporation and seepage in the dam and canal, there is still an estimated 11.33% (442 885 m³) unaccounted for, which may be due to any of the last three (unquantified) components listed in the table. Considering that the balancing dam has a total volume of approximately 90 000 m³ when full, even an extreme difference in water levels from one month to the next for all three months will not make up the unaccounted for water.

Table 24: Water balance results

	Dec (m³)	Jan (m³)	Feb (m³)	D+J+F (m³)	% of Inflow (%)	CI (%)	
						Min	Max
Inflow	1 261 844	1 487 872	1 158 187	3 907 903		-5	5
Usage	964 380	1 375 510	941 680	3 281 570	84.0%	-3	3
Gross losses	297 464	112 361	216 507	626 333	16.0%	-5	5
Gross losses detail:							
Evaporation (canal)	2 631	2 898	2 149	7 679	0.2%	-15	15
Seepage (canal)	53 120	58 686	53 399	165 206	4.0%	-30	30
Evaporation (dam)	3 502	3 493	2 846	9 842	0.3%	-15	15
Seepage (dam)	248	248	224	720	0.02%	-30	30
Unaccounted	237 961	47 035	157 888	442 885	11.0%	-30	30
Total	**297 464**	**112 361**	**216 507**	**626 333**	**16.0%**		
Un-quantified components:							
Change in dam level					?	-3	3
Canal and dam spills					?	-15	15
Unlawful abstractions					?	-20	20

The conveyance efficiency for the combined three month period was calculated as 0.84 (or 84%), which means that 16% of the water that flowed into the D-canal did not reach a farm off-take (water meter). Based on the estimated accuracy of the Parshall flume, the depth sensor and water meters it is probable that these results are within ± 5% of the actual value. According to personal communications with DWAF officials and other water management professionals, an efficiency higher than 80% is considered acceptable. These results therefore meet these criteria.

This may lead to consider what the magnitude of the remaining two components (spills and unlawful abstractions) may be. It could be a considerable amount, or it could be that the seepage and evaporation values are seriously under estimated.

4.3 Irrigation systems

4.3.1 Measurement methods used

Initially eight irrigation systems (G1-G8) – four centre pivots, one sprinklers and three micro sprinkler systems, were evaluated to determine their performance. Of these systems, five were identified as suitable for long term monitoring, including three centre pivot and two micro sprinkler systems. When the evaluation results were discussed with local stakeholders, the issue of comparing citrus water use under drip and micro sprinkler systems was raised, and it was decided that two drip systems should be included in the list of monitoring sites. Furthermore, it was also found that none of the evaluated pivot systems used to irrigate pastures, an important crop in the area, was included in the list (due to poor first evaluation results), and therefore three additional pivots were added. These additions required the evaluation team to return to the scheme to evaluate another five systems. Table 25 gives the final list of selected long-term monitoring sites at the Gamtoos Irrigation scheme.

In order to determine efficiency of water use on field level, the field water balance components were measured (or estimated) on the selected fields. The objective was to measure or estimate all water gains (rain and irrigation) and losses (transpiration, evaporation, runoff and deep drainage) in an effort to quantify the proportion of water that directly contribute to crop production. Short-term measurements of this nature are often misleading and therefore continuous monitoring of a number of fields for one or more entire growing seasons was undertaken.

Table 25: Selected Gamtoos Irrigation Scheme long-term monitoring sites

Field code	Irrigation system	Crop	Own IB water Meter?	IB water meter no.	PT or TBRG?	Monitoring Months	Comments
G4	Microjet	Citrus	2x old	36/2, 36/3	PT	0	All citrus; add 2 w/meter readings
G5	Pivot	Potatoes	No		TBRG	6	Half pivot potato – not own w/meter
G6	Microjet	Citrus	1x old	B5/1	PT	0	All citrus on w/meter; tree sizes differ
G8	Pivot	Potatoes	1x new		TBRG	6	Half pivot potato – use rain gauge data
G9	Drip	Citrus	1x old	33/1	PT	12	Evaluation needed; pressure problems
G10	Pivot	Potatoes	No		TBRG	6	Evaluation needed; Full circle
G11	Pivot	Potatoes	No		TBRG	6	Half circle, fully planted
G13	Drip	Citrus	No		PT	0	Select block
G14	Pivot	Potatoes	No		TBRG	6	Quarter circle; below road
G15	Pivot	Pasture	No		TBRG	12	

PT = Pressure transducer TBRG = Tipping bucket rain gauge

The long-term monitoring commenced in July 2007 and lasted until February 2009. This required the installation of probes (with continuous logging capacity) to measure soil water content, as well as either a water meter or pressure sensor at the block inlet. DFM Soil probes (Figure 9) were installed in the fields for continuous monitoring of soil water content. These probes work on a capacitance principle and take readings at 6 depths (up to 80 cm depth) once every hour. An irrigation scheduling consultant, who already used this system and had all the necessary software and dataloggers, was contracted to assist with data collection. Data was weekly downloaded from the probes in the fields, using a handheld datalogger and then transferred to a computer in the office. This was later upgraded to a system that could transfer data directly to a base station computer via telemetry. In order to record the time and duration of irrigation on a specific block, pressure transducers (PT) with logging function were installed at the micro irrigation block inlets. The PTs recorded when there was an increase or decrease in pressure, which signalled when irrigation was started or stopped. PTs could not be used for the centre pivot systems, as different crops were often planted simultaneously on different parts of the pivots, which made it difficult to quantify irrigation amounts for potatoes only. Manual rain gauges were initially used to measure rainfall and irrigation amounts for the centre pivots. However, the data collected from these were very unreliable as it seems that rain gauges were often emptied by farmers or farm workers before the data was recorded. During the second season, the centre pivots were fitted with electronic tipping bucket rain gauges and Hobo dataloggers (Figure 10) to give more accurate estimations of irrigation (and rainfall) amounts. Rainfall data was obtained from nearby automatic weather stations.

Figure 9: Examples of the capacitance probes that were used to monitor soil water content

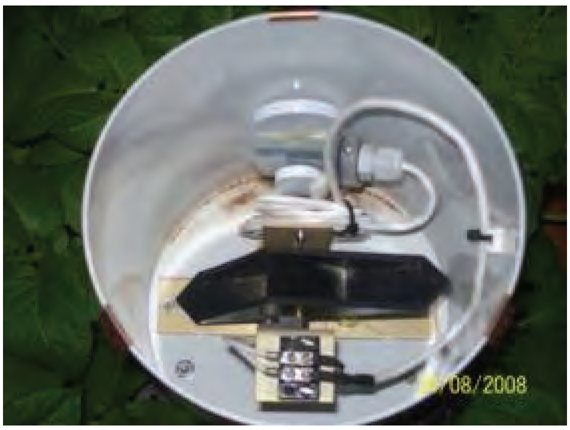

Figure 10: Tipping bucket rain gauge used to monitor irrigation amounts for the centre pivots.

Since it is very difficult to measure some components of the soil water balance (for example transpiration and evaporation losses) in the field, the SWB crop model was used to estimate these components. The driving weather variables needed to run the models were obtained from automatic weather stations in the area. The modeled crop water requirements for each field and growing season were then compared with the actual rainfall and irrigation amounts applied in order to quantify losses and the proportion of irrigation water that actually contributed to crop growth. This could only be done for the 2008 season, as the 2007 irrigation data (when manual rain gauges were used) was too unreliable.

4.3.2 System Evaluation Results

Results of the system evaluations are shown in Table 26 to Table 29**.** Results of the additional system evaluations undertaken in January 2008 are shown in Table 30.

Table 26: First round of evaluation sites at Gamtoos Irrigation scheme

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
G1	Centre pivot	Canola	30	7,1	NA
G2	Centre pivot	Grass	Not available	16,7	NA
G3	Sprinkler	Chicory	45	NA	4,9
G4	Micro sprayer	Citrus	Not available	NA	2,3
G5	Centre pivot	Pumpkins	20	10,7	NA
G6	Micro sprayer	Citrus	72	NA	3,8
G7	Micro sprayer	Citrus	Not available	NA	4,4
G8	Centre pivot	Potatoes	30	13,2	NA

Table 27: First round system evaluation test results for centre pivots at Gamtoos Irrigation scheme

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured
G1	85	83,3	75	81,3	80	92
G2		70,9		63,1		Not measured
G5		82,9		63,7		Not measured
G8		89,6		79		80,3

Table 28: First round system evaluation test results for sprinklers at Gamtoos Irrigation scheme

Test site code	Uniformity Parameters				Efficiency		Pressure variation (%)		Discharge variation (%)	
	CU(%)		DU_{lq} (%)		SE (%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (max)	Measured
G3	80	75,5	74	61	75	90,7	20	62	10	34

Table 29: First round system evaluation test results for micro irrigation at Gamtoos Irrigation scheme

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s(%)		EU(%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
G4	80	83,7	85	85,2	20	47	0,4	NA
G6		83,2		75,7		29		NA
G7		75,5		78,9		40		NA

Table 30: System evaluation test results for the additional system evaluations that were conducted at Gamtoos Irrigation Scheme

Site nr	Inlet pressure (kPa)	Emitter discharge (average) (l/h)	Gross application (Drip – mm/h) (Pivots – mm)	EU (drip) / CU & DU (pivots) (%)
G9 (PC Drip)	120	2.8	0.56	40
G13 (PC Drip)	265	3.9	0.65	93
G10 (Pivot)	N/A	N/A	4.65	78 & 74
G14 (Pivot)	N/A	N/A	6.78	70 & 56
G15 (Pivot)	N/A	N/A	9.46	85 & 63

4.3.3 Results of long-term monitoring

A summary of the amounts of irrigation water applied to each field during the relevant seasons is shown in Table 31.

Table 31: Amounts of irrigation water applied for the different fields monitored at Gamtoos Irrigation scheme

Field code	Irrigation system	Crop	Season	Application rate (mm/h)	Total seasonal irrigation	
					Hours	Amount(mm)
G4	Microjet	Citrus	Mar 08 – Feb 09	2.3	246	566
G6	Microjet	Citrus	Mar 08 – Feb 09	3.8	188	714*
G9	Drip	Citrus	Mar 08 – Feb 09	0.56	917	513
G1	Potatoes	Potatoes	Jun – Nov 08			273
G5	Pivot	Potatoes	Jun – Nov 08			316
G8	Pivot	Potatoes	Feb – Jun 08			209
G10	Pivot	Potatoes	Jul – Nov 08			354
G11	Pivot	Potatoes	Sept – Dec 08			309
G13	Drip	Citrus	Mar 08 – Feb 09	0.65	N/A	N/A
G14	Pivot	Potatoes	Jul – Dec 08			245
G15	Pivot	Pasture			N/A	N/A

* Note: the actual irrigation amount was over estimated due to irrigation system blockages – see text for details.

The datalogger at G13 malfunctioned and no water supply data could be recovered. The datalogger at G15 was damaged by livestock grazing the pasture and data could not be retrieved.

Figure 11 to Figure 15 provide examples of the capacitance probe output graphs for some of the monitored fields. These graphs were produced by the software supplied with the probes and illustrate the changes in soil water content over the growing season. The readings are expressed in relative units (not absolute volumetric soil water contents), but are still very useful to assist the irrigator in determining whether irrigation is needed, and what amount of irrigation to apply.

A 'Full' line (green line) and 'Refill' line (red line) is set up for each soil profile (usually by an experienced consultant), and the irrigator has to ensure that soil water content is maintained between these two boundaries (in the green area of the graph). If the measured water content remains in the blue area, the field is too wet and drainage losses can be expected. On the other hand, if the measured soil water content drops into the red area of the graph, the soil is getting too dry and the crop may be stressed.

The irrigator, therefore, has to observe response of the instrument readings to his current irrigation practice, and increase or decrease irrigation amounts and frequencies to ensure that the soil water content is maintained between the set boundaries (in the green area of the graph). The idea is thus to develop 'rules of thumb' over time through adaptive management.

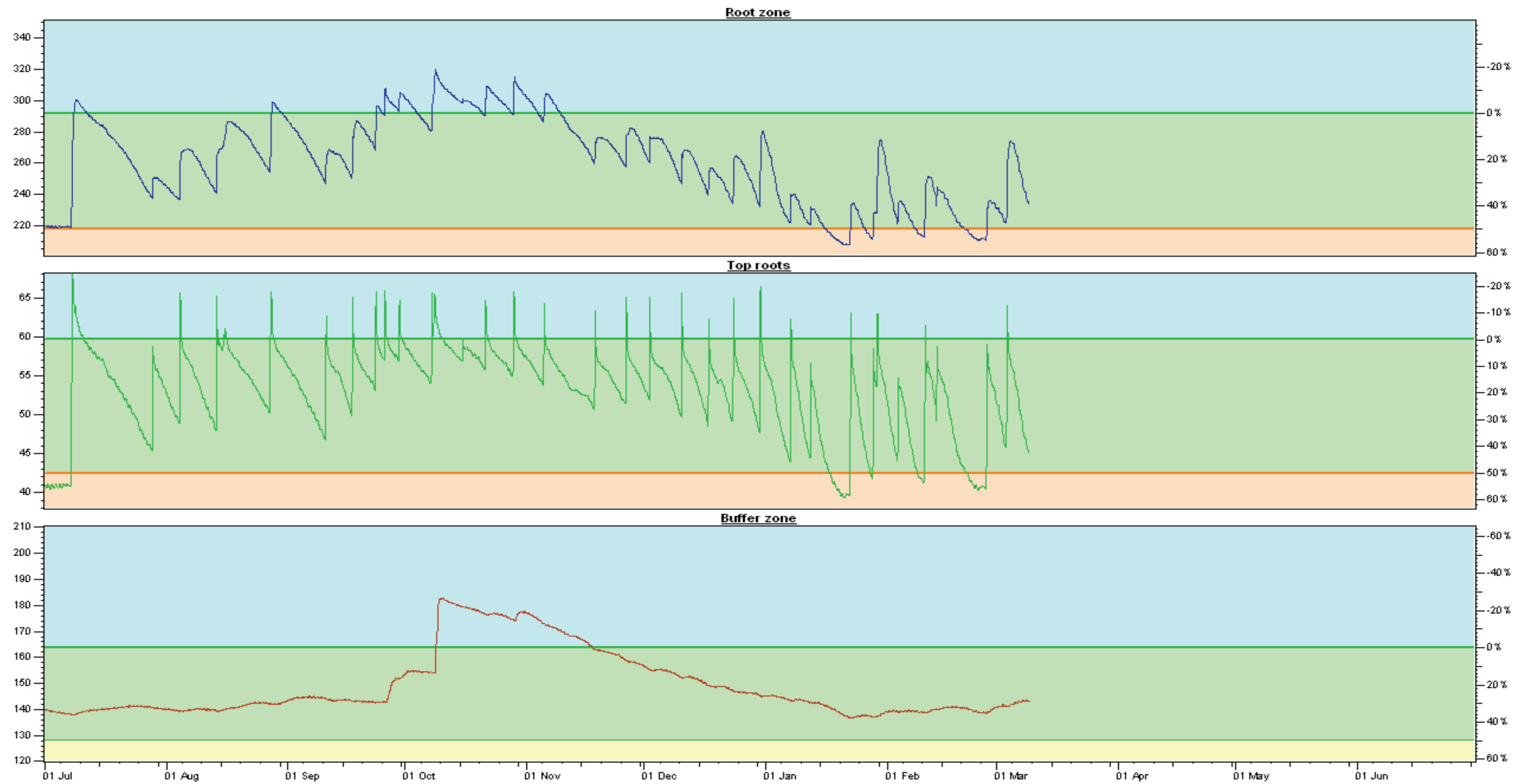

Figure 11: Changes in measured soil water content over the growing season for field G6 (citrus, micro jet irrigation, 2007/08).

Top graph – average for entire root zone; Middle graph – top layer of root zone; Bottom graph: buffer zone (bottom part of root zone)

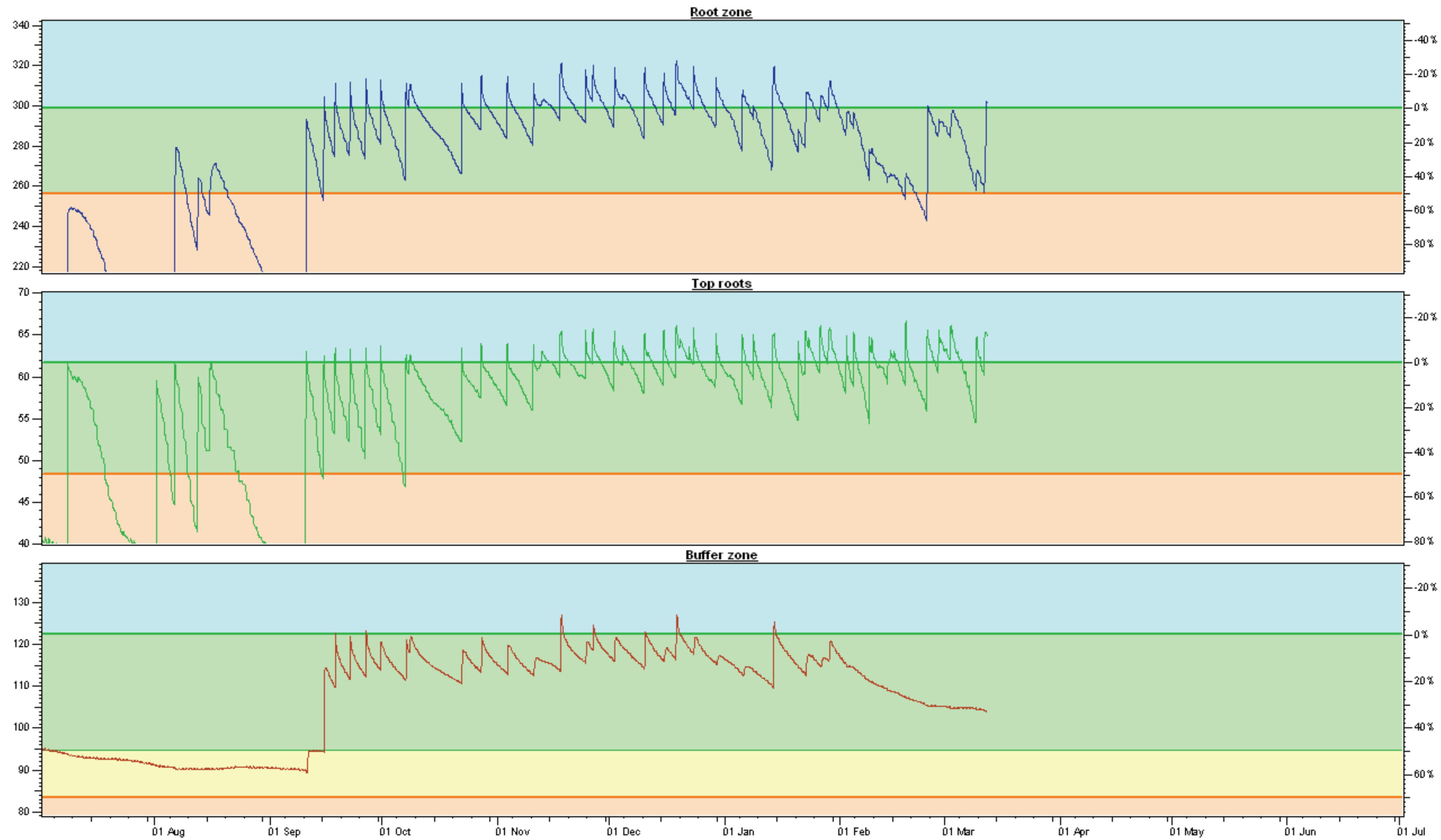

Figure 12: Changes in measured soil water content over the growing season for field G4 (citrus, micro jet irrigation, 2007/08).

Top graph – average for entire root zone; Middle graph – top layer of root zone; Bottom graph: buffer zone (bottom part of root zone)

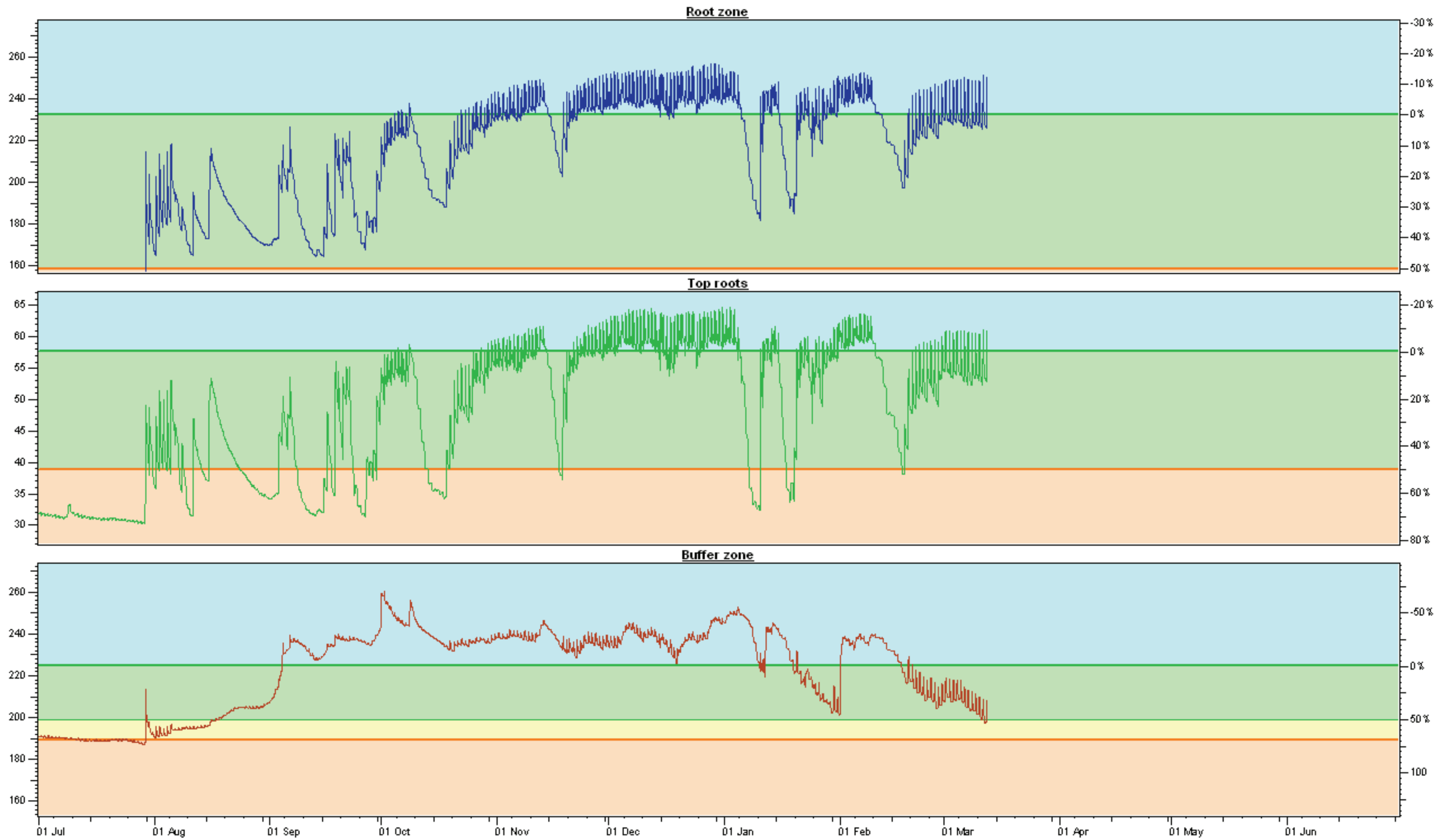

Figure 13: Changes in measured soil water content over the growing season for field G9 (citrus, drip irrigation, 2007).

Top graph – average for entire root zone; Middle graph – top layer of root zone; Bottom graph: buffer zone (bottom part of root zone)

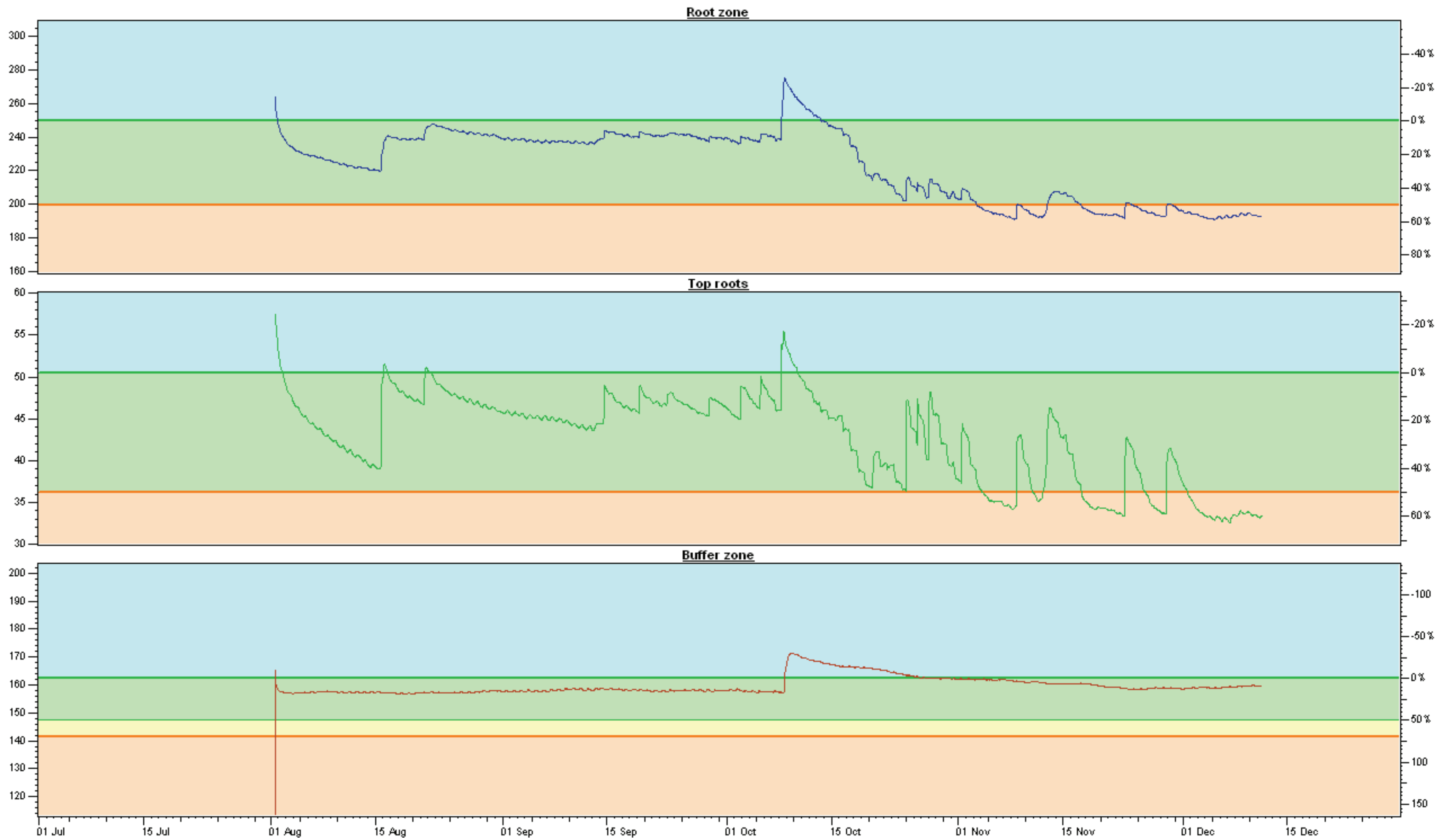

Figure 14: Changes in measured soil water content over the growing season for field G14 (potatoes, centre pivot irrigation, 2008).

Top graph – average for entire root zone; Middle graph – top layer of root zone; Bottom graph: buffer zone (bottom part of root zone)

Figure 15: Changes in measured soil water content over the growing season for field G5 (potatoes, centre pivot irrigation, 2008).

Top graph – average for entire root zone; Middle graph – top layer of root zone; Bottom graph: buffer zone (bottom part of root zone)

From Figure 11 is it clear that the micro irrigated citrus crop (field G6) was consistently under irrigated, as from October onwards, the soil profile started to dry out during the course of the season. The small irrigation amounts only wetted the top soil layer, while the deeper soil layers started to dry out and as a result, the profile buffer zone (bottom of the profile) also got drier as the season progressed. For this field, irrigation amounts (required number of irrigation hours) were based on the pre-determined system application rate. During field visits, it was established that blocked nozzles occurred at several randomly inspected places in the orchard. Some lateral ends were also blocked due to lack of systems flushing. It can, therefore, be concluded that the valve to the block was probably opened and closed at the correct times, but the amount of water applied was insufficient due to too low application rate as a result of poor system maintenance. The total irrigation amount indicated in Table 31 is therefore probably overestimated.

In the case of the two other citrus fields (Figure 12: field G4 – micro jet irrigation; and Figure 13: field G9 – drip irrigation) both fields were kept very wet, especially in the top layer, due to frequent irrigations. This practice most probably resulted in higher surface evaporation losses as well as deep drainage losses, as the soil buffer zone (bottom of the profile) was wetter than the 'full' point (green line) for most of the year. It can be concluded that these fields were probably consistently over irrigated, which resulted in substantial water losses.

Figure 14 and Figure 15 show some examples of the soil water content measurement data that was collected for the potato fields under centre pivot irrigation. In contrast to some of the micro irrigated fields, soil measurements did not provide any evidence of consistent wet conditions, resulting in deep drainage due to over irrigation for any of the centre pivots. The only exception was a number of incidents when unexpected rainfall occurred on a relatively wet profile. The opposite was often rather true: in a number of cases (for example field G14, Figure 14) the actual irrigation amounts were often lower than the amount of irrigation required for refilling the soil profile to field capacity (the 'full' point). As a result, the entire soil profile started drying out (line moved into the red zone) during the later crop growth stages. Discussions with farmers revealed that the design capacities of centre pivots are often stretched to their limits during periods of peak demand in midsummer, which leads to under irrigation. Under such circumstances producers should be advised, if at all possible, not to allow the soil profile to dry out too much at any stage during the season (keep the soil reserve relatively full), as it may not be possible to catch up the deficit again, which will result in crop water stress and yield losses. One factor that comes into play here is the "dry weeks" when not water is supplied in order to clean and maintain the canals systems on the scheme. This, however, usually occurs during the winter months when evaporative demand is lower.

In contrast to the scenario discussed above, where the soil profile was allowed to dry out substantially between irrigations, the opposite management strategy was sometimes also observed. Figure 15 (field G5) illustrates a case where the management strategy was to apply small irrigation amounts at very short intervals (especially early in the growing season). As a result the root zone was not wetted sufficiently and started to dry out over time. Although the average water content of the total root zone (top graph) was maintained within allowable limits (in the green zone of the graph), this practice most likely resulted in higher evaporative water losses. If the soil profile and crop growth stage allow for it (i.e. a suitably deep soil and well developed root system), larger irrigation amounts should be applied less frequently (without stressing the crop). The larger irrigation amounts should refill the soil buffer zone more regularly and less frequent wetting of the soil surface will result in less wasteful evaporative losses.

SWB model simulations were run for each of the potato fields to compare measured and simulated water use and soil water contents. Figure 16 shows an example of the soil water balance output graph for one of the fields. Calibrated capacitance probe data was plotted against model simulations and showed good agreement (Figure 17).

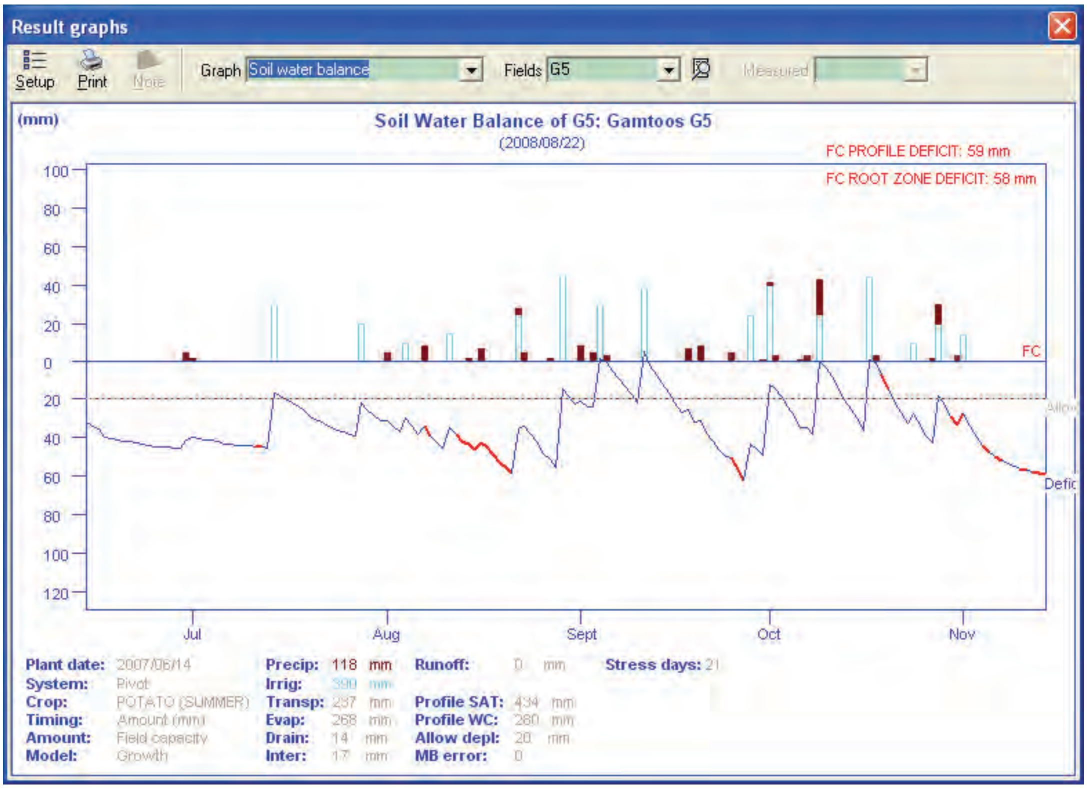

Figure 16: Example of the soil water balance graph for potato field G5 during 2007.

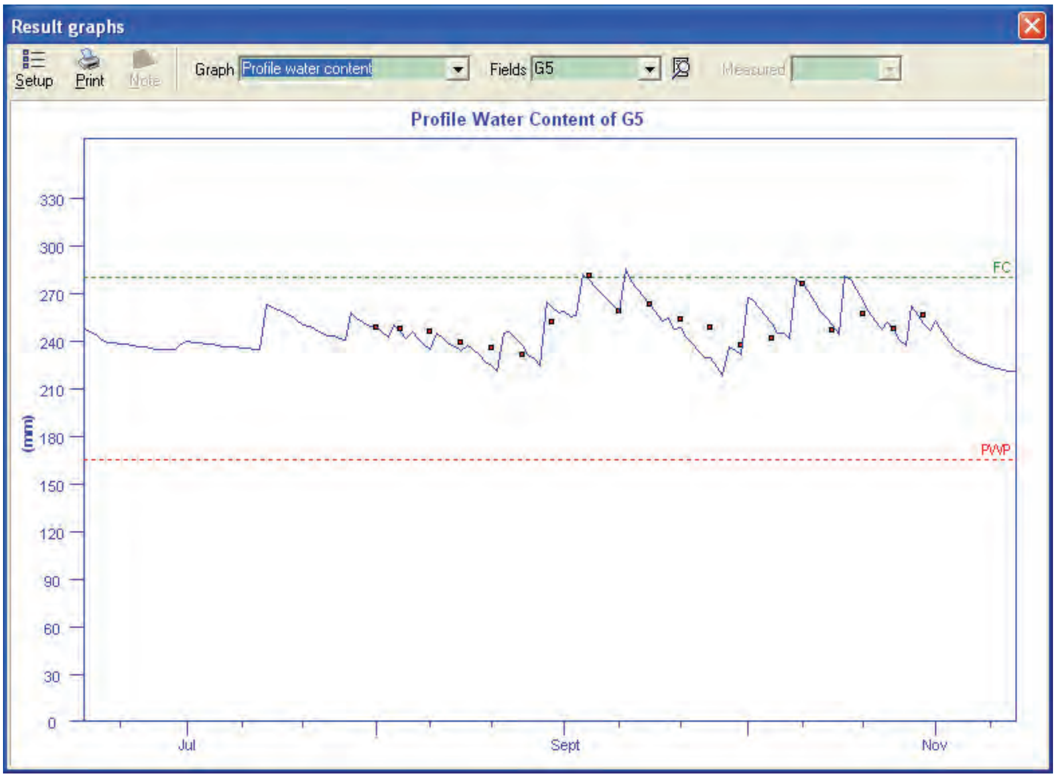

Figure 17: Calibrated capacitance probe data points showing good agreement with the simulated profile water contents (line) over the growing season.

Another objective of the modelling exercise was to compare actual irrigation amounts with simulated irrigation requirements in order to try establish whether total water applied (irrigation and rainfall) was in line with the crop water requirements.

Table 32shows the measured amounts of rainfall and irrigation, as well as simulated irrigation requirements for the potato fields during the 2008 season.

Table 32: Measured amounts of rain and irrigation, as well as simulated irrigation requirement for centre pivot irrigated potato fields during the 2008 season.

Field code	Season	Rain (mm)	Irrigation (mm)	Total = R + I	Simulated requirement (mm)
G1	Jun-Nov 08	170	273	443	410
G5	Jun-Nov 08	211	316	527	418
G8	Feb-Jun 08	157	209	366	337
G10	Jul-Nov 08	170	354	528	512
G14	Jul-Dec 08	176	245	458	532

In most cases there was good agreement between the actual amounts of rainfall and irrigation recorded, and the simulated irrigation requirement (Table 33), which suggests that, with a few exceptions, gross under or over irrigation did not occur. In the case of Field G5 the actual amount of water supplied was substantially higher that the simulated requirement due to too frequent small irrigations, as explained earlier. Similarly, too little irrigation was applied to field G14, which resulted in drying out of the profile towards the end of the growing season.

The Gamtoos Irrigation Board uses the following estimations as benchmark for total crop water requirements of citrus and potatoes (Gamtoos Irrigation Board Baseline report, 2004). These values include rainfall and irrigation:

Citrus:		781 mm
Potatoes:	planted on 15 March	352 mm
	planted on 15 July	556 mm
	planted on 15 Aug	655 mm
	planted on 15 Sept	716 mm

In the current study only March to July plantings were monitored (no August to September plantings). For these planting dates, the benchmarks requirements for potatoes showed very good agreement with our simulated requirements, which gives confidence in the model simulations.

4.4 Conclusion

The model of Perry was used to analyse the Gamtoos situation from dam wall release to root zone. The scenario that was created includes the scheme conveyance system and three optional on-farm irrigation systems (centre pivots, micro or drip irrigation).

Based on information collected during this and previous studies at the scheme, it is estimated that to deliver 100 units of water to a field, 167 units of water must be released from the scheme dam. Thereof, 65 units will be consumed in the scheme supply system and 2 units can be lost in the on-farm conveyance system.

In the field, it is estimated that of the 100 units of water reaching the field edge, 70, 65 and 75 units of water contribute to crop transpiration and 15, 10 and 5 units to beneficial in-field evaporation in the centre pivot, micro sprinkler and drip irrigation systems respectively (see Table 33). Under centre pivot systems, the greatest opportunity for improving efficiency lies in reducing the non-beneficial evaporation component, while under both the micro and drip systems, significant amounts of water is needed to increase the soil water content at the beginning of the season. In the case of the drip system that was monitored, unnecessary water was also lost to deep percolation and this could be reduced by changing the scheduling strategy

Table 33: Irrigation system components for Gamtoos Irrigation Scheme

System component	Water use	Framework component	
		Comp.	% of GIR
Irrigation water release	Increase flow in canal system	SC	167%
Bulk conveyance system (from on-river dam to scheme edge)	Not applicable)		
On-scheme conveyance system	Evaporation from canal Seepage in canal Leakages in pipes Unlawful abstractions Operational losses (unutilised) Return flows (unutilised)	NBC NRF NBC NBC NRF RF	2% 10% 25% 15% 8% 5%
On-farm conveyance system (from farm edge to field edge)	On-farm system leaks	NRF	2%
In-field application system (from field edge to root zone) – Option 1: Centre pivots	In-field evaporation – beneficial In-field evaporation – non-beneficial In-field deep percolation Drainage water (surface & sub) Transpiration by crop Increase soil water content	BC NBC NRF RF BC SC	15% 10% 0% 0% 70% 5%
In-field application system (from field edge to root zone) – Option 2: Micro sprinklers	In-field evaporation – beneficial In-field evaporation – non-beneficial In-field deep percolation Drainage water (surface & sub) Transpiration by crop Increase soil water content	BC NBC NRF RF BC SC	10% 5% 5% 0% 65% 15%
In-field application system (from field edge to root zone) – Option 3: Drip irrigation	In-field evaporation – beneficial In-field evaporation – non-beneficial In-field deep percolation Drainage water (surface & sub) Transpiration by crop Increase soil water content	BC NBC NRF RF BC SC	5% 0% 10% 0% 75% 10%

At scheme level, the irrigation board is already busy with a process of improvements to reduce the losses in siphons and underground pipes, the system components that they have identified to be the most loss inducing elements of the system.

4.4.1 Feasibility of improvements

The proposed changes to the water supply and management system are therefore:

- To improve irrigation scheduling management in order to reduce evaporation losses under pivots and deep percolation under micro irrigation systems

- To improve maintenance of drip and micro irrigation systems to improve uniformity

Implementation of the recommendations does not imply serious capital investment. The focus should mainly be on aspects such as awareness creation and training sessions on irrigation scheduling and irrigation system maintenance practices. This should be arranged in conjunction with the irrigation board and a scheduling consultant who has local knowledge. Courses can also be planned in conjunction with SABI.

5 Hartbeespoort Irrigation Scheme

5.1 *Scheme background*

Hartbeespoort Irrigation Board is located in the North West Province. The Scheme manager is Mr Nic Fourie. The irrigation scheme consists of a canal network that distributes irrigation water from the Hartbeespoort dam to about 914 irrigators on a total of ± 13 900 ha. The main irrigation systems used on the scheme include center pivots, drag lines, micro, drip and flood. The main crops planted on the scheme include wheat, maize, tobacco, lucerne, vegetables and sunflower.

Hartbeespoort Irrigation Board has two main canals, the East and the West canal. The scheme is divided into six water wards. Each water ward has a water bailiff who is responsible for the water distribution management of the specific ward. Water is ordered by the farmers on a weekly basis using water order forms. The water orders are posted in a post box in each water ward. The water bailiff empties the post box every Thursday and records all the water orders in what they call a 'groot boek', which is used to keep track of water quotas for each farmer.

A water distribution sheet is compiled for each water ward by the responsible water bailiff. The water release at the dam is calculated on a daily basis from the total water demands from the different water wards. Water losses are added as a percentage of the flow on the secondary canals and a fixed volume is added on the main canals depending on the total water demand. Lag times are based on previous experience depending on the flow rate in the respective canals. Water orders are captured in the WAS database at the main office and compared with the manual system of each water bailiff for verification purposes.

Water is delivered to the farmers through pressure regulating sluices that is set on a daily interval. The Hartbeespoort dam setting is changed on a twelve hourly interval. Water cancellations and additional orders for water are managed in real time depending on the limitations of the system.

5.2 *Conveyance system*

Hartbeespoort Irrigation Board is divided into seven water wards which are managed by a water bailiff for every ward. Distribution sheets are compiled manually for each water ward on a weekly basis. The volumes are then phoned through to the head water control officer who will add losses and calculated the water release settings for the Left and Right bank main canals.

Water orders are captured a week later at the main office in the WAS program to keep track of the water balances of each farmer. The opening of farm turnouts is managed by the water bailiffs in each water ward.

5.2.1 Calculation of losses

The total water loss from the dam wall to the farm edge were calculated using the WAS program. The raw data for the Left and Right bank main canals measuring stations at Hartbeespoort dam was imported from datasets supplied by the Hydro Directorate of DWA.

The water orders are historical data which were captured in the WAS database on a weekly basis by the scheme to keep track of each farmer's water quota balance. The water orders are audited externally by an accounting firm on a regular basis. Hartbeespoort Irrigation Board uses the same accountants as Loskop Irrigation Board. Water delivered is assumed to be equal to the water ordered. The water is delivered to the farm edge through a pressure regulating sluice which is calibrated for fixed gate openings and a constant head in the canal.

Figure 18 to Figure 27 are pairs of corresponding graphs which show the total water released compared to the total water ordered, and the cumulative values. Both sets of graphs have values for each week for the years 2000 to 2005.

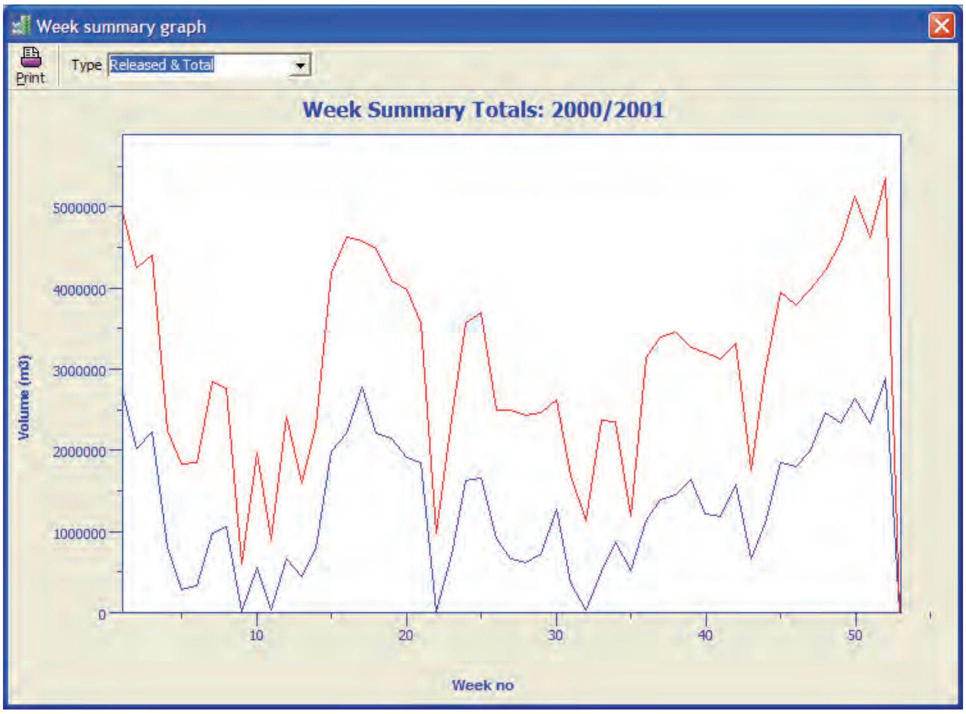

Figure 18: Hartbeespoort: Released vs. Ordered for 2000/2001

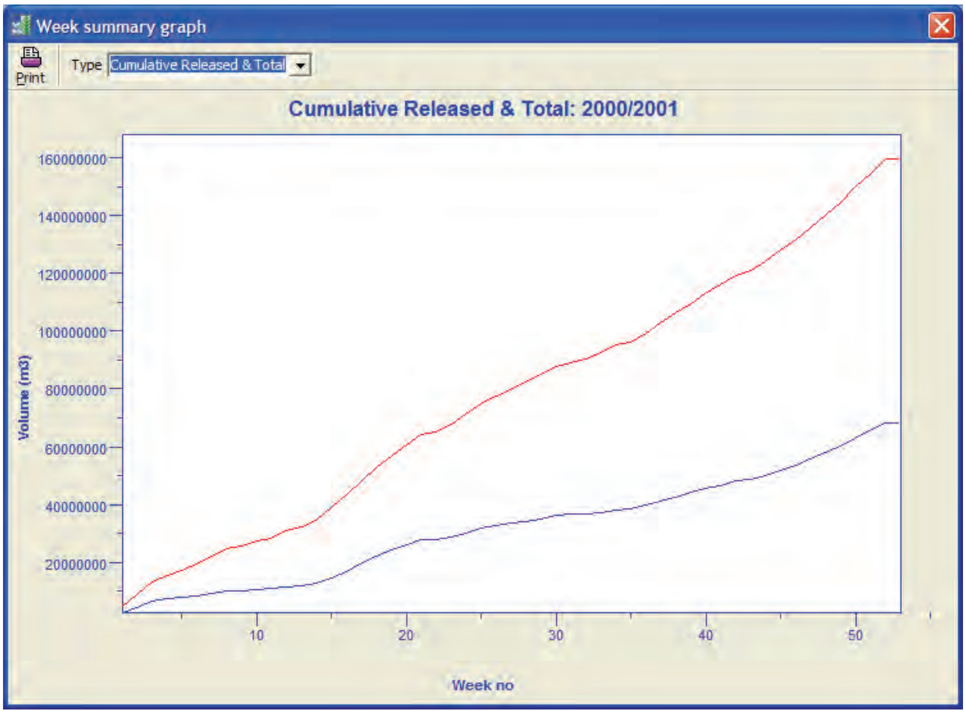

Figure 19: Loskop Cumulative Released vs. Ordered 2000/2001

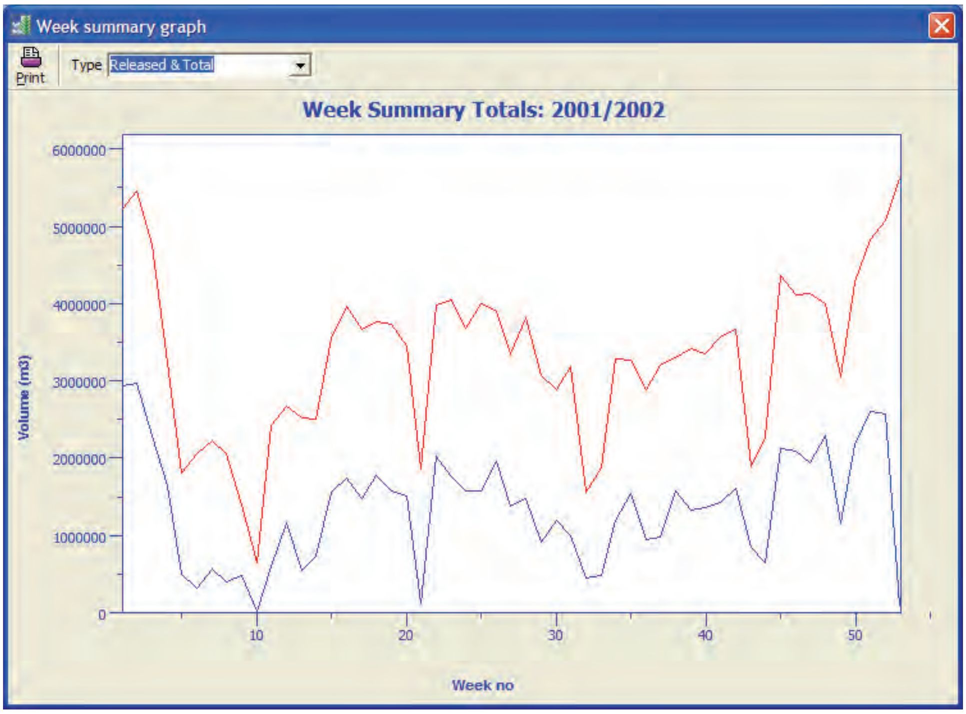

Figure 20: Hartbeespoort: Released vs. Ordered for 2001/2002

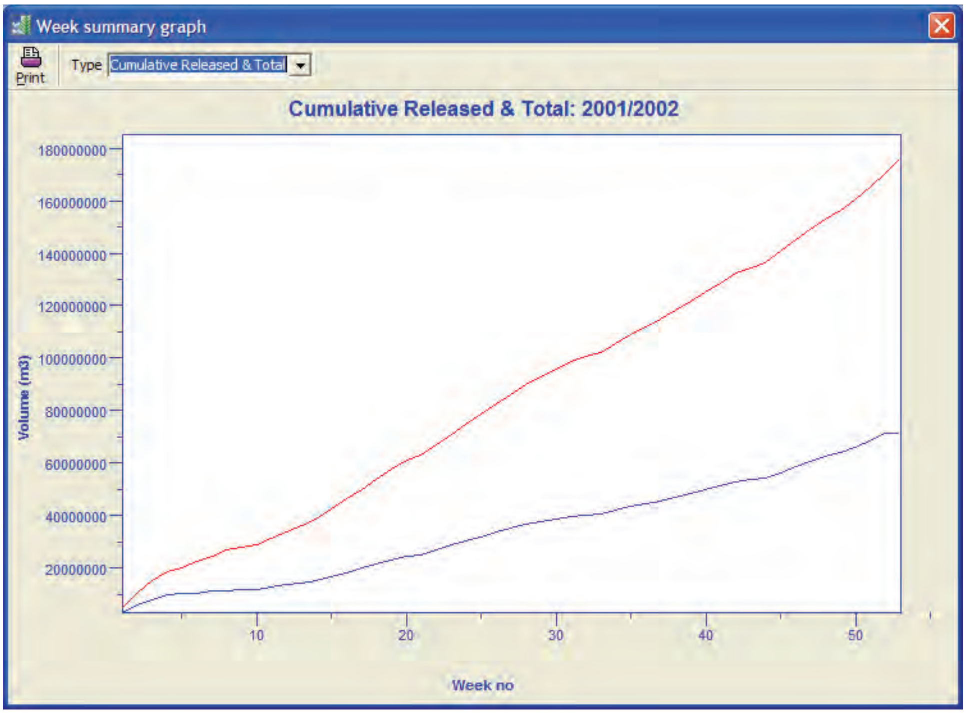

Figure 21: Loskop Cumulative Released vs. Ordered 2001/2002

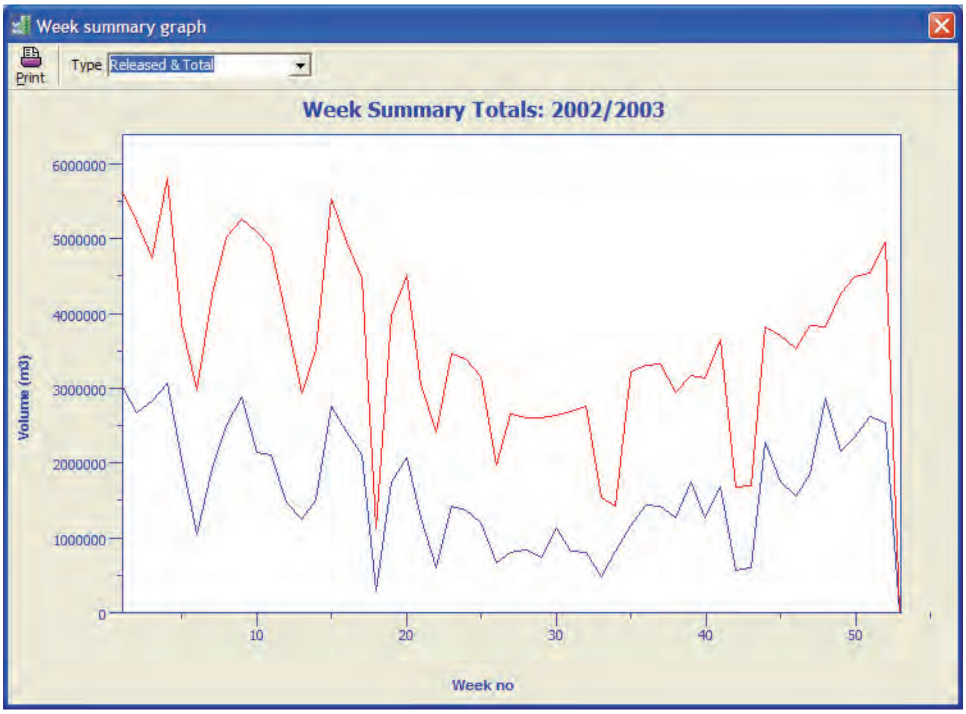

Figure 22: Hartbeespoort: Released vs. Ordered for 2002/2003

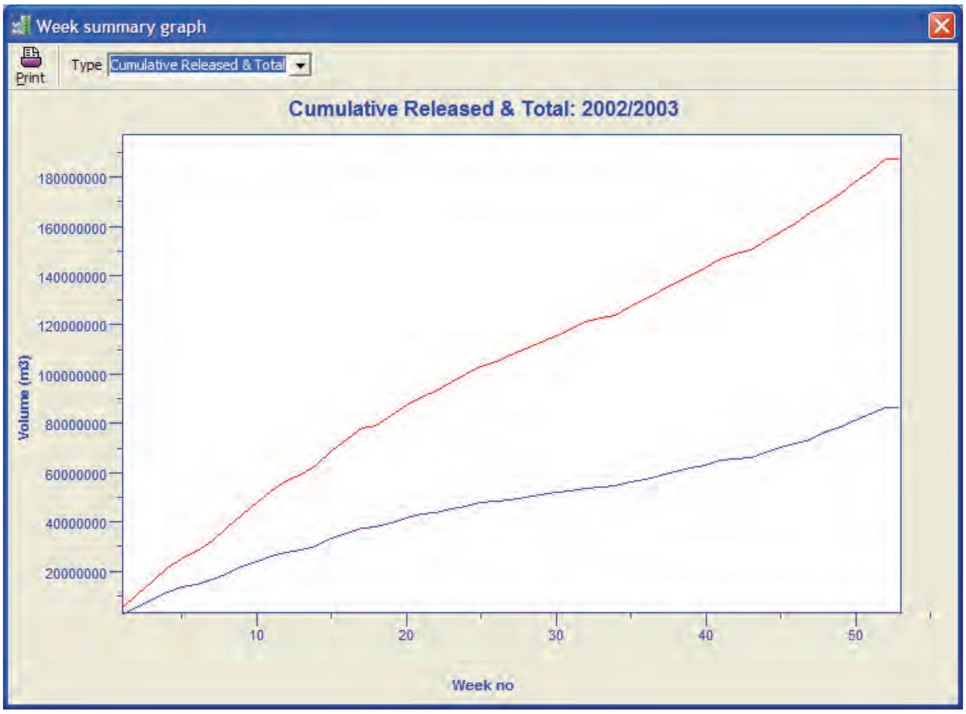

Figure 23: Loskop Cumulative Released vs. Ordered 2002/2003

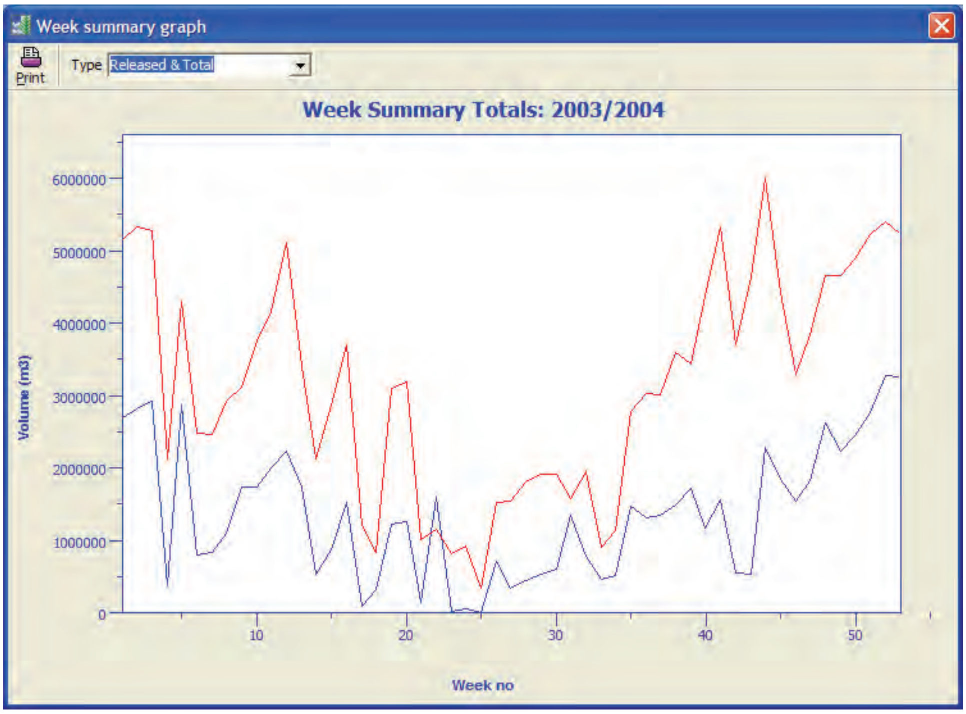

Figure 24: Hartbeespoort: Released vs. Ordered for 2003/2004

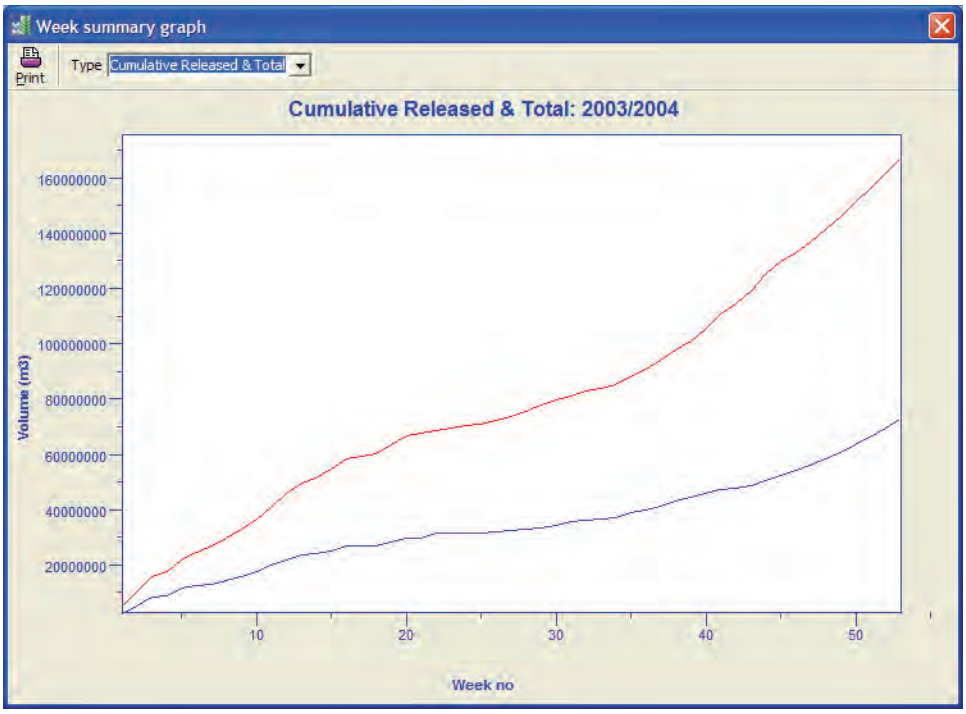

Figure 25: Loskop Cumulative Released vs. Ordered 2003/2004

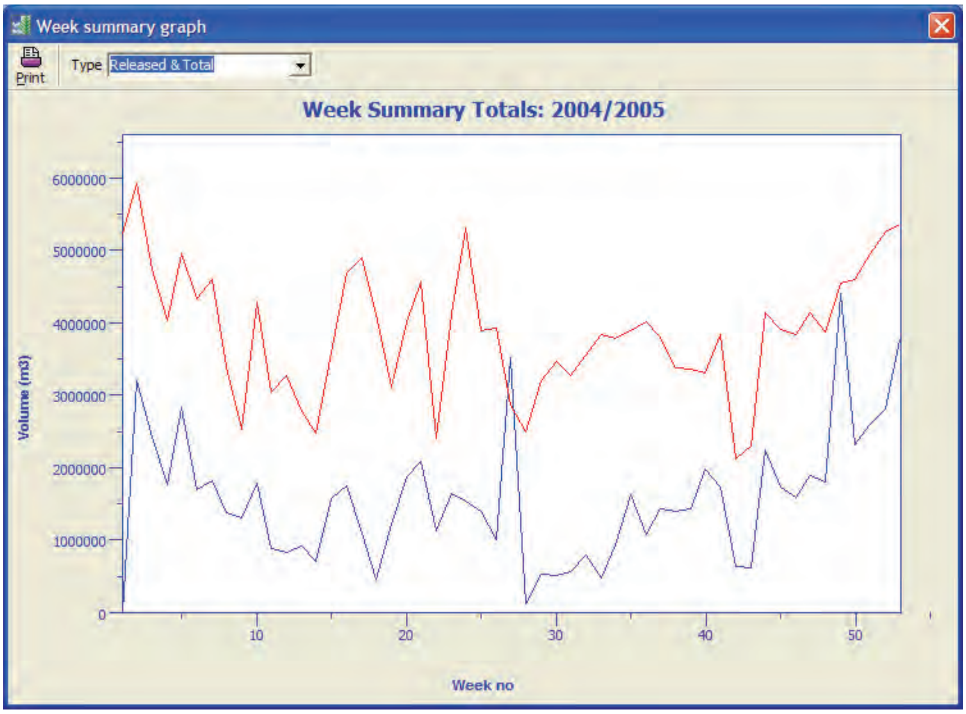

Figure 26: Hartbeespoort: Released vs. Ordered for 2004/2005

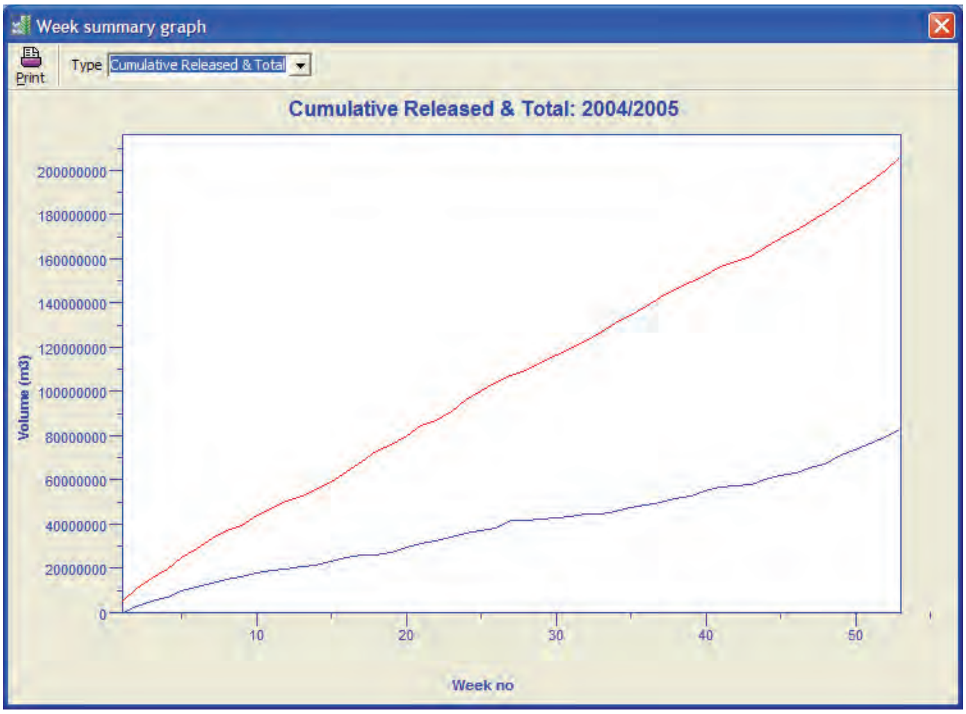

Figure 27: Loskop Cumulative Released vs. Ordered 2004/2005

5.2.2 Discussion

The percentage conveyance losses in the Hartbeespoort canal system is shown in Table 34, and presented graphically in Figure 28 and Figure 29.

Table 34: Hartbeespoort Irrigation Board % loss summary, period 2000 to 2005

Hartbeespoort Irrigation Board					
Year	Quota (m^3/yr)	Ordered (m^3)	Released (m^3)	Difference (m^3)	% Loss
2000/2001	83 468 307	68 581 073	159 885 416	91 304 343	57.1
2001/2002	83 518 527	71 559 867	176 284 859	104 724 992	59.4
2002/2003	83 805 587	86 399 854	187 618 768	101 218 914	53.9
2003/2004	84 705 827	72 815 775	167 041 102	94 225 327	56.4
2004/2005	86 278 767	83 347 231	205 797 559	122 450 328	59.5

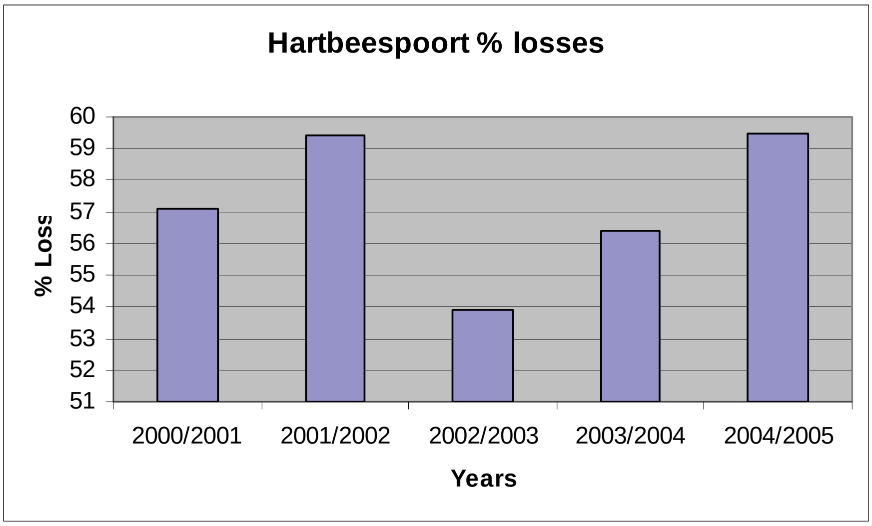

Figure 28: Hartbeespoort % Loss Graph for Period 2000 to 2005

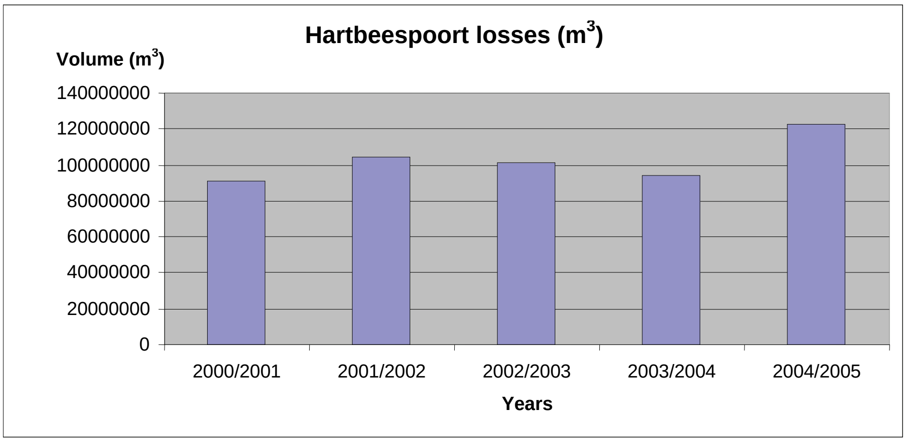

Figure 29: Hartbeespoort Total Losses for Period 2000 to 2005

5.3 Irrigation systems

The results for the Hartbeespoort Dam area are shown in Table 35 to Table 42. No long-term monitoring was done at the scheme.

Table 35: General information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
H1	Centre pivot	Maize	15	31,6	NA
H2	Centre pivot	Maize	10	12,1	NA
H3	Micro	Grapes	9	NA	3,2
H4	Sprinkler	Maize	10	NA	3,3
H5	Micro	Tomatoes	-	NA	2,0

Table 36: General information of pump

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
H1	148	Not measured	30	Yes	Yes	No screens over couplings
H2	138	Not measured	38	Yes	Yes	No screens over couplings
H3	20	320	7,5	Yes	Yes	Good condition
H4	94	Not measured	17,5	Yes	Yes	Good condition
H5	Not measured	Not measured	30	Yes	Yes	Open electrical conducts

5.3.1 Centre pivot

Table 37: General information

Test site code	Pressure regulators (Yes/No)	Operating pressure (kPa)	Flow rate (m^3/h)	Speed adjustment (%)		Gross application (mm)	
				Control box	Measured	Control box	Measured
H1	Yes	193	Not measured	10	Not measured	38	32
H2	Yes	255	138	22,5	Not measured	12	12

Table 38: Test results

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured
H1	85	90	75	76	80	Not measured
H2		91		80		Not measured

5.3.2 Sprinkler irrigation system

Table 39: General information

Test site code	Type of sprinkler system	Sprinkler spacing (m)	Nozzle size (mm)	Operating pressure (kPa)			Sprinkler discharge measured (ℓ/h)
				Hydrant (measured)	Nozzle pressure Calculated	Average nozzle pressure measured	
H4	Quick coupling	12 x 12	8	Not available	NA	241	1238

Table 40: Test Results

Test site code	Uniformity Parameters				Efficiency		Pressure variation (%)		Discharge variation (%)	
	CU(%)		DU_{lq} (%)		SE (%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (max)	Measured
H4	80	50	74	70	75	38	20	29	10	46

5.3.3 Micro irrigation systems

Table 41: General information

Test site code	Type of micro system	Filter type	Emitter spacing (m)	Operating pressure measured (kPa)		Emitter discharge (ℓ/h)	
				Average measured (block)	Hydrant	Average measured (block)	Design
H3	Micro sprayer	Disc	4 x 4	78	Not measured	51,4	Not available
H5	Drip	Sand	1,3 x 0,6	62	Not measured	1,6	2

Table 42: Test results

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s(%)		EU(%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
H3	80	84	85	86	20	51	0,4	Not measured
H5		85,5		79		58		Not measured

5.4 Conclusion

The total water loss from the dam wall to the farm edge at Hartbeespoort is very high with an average of 57% over a period of 5 years. The percentage losses are constant from year to year and the actual volumes of water lost are also the same except for 2004/2005 which was a little higher compared to the other years.

According to the personnel at Hartbeespoort, the high losses can be attributed to the bad state of the canals where concrete slabs are falling over and canal linings are disintegrating. If the deterioration of the canals continues, it would probably show on the loss calculation figures of the following years. Another contributing factor to water distribution management at Hartbeespoort is algae growth, which has been a major problem for a number of years.

The WAS release module is not used at Hartbeespoort to calculate the water releases from the dam

- By implementing WAS at Hartbeespoort might increase the control of the water and thereafter the efficiency.

6 Hex River Valley irrigation scheme

6.1 Scheme background

The Hex Valley is a pronounced valley between the Hex River Mountains to the north-west and the Kwadouws Mountains to the south east. The valley is approximately 20 km long and 5 km wide. The town of De Doorns with a population of 6 000 is located roughly in the middle of the valley. The Board oversees water supply from the Sanddriftkloof Scheme, via the Sanddrift tunnel to farmers in the Hex Valley around the town of De Doorns. The complete distribution system of the scheme is piped (100 km), and water is supplied under gravity to the farmers.

The Sanddrift River Government Water Supply Scheme is major supplier of water in the Hex Valley. The scheme comprises the Lankenvallei and Roode Elsberg Dams, situated in the Sanddrift River, a tributary of the Hex River, together with a sophisticated distribution system distributing water to the De Doorns and irrigators in the Hex River Valley. The total capacity of the two dams is 18,0 million m^3.

In 1991 the firm yield of the Sanddrift Scheme was accepted to be 9 million m^3/a. At that date the Worcester East Main Irrigation Board started pumping water from the Breede River, and relinquished its share of 54% of this quantity, i.e. 4,86 million m^3/a, but was compensated by an allocation from Greater Brandvlei Dam. The Sandhills area is presently supplied with up to 2,2 million m^3/a of compensation water from the Sanddrift Scheme.

It has become clear that previous estimates of the yield of the Sanddrift Scheme were too optimistic, and that the combined firm yield of the two dams is about 7,9 million m^3/a. This yield is over-subscribed, and the current demand of about 11,5 million m^3/a is supplied at a relatively high risk of failure.

The district also overlaps three smaller boards namely the Bovenstein, Groothoek , and Matroosberg Irrigation Boards. Although these boards have their own sources of mountain water, and their own operational structures, these boards get a large proportion of their water from the Hexvallei Irrigation Board, and overlapping occurs. There are also plans to link some of the mountain sources with the Hexvallei distribution system in order to simplify operations.

The Groothoek Irrigation Board has a scheduled area of 982,847 ha, but this is significantly greater than the actual irrigated area of 450 ha of which 420 ha is currently under irrigation. The Chairman says that they have an annual water demand of 4,02 million m^3/a, which is a quota of 9 576 (m^3/ha)/a.

Bovenstewater Irrigation Board has a scheduled area of 116,6 ha. Bovenstewater Irrigation Board gets water from an un-named stream on the Hex River Mountains. Water is diverted into a concrete canal for distribution to the farms. The canal was constructed in 1933 and is maintained well. Losses are estimated at 15%.

Matroosberg has a scheduled area of 168 ha. The Matroosberg Board has four sources of water, namely three mountain streams, and the Hex River. The Board gets a combined volume of 2,133 million m^3/a from the mountain streams, and 17 145 m^3/a from the Hex River. Matroosberg Irrigation Board has a total area of 228 ha under effective irrigation and works on an approximate quota of 9 400 (m^3/ha)/a. Crops include table grapes (95%), wine grapes and citrus (5%).

The Hexvallei Irrigation Board supplies the following water from the Sanddrift scheme:

- 744,1 ha @ 1 500 (m^3/ha)/a (4,116 million m^3/a) water to supplement supply from existing schemes in the valley.
- 682 ha @ 6 500 (m^3/ha)/a (4,433 million m^3/a) additional scheduling obtained in 1987 from the State scheme. The Board also supplies 700 000 m^3/a for urban domestic use.

The scheduled area of the scheme is approximately 3 400 ha. Approximately 30% of the quota of 6500 m^3/ ha is supplied from the Sanddrift SW Scheme by the board, and the balance of the quota is supplemented by groundwater and private storage dams.

One of the biggest management problems to the scheme management is water losses due to pipe breakages. This happens mostly as a result of damage by farmers during cultivation of their lands. An appropriate warning system could be of great assistance and could help to save water.

Land transactions often lead to water right confusion, and better admin/legal procedures, which include involvement of the irrigation board, in this regard is desirable.

During recent years the farmers are experiencing increasingly water shortages. New boreholes are implemented, resulting in decreasing groundwater levels. A new dam in the valley, called Oshoek, will be of great help in solving some of the shortages. The expected cost of the new project will be R 44 million.

All water is metered, i.e. the total water supply where it flows into the pipe network of the board, as well as all farmer offtakes.

The irrigation manager reads all meters on a weekly basis. He uses this information to give feedback (on a weekly basis) to the farmers on their water usage and remaining quotas (all farmers receive the same information, and therefore the usage of all other farmers is available to all).

Telemetric systems are in place at some strategic locations.

6.2 Irrigation systems

6.2.1 Crop water requirements

Long term Penman-Monteith reference evaporation (ETo) data as well as long term rainfall data for the Hex Valley is shown in Figure 30. The typical agricultural enterprise in the Hex Valley is the growing of table grapes, as described in Table 43, whilst Table 44 shows the irrigation systems in use in the Hex River Valley area.

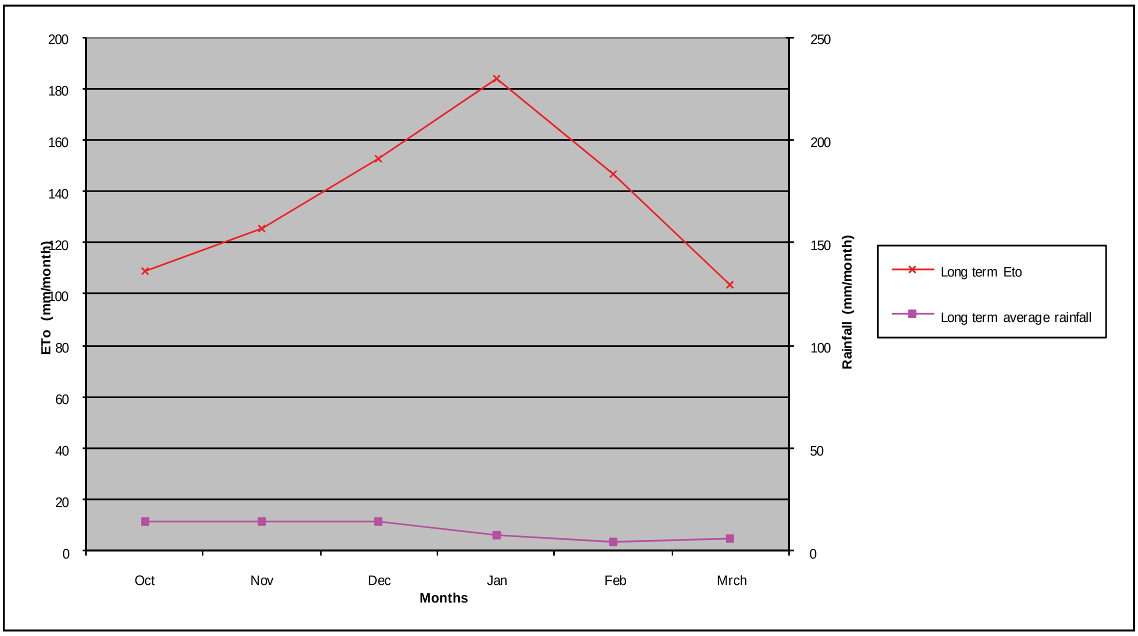

Figure 30: Long term evaporation and rainfall data for the Hex Valley

Table 43: Crops in the Hex Valley area

CROP	PERCENTAGE OF AREA
Wine grapes	2.5%
Table grapes	95.0%
Citrus	2.5%

Table 44: Irrigation systems in the Hex Valley area

IRRIGATION SYSTEMS	PERCENTAGE OF AREA
Drip/trickle	90%
Sprinkler	10%

The SAPWAT and Vinet programs are widely recognised by irrigation designers as the tools to determine irrigation system capacities.

The weekly applied irrigation figures for sixteen blocks for the last three years (based on readings by the Department of Agriculture as part of their water conservation campaign) were summarised, and are shown in the three graphs in Figure 31 to Figure 33. The graphs also show the yield per ha for the particular blocks, the yield per cubic meter of water applied, and the nett irrigation requirement.

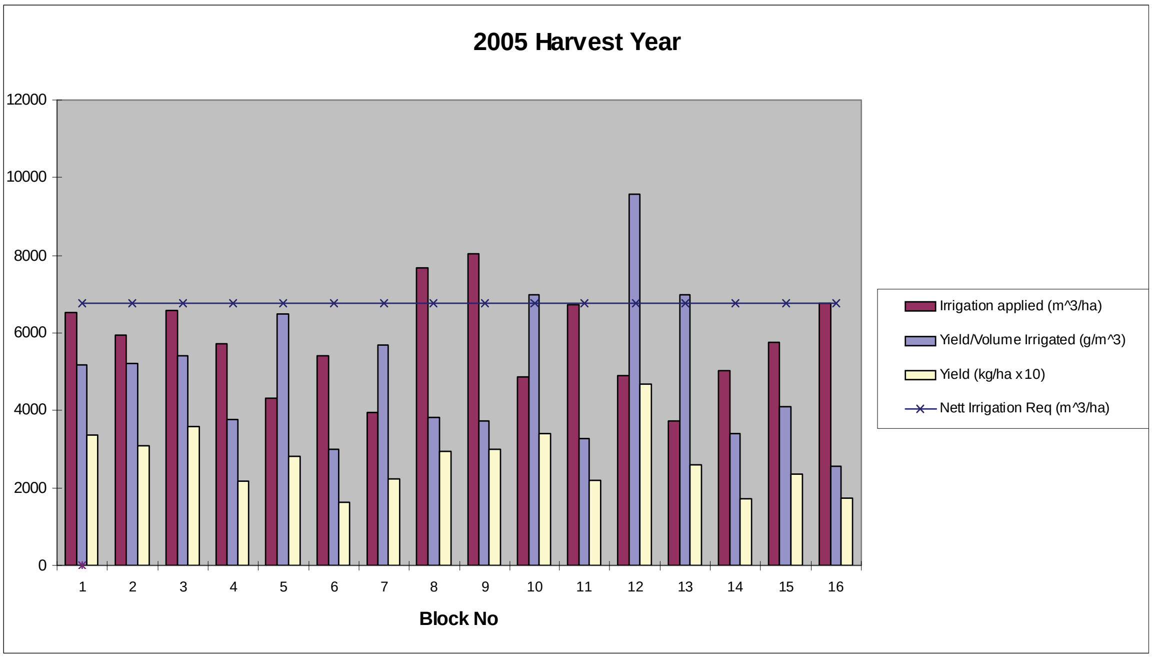

Figure 31: Historic relevant data for 16 blocks in the Hex River Scheme 2005 harvest year

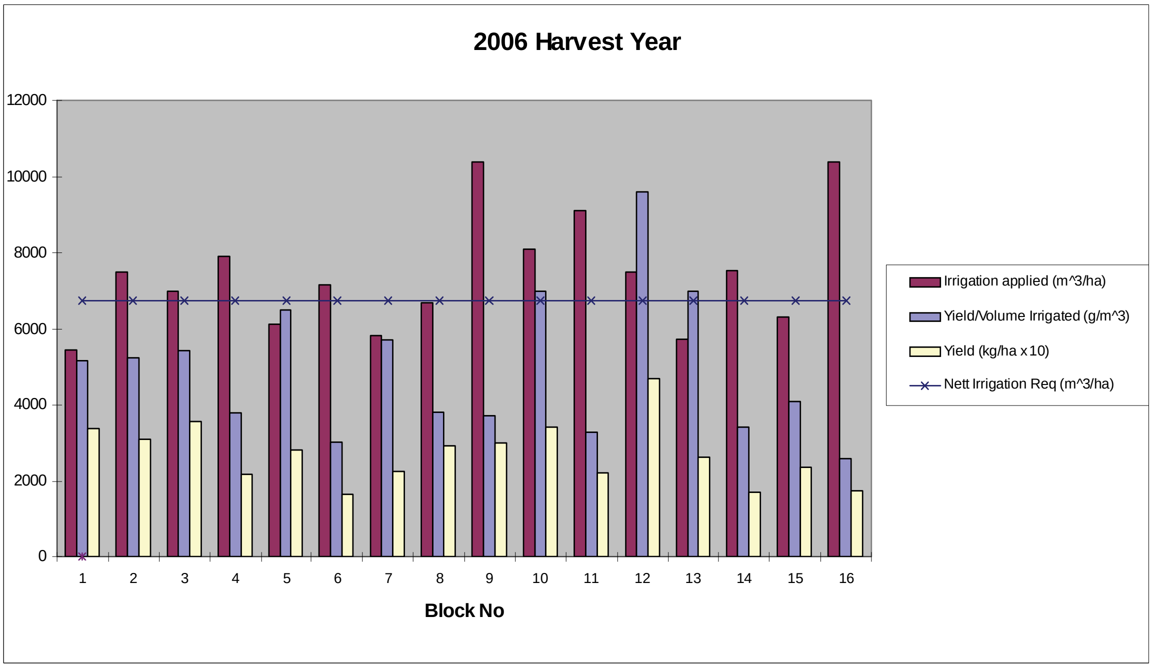

Figure 32: Historic relevant data for 16 blocks in the Hex River Scheme 2006 harvest year

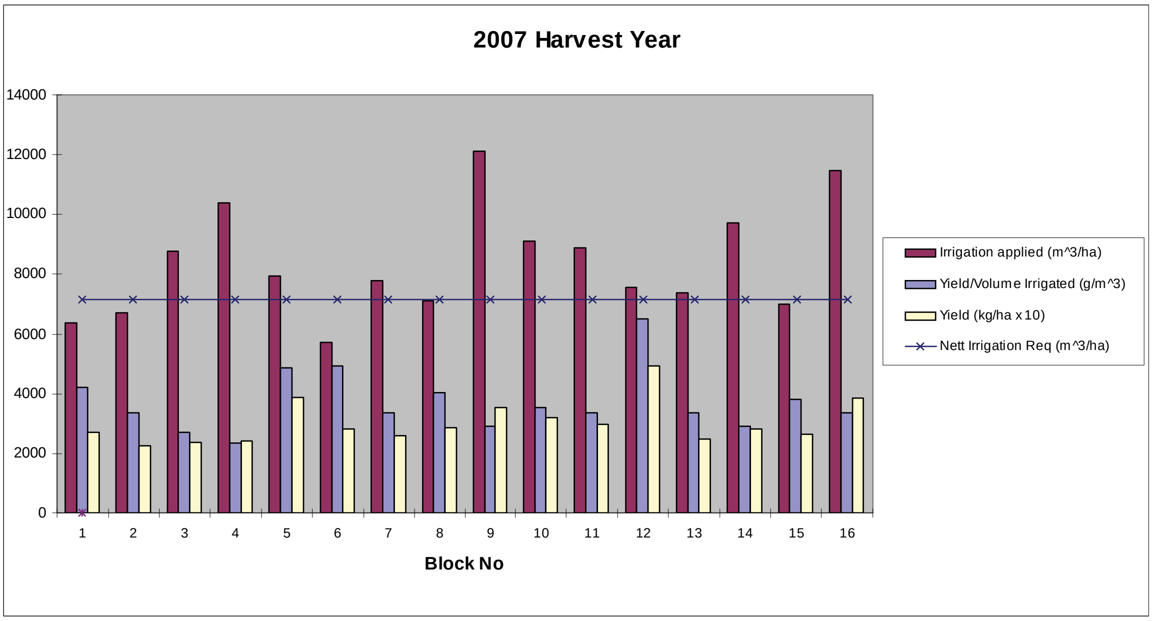

Figure 33: Historic relevant data for 16 blocks in the Hex River Scheme 2007 harvest year

6.2.2 System evaluations

The results for De Doorns area illustrated in Table 45 to Table 48. From Table 45, it can be deducted that the gross irrigation requirement ranged from 2,4 to 8,9 mm/day for table grapes.

Table 45: General information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
D1	Micro sprayer	Table grapes	30	NA	6,4
D2	Micro sprayer	Table grapes	34	NA	4,0
D3	Micro sprayer	Table grapes	38	NA	1,2
D4	Micro sprayer	Table grapes	15	NA	1,3
D5	Drip PC	Table grapes	23	NA	1,2
D6	Drip PC	Table grapes	34	NA	1,2
D7	Drip PC	Table grapes	18	NA	1,5

The general information obtained from the pump showed that most of the pumps are in good working condition, but there are a few that have drainage and ventilation problems. The reason for not measuring the flow rate and operating pressure are due to the fact that limited space was available for measurements in the pump house.

Table 46: General information of pump

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
D1	Not measured	220	15	Yes	Yes	Good condition
D2	Not measured	Not measured	18,5	Yes	Yes	Drainage and ventilation problems
D3	Not measured	Not measured	11	Yes	Yes	Drainage and ventilation problems
D4	Not measured	380	15,5	Yes	No	Good condition
D5	50	Not measured	15	Yes	Yes	Good condition
D6	Not measured	430	30	Yes	Yes	Good condition
D7	Not measured	Not measured	18,5	Yes	Yes	Good condition

6.2.3 Micro irrigation systems

Most of the systems only use disc filters for the irrigation systems. The low emitter discharge of block D3 and D4 are due to the fact that the average pressure in the block are very low due to reasons that ranges from low hydrant pressure to clogging problems.

Table 47: General information

Test site code	Type of micro system	Filter type	Emitter spacing (m)	Operating pressure measured (kPa)		Emitter discharge (ℓ/h)	
				Average measured (block)	Hydrant	Average measured (block)	Design
D1	Micro sprayer	Disc	3,05 x 1,22	41	90	23,9	32
D2	Micro sprayer	Sand / Mesh	3,15 x 1,7	87	300	21,5	20
D3	Micro sprayer	Disc	2,4 x 1,8	64	190	5,3	32
D4	Micro sprayer	Disc	2,74 x 1,83	30	60	6,6	50
D5	Drip PC	Disc	3 x 0,6	219	230	2,2	2,3
D6	Drip PC	Disc	3 x 0,6	67	250	2,2	2,3
D7	Drip PC	Disc	Not measured	150	180	2,6	2,3

The low EU, Us and CV values are due to the fact that the systems operates at too low and in other cases too high pressure which can be attributed to, too many blocks that irrigate together, or in the other cases only one block operates. The low flushing velocity can also be due to the above mentioned reasons.

Table 48: Test results

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s (%)		EU (%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
D1	80	83,2	85	76,6	20	49	0,4	NA
D2		65		50		69		NA
D3		85,4		80,8		31		NA
D4		83		75		117		NA
D5		78,3		80,3		27		1,6
D6		78,6		81		171		0,2
D7		79,5		88,8		47		0,8

6.3 Conclusion

The following can be concluded from the data that were analysed:

- The block which achieved on an average the highest yield per volume of irrigation applied (Block 12) also on an average yielded the highest tonnage per ha. The annual depth of irrigation applied for this block correlates well with the theoretical irrigation requirement.
- The yield of Block 9 yielded considerably lower (kg/ha as well as kg/m^3) than Block 12. The annual irrigation applied in Block 9 was approximately more than 50% higher than the application in Block 12.
- Both under – and over-irrigation seems to affect the two yield criteria adversely, but from the available data it is not possible to establish what this tolerance band is.
- The available data does not provide information about the quality of the produce, which is a very important aspect for table grape farmers.

7 KZN Irrigation Scheme

7.1 Scheme background

In this section of the report, the focus is on an irrigation of sugarcane in KwaZulu-Natal. Included are a situation assessment of a case study scheme, a description of the measurement/assessment methods applied to assess performance levels, results of the performance assessment, and recommendations for new and improved scenarios and how the feasibility of these recommended scenarios was determined. The name of the scheme referred to in Phase I cannot be divulged due to a confidentiality agreement signed with the stakeholders.

The report is based mainly on more detailed MSc Eng dissertations written by Greaves (2007) and Jumman (2009). In the first phase of the performance assessment (Greaves, 2007) the focus was on the scheme as a whole and the on-farm performance of irrigation and water management systems. The second phase of the performance assessment (Jumman, 2009) was initiated to address many of the issues which arose when analysing the results of the first phase. These included: strategies to optimise the design and operation of drag-line systems for shallow soils, an assessment of electricity tariff options, an assessment of the potential for deficit irrigation and development and application of tools for in-field monitoring of soil water and plant growth.

Phase 1 of the performance assessment focused on three main objectives. The first objective was to calculate a set of internationally applied external irrigation benchmarking indicators. External indicators from the International Water Management Institute (IWMI), the International Program for Training and Research in Irrigation and Drainage (IPTRID) and the Irrigation Training and Research Center (ITRC) were reviewed for application in a South African context.

The second objective was to determine the losses, and consequently the efficiency, with which the irrigation scheme was able to deliver irrigation water from the water source to the farm boundary during the years 2004 and 2005. This was achieved by completing the water balance for the scheme with specified geographic and temporal boundaries.

The third objective was to rank individual farm performance of all the farms in the scheme, in terms of total farm crop yields and seasonal irrigation water use. Farm yield and irrigated area were obtained to investigate the relationships between yield and irrigation water application.

As part of this investigation, the individual seasonal farm water use was also compared to a simulated irrigation demand and on-farm irrigation system evaluations were performed to determine if irrigation system capacity constraints were a restriction. Thus, performance assessment was done at both scheme and farm levels.

7.2 *Conveyance system*

A detailed description of the scheme management, soils, water quality, irrigated and scheduled areas, and the types and management of irrigation and conveyance systems is presented in Greaves (2007). Due to a confidentiality agreement, the name of the scheme cannot be given. What is perceived as being a high allocation of water to irrigators on the scheme has been the focus of much debate and is a key issue on the scheme. The quantification of losses that occur from when irrigation water is pumped from the river until it reaches the farm boundary via the system of canals and balancing dams was also of great interest to both water resources planners and local stakeholders.

7.2.1 Evaluation and measurement methods – scheme level

Two different methodologies of analysing performance at a scheme level were applied. The first approach was to take information available at the scheme and apply a benchmarking approach with external performance indicators in order to test this approach in a case study. The second approach was to undertake a detailed water balance analysis of the scheme delivery system of balancing dams and canals, to determine how efficient the scheme was in delivering water from the river source to the farm boundary. The excellent records at the scheme, including extensive electronic flow metering enabled these investigations.

7.2.2 Scheme level results – external indicators

The results which were obtained from the external indicators that were computed for both the 2004 and 2005 calendar years are contained in Table 49**.**

Table 49: Results for calculated external indicators

Indicator No.	Indicator Name	2004	2005
1	Total annual value of agricultural production (R)	34 236 482.46	37 128 965.63
2	Output per cropped area (R/ha^{-1})	9 200.88	9 827.68
3	Output per unit command area (R/ha^{-1})	6 224.81	6 750.72
4	Output per unit irrigation supply (R/m^{-3})	2.17	2.43
5	Output per unit water consumed (R/m^{-3})	0.76	0.83
6	Total annual volume of irrigation water supply (m^{3})	15 757 900	15 284 660
7	Relative Water Supply (RWS)	1.16	0.97
8	Relative Irrigation Supply (RIS)	0.61	0.58
9	Water Delivery Capacity Ratio (WDCR)	1.08	0.95
10	Irrigation water supply per unit command area (m$^{3/}$ha)	2 865	2 779
11	Irrigation water supply per unit irrigated area (m$^{3/}$ha)	4 235	4 046

It can be seen from Table 49 that the production indicators, Indicators 1 to 5, show that production was better in 2005 than in 2004. The better production was a result of significantly higher biomass combined with a higher sucrose price. The higher level of production was then carried trough in all the indicators that utilised it as an input. The level of production in 2005 would have been even greater if the average amount of sucrose contained in the total biomass had been the same as that of the 2004 year.

When analysed in conjunction with each other, the results of Indicator 7 and 8 reveal an interesting observation. Both 'Relative Water Supply' (RWS) and 'Relative Irrigation Supply' (RIS) relate water supply and demand and give an indication of how closely supply and demand were matched (Molden et al., 1998). The RWS for 2004 and 2005 is 1.16 and 0.97 respectively. A RWS of greater than one indicates that the total water application, i.e. irrigation plus total rainfall is meeting crop demand at a temporal timescale of one year. However, ideally the RWS should be significantly higher than one to account for the variable nature of rainfall that may be occurring. For example, if relatively few significant rainfall events comprise a large proportion of the total annual rainfall, it is unlikely that the rainfall from these large events will all be beneficially used, because the majority of it would be lost to surface runoff and deep percolation. Therefore, when just analysing the annual value for RWS, such rainfall events would not be accounted for and it could be incorrectly assumed that crop demand is being met. The annual rainfall values for the scheme for 2004 and 2005 were 994.5 mm and 788.5 mm respectively. A large proton of this rainfall fell within the summer season and therefore only a portion of it would have been effective. It is at this point when the values yielded by RIS become invaluable. If the RWS was close to unity and the RIS was also close to unity it would imply that the majority of rainfall was effective and that the extra water provided by irrigation was sufficient. However, if the RWS is close to unity and the RIS is significantly below unity, it would imply that the majority of rainfall was not effective and that irrigation demand was not being matched by irrigation supply. The results from the study area show that the RIS values are 0.61 and 0.58 for 2004 and 2005 respectively. This indicates that an insufficient amount of water was being applied at a scheme scale. This would have negative effects on yield and could be a contributing factor to the current yields being below expected yields.

The 'Water Delivery Capacity Ratio' (WDCR) indicated that the scheme water delivery infrastructure was not a constraint to meeting the irrigation water demands. The values were 1.08 and 0.95 for 2004 and 2005 respectively. These values for WDCR were determined based on the command area of 5 500 ha and a maximum pumping duration of sixteen hours a day. In 2004 the canal capacity may not have been constraining and in 2005 the capacity may have had a slight negative effect. However, the actual irrigated area was less than the command area and therefore the peak demand would have been considerably less and the WDCR would have indicated an even more favourable scenario with a water capacity delivery ratio of 1.44 and 1.27 for 2004 and 2005 respectively. Therefore, it can be concluded that during the peak demand months of 2004 (December) and 2005 (September), the scheme infrastructure was not constraining the application of irrigation water. However, if the actual irrigated area had to be increased to the command area, the risk of not supplying water during peak periods would increase.

7.2.3 Scheme level results – water balance analysis

Historical water use records for the entire scheme and for individual sections were analysed for the 2004 and 2005 years. Several water balances were computed in order to determine the efficiency with which the scheme was able to deliver irrigation water to the farm boundary. Surface water evaporation, dam seepage, volume contribution from direct rainfall and the pumped inflows and pumped outflows were all used to determine the extent of unaccounted for, or missing water in each section.

The scheme delivery efficiencies for the entire scheme over the temporal boundaries, namely the 2004 and 2005 years, was between 85.9 and 91.3%. If the inconsistent values (where missing data had been poorly estimated by scheme management) were replaced with more realistic values, the efficiency would be in the range of 93.5 and 99.5%. Therefore it can be concluded that the scheme was being managed in an effective manner and that there were no unacceptable losses which occurred between the scheme intake works at the river, and the respective farm boundaries, in any of the sections. Nevertheless, there were a number of recommendations made that yielded further improvement.

7.2.4 Recommended scenarios – scheme level

7.2.4.1 External Indicators

The results for the Indicators 1 to 6 and 10 to 11 in Table 49 do not provide much useful information unless viewed in conjunction with results from other irrigation schemes. The benchmarking process requires the results and practices of an organisation to be compared with those of a more successful similar business in the market. If these external indicators are determined for a wide range of irrigation schemes within South Africa the results presented in Table 49 could then be viewed in perspective and provide an indication of performance, relative to other schemes in the country. For example, the output per cropped area, output per command area, output per irrigation water supply and output per water consumed, are valuable for comparison to other schemes.

The selected scheme had no subsurface drainage and therefore the quality of the drainage water was not sampled. The inflow water was sampled at a frequency which is suitable for the calculation of the environmental external performance indicators described. It is recommended that if drainage systems are installed in the future, that the quality of water emanating from these systems be sampled and compared to the quality of the inflow water. Such procedures would provide insight into leaching requirements, as well as potential soil salinity or sodicity problems.

The scheme management were also unwilling to release information pertaining to the running costs of the scheme and other sensitive financial information. This was not unreasonable, given the issues that are currently present in the catchment. This was an issue which could be encountered when benchmarking other irrigation schemes. As a solution to the problem of the release of sensitive information, the Australian approach with three different tiers of indicators, each with its own confidentiality class, is suggested. For instance, only the scheme management would be able to see results from the financial performance of the scheme in relation to others, and such information would not be available to anyone except the stakeholders involved. For such an initiative to be a success, a South African equivalent of the Australian National Committee of Irrigation and Drainage (ANCID) approach to confidentiality would be required to actively pursue the concept of irrigation benchmarking with external indicators in South Africa.

Detailed analysis of on-farm irrigation practices and systems is recommended to investigate and verify the potential under-irrigation indicated by the external performance indicators and to provide recommendations for improvement. Methods, technologies and the feasibility of undertaking such analyses are discussed in another section of this report.

7.2.4.2 Water Balance Analyses

It was concluded in conjunction with scheme management, that it would be beneficial to compute the water balances and update the water balance trend graphs on a weekly basis to assist with the early detection of possible water management problems. This study highlighted the benefit of analysing the scheme water use with the water balance trend graphs. When used in conjunction with a water balance, it was possible to identify inconsistencies and problems. The scheme management requested that a Microsoft Excel® Spreadsheet with the water balance results and water balance trends graphs be made available to them so that the scheme water management could be improved. The spreadsheet was made available and the scheme management were utilising the water balances and trend graphs on a weekly basis to aid with water management in the scheme. The water balance methodology combined with the water balance trend graphs will facilitate the identification of the cause of inefficiencies and the nature of the inefficiencies in the future. The water balance trend graphs could also be used as a testament to water use by the individual farms in the scheme as a collective group.

The water balance and the analyses thereof could be improved by a more accurate estimate of evaporation and recording the water level of the balancing dams. However, the magnitude of the overall losses indicated that these are not priority issues. In regions and specific cases where the storage capacity of balancing dams is small relative to the volume of water passing through the dams on an annual basis, the accurate determination of surface water evaporation may not be necessary. This is because in such situations, the loss by surface water evaporation may be insignificant relative to the amount of water passing through the dam.

7.3 Irrigation systems – Phase I

At the scheme level the focus was on assessing performance with external indicators and water balances respectively. Analysis of the external indicators at the scheme level indicated that the farmers were not applying sufficient quantities of water during the year to meet evaporative demand at a scheme level. However, the external indicators did not show when during the year this under-irrigation was occurring, and gave little indication of the possible causes. The level of water metering at the scheme meant that it was possible to analyse the trends in the water application patterns for individual farms and compare these trends between farms and to a given standard or benchmark. Such an analysis was, therefore, the next logical step in assessing irrigation performance.

The focus in this section of this report is on assessing irrigation performance from the farm boundary onwards and to identify possible best management practices and/or problem areas. This information could then be utilised by all of the farmers in the scheme, thereby contributing to an improvement in overall scheme performance.

7.3.1 Evaluation and measurement methods – farm level

Figure 33 shows the process that was used to assess irrigation systems performance at the farm level. The interpretation of Figure 34 starts with the text box labelled "1." and proceeds in an anticlockwise direction.

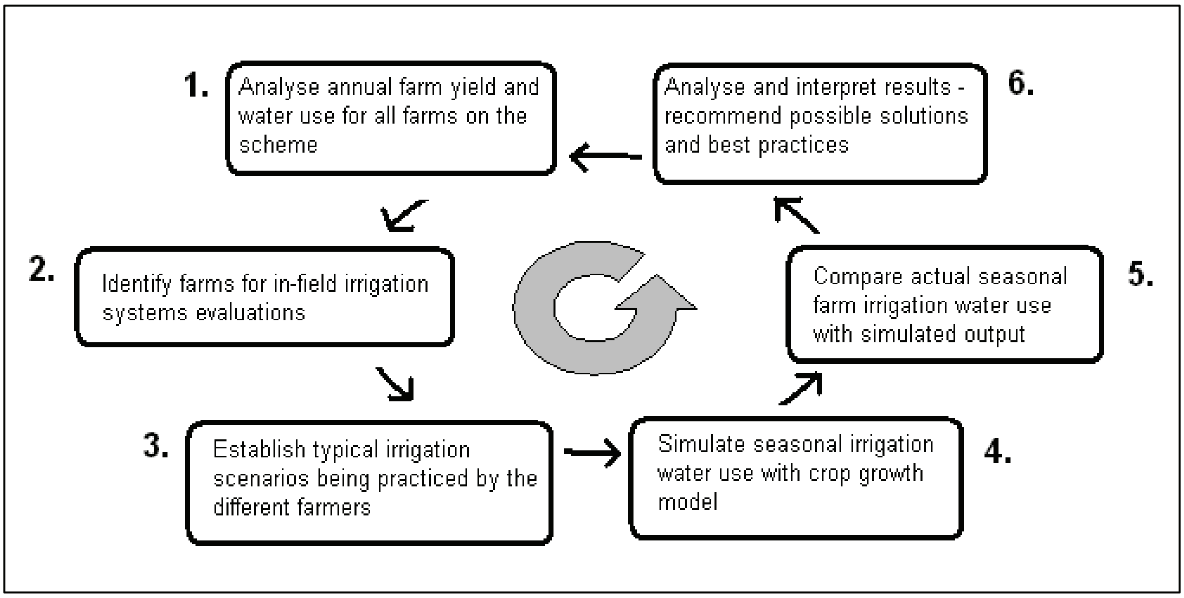

Figure 34: Flow diagram of methodology developed to assess individual farm performance (Greaves, 2007)

The first aspect of the on-farm methodology was to obtain the total farm yields and areas, in order to determine the potential production factor of all the farms in the scheme. The potential production factor indicator that was applied is described by Equation 1:

$$\text{Potential production factor} = \frac{\text{Potential production per hectare with irrigation}}{\text{Production per hectare with irrigation}}$$

Equation 1

The 'potential production per hectare with irrigation' was defined as the highest farm production obtained by one of the farms in the scheme. The potential production factors were then ranked from best to worst, and compared to the total annual farm water use of each farm. Following this, in-field evaluations were performed on a selection of the farms. The selected farms were chosen from the potential production factor results. After the evaluations were completed, simulations with the *SAsched* crop yield and water balance simulation model (Lecler, 2004), using irrigation system and management inputs from the in-field evaluations, was used to produce a theoretical irrigation requirement time series. Finally, a comparison of the observed trends for the 2004 and 2005 seasons were compared to the theoretical irrigation requirement time series. The performance of the in-field irrigation systems infrastructure was assessed in order to determine if it had an impact on the total farm water application trends, and consequently the crop yields obtained, i.e. to try and identify if the farms with a poor level of in-field irrigation system performance were also the farms with relatively low annual water applications and low crop yields. The water meter records were also used to determine the trends in the seasonal application of water on all the farms in the scheme. This was done in order to highlight favourable practices which are evident on certain farms and lacking on others and to improve the understanding of water use in the scheme.

7.3.2 Farm Level: Results

Details of all the on-farm irrigation performance evaluation results are given in Greaves (2007). This report contains only a summary of the main findings.

A large variation in the potential production factor was observed in both the 2004 and 2005 years. The farm with the greatest potential for improvement had a potential production factor of just over 0.4. Therefore, the potential for improvement relative to other farms in the scheme was large. However, the farm with a potential production factor of 1, which means it was the best producing farm in the scheme, also has potential to improve. This was because the potential production factor was based on the highest observed farm yield. But, evidence from model simulations showed that higher crop yields were still obtainable, even from the better performing farms in the scheme. The simulated crop yields were 30% higher than the best observed yields and the relative net farm application graphs are low relative to the simulated net irrigation water requirement. Even the top performing farms were applying far less than the theoretical demand as calculated with the *SAsched* model and thus if more water was applied to these farms it is likely that the yields would increase as a consequence.

The water application trend comparisons revealed that the better performing farms in the scheme generally applied a greater amount of water relative to the poorer performing farms. This is further evidence that a higher water application could produce a better yield and this is explored further in the sections which follow. It must be emphasised, however, that farm production is not totally dependent on water application alone. Soils, management and different farming practices will all have a significant impact on crop production. These different aspects of farm management were not the focus of this research, but they cannot be discounted from having had a significant effect on the crop yields.

The possibility of soil influencing farm production was investigated. The better soil parent materials (Dolerite and Clarens Sandstone) occurred in the South East border of the scheme. The farms in this area of the scheme were the better performing farms. This is especially noticeable with Farm 9, which was ranked second and third for 2004 and 2005 respectively. Farm 9 is located in the South East of the scheme on the dolerite soils, and has a very low net water application relative to the other farms in the scheme. Yet, Farm 9 was a top performer. Thus the location of the farm, with the good soils, was likely a major contributing factor for the good production. The farmer on Farm 9 also believed that the good dolerite soils on the farm were a large contributing factor for the good production.

Figure 35 is a scatter plot of the 2004 and 2005 potential production factor and net farm water application data. The pattern of data supports earlier observations that higher water applications resulted in higher yields.

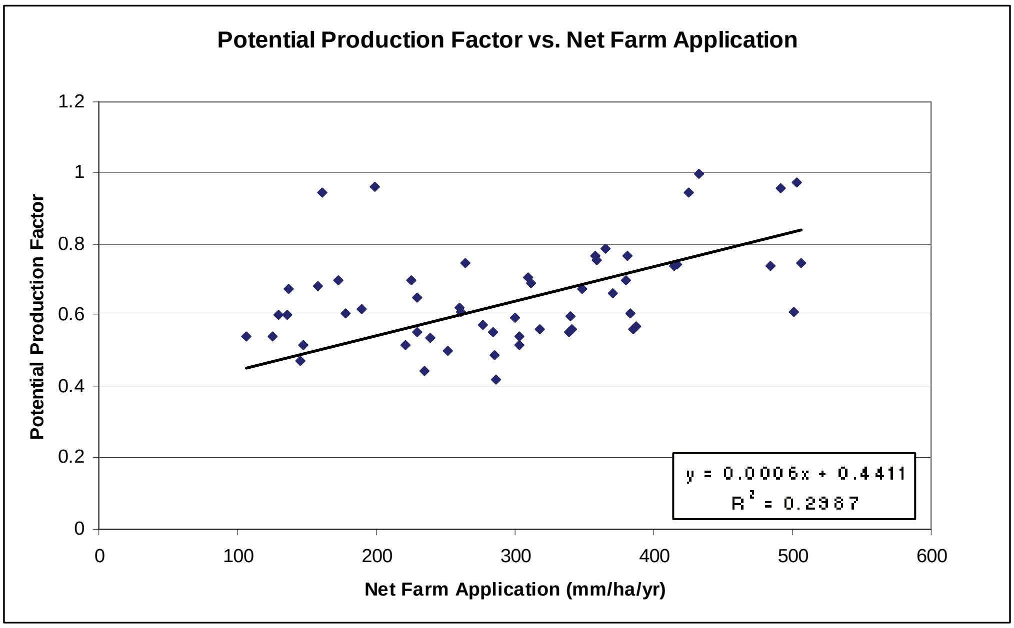

Figure 35: Relationship between annual potential production factor and annual net farm irrigation water application (Greaves, 2007).

The two points in the scatter plot that had an excellent potential production factor, with a net farm application that was low relative to the other farms in the scheme were those of

Farm 9, that, despite having a low net farm application, performed very well in both 2004 and 2005.

The infield irrigation systems evaluations were performed on the following farms:

- Farm 9 – drip irrigation,
- Farm 1 – drip irrigation,
- Farm 22 – combination farm, overhead irrigation evaluated,
- Farm 17 – drip irrigation,
- Farm 12 – drip irrigation,
- Farm 24 – overhead irrigation, and
- Farm 20 – overhead irrigation.

These farms were selected based on the potential production factors and annual net farm application results. Farm 9 was of particular interest because the farm had relatively high yields, yet relatively low net water applications. The results of the in-field evaluations of the drip irrigation farms are presented in Table 50.

Table 50: Pertinent irrigation system evaluation results for evaluated drip irrigation farms (Greaves, 2007)

Farm and System Information	DU (%)	SU (%)	CV (%)	Measured gross application per day of cycle (mm/day)
Farm 9 **Dripper: 2.3 l/h Netafim RAM** **Spacing: 2.6 x 1.0 m** **Schedule: 6 hrs every day**	95.7	96.6	3.44	5.45
Farm 1 **Dripper: 1.2 l/h Netafim RAM** **Spacing: 2.74 x 0.8 m** **Schedule: 12 hrs every day**	90.2	92.4	7.59	6.57
Farm 17 **Dripper: 2.3 l/h Netafim RAM** **Spacing: 3.0 x 1.0 m** **Schedule: 12 hrs every day**	76.9	63.0	37.03	5.25
Farm 12 **Dripper: 2.3 l/h Netafim RAM** **Spacing: 2.68 x 1.0 m** **Schedule: 6 hrs every 2.5 days**	86.1	91.0	8.99	2.47

Note: DU = Distribution Uniformity

SU = Statistical Uniformity

CV = Coefficient of Variation

The Farm 1 drip irrigation system was capable of applying a gross application of 6.57 mm/day of cycle, and the Farm 12 system had a capacity of 2.47 mm/day of cycle. These were the highest and lowest system capacities among the drip irrigation farms that were evaluated. The other two farms had relatively high system capacities greater than 5 mm/day. Although Farm 17 had a relatively high system capacity, the distribution uniformity of 76.9% was below the recommended SABI norm of 90%. The distribution uniformities of the other systems were good. From Table 50, the scenario that was selected to represent a 'good' system was to simulate a system with the capacity to apply a 6 mm application every day. The 'poor' system was a system with a capacity to apply a 5 mm application every two days. These two scenarios were based on the measurements taken from Farm 1 and Farm 12.

In Table 51 shows the results that were obtained from the overhead irrigation system evaluations.

Table 51: Pertinent irrigation system evaluation results for farms with overhead sprinkler irrigation systems (Greaves, 2007)

Farm and System Information	Average Pressure and pressure variation	Nozzle size and wear	Flow variation	Measured gross application per day of cycle (mm/day)
Farm 24 **Cycle: 9 days** **Stand time: 8 hours** **Spacing: 18 x 18 m** **Average delivery: 1.24 m^3/h**	322 kPa (30.45%)	4.8 mm (5.2%)	13.1%	3.4
Farm 22 **Cycle: 6 days** **Stand time: 6 hours** **Spacing: 18 x 18 m** **Average delivery: 1.73 m^3/h**	320 kPa (20.20%)	4.8 mm (4.9%)	12.8%	5.5
Farm 20 **Cycle: 6 days** **Stand time: 8 hours** **Spacing: 18 x 18 m** **Average delivery: 1.17 m^3/h**	225 kPa (27.18%)	4.4 mm (6.2%)	17.6%	4.8

According to system information shown in Table 51, gross application capacities of the irrigation systems ranged from 3.4 mm/day to 5.5 mm/day of cycle. The schedule with which these amounts were determined is presented in the first column of Table 1.3. Evaluations did not include rain gauge assessments of distribution uniformity because the sugarcane was of too tall. Nevertheless, the remainder of the evaluations was completed following the recommendations of Koegelenberg and Breedt (2003). The SABI norms state that pressure variation should not exceed 20% and that flow variation should not exceed 10%.

A low system capacity of 3 mm/day of cycle, and a high capacity of 5.3 mm/day were used to represent the worst and best case scenarios for the overhead irrigation simulations. These were used in two different irrigation scenarios described as follows:

- a sprinkler stand time of six hours and a cycle length of six days, i.e. facility to apply 32 (high capacity) or 18.5 mm (low capacity) every 6 days, if required, and
- a sprinkler stand time of ten hours and a cycle length of ten days, i.e. facility to apply 53 mm (high capacity) or 30 mm (low capacity) every 10 days.

Soils in the scheme were generally shallow with low total available moisture. For the purposes of the simulations, it was decided to use two representative total available moisture (TAW) values for the *SAsched* simulations. The poor soil, representing the worst case scenario, had a TAW of 50 mm. The soil representing a good situation had a TAW of 75 mm. These values were based on previous surveys reported and were agreed upon in conjunction with the farmers.

The simulated net irrigation requirements for overhead irrigation in the study area for 2004 and 2005 are shown in Table 52. The results are shown for the two different soil TAW values, two different cycle lengths and two different system capacity limitations.

Table 52: *SAsched* simulated net overhead irrigation water demands (Greaves, 2007).

Irrigation Schedule	2004 (mm/ha)/year	2005 (mm/ha)/year
Overhead irrigation – Poor Soil (TAW = 50 mm) 10 day cycle, 53 mm application	518.3	585.5
Overhead irrigation – Poor Soil (TAW = 50 mm) 10 day cycle, 30 mm application	518.3	585.5
Overhead irrigation – Poor Soil (TAW = 50 mm) 6 day cycle, 32 mm application	669.3	694.5
Overhead irrigation – Poor Soil (TAW = 50 mm) 6 day cycle, 18.5 mm application	566.2	621.7
Overhead irrigation – Good Soil (TAW = 75 mm) 10 day cycle, 53 mm application	577.9	607.0
Overhead irrigation – Good Soil (TAW = 75 mm) 10 day cycle, 30 mm application	493.3	566.7
Overhead irrigation – Good Soil (TAW = 75 mm) 6 day cycle, 32 mm application	585.7	628.5
Overhead irrigation – Good Soil (TAW = 75 mm) 6 day cycle, 18.5 mm application	469.6	521.0

Note: TAW = Total Available Moisture

The annual values in 2004 ranged from a low of 469.6 (mm/ha)/year to a high of 669.3 (mm/ha)/year. In 2005, the low was 521.0 (mm/ha)/year and the high was 694.5 (mm/ha)/year. With the same irrigation schedule, soils with a low TAW showed a higher irrigation demand than soils with a high TAW. This was because rainfall was more effective on a deeper soil, and therefore, the number of irrigation water applications required would decrease.

On the same soils, a system that applies a low irrigation amount frequently resulted in a higher irrigation application than a system that applies a larger irrigation amount less frequently. On the same soils, systems with the same cycle time but different capacities will apply different quantities of water. A system with a higher capacity applied more water than a system with a lower capacity, indicating that the lower capacity systems were below what was required to meet full crop water demands. However, this does not necessarily mean that these systems were not optimal from an economic perspective.

The simulation results were based on field measurements. Therefore, the observed net farm water applications should have been in between the envelope formed by the lowest simulated irrigation demand and the highest simulated irrigation demand. Table 53 shows the simulated net irrigation requirements for drip irrigation in the study area for 2004 and 2005. The results are shown for the two different soil TAW and two different net application capacities.

Table 53: *SAsched* simulated net drip irrigation water demands (Greaves, 2007).

Irrigation Schedule	2004 (mm/ha)/year⁻	2005 (mm/ha)/year
Drip irrigation – Poor Soil (TAW = 50 mm) Capacity to apply 6 mm every day	706.0	735.3
Drip irrigation – Poor Soil (TAW = 50 mm) " 5 mm application every 2 days	511.9	568.3
Drip irrigation – Good Soil (TAW = 75 mm) " 6 mm application every day	650.7	670.7
Drip irrigation – Good Soil (TAW = 75 mm) " 5 mm application every 2 days	482.2	541.4

Note: TAW = Total Available Water in the profile

The highest net irrigation demand for both 2004 and 2005 occurred when a drip system with good capacity was used on shallow soil, with a poor TAW of 50 mm. The lowest irrigation demand for 2004 and 2005 occurred when a drip irrigation system with poor capacity was used on a good soil with a TAW of 75 mm. These findings can be explained in the same manner as the overhead irrigation scenarios. For the same irrigation system, a soil with a higher TAW always resulted in a lower irrigation application than a soil with a lower TAW. This was due to the higher effective rainfall simulated for the deeper soil. It is also a logical outcome that a drip irrigation system with a poor capacity will apply less water than a system with a good capacity.

The annual net farm water applications of the farms in the scheme were low relative to a simulated irrigation demand. An example of the results obtained by using the historical water meter records to determine seasonal watering patterns or trends are shown in Figure 36 together with patterns obtained for the highest and lowest simulated irrigation water requirements. This facilitates a comparison between what the farmers should be applying, and what they actually were applying, for both high and low system capacity and soil constraints. In this report, only the 2004 graph for the overhead irrigation farms is presented. The most important aspect shown by the seasonal application graphs are the upper and lower limits of the net irrigation water requirements that were determined using the *SAsched* model. Ideally, if all the farms were applying water according to scientifically based recommendations, all the seasonal water application trends should fall in the envelope between these two simulated net irrigation water requirement trends.

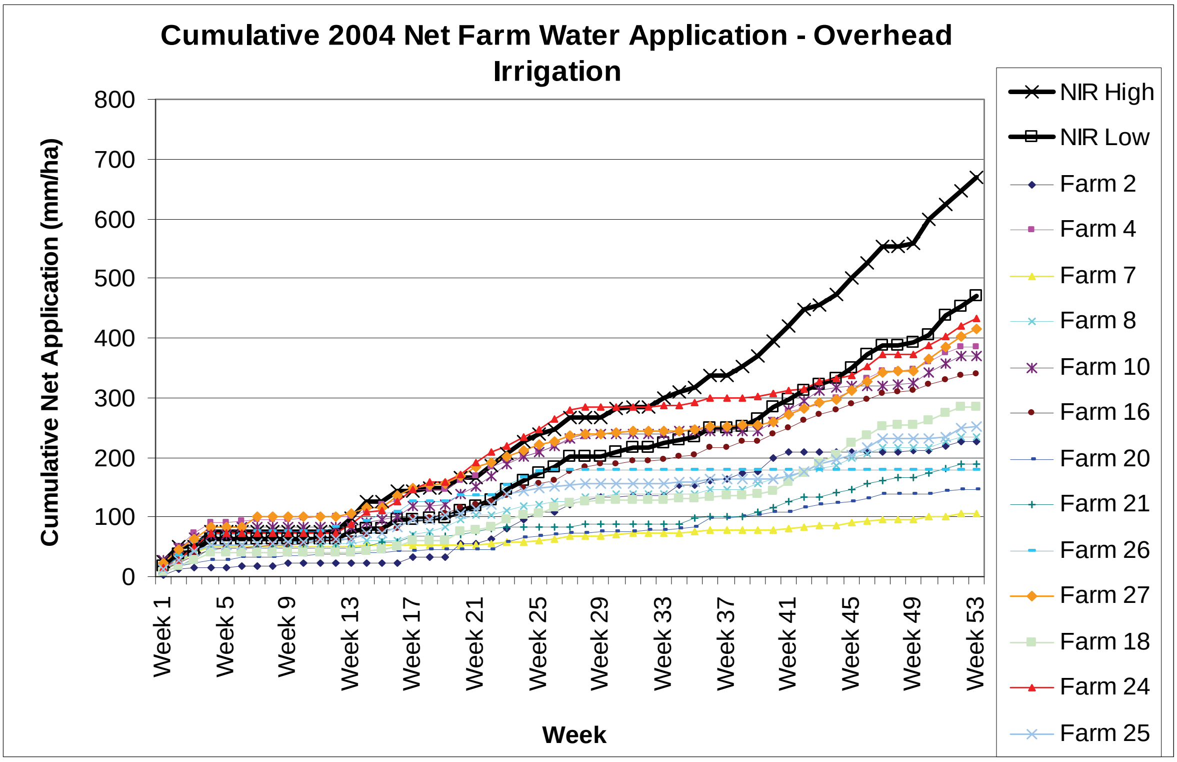

Figure 36: Cumulative 2004 net farm water applications for overhead irrigation farms Greaves, 2007).

The water application trend relative to the simulated demands for the overhead irrigation farms was the same as that observed for the drip irrigation farms. The majority of the farms were under applying relative to the simulated envelopes. There were farms, most notably Farm 7 and Farm 20, which were applying very low amounts of irrigation water over the year. From the potential production factor results, Farm 20 and Farm 7 were poor producing farms with low potential production factors and it is likely that the very low observed irrigation water application rates were a major contributing factor to the poor production.

Farm 26 applied irrigation water in a similar fashion to the majority of the other farms until week 26. After week 26, no irrigation occurred for the remainder of the year. In communications with stakeholders, it was found that there were no water meter errors with the farm during that period, and therefore, it is assumed that there must have been a problem with the infield irrigation systems and the management thereof. The results for the 2005 year showed that the same farm had an unusual water application trend compared to all the other farms in the scheme. In the initial stages of the year, Farm 26 continued to apply water when all the other farms, and the simulated irrigation demand, was relatively low. The initial stages of the year had substantial rainfall, and evidently Farm 26 did not cease irrigation during this period. These observations highlight the usefulness of farm water application trend comparisons in a benchmarking environment. As a result of this study, the owner of Farm 26 could observe that his/her irrigation management practices were very different to other farmers in the scheme, and could react accordingly.

It should be reiterated that the lower simulated requirement was the worst case scenario, with a poor system operating on a shallow soil with a long cycle time. It is unwise to view the lower requirement as the suitable net irrigation water requirement. It was included to create an envelope, just to illustrate the fact that the farmers were not applying sufficient quantities of irrigation water. A number of farms applied an annual net irrigation depth less than 200 (mm/ha)/year. The theoretical requirement should have been in the range of 500-700 mm/ha for the 2004 and 2005 seasons.

7.3.3 Farm Level: Recommended Scenarios

The extensive water metering on this scheme facilitated the study into individual farm water use. This type of water measurement and monitoring, if implemented at other irrigation schemes will assist in identifying problem areas at each scheme, as well as promoting the efficient use of irrigation water. This is necessary given the situation in South Africa where irrigation is the largest water user, and is being highlighted as an inefficient user of water. In this case study it was apparent that farmers were not inefficient but that they could be more effective water users.

From the analysis of the individual farm performance of all the farms on the scheme, it was found that there were wide variations in both farm production and farm water use. Furthermore, it was discovered that, in general, the farmers that had higher net annual water applications, also had higher crop yields. As expected, soils played a substantial role in farm performance, maybe even over-riding management inputs. It was also discovered that as a group, the farmers applied too little water relative to the simulated reference irrigation requirement as calculated with the *SAsched* model. This observation was identified as one of the areas that needed to be addressed if production on some of the farms were to improve. Since this is an unusual finding, i.e. that farmers are applying too little water, further in-field monitoring of crop growth and soil water potential during the season was recommended to help substantiate this assertion. Despite the science inherent in the *SAsched* model, many people, including DWAF, were a little sceptical about the *SAsched* irrigation water requirement results because they exceeded the actual farm water use by such large amounts.

When the systems constraints that were identified during the on-farm system evaluations were used in the *SAsched* model, the simulated irrigation water requirements did decrease. However, the decrease in the simulated irrigation water requirements due to the system constraints determined during in-field performance assessments was, in theory, still insufficient to bring water applications down to a level that coincided with the observed net farm applications. The theoretical system constraints could, however, have been amplified in practice by security, labour and theft issues. Labour and theft constraints may have had a great impact on actual water applications. The view of the stakeholders at the scheme was that labour, theft and security constraints that prevented irrigation systems being used at night had a great impact on total water applications.

A concomitant issue is that dragline systems with long stand times, say, 11 hrs, were often not well suited to the low TAW soils. Theoretical options to reduce stand times to, say, 8 or 6 hrs were not really feasible with existing system designs because of the night move/s which would be required and farmer and labour reluctance to do night moves for various reasons, including security concerns. Thus, although in theory the systems had sufficient capacity, in practice, a good proportion of the total time available to irrigate was either not used or used inefficiently, i.e. to have a 12 hr overnight stand time on shallow, low TAW soils, was considered by many farmers, quite correctly, to be wasteful of water and electricity. As a result one scenario deemed worth investigation was to design and assess the cost of sprinkler system options which could be used to apply a lower amount of water more frequently. An additional issue on the scheme is the electricity tariff options and whether existing options are optimal.

7.3.4 Summary Recommendations and Feasibility of Making Changes

The analysis of the scheme's delivery infrastructure did not indicate any major problems rather it highlighted how well a scheme could perform with appropriate design, monitoring/measurement and maintenance. Thus, most of the effort aimed at improving performance on the scheme should be aimed at developing, assessing and supporting, improved on-farm water management scenarios.

The priority issues were deemed to be as follows:

- continue with the development and application of appropriate instrumentation including continuous soil water measurement devices in order to: substantiate evidence that crops were being under-irrigated, or in other cases/times, over-irrigated, and engender further confidence in the management tools such as *SAsched*;

- develop and apply a framework to evaluate alternative irrigation design and operating strategies and associated costs and benefits. A major application is to determine costs and benefits of alternative irrigation design scenarios and associated operating strategies, in particular the costs and benefits of alternative sprinkler irrigation designs, which are better suited to shallow soils with low TAW values. An investigation into implications of using different electricity tariff options is also considered to be a priority.
- refine irrigation management tools and develop strategies for improved implementation.
- develop and/or promote simple irrigation hardware evaluation techniques. Standard evaluation procedures need to be simplified so that, for example, farm labour at the supervisor level can take appropriate measurements with little disruption to daily routines. For example, the simplified procedures used by Greaves (2007) are considered efficient and effective for most applications. The data and information from these evaluations is fundamental to improving irrigation performance.
- liaise with DWAF and other stakeholders with regard to water allocation, licensing and associated licensing conditions. For example, liaisons to date have shown that even if irrigators take more water than they do at present, i.e. equivalent to *SAsched* model predictions, especially during the drought years, where relatively high irrigation water requirements are predicted, the catchment will not run short of water. Thus, instead of curtailing irrigators during drought years when they actually need higher irrigation water requirements, curtailment during normal or high rainfall seasons should be considered as a potential win-win scenario, to promote effective use of rainfall and to ensure that the main storage dam will refill relatively rapidly to carry stakeholders through the next drought. Such a scenario will likely resolve the conflict around the existing high irrigation water allocations. At present the irrigators are arguing for high irrigation water allocations so that when they are curtailed during drought years they will still have sufficient water to stay in business. DWAF, however, is reluctant to allocate such high water allocations because if these relatively high allocations were used in normal or high rainfall years, the catchment would run short of water, hence the need for a paradigm shift in water licensing regulations and operating rules.

7.4 Irrigation systems – Phase II

The purpose of Phase II of the performance assessment was to address many of the issues raised in Phase I of the study. To achieve this, a framework to assess irrigation design and operating strategies was developed. The framework was used to investigate:

- the costs and benefits of potential irrigation design and operating solutions to ineffective irrigation on shallow soils with drag-line systems;
- different electricity tariff options,
- costs and benefits of deficit irrigation strategies, whereby a crop is deliberately allowed to undergo some soil water stress in order to save water and reduce irrigation capital and operating costs. The benefits and costs of shifting electricity use out of expensive peak periods when using the Ruraflex electricity tariff option was included as one of the deficit irrigation strategies.

Finally, a field work component, relating to the precise monitoring of irrigation strategies and corresponding crop responses was included as a means to substantiate predictions of under-irrigation and to potentially support implementation of recommended operating strategies.

7.4.1 Development of a Decision Support Framework

Assessment of an irrigation system should include three components, namely engineering, agronomic and economic performance. The first component is the engineering design and performance which to a large degree dictates the capital and operating costs of the system. More uniform and, therefore, effective systems may involve a tradeoff between increased capital expenditure on equipment and the benefits of reduced water application associated with high uniformity (Brennin, 2008). For example, sprinkler "A" has to be operated at 12 x 12 m spacing at 250 kPa in order to perform at the acceptable uniformity level. The sprinkler and lateral spacing will dictate the number of sprinklers and pipes required, while the pressure requirements will be used to determine the size of pipes and pumps. Hence, the design impacts on both the capital and electricity costs. A poorly designed system, for example sprinkler "A" operated at a wider 15 x 15 m spacing and 200 kPa, may have lower costs but will result in a less uniform application of water. Hence a direct relationship exists between system hardware costs and engineering and agronomic performance.

The second component is the agronomic performance of the crop in terms of yield and is largely dependent on the capability of the irrigation system and management. For example a system capable of applying 42 mm every 10 days would cost and perform differently to a system capable of applying 42 mm every 20 days. The crop yields and water use of both systems would also be determined by the scheduling strategy adopted by management and the uniformity of water applications. Finally, the third component is the economic performance which is both a function of irrigation design and operating strategy to determine costs and crop yield to determine revenue generated by the irrigation system for a given operating strategy.

These three components are inter-related and need to be accounted for concurrently to holistically asses an irrigation strategy. In practice, however, even though the analytical tools to assess the three components exist, it appears that they are not frequently used conjunctively. Irrigation designers often generate and implement irrigation designs that simply meet the recommended and widely accepted engineering standards and norms. Optimising and refining a design is considered too costly an exercise in terms of tools required and more importantly the perceived lack of benefit for the time consumed. The development of an efficient and relatively quick method to generate and assess alternative irrigation strategies was therefore developed and is introduced in this Section. It was envisaged that researchers would use the framework to assess alternatives and develop recommendations for practical and real problems faced by irrigation designers and practitioners. The framework proposed to holistically asses alternative irrigation strategies is shown in Figure 37.

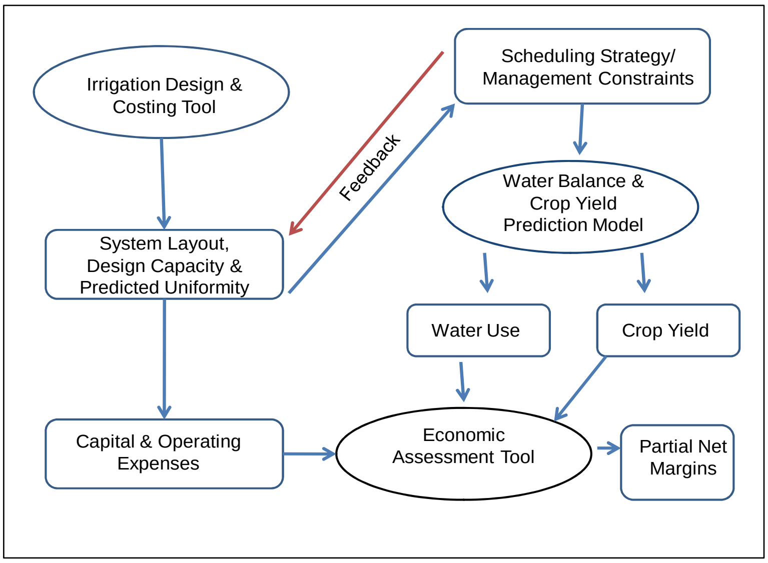

Figure 37: Framework for assessing alternative design and operating strategies (Jumman, 2009)

In Figure 37, the first tool on the top left hand corner is an irrigation design and costing tool. For this component a novel Excel-based tool was developed to allow a knowledgeable person to quickly generate a series of alternative irrigation designs and assess the cost implications of different irrigation hardware. At this stage only semi-permanent sprinkler irrigation systems are incorporated in the tool. A schematic of the different components in the design and costing tool is shown in Figure 38.

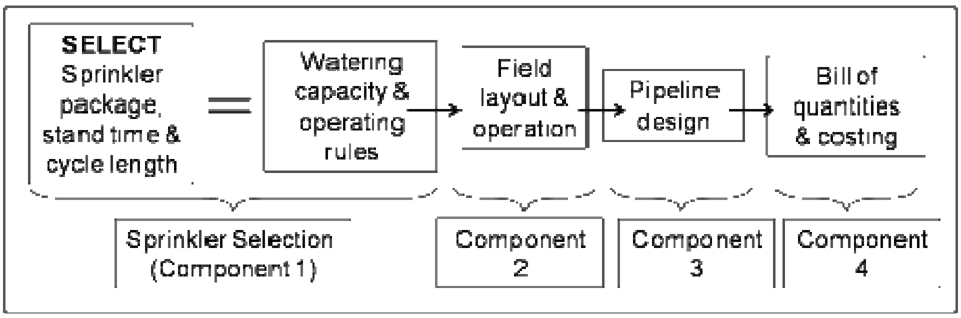

Figure 38: Components of the design and costing tool (Jumman, 2009)

The tool constitutes of four components, namely, sprinkler selection, field layout & operation, pipe design and finally, the bill of quantities and costing. Figure 38 demonstrates the logical sequence with which the tool was designed. Details of the development and functioning of this tool are given in Jumman (2009). The engineering performance of the irrigation system, in terms of uniformity, forms part of the minimum design criteria.

The second tool in the framework shown in Figure 37 is the water balance and crop yield prediction model. *ZIMsched* 2.0 (Lecler, 2004a) was used to assess the agronomic performance in terms of crop yield for a given irrigation regime and its constraints, including the uniformity of irrigation water applications. The *ZIMsched* 2.0 model was developed to predict how field derived indices of irrigation performance, such as the coefficient of uniformity (CU) impacted on yields and the water balance" (Lecler, 2003). The model was unique in that it possessed the ability to account for irrigation systems performing at different levels of uniformity. This was important when accounting for the impact of irrigation hardware and strategies on yield (Moult et al., 2006). In *ZIMsched* 2.0, "the complexities of water budgeting were integrated in the form of robust algorithms based on leading research by, inter alia, Schulze (1995) and Allen et al. (1998)". Processes such as:

- evaporation from the soil surface and transpiration (in relation to atmospheric evaporative demand, available soil water, crop and rooting characteristics and irrigation system type), and
- surface runoff and deep percolation, as impacted on by rainfall effectiveness and uniformity or non-uniformity of irrigation water applications are all accounted for (Lecler 2004a).

The inputs into the model are not exhaustive and include the following: agronomics details such as planting date and length of season, irrigation system constraints including irrigation frequency and depth, soil and climate characteristics such as reference evaporation and rainfall, amongst others (Greaves, 2007). The outputs include the water use and corresponding yield or soil water deficit for irrigation scheduling purposes. The yields and water use simulated by *ZIMsched* 2.0 can therefore be used to assess the performance of various irrigation strategies, including deficit strategies.

The final component of the framework shown in Figure 37 is the economic assessment tool. *Irriecon v2* (Lecler, 2008) was used for this component to determine the fixed and variable costs associated with different irrigation systems and operating strategies. *Irriecon v2* is a spreadsheet based tool used to assess different irrigation strategies through determining detailed capital, operating and marginal costs (Armitage et al., 2008). As shown in Figure 39, the specific costs associated with sugarcane farming practices such as the application of fertiliser and herbicide, planting, harvesting and haulage together with irrigation systems, water and electricity costs are accounted for (Armitage et al., 2008). The tool was developed based on cost estimation procedures for irrigation systems as presented by Oosthuizen et al. (2005).

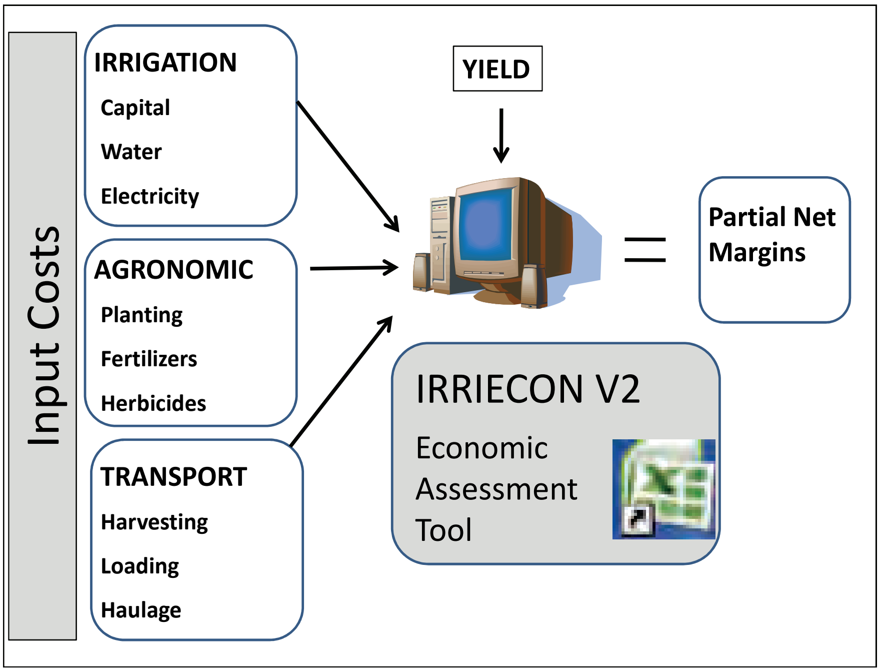

Figure 39: Schematic of the Irriecon V2 model (after Jumman, 2009)

An example of the application of the model is profitability assessment of irrigated versus dry land sugarcane farming (Armitage et al., 2008). Other applications include comparison of systems (e.g. sprinkler versus drip) and different irrigating strategies such as more frequent smaller water applications versus less frequent larger applications, when used in conjunction with a model such as *ZIMsched* 2.0 (Armitage et al., 2008). The model was a suitable tool for determining optimum irrigation strategies for different systems and contexts which take into consideration economic aspects, including water costs, various electricity tariff options, irrigation design, irrigation constraints, agronomic practices and associated crop yield expectations. *Irriecon v2*, however, must be used in conjunction with yield and water use data, which may be simulated using water balance and crop prediction models such as *ZIMsched* 2.0.

7.4.2 Application of the Decision Support Framework

The framework was used to investigate the costs and benefits of potential design and operating solutions to a selection of irrigation issues raised during Phase I of the study.

7.4.2.1 Design and operating strategies for shallow soils

Irrigating shallow soils efficiently generally requires small applications on a frequent basis. This is because the shallow depth limits the volume of water that maybe stored in the soil profile and application of too much water results in non-beneficial runoff and deep percolation. Hence, effective irrigation of shallow soils requires application of smaller amounts of water more frequently. The trouble arises when shallow soils are irrigated with dragline sprinkler irrigation systems.

A limitation is that labour is used to move sprinklers and it is impractical to move sprinklers at night. A common dragline strategy, therefore, is to irrigate for 12 hours during the day, then move the sprinklers and irrigate again for the next 12 hours during the night. The sprinklers can then be moved to the next position in the morning when there is enough light again. However, a 12 hour application often results in too much water for most shallow soils. The trade off for most growers was a cheaper irrigation system but poor use of water.

For this reason, a lot of dragline sprinkler systems are operating inefficiently resulting in over irrigation on a large portion of the sugar industry (Lecler et al., 2008). Automating the irrigation system so that sprinkler applications could be better matched to the soil and operated on, say, an 8 hour stand time would help solve this problem. Automation of draglines is practically impossible. For this reason, an alternative semi-permanent (hop along) system was considered. In this chapter a typical “12 hour stand time system” was compared to an innovative, better matched, semi automated “8 hour system”. The framework, as described in Chapter 3.1 was used to cost and assess the performance of these two systems. The hypothesis was that the yield improvement from more effective use of water will offset the additional costs for partially automating the 8 hour system.

Before designing the systems, the following important criteria were selected. The targeted irrigation depth was set at 5 mm/day, and the soil was assumed to be a 0.6 m deep Sandy Clay Loam with a “Total Available Water” content (TAW) of 57 mm as shown in Figure 40. Again, this was fairly representative of a shallow soil. It was assumed that 60% of the TAW would be allowed to deplete before an irrigation event was triggered. Hence the depth of water required from irrigation to refill the depleted amount was 34 mm (60% of 57 mm).

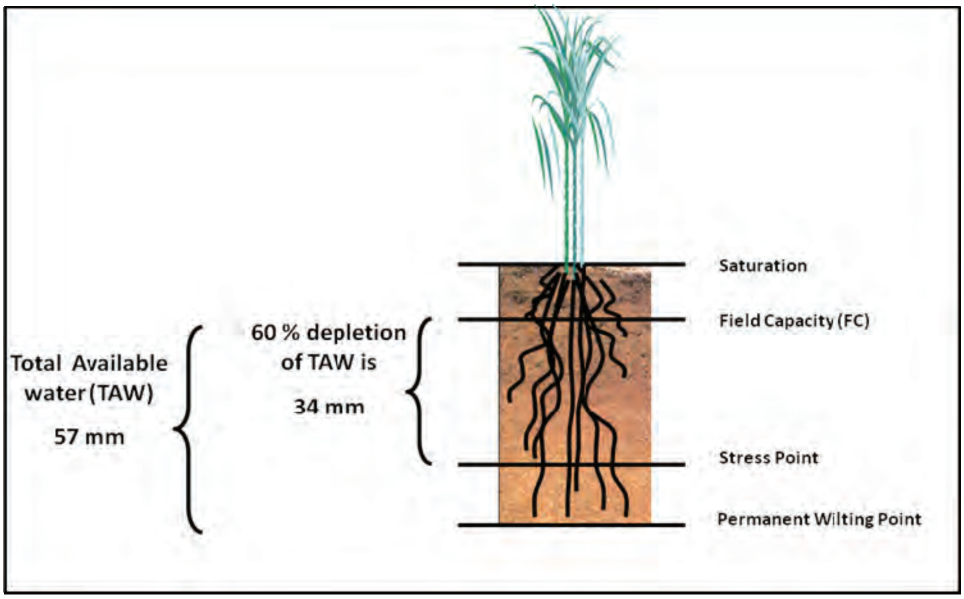

Figure 40: Illustration of soil criteria selected for irrigation design (Jumman,2009).

Using the irrigation design tool, two irrigation designs were generated. In the first system, a stand time of 12 hours, similar to current practices, was used. The details of this system are as follows. A VYRSA 35 sprinkler with 4 mm brass nozzle was selected. This sprinkler was capable of delivering 4.3 mm/hour with a coefficient of uniformity of 87% if operated at 300 kPa and sprinkler and lateral spacing of 18 × 21 m. Running the sprinkler on a 12 hour stand time will deliver 51.6 mm (4.3 mm/hr × 12 hrs) every 10 days. This translates into an equivalent of 5.16 mm/day, which is well matched to the target depth of 5 mm/day. Applying 51.6 mm per irrigation event, however, exceeds the 34 mm refill depth. This is illustrated in part A of Figure 41. In this figure it is easy to see how application of excess water is lost.

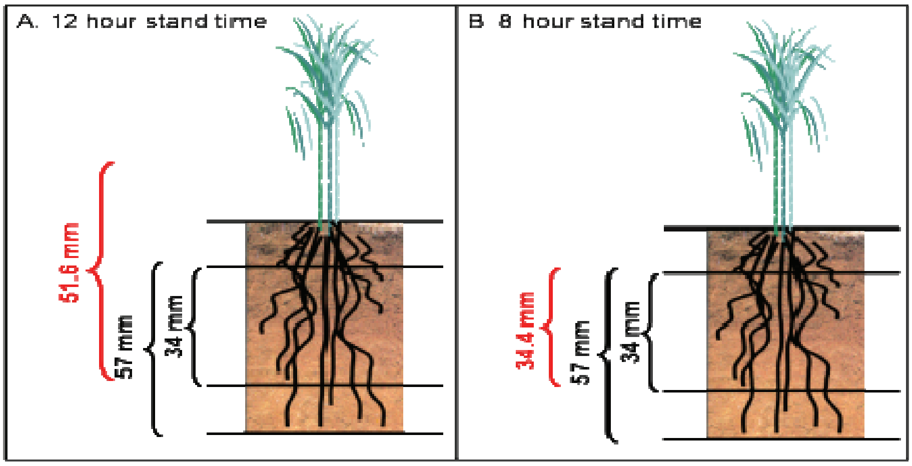

Figure 41: Illustration of poorly matched irrigation application to the soil (Jumman, 2009).

For the second system, however, the same sprinkler package, spacing and operating pressure was now operated on an 8 hour stand time and a 6 day cycle. Hence, 34.4 mm (4.3 mm/h × 8 hrs) was applied every 6 days, translating into 5.73 mm/day. The 8 hour system, demonstrated in part B of Figure 41, was better matched to the soil and still met the target depth of 5 mm/day. The challenge, however, was to automate and operate a sprinkler system so that labour was not required to move the sprinklers at night. Before describing the innovative 8 hour design, the commonly occurring 12 hour system (Reinders, 2001) is first described in Figure 42 below.

In Figure 42, the numbers along the two laterals in the figure represent sprinkler positions, where the 1st digit represents the day in the cycle. A cycle length of 10 days represents 10 sprinkler positions. The 2nd digit represents the number of moves for that day. In other words, 6.2 refer to the 2nd move on day 6. Also, as indicated in Figure 42, the numbers in black indicate sprinkler moves that occur in the morning for irrigation during the day and the numbers in grey indicate sprinkler moves that occur in the afternoon for irrigation during the night. Furthermore, in Figure 42, only the left portion of lateral A and B are show. Take note that the right portion was a mirror image but designed to operate independently. The system would operate as follows. The sprinkler would begin in position 1.1 and operate for the day in that position. At the end of the day, labour would then move the sprinkler to position 1.2, where it will operate for the evening. The cycle would continue, similarly, on day 2 and over the next 10 days.

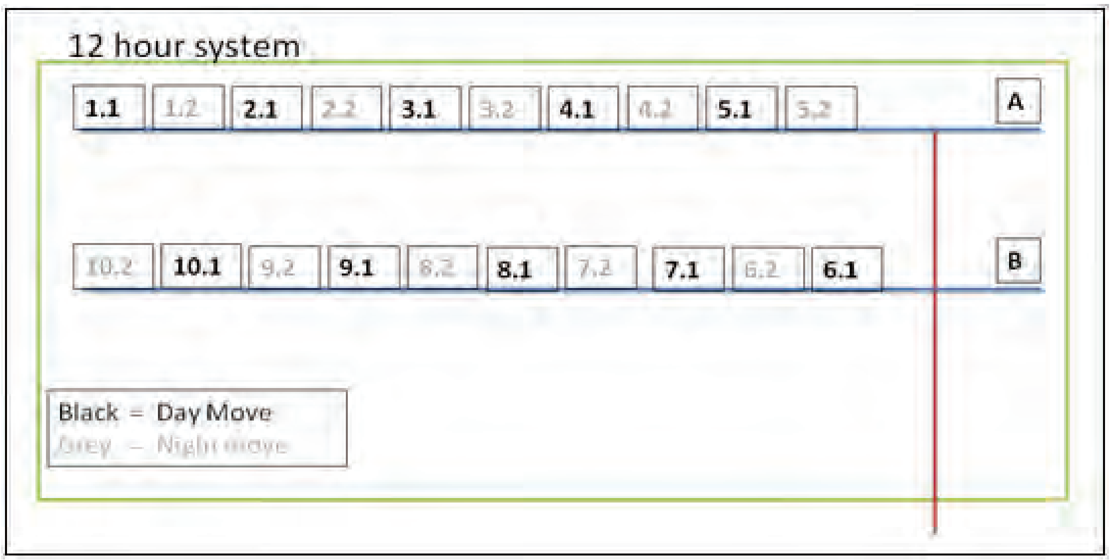

Figure 42: Field operation of sprinkler for the 12 hour system (Jumman, 2009).

Figure 42 above illustrates the layout and sprinkler operation of 2 laterals with 2 sprinklers. The 12 hour system was designed to use 66 sprinklers and 66 laterals to irrigate an area of 50.65 ha. The 8 hour system, however, required some modification. This system required for a sprinkler to be operated in three different positions within 24 hours. This implied that labour would have to work in the dark, if operated traditionally. Instead, an additional set of sprinklers was introduced to the system. The additional sprinkler would be placed on a lateral which is then isolated during traditional operation in the day. Hence, when the time for operation at night arrived, the isolated sprinkler could be switched on via a valve and the lateral that was working during the day would now be switched off. Hence, instead of having to move sprinklers at night, an irrigation supervisor would simply walk or drive along the sub main and switch the appropriate laterals on and off. This is demonstrated in Figure 43below.

As in Figure 42, the 1st digit was the day in the cycle; the 2nd digit was the number of moves in the day and the black equals day moves whilst grey equals night moves. In this case, for the 2nd digit, 1 represent a move in the morning, 2 represents a move in the afternoon and 3 represents a move in the evening. Each lateral, both on the left and right was equipped with a simple gate valve on a hydrant type set up. Unlike the 12 hour system, each lateral was also equipped with a sprinkler. Hence, for 66 laterals, 132 sprinklers were used. The system was designed to operate as follows. A sprinkler would be placed at position 1.1 and 1.3, on lateral A and B respectively. .In the morning, lateral A would be switched on and lateral B switched off. The sprinkle at 1.1 would operate here for 8 hours, after which labour would move the sprinkler to position 1.2. The sprinkler at 1.2 on lateral A would then operate for 8 hours into the evening. At the end of the 8 hours, the irrigation supervisor would venture out in the dark to simply switch lateral A off and Switch on lateral B, activating the sprinkler at 1.3. The sprinkler at 1.3 would then irrigate until the next morning.

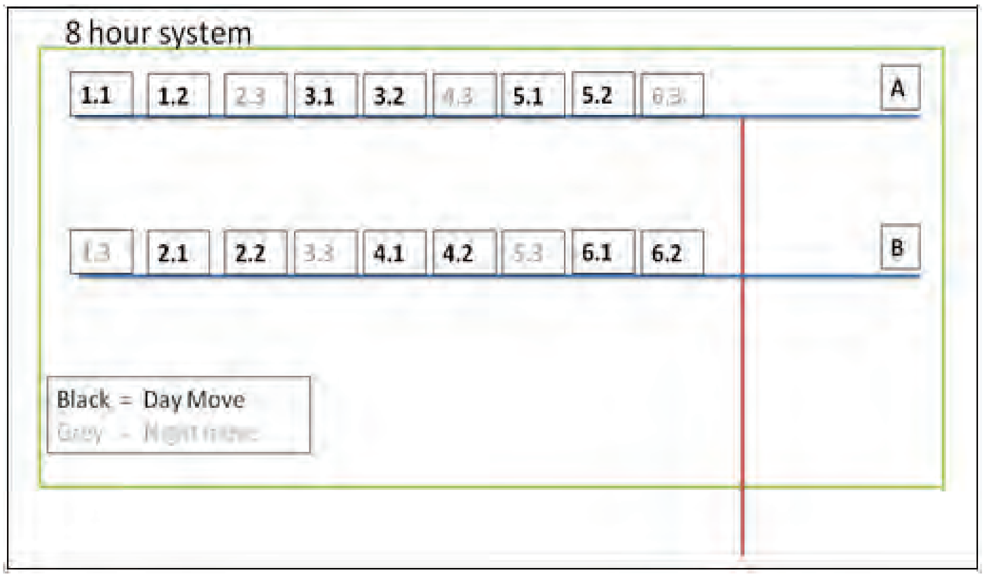

Figure 43: Field operation of sprinkler for the 8 hour system (Jumman, 2009).

The next morning, labour would move the both the sprinklers on lateral A and B from 1.2 to 2.3 and 1.3 to 2.1 respectively. Lateral B would remain open and irrigation would proceed at 2.1, while lateral A remains closed but ready for the next night move. The operation of the system would continue in this manner to the end of the cycle on day 6. At the end of day 6, all sprinklers would be returned to the original starting positions. Take note that this system was only semi-automated since labour was still required to move sprinklers. The innovation, however, allows for easy irrigation at night at an increased cost. The first task was to quantify what the costs differences were for each system. The newly developed irrigation design and costing tool was used to optimally size the pipes and cost both systems. The summary of costs is provided in Table 54.

Table 54: Summary of system costs per hectare for 12 and 8 hour stand time designs (Jumman, 2009)

Description	**12 Hour (R/ha)**	**8 Hour (R/ha)**
Sprinkler package	R 1, 039	R 2, 309
Laterals	R 4, 301	R 4, 301
Sub Mains	R 1, 779	R 1, 967
Mainline	R 81	R 90
Senniger Valves	R 125	R 139
Crosses/Tees/Hydrants	R 758	R 2, 407
Trenching	R 3, 110	R 3, 143
Total	**R 11, 193**	**R 14, 356**
% increase in costs	**100%**	**128%**

Table 54 illustrates that the 8 hour system costs 28% more than the 12 hour system. This translates into an additional R 3, 163 per hectare. The difference, as expected, was largely due to the additional set of sprinklers and the components required for the hydrants and valves at each lateral for the 8 hour system. Marginal differences were also accounted for in the cost of sub-mains and mainlines. These were due to varying pipe diameters and classes to balance and optimise friction losses. At this stage it should also be noted that the pumping requirements of both systems were very similar. The 12 hour system required an 18.43 kW pump to pump 107.28 m^3/hr at a head of 44.54 m while the 8 hour system required an 18.60 KW pump to pump 107.28 m^3/hr at a head of 44.13 m. Hence for all intensive purposes, the capital and operating costs for both pumping systems were assumed to be the same. This will be discussed further in the economic analysis section. The next task was to assess the agronomic performance of the different irrigation regimes.

7.4.2.2 Agronomic assessment

The *ZIMsched* 2.0, water balance and crop prediction, model was configured to simulate the performance of both systems over 12 seasons from 1988 until 1999. The following parameters were selected or assumed in the model:

- 0.6 m deep Sandy Clay Loam with a TAW of 57 mm
- poor drainage conditions
- 10% of total applied water was assumed to be lost by wind drift and spray evaporation (after McNaughton (1981), Tolk et al. (1995) and Thompson et al. (1997)
- planting date on 30 March
- coefficient of uniformity of 87% as per ARC sprinkler test
- weather data for Komatipoort was obtained from the South African Sugarcane Research Institute's (SASRI's) meteorological database to drive the model. These

include maximum and minimum daily temperatures, daily FAO evapotranspiration and rainfall.

- irrigation scheduling rules were as follows: Irrigation was applied when 34 mm of soil water was depleted (60% × TAW), provided that the minimum cycle time was exceeded and that the period did not fall within the "dry off" period. The "dry off" period was calculated as the amount of time required to deplete 85.5 mm of soil water (1.5 × TAW)
- system operation rules: 12 hour system

  Gross application = 51.6 mm

  Cycle length = 10 days

  Peak application depth = 5.16 mm/day
- system operation rules: 8 hour system

  Gross application = 34.4 mm

  Cycle length = 6 days

  Peak application depth = 5.73 mm/day

The results obtained are represented in Figure 44 to Figure 46, below. Figure 44 illustrates the seasonal water applications for both systems. Due to similar system capacities, both systems applied very similar amounts of water over the 12 year period. The slightly higher capacity "8 hour system" was able to apply marginally more water in the drier years of 1995, 1996 and 1997. On average both systems applied in the region of 1400 mm of water per a season. These systems were not optimised in terms of water use, as shown by Lecler and Jumman (2009), but were fairly representative of high yielding systems for Komatipoort. At this stage, an 8 hour system which costs more but applies similar amounts of water appears less attractive.

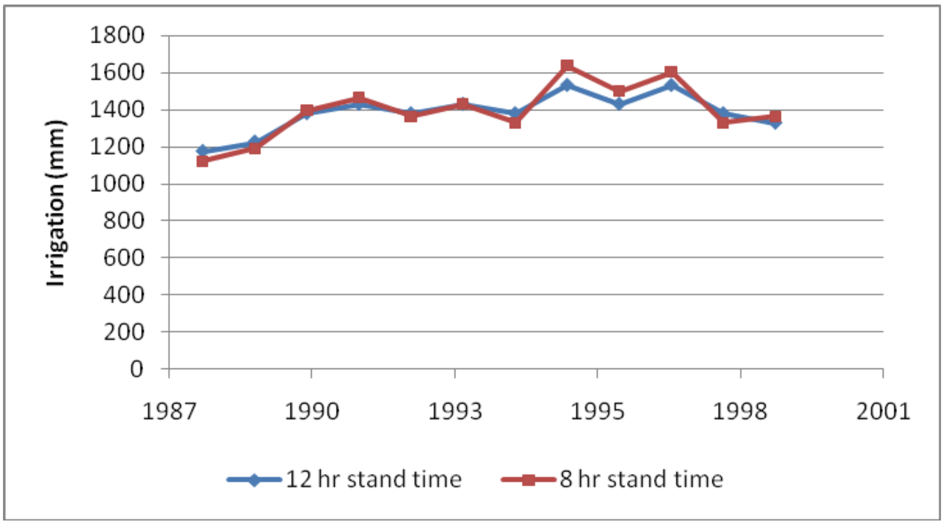

Figure 44: Time series of seasonal water application for 12 and 8 hour systems (Jumman, 2009).

Interestingly, Figure 46 shows that the 8 hour system performs significantly better in terms of yield as compared to the 12 hour system for similar water applications. The average yield for the 12 hour system was 128 tons/ha with a maximum of 139 tons/ha in the 1992 season. The 8 hour system, however, for the same rainfall and similar water applications on average yielded 138 tons/ha with a maximum of 148 tons/ha in 1992, also.

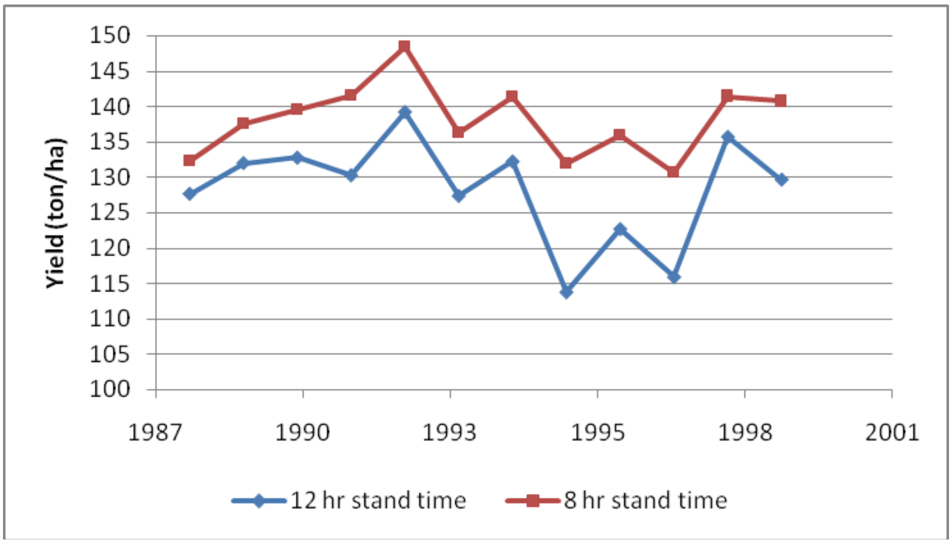

Figure 45: Time series of seasonal yield for 12 and 8 hour systems (Jumman, 2009).

To better understand why the 8 hour system yields so much higher one needs to consider Figure 41 again. In Figure 41, the application of water by the 12 hour system beyond the soils water holding capacity is demonstrated. This implies that excess water applied cannot be stored in the soil and was therefore not available to the crop. The excess water was lost through runoff and deep percolation. This is shown in Figure 46. The 8 hour system, however, was better matched to the soil. Hence a larger portion of the applied water can be stored in the soil and is therefore available to the crop. So even though similar amounts of water are applied, the 8 hour system delivers better yields because it allows for more effective use of water.

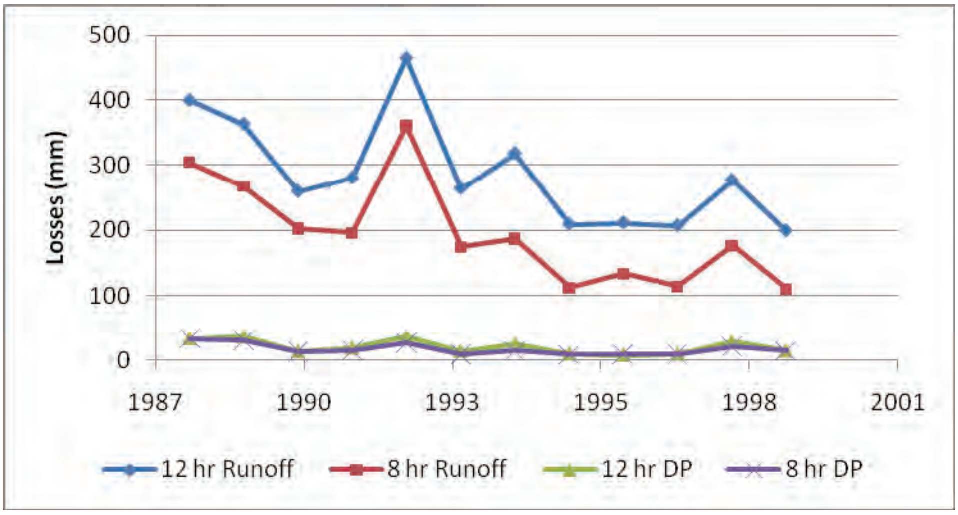

Figure 46: Time series of deep percolation and runoff losses for the 12 and 8 hour systems (Jumman, 2009).

In Figure 46, the deep percolation losses, abbreviated as DP in the legend, are similar for both systems and considerably smaller when compared to the runoff losses. This was attributed to the assumption of poor drainage conditions in the model and was also representative of sprinkler irrigation. Over irrigation by an overhead sprinkler system was more likely to result in increased runoff then deep percolation. On average, the 12 hour system lost an additional 100 mm of water to runoff compared to the 8 hour system. With the help of the Z*IMsched* 2.0 model, the agronomic assessment revealed that the 8 hour system outperformed the 12 hour system in terms of yield. The next task was to assess if the revenue gained from the increase in yield was enough to balance the additional costs of the 8 hour system.

7.4.2.3 Economic assessment

The *Irriecon v2* model was used to conduct the economic assessment. The model was configured with the necessary input information as described below.

- Seasonal water use and cane yield as predicted by the *ZIMsched* 2.0 model.
- Irrigation system and pumping costs determined by the design and costing tool. These costs were important to represent the 28% increase in capital investment for the 8 hour system.

- 2007/2008 cost of electricity on the land rate tariff option (ESKOM, 2007).
- Water tariffs, obtained from DWAF (2008), were 4.06c/ m^3.
- Following Hoffman et al. (2007), labour requirements for sprinkler systems were set at 1.65 hrs/ 1000 m^3, where cost of labour was R 6.88/hour.
- RV Price of cane at the time was R 1583.12/ton.

And finally, an annual inflation of 7% and interest rate of 13.5% was assumed to calculate the interest and depreciation costs of the equipment.

In certain instances, the costs for both systems were fairly similar if not identical. These included the mainline operating costs largely consisting of electricity and the planting and ratooning costs as shown in Table 55. The mainline operating costs were similar as a result of identical pumping systems and similar water applications per season for both systems, as pointed out previously. The agronomic, harvesting and transport costs for both systems, shown in Table 55 were represented but are not discussed in great detail here due to the lack of direct relevance to this work. It should be noted, however, that costs associated to harvesting and transport are dependent on yield and yield in turn dependent on irrigation. Hence, consideration of these costs was important for holistic assessment of the systems. The major differences between the two systems were the revenue generated for cane yields and the mainline and system fixed costs.

Table 55: *Irriecon V2* results presented as the average over 12 years in units Rand per hectare (Jumman, 2009)

REVENUE		12 hour (average)	8 hour (average)
	Cane sales	23,618.17	25,427.88
IRRIGATION COSTS			
	Mainline costs		
	Mainline fixed costs	1,065.33	1,241.63
	Mainline operating costs	1,310.94	1,323.11
	Total mainline costs	2,376.27	2,564.74
	System costs		
	System fixed costs	141.45	314.31
	System variable costs	869.64	1,012.58
	Total system costs	1,011.09	1,326.89
	Total irrigation costs	3,387.35	3,891.63
OTHER DIRECT COSTS			
	Planting costs	942.93	942.93
	Ratooning costs	3,289.92	3,289.92
	Harvesting costs	1,493.95	1,608.42
	Haulage costs	4,065.36	4,376.86
	Total other direct costs	9,792.15	10,218.13
NET MARGIN	**R/ha**	**10,438.66**	**11,318.12**

Systems variable costs also differed significantly. This was due to the cost of repairs and maintenance, which was calculated as 2% of the systems fixed cost (Oosthuizen et al., 2005). Hence, the 8 hour system, having an additional set of sprinklers, was likely to cost more in terms of repairs and maintenance. The information most sort after from this assessment was the net margin above allocated cost. The economic assessment revealed that the 8 hour system generated better net margins on average when compared to the 12 hour system.

In Table 55, the average net margins for the 12 and 8 hour systems were R 10, 438.66 and R11, 318.12 per hectare respectively. This implies an average gain of R879.46 per hectare for the 8 hour system. The annual net margins for both systems are shown in Figure 4-8 below. Figure 47 reflects the seasonal variation for both weather and yields for both systems

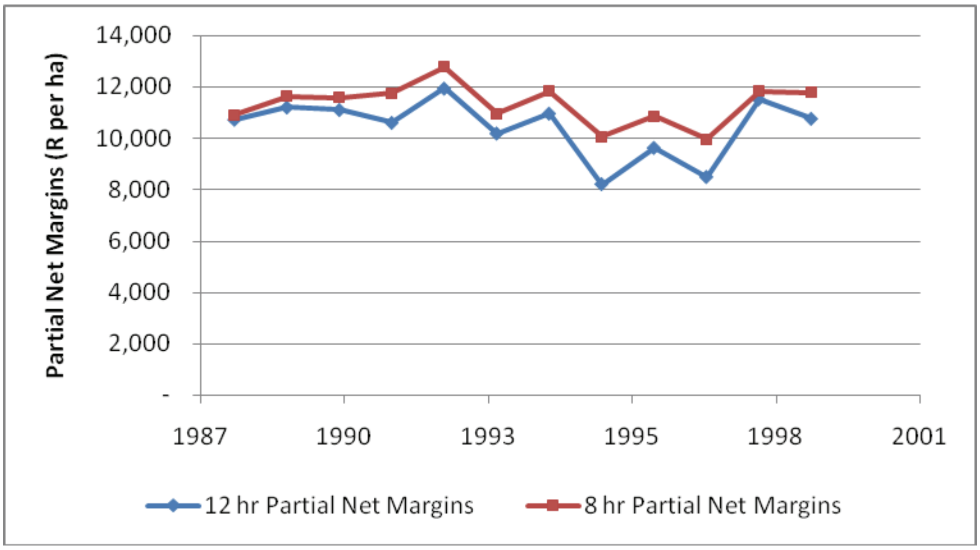

Figure 47: Partial net margins in Rand per hectare for the 12 and 8 hour systems (Jumman, 2009).

Figure 47 clearly reflects the better performance of the 8 hour system in all years, irrespective of the seasonal variation. In addition the degree of performance, for the 8 hour system, improves in 1995, 1996 and 1997 were rainfall was less than 230 mm. This confirms the hypothesis that the additional costs of the 8 hour system was offset by the increase in yields due to more effective use of water.

7.4.2.4 Conclusions and recommendations

In this Section, strategies to better irrigate shallow soils with semi-permanent sprinkler systems were investigated. Traditionally, normal practices made use of a 12 hour stand time to prevent the use of labour during the evening and to make use of the full 24 hours in a day. 12 hour stand times, however, often applied more water than what could be stored in the soil profile. This resulted in losses through runoff and deep percolation. A new and innovative method to irrigate in shorter intervals was developed and assessed. In this case, the new system applied water over an 8 hour stand time and was compared to the traditional 12 hour stand time. As a result of the modifications, the 8 hour systems cost 28% more in fixed costs. The 8 hour system, however, performed better than the 12 hour system, both in terms of yield and profit generation. In addition, the 8 hour system used similar amounts in terms of water and electricity resources.

This was significant in the context of this study. The increased investment to modify and partially automate an irrigation system, to match the application of water to the soil profile, proved to be beneficial economically.

In addition, the 12 hour system resulted in more runoff. Not only does this result in ineffective use of water but also has serious environmental impacts (Perry, 2007). Runoff often carries with it, valuable top soil and nutrients. Over a period of time, the loss of soil and nutrients can have significant impacts on crop yield. The economic impact of this was not determined but, such environmental impacts add to the motivation for farmers to invest in systems that are better matched to the soil. Farmers and irrigation designers are therefore recommended to ensure that irrigation systems are well matched to soils. The economic and environmental benefits of well designed and operated systems appear to outweigh the additional investments for such systems. Moreover, this highlights the importance of considering the water budget during the design phase. The fate of the various fractions of water applied should be considered (Burt et al., 1997)

Furthermore, the use of the “Irrigation Assessment Framework” was demonstrated. If this assessment was stopped at the 1st stage where the alternative systems were only designed and priced, it would have appeared that the 12 hour system was the better option since it was cheaper. However, looking beyond into the agronomic assessment, the 8 hour system proved to deliver better yields for similar water use. The economic assessment then confirms that the 8 hour system is indeed a better system. Firstly, this emphasises the importance of assessing alternate strategies holistically and secondly, highlights the role of the framework and tools described in Chapter 3. In the next chapter, the frame work is used to explore the more current and burning topic of electricity tariffs in the context of irrigation.

7.4.3 Electricity tariff options

The aim of this study was to better understand and demonstrate the differences between the Landrate and Ruraflex electricity tariff structure. The procedure to achieve this was as follows. A hypothetical irrigation system was assessed, using *Irriecon V2*, as if it was operated on the Landrate option first, and then on the Ruraflex option. The irrigation design and costing tool and *ZIMsched* 2.0 was used to provide the costing and agronomic input for the economic assessment in Irriecon V2. In this way the capital costs of the irrigation system, the seasonal water applications and crop yields are all identical for both scenarios. The only variation therefore will be in the operating costs due to the different electricity tariff options.

7.4.3.1 Methodology and model configuration

The irrigation system was designed to apply 48 mm in 10 days on a 12 hour stand time. This translated into the equivalent application of 4.8 mm/day, which was a pre-selected capacity appropriate for a 1.2 m deep sandy clay loam in the Heatonville area. The TAW for the soil was calculated to 114 mm. A VYRSA 35 sprinkler with a 4.4 mm brass nozzle was selected. The sprinklers were spaced at 21 × 21 m and operated at 352 kPa at a coefficient of uniformity of 88%. For the designed 60 hectares, the pumping system was required to pump a flow of 116.42 m^3/h at a head of 50.39 m, and a power rating of 25.38 kW. The total capital investment required was R 687 750 which equated to R 11 638/ha.

The *ZIMsched 2.0* model was configured with the system constraints as described above and 15 years of weather data for Heatonville, ranging from 1985 to 1999. As in the previous chapter, 10% of total applied water was assumed to be lost by wind drift and spray evaporation. In terms of scheduling, irrigation was applied when 60% of TAW was depleted, provided that the minimum cycle time was exceeded and that the period did not fall within the "dry off" period. The "dry off" period was calculated as the amount of time required to deplete 171 mm of soil water (1.5 × TAW). Running the *ZIMsched 2.0* model for the 15 year period returned the following results.

The average crop yield over the 15 years was 125.25 tons/ha with an average rainfall of 918.6 mm and an average seasonal irrigation application of 734.98 x mm. The crop yields and the irrigation water applications were then input into the *Irriecon V2* model together with the system capital costs and other relevant data such as water tariffs. *Irriecon V2* was configured for two scenarios, namely Landrate and Ruraflex. In addition, both scenario were analysed using electricity tariffs from the 2007/08, 2008/09 and 2009/10 years. This was included to demonstrate the impact of increasing electricity tariffs on farmers and there profitability.

7.4.3.2 Results and discussion

Presented in Table 56 below is the results obtained from the economic analysis from the Irriecon V2 model. Take note that the values presented in Table 56 are in units Rand per area under cane. Furthermore, the tabulated values are the averages for the 15 cropping seasons. Presented in the second row is the year for which the electricity tariffs were used. i.e. 07/08 indicates that the electricity tariffs for the year 2007/2008 were applied for all 15 cropping seasons.

Table 56: Output from Irriecon V2 model, expressed as an average in units R/area under cane, for scenario A and B (Jumman, 2009).

Revenue	**Landrate**	**Ruraflex**	**Landrate**	**Ruraflex**	**Landrate**	**Ruraflex**
Tariff years	(07/08)	(07/08)	(08/09)	(08/09)	(09/10)	(09/10)
Cane sales	R 23,066	R 23,066	R 23,066	R 23,066	R 23,066	R 23,066
Irrigation Costs						
Mainline costs						
Mainline fixed costs	**R 976**	**R 1,000**	**R 1,002**	**R 1,036**	**R 1,024**	**R 1,030**
Mainline operating costs	**R 588**	**R 480**	**R 754**	**R 609**	**R 984**	**R 921**
Total mainline costs	R 1,564	R 1,480	R 1,756	R 1,645	R 2,008	R 1,952
System costs						
System fixed costs	R 121	R 121	R 121	R 121	R 121	R 121
System variable costs	R 490	R 490	R 490	R 490	R 490	R 490
Total system costs	R 612	R 612	R 612	R 612	R 612	R 612
Total irrigation costs	R 1,935	R 1,851	R 2,127	R 2,014	R 2,379	R 2,322
Other Direct Costs						
Planting costs	R 943	R 943	R 943	R 943	R 943	R 943
Ratooning costs	R 3,290	R 3,290	R 3,290	R 3,290	R 3,290	R 3,290
Harvesting costs	R 1,459	R 1,459	R 1,459	R 1,459	R 1,459	R 1,459
Haulage costs	R 3,970	R 3,970	R 3,970	R 3,970	R 3,970	R 3,970
Total other direct costs	R 9,662	R 9,662	R 9,662	R 9,662	R 9,662	R 9,662
Net Margin	R 11,228	R 11,312	R 11,036	R 11,148	R 10,784	R 10,841

Tbale 56 clearly shows that, with the exception of the mainline costs, all other costs were identical. This was as expected, since the irrigation system, watering regime and crop yield were all identical. Interestingly, for both scenarios the actual electricity consumed was the same, but the mainline costs reflected a difference. This difference reflected the variation in the tariff structure between the Landrate and Ruraflex options.

The mainline fixed costs comprised of interest and depreciation of equipment, insurance and electricity fixed costs, not shown in Table 56. Similarly mainline operating costs consisted of electricity and repairs and maintenance costs. As described before, all components were identical except for the electricity fixed and operating costs. As shown in Table 56, in the mainline fixed costs section, the Ruraflex option was generally more expensive then the Landrate option for all tariff years (07/08, 08/09 and 09/10). Inversely, for the mainline operating costs, the landrate option appeared to be more expensive then the Ruraflex option. In total, the Ruraflex option was cheaper than the Landrate option. Also, when looking at the Landrate option only, the increase in tariffs and resultant decrease in net margins from the 2007/08 season to the 2009/10 season was evident. The same applies for the Ruraflex option.

To better gauge the impact of tariff hikes, the actual charges for a season are presented in Table 57, below. The electricity tariffs represented in Table 57 were simulated by the *Irriecon V2* model for the 1998/99 crop season. In that season, irrigation application as determined by *ZIMsched 2.0* amounted to 807.84 mm. *Irriecon V2* predicted that 97, 932 kWh of electricity was required to pump the required volume of water to the 60 hectare field. Table 57, therefore, illustrates how the electricity tariffs for a farmer with the above system would have varied for the different tariff options and the electricity tariff hikes.

Table 57: Break down of model-predicted electricity costs for irrigation on 60 ha in the Heatonville area: 1998/1999 season (Jumman, 2009)

Ruraflex					**Landrate**		
Fixed Costs					**Fixed Costs**		
	Service	Network		**Total**	Basic	Network	**Total**
2007/2008	R 1,507	R 2,490		**R 6,202**	R 2,340	R 2,460	**R 4,800**
2008/2009	R 2,022	R 3,336		**R 8,318**	R 3,096	R 3,254	**R 6,350**
2009/2010	R 2,683	R 4,560		**R 8,009**	R 3,449	R 4,212	**R 7,661**
Variable Costs					**Variable Costs**		
	Reactive	Voltage Surcharge	Transmission Surcharge	**Total**	Active		**Total**
2007/2008	R 403	R 3,829	R 264	**R 26,421**	R 31,506		**R 31,506**
2008/2009	R 541	R 5,138	R 354	**R 35,456**	R 42,276		**R 42,276**
2009/2010	R 689	R 8,301	R 570	**R 57,161**	R 57,228		**R 57,228**
Total costs				**Ruraflex**			**Landrate**
2007/2008				R 32,623			R 36,306
2008/2009				R 43,774			R 48,626
2009/2010				R 65,170			R 64,889

There are three important things to point out in Table 57. The first was that the mainline fixed costs were higher, while the variable costs were cheaper, for the Ruraflex option. Since the variable costs were considerably higher than the fixed costs, the Ruraflex option, as shown before, was cheaper overall except for when the 09/10 tariffs were applied. This was the first deviation from the trends demonstrated by the average values in Table 56. This will be discussed later.

The second aspect to point out was the impact of increasing the tariffs from 2007/08 up to 2009/10. If the farmer was operating on the Landrate option, the electricity bill was predicted to increase from R36, 306 to R64, 889, an increase of 78%. Similarly, if the farmer was operating on the Ruraflex option, the bill was expected to increase from R32, 623 to R65, 170, an increase of 99%. This was worrying considering that the revenue from cane sales remained constant while these costs were inflating at such significant levels. This clearly highlights the need to develop innovative irrigation strategies to reduce the cost of irrigation and will be discussed in more detail in the next chapter.

The third and probably most significant point was related to the deviation in trends for the 09/10 tariff year when comparing the average values in Table 56 to the values for a single season as shown in Table 56. To recap, Table 56 with the averages showed that the Landrate option was more expensive. Table 57 with single season values, on the other hand, showed that for the 09/10 prices, Landrate was cheaper. Relating to this was the inconsistency in the percentage increases for the Landrate and Ruraflex options. Why did the increase for Landrate amount to 78% while the increase for Ruraflex was 99%? It appears that the differences between Landrate and Ruraflex for the 07/08 and 08/09 were relatively big, but as result of the latest tariff hikes, these differences have almost disappeared. This is better demonstrated in Figure 48 below. Figure 48 is simply a graphical representation of the total electricity costs shown Table 57.

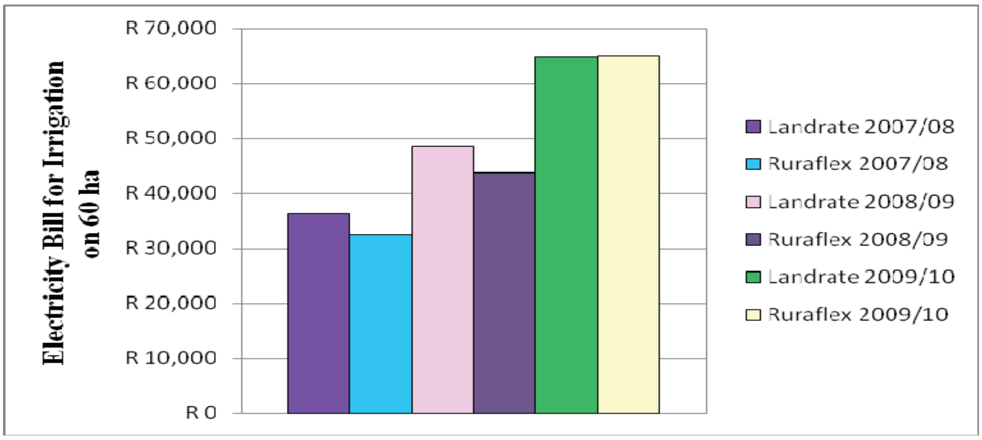

Figure 48: Graphical display of the total electricity costs for the 1998/99 crop season (Jumman, 2009).

From Figure 48**,** the difference between the Landrate and Ruraflex options for 2007/08 and 2008/09 were R 3, 683 and R 4, 852, respectively. The difference for 2009/10, however, was only R 281. This implied that the cost of electricity since the 2009/10 tariff increases reflected a better representation of the timing of energy consumption.

This concept is discussed in more detail below. In this exercise, the irrigation system was designed to operate for 24 hours a day. Hence the timing of electricity use, be it high or low demand or peak or off-peak periods, was identical for both scenarios. In addition, the actual electricity consumption was also identical for both systems. Hence, it would be expected that both scenarios would yield similar electricity costs.

The results demonstrate that prior to the 2009/10 tariff hike, the Ruraflex option was cheaper. The Ruraflex option, however, was designed to provide incentives for users to shift the use of electricity into off-peak periods. In other words, it was intended that users should be rewarded with lower tariffs if electricity use was shifted into low demand and off-peak periods. The results of this study, however, indicate that farmers may have been incorrectly rewarded for simply switching onto the Ruraflex option without shifting the timing of the electricity use. This appears to have been corrected for in the 2009/10 tariff hike.

7.4.3.3 Discussion and Conclusions

The decision as to whether to operate on the Ruraflex or Landrate option is dependent largely on the timing of use of electricity and the actual quantity of consumption. Ruraflex has higher fixed costs but is balanced out by the lower variable costs component. At the present time, if timing and consumption are identical, both Ruraflex and Landrate yield similar costs.

This study, however, has highlighted the opportunities to reduce costs by shifting use of electricity into low demand and off-peak periods on the Ruraflex option. In terms of irrigation this implies reducing pump operating hours into standard and off-peak periods. Two strategies can be adopted. The first requires one to increase the system capacity so that the same volume of water can be applied over a shorter period of time. This option would have implications of capital investment since bigger pumps and pipes would be required. In addition, care must be taken to ensure water applications are well matched to the soils infiltration and water holding characteristics.

The second option, however, appeared more attractive and was investigated further. The second strategy was to simply reduce pump operation during the high demand and peak periods in order to decrease electricity tariffs. This, however, would result in reduced water applications and potentially yield penalties due to water stress. So the question posed is does the benefit of reduced electricity and water costs outweigh the penalties for yield loss? This question ties in with the concept of deficit irrigation and is explored further in the next Section.

7.4.4 Design and operating strategies for deficit irrigation

The "irrigation assessment framework" provided the ideal platform to analyse and assess deficit irrigation strategies. The strength of the "assessment framework" was largely attributed to the ease with which tradeoffs between various parameters such as watering regimes, associated costs and yields could be quantified and assessed.

For this study, a high capacity irrigation system, with the ability to meet the crop water requirements during the peak summer growing months was designed for the Heatonville area. The system served as the base system and was designed to ensure that the crop experienced no water stress during the season. This base system served as the benchmark for which other deficit strategies could be compared to. The base system made use of the VYRSA 35 sprinkler with a 4.4 mm brass nozzle. The sprinklers were designed to operate: at 21 m spacing, on a 12 hour stand time, with 352 kPa of pressure, delivering 48 mm on a 7 day cycle. This was equivalent to an application of 6.9 mm a day. A soil with a TAW of 114 mm soil was assumed.

It should be noted that the crop water requirements and therefore the target depth (gross irrigation requirement) was determined following the methods laid out in the commonly used *South African Irrigation Design Manual* (ARC-ILI, 2004). The methods included traditionally accepted norms and commonly used equations for determining the net irrigation requirement from climate, crop and soils data. Traditional design methods, such as the one used in the base system, are conservative and aim to design for a high enough capacity so that no water stress is experienced. This was confirmed when the 6.9 mm base system was simulated in the *ZIMsched* 2.0 model. The soil water balances for a dry and wet year, as simulated by the *ZIMsched* 2.0 model, are shown in Figure 49 below.

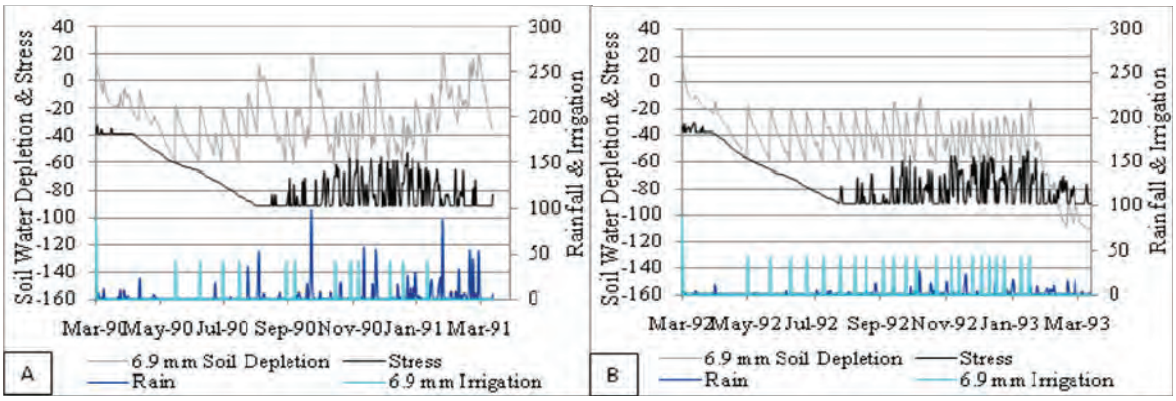

Figure 49: Soil water balance for the 6.9 mm base system for a specific season. A) Wet Year. B) Dry Year (after Jumman, 2009).

Graph A in Figure 49, represents a wet year where 1225 mm of rainfall was received in 1990. Similarly in 1992, only 388 mm of rainfall was received and is depicted as the dry year in Graph B. As show in Figure 49, the soil water depletion curve very rarely drops below the stress curve for both the wet and dry years, indicating negligible stress. For this reason the high capacity "base system" was assumed to be typical of what would be used on a farm for this particular soil and geographical location.

The idea then was to develop and assess deficit strategies with reduced watering capacities. It was assumed that the 6.9 mm system already existed and was operating successfully in the field. Hence, the development of deficit strategies was limited to those strategies which would make use of the existing hardware already in the field. This step was considered important so as to ensure that only implementable, realistic and appropriate strategies were developed for a grower. Furthermore, opportunities existed to reduce electricity costs on the Ruraflex option. Hence the Ruraflex option, based on 2009/10 prices was applied for all strategies. Essentially, two components were targeted. The first component probed into the design of irrigation systems and the use of hardware. The second component explored irrigation operating rules such as stand times and the potential to take advantage of off-peak pumping.

First consider the design component. As described in the literature review, deficit strategies allows for more flexible irrigation designs and variation from design norms. For this reason, variations of the 6.9 mm system, as described above, were developed and are shown in Table 58.

Table 58: Summary of systems developed to implement deficit irrigation (Jumman, 2009)

	System 1	System 2	System 3
Peak application associated with system strategy (mm/day)	6.9	4.8	4.0
Application per cycle (mm)	48	48	48
Cycle length (days)	**7**	**10**	**12**
Stand Time (hours)	12	12	12
No of sets/day	2	2	2

Three systems were developed. System 1, represent the base system as described in detail above. The major differences between System 1, System 2 and System 3 were the cycle length as highlighted in Table 58. Basically, all systems make use of the same sprinkler package and therefore apply the same amount of water per cycle, 48 mm. The difference in peak applications was therefore the result of applying the same amount of water over different periods. For example, in System 1, 48 mm applied once in 7 days equates to 6.9 mm a day, whilst for System 2, 48 mm applied once in 10 days equates to 4.8 mm a day. Implementing System 2, however, involved adding to the existing hardware of system 1. By increasing the cycle length, additional sprinkler positions on the laterals were required. System 2 was achieved by simply adding 3 lengths of lateral to the 6.9 mm system to create the sprinkler positions for the 3 additional days. This is shown in Figure 50, where the positions marked X and the shaded area represents the system hardware additions.

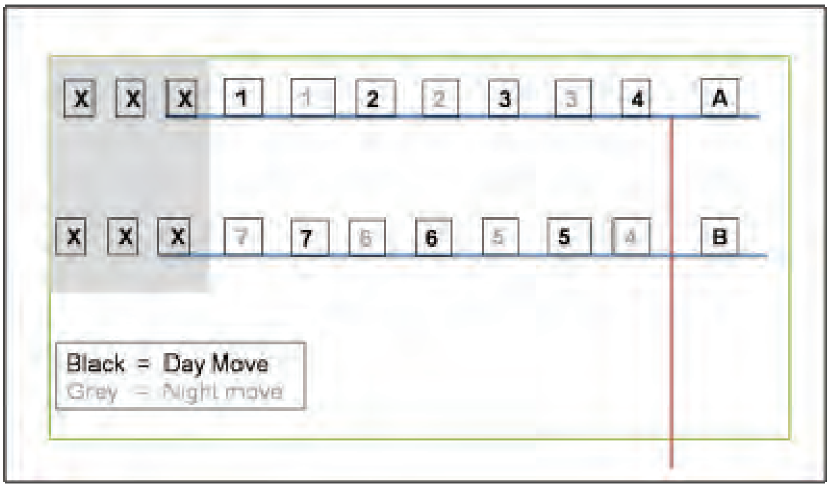

Figure 50: Illustration of modifications to the base system to obtain system 2 (Jumman, 2009).

Similarly, system 3, involved increasing the cycle length to 12 days reducing the 48 mm application to a 4 mm a day system. Since these systems were designed to operate with one sprinkler per lateral, increasing the length of laterals did not have major impacts on the pipe hydraulics in terms of flow, friction, pipe diameter and required pressure. This implies that for the same pump, mainline, sub mainline and sprinklers, a much larger area can be irrigated by altering the cycle length and inserting the additional length of laterals as required. Systems 2 and 3 were therefore expected to cost less per hectare than system 1. These can be summarised diagrammatically as shown in Figure 51.

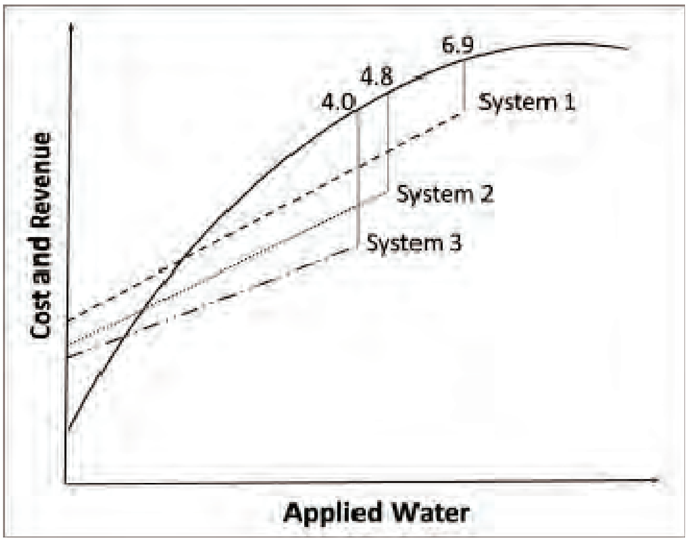

Figure 51: Schematic of conceptual variations between systems 1, 2 and 3 (Jumman, 2009).

In this case, the base system made use 66 sprinklers to apply 6.9 mm/day on 44.32 hectares at a cost of R 11 515 per hectare. The modified 4.8 mm system, uses 66 sprinklers to apply 4.8 mm/day on 62.05 hectares at a cost of R 10 439 per hectare. This resulted in a reduction in capital costs per hectare since the hardware was now spread over a greater area. Therefore, in Figure 51, System 2 was depicted with lower capital costs on the y intercept compared to system 1. In addition, the slope for System 2 was gentler due to anticipated reduction in water and electricity tariffs per hectare. Similarly, System 3 had lower capital and operating costs compared to both system 1 and 2. Systems 2 and 3, therefore, achieved the target of making use of the existing hardware from System 1, while applying a deficit irrigation strategy with reduced fixed and operating costs.

The next component explored irrigation operating rules and the opportunity to take advantage of off-peak pumping. Four strategies were developed and are presented in Table 59.

Table 59: Summary of strategies developed to implement deficit irrigation (Jumman, 2009)

	System 1			
Strategy	A	B	C[1]	D[2]
Peak application associated with system strategy (mm/day)	6.9	4.6	6.9 and 4.6 deficit	6.9 mm fixed winter and summer cycle
Application per cycle (mm)	48	32	off-peak = 32 and Peak = 48	Winter = 32 Summer = 48
Cycle length (days)	7	7	7	7
Stand Time (hours)	12	8	8 (germination + tillering) & 12 (Yield Formation)	8 and 12
No of sets/day	2	2	2	2

1 For strategy C, system operated on two 8 hour stand times per day during germination and tillering, and two 12 hour stand times per day during the yield formation phase.
2 For strategy D, system operated on fixed cycle (i.e. with no scheduling) with two 8 hour and two 12 hour stand times in winter and summer, respectively

It should be noted upfront that strategies A, B, C and D all make use of exactly the same system hardware, in this instance System 1. The difference, as highlighted in Table 59, was that the stand time for each strategy was varied. Altering the stand time therefore reduces water application and operating costs. This is shown in Figure 52, where all systems have the same y intercept, indicating identical capital costs but varying slopes to indicate varying water and electricity tariffs. The rationale for the strategies was as follows: Strategy A was designed to operate on a 12 hour cycle utilising the full capacity of the system. Hence strategy A, as shown in Figure 52, was anticipated to apply the most water and achieve the highest yields, provided that no anaerobic conditions were created.

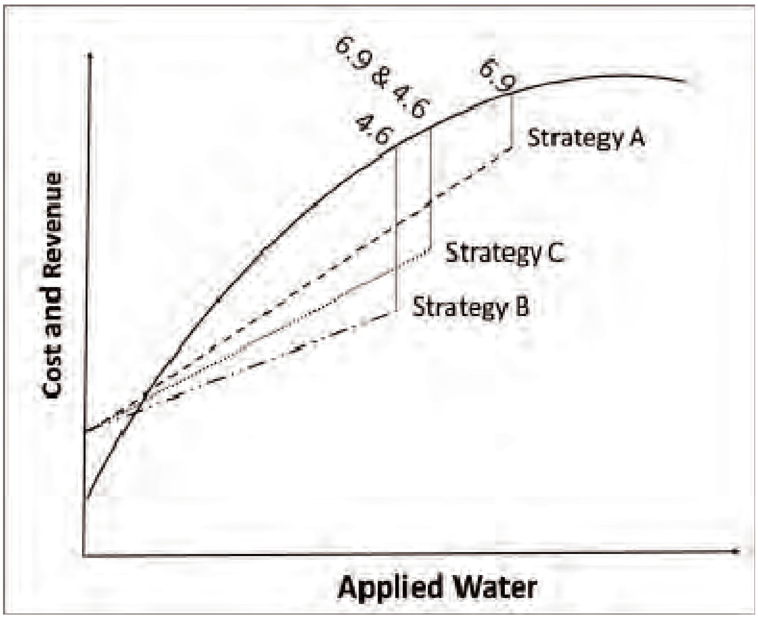

Figure 52: Schematic of conceptual variations between strategies A, B and C (Jumman, 2009).

Strategy B made use of the same hardware from A, but only operates for two 8 hour sets in a day instead of two 12 hour sets. This allowed for shifting the use of electricity into standard and off-peak hours. Considering the Ruraflex option discussed in the previous chapter, the first 8 hour set can take place during the standard period between 10:00 and 18:00. The second 8 hour set can run during the off-peak period between 22:00 and 06:00. Reducing the stand time, however, reduces the system capacity to 4.6 mm/day, thereby incurring crop stress and loss of revenue from yield losses.

Strategy C consisted of a combination of the strategy A and B. As explained previously, for the sugarcane crop, water stress in the establishment phase during tillering did not impact significantly on final yields. Hence strategy C aimed to make use of strategy B during the establishment phase and the higher capacity strategy A in the vegetative and yield formation phases. In general, the sugarcane crop requires 30 days for emergence and a further 90 days for tillering (FAO, 2009). Hence reduced irrigation can occur for 120 days from planting without significantly impacting on final yields. In addition, if the crop was planted in April, the low crop water requirements in the germination and tillering phase partially coincide with the electricity high demand period, from June to August. Hence reduced applications and pumping costs during periods of elevated electricity costs will be of greater benefit. This is shown in Table 60.

Table 60: Timeline illustrating deficit strategy during specific crop phases and expensive high energy demand periods (Jumman, 2009)

Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March
Emergence + Tillering				Canopy development + yield formation							Maturation
		High Demand Season			Low Demand Season						
4.6 mm strategy B					6.9 mm strategy A						

Hence, as shown in Table 60, it was decided that strategy B was used until the end of the high demand period. The *ZIMsched* 2.0 model was, therefore, configured to apply strategy B for the first 150 days, until the end of August, and strategy A for remaining period until dry off. In other words, this translated into operating the system on two 8 hour sets for the first 150 days and then on two 12 hour sets for the remainder of the irrigating season. This was also represented in Figure 52, where strategy C was anticipated to deliver an intermediate water application and yield for the same system fixed costs.

Finally, strategy D was developed to illustrate the importance of scheduling. In strategy D, the irrigation was applied on a fixed summer and winter cycle, as shown in Table 60. In strategy D, irrigation was applied in accordance with cycle length irrespective of soil water depletion and crop stress levels. No scheduling was used except that irrigation was delayed when rainfall greater than 10 mm was received. The anticipated result if strategy D was applied with systems 1 and 2 is shown in Figure 53. This strategy was anticipated to incur high costs whilst irrigating excessively.

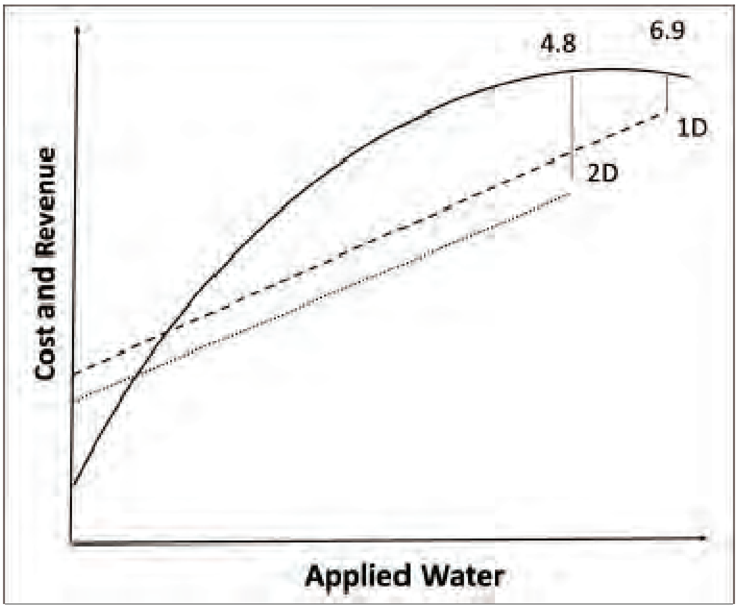

Figure 53: Schematic of irrigation strategy D with no scheduling for two different systems with different peak design capacities, namely 4.8 mm/d and 6.9 mm/day (Jumman, 2009).

The combination of the proposed deficit irrigation systems and strategies are summarised in Table 61. The idea was to assess the significance of the reduced watering capacity and resultant yield loss versus the reduction in capital and operating costs.

The *ZIMsched* 2.0 model was configured with 15 years of weather data for the Heatonville area. The performance of each scenario was simulated for the 15 cropping seasons. The water and yield outputs were then entered into the *Irriecon V2* model together with the other relevant costs, to determine the economic performance of each strategy. A dry land (no irrigation) scenario was also simulated and will be discussed later. The results are presented in Table 61.

Table 61: Summary of irrigation strategies developed to implement the deficit concept (Jumman, 2009)

	System 1				System 2				System 3		
Strategy	A	B	C	D	A	B	C	D	A	B	C
Peak application associated with system strategy (mm/day)	6.9	4.6	6.9 and 4.6 deficit	6.9 mm fixed summer and winter cycle	4.8	3.2	4.8 and 3.2 deficit	4.8 mm fixed summer and winter cycle	4.0	2.7	4.0 and 2.7 deficit
Application per cycle (mm)	48	32	Peak = 48 or off-peak = 32	Summer = 48 Winter = 32	48	32	peak = 48 or off-peak = 32	Summer = 48 Winter = 32	48	27	peak = 48 or off-peak = 32
Cycle length (days)	7	7	7	7	10	10	10	10	12	12	12
Stand Time (hours)	12	8	12 or 8	12 or 8	12	8	12 or 8	12 or 8	12	8	12 or 8
No of sets/day	2	2	2	2	2	2	2	2	2	2	2

Strategy A – 2 × 12 hour stand times per day
Strategy B – 2 × 8 hour stand times per day → same hardware, no peak pumping
Strategy C – 2 × 12 hour stand time in low demand off-peak period and 2 × 8 hour stand time in high demand peak period (Same hardware)
Strategy D – Fixed winter & summer cycle irrigation → no scheduling except for rainfall delay calculation
System 1 – 7 day cycle with 14 sprinkler positions on lateral
System 2 – 10 day cycle with 20 sprinkler positions → longer lateral → greater areas covered for same sub mainline, mainline and pump.
System 3 – 12 Day Cycle with 24 sprinkler positions → longer lateral → even greater area covered for same sub mainline, mainline and pump.

7.4.4.1 Results

The average annual irrigation applications and yields as predicted by the *ZIMsched* 2.0 model are shown in Table 62. As expected, the fixed cycle system with no scheduling used the most water. Not surprisingly, these systems also delivered lower yields, indicating crop stress due to over irrigation and potentially anaerobic conditions. The 6.9 mm fixed cycle system (1D), on average used 1 318 mm annually. This strategy far exceeded what was representative, in terms of water application, for the Heatonville area (Greaves, 2007). For this reason the strategy 1D was considered impractical and discarded. The base system (1A) delivered on average 147 ton/ha for an average annual water use of 855 mm.

Table 62: Summary of the average irrigation water applications and yield (Jumman, 2009)

System & Strategy (as per Table 61)	Average annual water (mm)	Average yield (ton/ha)
6.9 mm fixed cycle (1D)	1318	136
4.8 mm fixed cycle (2D)	937	133
6.9 mm (1A)	855	141
6.9 and 4.6 deficit (1C)	785	140
4.8 mm (2A)	783	139
4.8 and 3.2 mm deficit (2C)	759	138
4.0 mm (3A)	745	136
4.0 and 2.7 mm deficit (3C)	712	136
4.6 mm (1B)	705	137
3.2 mm (2B)	636	132
2.7 mm (3B)	593	127

Inversely, the 2.7 mm strategy delivered the lowest yield for the lowest water application. The difference between the base 6.9 mm and 2.7 mm strategies amounted to a yield loss of 20.17 tons/ha for a water savings of 262 mm of water. So the burning question was "Would the cost savings from not applying the 262 mm of water make up for the 20 tons/ha yield loss?" The answer is provided by the economic analysis in Table 63.

Table 63: Economic performance for each scenario expressed as an average of the 15 cropping seasons in units Rand per area under cane (Jumman, 2009).

System	System 1			System 2				System 3			
Strategy	A	B	C	A	B	C	D	A	B	C	Dry land
	6.9 mm	4.6 mm	6.9 and 4.6 mm	4.8 mm	3.2 mm	4.8 and 3.2 mm	Fixed Cycle	4.0 mm	2.7 mm	4.0 and 2.7 mm	
Revenue											
Cane sales	25, 974	25, 336	25, 863	25, 594	24, 354	25, 544	24, 563	25, 201	23, 434	25, 054	13,815
Irrigation Costs											
Mainline costs											
Mainline fixed costs[1]	1, 118	1, 118	1, 118	981	981	981	981	927	927	927	0
Mainline operating costs[2]	984	681	918	988	653	916	1, 105	968	627	874	0
Total mainline costs	2, 102	1, 799	2, 037	1, 969	1, 634	1, 897	2, 086	1, 894	1, 554	1, 800	0
System costs											
System fixed costs[3]	162	162	162	115	115	115	115	97	97	97	0
System variable costs[4]	541	471	523	522	425	506	624	497	397	475	0
Total system costs	702	632	685	637	540	622	739	594	494	572	0
Total irrigation costs	2, 805	2, 432	2, 721	2, 606	2, 174	2, 519	2, 825	2, 488	2, 047	2, 372	0
Other Direct Costs											
Planting costs	943	943	943	943	943	943	943	943	943	943	943
Ratooning costs	3, 290	3, 290	3, 290	3, 290	3, 290	3, 290	3,290	3, 290	3, 290	3, 290	3,290
Harvesting costs	1, 643	1, 643	1, 643	1, 643	1, 643	1, 643	1,517	1, 643	1, 643	1, 643	874
Haulage costs	4, 471	4, 471	4, 471	4, 471	4, 471	4, 471	4,129	4, 471	4, 471	4, 471	2,378
Total other direct costs	10, 347	10, 347	10, 347	10, 347	10, 347	10, 347	9,879	10, 347	10, 347	10, 347	7,485
NET MARGIN	12, 822	12, 708	12, 821	12, 730	12, 215	12, 780	11, 723	12, 548	11, 638	12, 551	6,330

1 = Interest, depreciation and insurance on all underground pipes and pumping system + electricity fixed costs
2 = Electricity variable costs + repairs and maintenance (repairs and maintenance expressed as percentage of fixed cost)
3 = Interest and Depreciation on sprinkler package only
4 = Water tariffs + labour + repairs and maintenance (repairs and maintenance expressed as percentage of fixed cost)

The answer to the above question is therefore: “No”. The cost savings from not applying the 262 mm of water do not make up for the yield loss. As shown in Table 63, the net margin for the 2.7 mm system was lower than that for the 4.8 mm fixed cycle system. Even though both fixed and operating costs for irrigation were much lower for the 2.7 mm system, the cost of yield loss was much greater. This trend applied for all scenarios.

7.4.4.1.1 Fixed costs – hardware

Elaborating further, system 1, irrespective of the applied strategies, have the same mainline and system fixed costs since all of the strategies (1A, 1B, 1C and 1D) make use of the exact same hardware. Similarly, this applies to systems 2 and 3. As was anticipated in Figure 51, system 3 and 2 were cheaper in units Rand per area under cane since the same sprinklers, sub mainlines and mainlines were used to irrigate a larger area by increasing the cycle length. In this case, the mainline fixed cost for 12 day “system 3” cost R927 per area under cane, compared to the 10 day “system 2” and 7 day “system 1”, which cost R981 and R1,118 per area under cane, respectively. Similar trends apply for the system fixed costs.

7.4.4.1.2 Operating costs – water and electricity

Unlike the fixed costs though, the operating/variable costs for each scenario varies. The mainline operating costs were dependent on the use of electricity while the system variable cost was a function of water tariffs. As expected, systems applying more water on a 12 hour stand time, incurred higher mainline operating and system variable costs. For example the mainline operating costs for the 6.9 mm and 4.6 mm system were R984 and R681 per area under cane, respectively. This demonstrates the economic benefit of shifting electricity use to lower costing standard and off-peak hours. Similarly, the system operating costs for the 6.9 mm system and 4.6 mm system was R541 and R471 per area under cane, respectively. This demonstrated the impact of reduced water applications and therefore reduced water tariffs. Take note, also made apparent in this analysis was that the cost of electricity was higher than the cost of water.

7.4.4.1.3 Saving irrigation costs versus losing revenue from yield loss

Taking it a step further, the impact of the irrigation costs appears to be smaller than revenue from yields. For example, when comparing the 6.9 mm base system to the 2.7 mm system, the water savings was 262 mm and the yield loss was 20.17 tons/ha. The difference in irrigation costs, from Table 63, amounts to R757 per area under cane. The difference in revenue from cane sales, however, amounts to R2, 540 per area under cane. This implies that the direct costs of water and electricity are considerably smaller in comparison to cost of yield losses. At this stage it appears that applying a deficit strategy to conserve water and reduce costs, while incurring yield loss, does not benefit a grower financially. The exception in this case was for strategy C, were water was held back at non critical growth stages. This resulted in water savings with minimal crop stress and therefore reasonably high yields and net margins.

7.4.4.1.4 Opportunity cost of water

The concept of deficit irrigation, however, cannot be ruled out. The value of a deficit strategy can be realised in the opportunity cost of water. In other words, increased profits can be realised if water savings from a deficit strategy are used to convert dry land cane into irrigated cane, assuming that land is not limiting. This is demonstrated in Table 64.

In Table 64, the irrigable area ratio is an indicator of the additional dry land area that can be irrigated with water savings. For example, in Table 62, the “fixed cycle”, 2D, and “2.7 mm” strategies on average used 937 mm and 593 mm per annum, respectively. Hence, for every hectare converted from the fixed cycle to the 2.7 mm strategy, a water savings of 262 mm would be realised. An irrigable area ratio was then used to determine what dry land area could be converted to irrigation with the water savings. This was shown in Table 64. The net margins, including dry land margins, from Table 63 are carried through to Table 64. The irrigable area ratio was then applied to the “net margins above dry land” to determine the “relative potential increase in net margins when dry land cane was converted to irrigated area with the water savings”.

Table 64: Potential increase in net margins if dry land cane is irrigated with water savings from deficit strategies in units Rand per area under cane (Jumman, 2009)

Systems	System 2	System 1			System 2			System 3			
Strategies	D	A	B	C	A	B	C	A	B	C	
	Fixed 4.8 mm summer and 3.2 mm winter cycle	6.9 mm	4.6 mm	6.9 and 4.6 mm	4.8 mm	3.2 mm	4.8 and 3.2 mm	4.0 mm	2.7 mm	4.0 and 2.7 mm	Dry land
Net Margin	11,723	12,822	12,708	12,821	12,703	12,215	12,780	12,548	11,638	12,551	6,330
Net partial margin above dry land (R)	5,392	6,492	6,377	6,491	6,400	5,884	6,450	6,218	5,307	6,221	0
Irrigable area ratio[1]	1	1.10	1.33	1.19	1.20	1.47	1.23	1.26	1.58	1.32	0
Relative potential increase in margin obtained by converting dry land cane area to irrigated cane area with water savings[2] (R)	0	617	2,091	1,258	1,261	2,786	1,507	1,605	3,069	1,966	0
Net margin totals after converting dry land area to irrigated with water savings (R)	**11,723**	**13,439**	**14,799**	**14,079**	**13,991**	**15,001**	**14,287**	**14,153**	**14,707**	**14,517**	**6,330**
% increase	**0%**	**14.6%**	**26.2%**	**20.1%**	**19.3%**	**28.0%**	**21.9%**	**20.7%**	**25.5%**	**23.8%**	

[1] For example, the fixed cycle strategy uses 937 mm so the irrigable area ratio is 937/937 = 1, whereas the 2.7 mm strategy uses 593 mm so the equivalent ratio is 937/593 = 1.58 (See Table 4-10 for average water use of each strategy).

2 The relative potential increase in net margins from converting dry land cane was determined as follows:

$$\frac{\text{Relative potential increase}}{\text{in net margins}} = \left(\frac{\text{net margins}}{\text{above dry land}} \times \text{irrigable area ratio}\right) - \frac{\text{net margins}}{\text{above dry land}}$$

As shown in Table 64, an increase in profits can be realised by using water savings to convert dry land cane into irrigated cane. This was only applicable, however, if area was not limiting. In most cases in South Africa, water is usually the limiting resource, not land. Continuing with the previous example, for every hectare converted from the fixed cycle to the 2.7 mm strategy, the 262 mm water savings could be used to irrigate an additional area of 0.58 ha. This translated into an increase in net margins by R 3, 069. Hence, the 2.7 mm strategy has the ability to generate a relative increase in net margin to R 14, 707 compared to R 11, 723 for the fixed cycle strategy. Similarly the other strategies also possess the ability to generate increases in net margins ranging from a 14.6% to a 28% increase.

The irrigable area ratio indicates that the systems and strategies applying the smallest amount of water has the ability to benefit the most from converting dry land cane into irrigated cane. In this case, that corresponds to strategy B for each system, i.e. the 4.6 mm, 3.2 mm and 2.7 mm strategies. These systems save more water and were therefore able to convert larger dry land areas as shown by the relatively higher irrigable area ratios in Table 64.

These systems therefore also realised the highest final net margins after factoring in the dry land conversion. In this particular exercise, for these circumstances, the 3.2 mm system yielded the highest net margin after realising the opportunity cost of water. This was an interesting result considering that strategy B applied the lowest amount of water and therefore incurred the most stress and delivered the lowest yields. Not only did strategy B achieve higher profits, but it also possesses the potential to reduce the country's electricity load during peak hours. Strategy B operated on two 8 hour stand times and therefore prevented pumping during peak periods, saving the grower in terms of electricity costs and benefiting the country at a time when energy conservation was crucial.

7.4.4.2 Summary and conclusions

In the above exercise, the direct cost of water and electricity versus the cost of yield loss was clearly illustrated. To summarise, reducing the cost of water and electricity by under irrigating had a big impact on yield and therefore profit margins. In South Africa, the direct cost of electricity and water appear to be small in comparison to the cost of yield losses. Hence, cost savings from applying less water did not offset yield losses. The opportunity cost of water, however, can justify the implementation of deficit strategies. In other words, the financial benefits of deficit strategies were only realised when the water savings were used to convert dry land cane into irrigated cane. This was only applicable when land was not limited relative to water. Hence, provided the opportunity cost of water is realised, deficit strategies result in higher profits.

The strength and value of the irrigation assessment framework and the individual analytical models was again clearly demonstrated. In this chapter, various solutions/alternatives for a specified context were assessed with relative ease. Other scenarios and contexts could be analysed relatively easily.

Finally, deficit systems which applied the least amount of water yielded the highest net margins after realising the opportunity cost of water. Reduced water applications results in crop stress and this suggests that it may prove difficult to convince farmers to implement deficit strategies. The implementation of deficit strategies, due to the precise nature and narrow margins for error, would require precise irrigation scheduling and monitoring of the soil and/or crop responses. Monitoring tools will, not only help to implement these strategies, but also assist to gauge the performance of such strategies. Proof of performance, through near real time monitoring, will help instill confidence in growers. These issues are addressed in the next section.

7.4.5 In-field monitoring and Evaluation Tools

Tools to monitor and evaluate the performance of irrigation strategies are described in this Section. It was envisaged that the successful implementation of any irrigation strategy was largely correlated to the ability to manage and monitor the implementation of the strategy. In addition to monitoring and assessing irrigation strategies, monitoring systems also have value as decision support mechanisms for irrigation scheduling.

Three monitoring systems are presented. The first system was a continuous soil moisture monitoring system comprising of a hobo data logger and watermark soil water potential sensor. The next two systems presented were the Alti4 and Campbell Scientific systems. These systems followed a more holistic approach were sensors were used to monitor the atmosphere, the crop and the soil water balance simultaneously. The work completed included:

- identification and researching data logger and sensor combinations;
- calibrations, where necessary;
- construction and synthesis of housing units for field installation;
- costing of systems;
- to a certain degree field installation, testing and assessment.

The criteria for assessing the systems, in order of priority, were as follows: ease of use, cost, robustness and accuracy. In the subsequent sections, a technical description of the components and the merits and challenges of each system is presented, starting with the "Continuous Soil Moisture Monitoring System".

7.4.5.1 Continuous Soil Moisture Monitoring System

A detailed review of soil water sensors is given by IAEA (2008). Pertinent aspects of the review are summarised here as follows. In the irrigation sector, soil water status may be measured in terms of volumetric water content or soil water potential. Soil water content is a description of how much water is present in a given volume or depth of soil, expressed typically in m^3 water per m^3 soil (White, 2003). The Neutron Probe, capacitance sensors and Time and Frequency Domain Reflectometers can be used to measure soil water content.

The Neutron Probe and Time Domain Reflectometers (TDR) are very accurate methods of monitoring soil water status. The equipment, however, is relatively expensive and requires specialised knowledge to both record measurements and interpret the data. Furthermore, in the case of the Neutron Probe it is time consuming and labour intensive to gather the data from the fields. The Neutron Probe also makes use of radioactive materials and therefore a strict safety programme regarding the operation, transporting and storage of the equipment is necessary. In addition the Neutron Probe cannot accurately measure the soil water content in the top 20 cm of the soil layer (White, 2003).

Capacitance sensors are relatively inexpensive compared to Neutron Probes and TDR instruments, and are becoming increasingly more popular. The IAEA (2008) stated, however, that the volume of soil sensed by capacitance sensors is so small that it may not be representative. A universal challenge with measuring soil water content is to determine whether the water content measured is too wet, i.e. above the drained upper limit (DUL), or too dry, i.e. below the water content at which the plant experiences stress (Charlesworth, 2000).

Soil water potential, on the other hand, is a measure of the suction energy required by the crop to extract water, and is, therefore, a more direct indicator of potential crop stress and whether or not the soil is above the DUL. Tensiometers and porous type instruments such as gypsum blocks and Watermark sensors can be used to monitor soil water potential. Tensiometers are limited to soil water potentials above -85 kPa (White, 2003). Should the soil dry out to water potentials below -85 kPa, air enters the device breaking the vacuum with which the tensiometer operates. For this reason, tensiometers can be high maintenance apparatus.

Gypsum blocks are inexpensive but a major problem is that the gypsum block breaks down and dissolves over a period of time and for this reason the calibration relationship between gypsum block readings and soil water potential is not fixed.

“The Watermark is a granular matrix sensor, similar to a gypsum block. It consists of two concentric electrodes embedded in a porous reference matrix material, which is surrounded by a synthetic membrane for protection against deterioration. A stainless steel mesh and rubber outer jacket makes the sensor more durable than a gypsum block. The porous sensor exhibits a water retention characteristic in the same way, as does a soil. So, as the surrounding soil wets and dries, the sensor also wets and dries. Movement of water between the soil and the sensor results in changes in electrical resistance between the electrodes in the sensor. The electrical resistance can then be converted to soil water potential through a calibration equation” (Chard, 2008).

It should be noted that the Watermark sensor is sensitive to soil temperature and soil temperature needs to be monitored and accounted for in the calibration equation

(Shock et al., 1998). Watermark sensors, however, are compact, robust, easy to use, relatively inexpensive and widely accepted by irrigation scientists for their ability to account for changing soil moisture conditions (Vellidis et al., 2008). Furthermore, watermark sensors operate over a broader range when compared to tensiometers and are more robust than gypsum blocks.

From the above assessment of soil moisture sensors, the Watermark soil water potential sensor was selected for use. The next step was to find an appropriate logger data logger.

7.4.5.1.1 H8 Hobo data logger and Watermark combination

The 'H8 Hobo' four-channel data loggers from the Onset Computer Corporation were selected following the already completed work on Watermark sensors reported by Allen (2000). The H8 Hobo loggers were readily available and provided a relatively inexpensive source of continuous hourly data. Furthermore, the loggers were small, inconspicuous and require only a small watch-type battery and therefore are not likely to be tampered with or stolen. The Onset Hobo Logger uses DC current to excite the sensor. The Watermark sensors, however, are more suited to high frequency AC excitation. DC excitation can cause polarisation over time by causing the cations or anions to migrate to the electrodes. The Hobo excites all sensors simultaneously and then proceeds to read each channel in succession, completing readings in as little as 10 to 40 milliseconds. Hence, very little time exists for migration to occur and polarisation is unlikely to be a problem (Allen, 1999).

Electrolysis, however, occurs at the electrodes of sensors when the excitation lingers for more than 2 milliseconds. Electrolysis results in formation of micro gas bubbles that alter the resistance of the water medium and therefore the sensor reading. In the case of the H8 Onset Hobo logger, the channels are excited for different periods of time and the associated formation of the micro gas bubbles affects the resistance readings of the different channels. Nevertheless, for most practical purposes, any resulting bias in the readings can be addressed by using a different calibration relationship for each channel (Allen, 1999).

7.4.5.1.2 Calibration

Three watermark soil water potential sensors and a soil temperature sensor were attached to the Onset H8 Hobo Data logger. All sensors were then placed in a saturated soil medium in a pressure plate chamber in a laboratory at the University of KwaZulu-Natal in South Africa. The pressure plate chamber was then used to systematically exert pressure on the soil forcing water to leave the soil. The pressure plate chamber provided a controlled environment in which the soil water potential was determined and compared to the voltages logged by the Onset Hobo logger. Using regression methods, relationships were developed to relate soil water potential to voltage readings for each channel, taking into account the soil temperature. The regression relations, together with the recorded data, are illustrated in Figure 54.

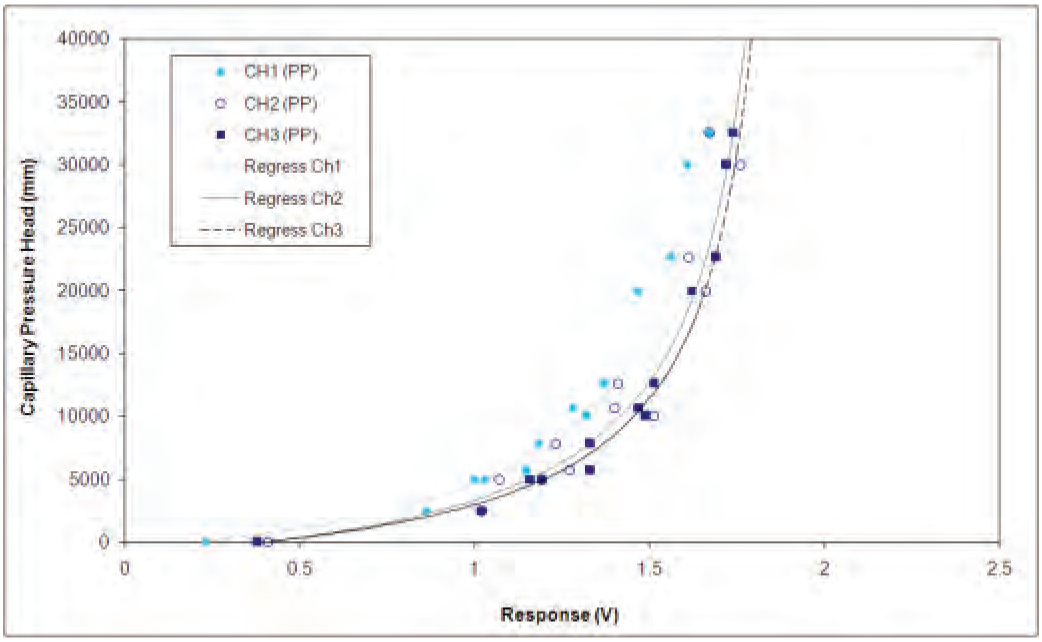

Figure 54: Calibration curve of Onset Hobo Logger and Watermark sensor.

Note: CH1, CH2 and CH3 refer to Channels 1 to 3 of the Hobo Logger and PP refers to data from the pressure plate apparatus (Jumman, 2009).

As illustrated in Figure 54, higher voltage responses were recorded for channels 2 and 3 when compared to channel 1 for the same capillary pressure head. This illustrates the variable resistance in the water medium due to electrolysis and hence the need for calibration of each channel separately. The accuracy of the calibrations can also be assessed by referring to Figure 54. Whilst there is potential to refine the calibration relationships, especially for channel 2, the relationships were considered to be adequate for the study objectives.

7.4.5.1.3 System housing and costs

A general purpose, weather resistant electrical box (code: RL1 – HP) was sourced from ARB Electrical Wholesalers (Pty) Ltd. (2008) to house the data logger. The box was 150 x 150 x 100 mm deep with a hinged screw on lid as shown in Figure 55. A 20 mm hole was drilled into a side wall to allow for the cables from the Watermark sensors to be connected to the data logger.

Figure 55: General purpose box used to house Onset Hobo data logger (ARB Electrical Wholesalers (Pty) Ltd., 2008).

The total cost of the soil water potential monitoring system was R 3450 as shown in Table 65.

Table 65: Cost break down of soil water potential monitoring system in 2007 (Jumman, 2009)

Description	Quantity	Cost
Watermark Sensors	3	R 1770
Soil Temperature Probe	1	R 340
Onset Hobo Logger	1	R 1200
General Purpose Box	1	R 140
Total		R 3450

7.4.5.1.4 Installation of soil moisture monitoring system

In order to assess the hypothesis of under irrigation from a previous benchmarking study (Greaves, 2007), the continuous water potential monitoring system was installed in two farms. The watermarks were installed in the cane row at depths of 15cm, 30 cm and 60 – 80 cm, dependant on site conditions. A standard soil auger was used to auger a hole to the required depth. The soil removed from the hole was sieved to remove rocky material, leaves and grass and mixed with water to obtain a thick slurry. The slurry mixture was then poured into the hole, approximately 5 cm deep, to create a seat for the deepest Watermark sensor. A PVC pipe was fitted around the collar of the Watermark sensor and used to locate the sensor snugly into the slurry at the correct depth. The slurry mixture and the soil were then backfilled into the hole in layers until the required depth for the next sensor was attained. The backfill was firmly tapped in using the handle of an old broomstick to ensure good contact between the sensor and the soil. The remaining 2 sensors were placed in the same hole in the same manner at 30 cm and 15 cm depths. The Soil Temperature Probes were placed in the same hole just above the 30cm Watermark sensor. The cables were then threaded through the hole in the housing unit and connected to the Onset Hobo logger. Silicone was used to fix the cables in place and seal any gaps in order to protect the logger from water. Finally, the lid of the housing unit was screwed on and the box was placed on the ground in between the sugarcane, out of harm's way.

7.4.5.1.5 Results

The system was used to record field data for the 2007/08 season and the detailed description of the findings are presented in Jumman and Lecler (2008). Shown in Figure 56 is the soil water potential data captured for this study. In Figure 56, the water potential is represented in kPa on the Y-Axis, were a higher kPa value indicates a drier soil. Inman-Bamber (2002) reported that the threshold water potential for stress in sugarcane is approximately 100 kPa. Studying Figure 56, it can be seen that the stress threshold of 100 kPa is exceeded for large periods of time.

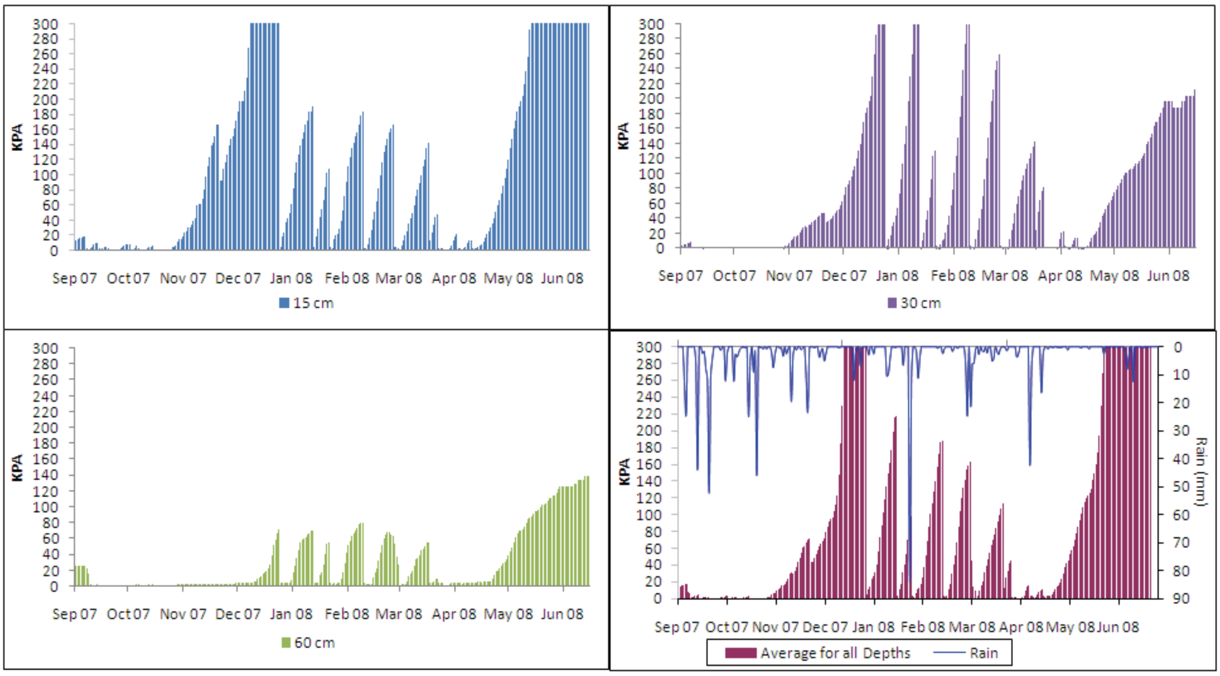

Figure 56: Time series of soil water potentials for each depth and average of all depths (Jumman, 2009).

7.4.5.1.6 Summary and Conclusions

The Watermark soil water potential sensors proved to be a valuable tool in substantiating Greaves' (2007) hypothesis of under-irrigation. Availability of continuous soil water potential data assisted farmers to monitor the performance of their irrigation strategies and identify areas for improvements.

The Watermark sensor and Onset Hobo data-logger combination provided a relatively cheap and robust system to capture valuable soil water potential data. Downloading data, however, can be tedious and time consuming if data is required on a frequent basis, as required, for example, to make irrigation application decisions. A user was required to travel to the logger and use a laptop with appropriate cables to download the data. Remote access to data, via GPRS, for example, was not available for the hobo loggers at the time of the study but would have been preferred. Nevertheless, monitoring systems such as the one described, can provide valuable information, for as little as R 3 450, to inform irrigation management decisions and contribute to optimising the use of water for crop production. This will be of great benefit to individual farmers and the wider community.

In the next section, systems allowing for remote access to data were investigated. These systems followed a holistic approach were components of the atmosphere crop and soil moisture were monitored. These systems were compiled, priced and tested for robustness and ease of use. Installation and gathering of field data for a cropping cycle, however, was beyond the scope of this project.

7.4.5.2 Alti4 growth station

Effective and accurate monitoring, in order to maximise water use efficiency, is considered to be best achieved by physically monitoring the integrated soil-plant-atmosphere continuum (Hoffman and Martin, 1992). Smit (2006), following Inman Bamber (1995), developed the first growth monitoring station for sugarcane at the South African Sugarcane Research Institute. In comparison to the Watermark and Hobo logger system, the growth station offers a more holistic approach. The growth station was designed to measure and capture important crop, soil and climatic data for field trials in the research environment. In previous versions of the growth station the main use of this tool was to understand crop physiology and reactions to environmental constraints in a research environment. In this version, however, the focus was more on monitoring the irrigation water balance with an emphasis on assessment criteria, such as ease of use, cost and robustness. It was envisaged that the tool would be used by farmers for irrigation management (Kennedy, 2008).

7.4.5.2.1 Data logger

The Alti 4 data logger comprised of 4 analogue and two pulse channels with a lithium ion battery pack consisting of two batteries rated at 3.6 volts @ 12 Amp hours each. The logger is capable of logging at 5 minute time intervals at the maximum capacity. For this project a one hour logging interval was used. Each analogue channel provides 2.5 volts at 50 milliamps for 50 milliseconds, for sensor excitation. The lithium ion battery pack was also used to provide power for remote communication/transfer of data. The Alti 4 data logger makes use of GSM/GPRS facilities to transfer data, once a day, to a central server which then could be accessed from anywhere in the world via the world wide web. A monthly subscription fee is payable for this service. The life expectancy of the battery if operated as described above is 5 years (Kennedy, 2008). This is a substantial advantage over many other loggers which typical make use of more expensive solar panels or cumbersome rechargeable batteries (CS Africa, 2009). The trade off for alternative logging options is either cheaper lower power requirements with no remote access to data, as demonstrated by the Hobo data logger in the previous section, or more expensive higher power requirements for remote access. The Alti 4 loggers appear to have the competitive edge with the correct balance between cost and power requirements for remote access to data. This will be elaborated on further in the costing section. The Alti 4 data logger hardware, including sim card and battery, was encased and sealed from water in a 60 mm diameter × 330 mm long hard plastic tube as shown in Figure 57.

Figure 57: Alti 4 data logger (Jumman, 2009).

The Alti 4 logger, shown in Figure 57 above, is compact, robust and inconspicuous because the battery and hardware components are sealed and hidden within the casing. As noted above, several sensors were connected to the Alti 4 data logger to monitor the soil-plant-atmosphere continuum. Presented below is a description of the importance of each monitoring component and, technical information of the instruments if unique or new.

7.4.5.2.2 Temperature and rainfall

The upper limit of crop production is set by the climatic conditions and genetic potential of the crop (Doorenbos and Kasam, 1979). Monitoring the relevant climatic parameters, therefore, provides insight as to what the potential for crop growth was. The two major atmospheric components that are generally monitored are air temperature and rainfall. Air temperature serves as an indicator of solar radiation energy available for growth and vapour pressure deficits to drive evapotranspiration (Schulze 1995). Lower temperatures are indicative of slower growth due to natural, uncontrollable, constraints in the field. Reduced growth, however, may also be experienced during high temperature periods when the plants experiences water stress. Rainfall contributes to determining the soil water balance and, therefore, real time rainfall data is significant to managing and implementing irrigation strategies. For these reasons, measurement of air temperature and rainfall was incorporated into the Alti 4 growth Station. The technical specifications for air temperature sensors and rainfall gauges are not discussed as they are easily accessible "off the shelf components" from companies such as Campbell Scientific (CS Africa, 2009).

7.4.5.2.3 Plant growth

Inman-Bamber (1995) reported that leaf and stalk extension rate are the best indicators of crop water status in sugarcane. The extension of stalks and leaves shut down before photosynthesis stopped on the onset of stress. Stalk extension contributed to the process of yield development and was, therefore, reported to be more relevant then leaf extension (Inman-Bamber, 1995).

In a study in Australia, mini-pans were used to calibrate the evaporation from these pans to the crop water requirements via stalk extension rates for a given soil type and time of year (Attard, 2002). Hence robust scheduling techniques were developed by measuring stalk extension and relating it to the evaporation from mini pans.

Furthermore, monitoring the extension rate of sugarcane stalks allows one to determine the allowable degree of water deficits before yields are significantly penalised. In Australia, in order to achieve maximum yields, the relative stalk extension rate is allowed to drop to 50% of the maximum stalk extension rate before irrigation is applied. Inman-Bamber (2003) and (2005) indicated that if irrigation was applied when relative stalk extension rate dropped to 30% of the maximum, less water will be applied resulting in decrease in cane yields but not sucrose content. Hence, in the context of irrigation optimisation and precision engineering, the ability to continuously monitor stalk extension is important.

In the past stalk extension was laboriously measured with a ruler (Inman-Bamber, 1995). Inman-Baber (1995) used a growth transducer (potentiometer) to automatically measure and log plant elongation. Limitations of this system, however, included extensive rigging to mount in the field, wind disturbances and technical problems with the data logger (Smit et al., 2005). Smit (2006) improved on this system and registered a patent titled "Apparatus for measuring the growth of a plant". This system was used in the Alti 4 growth station as shown in Figure 58 A,B,C.

The growth measurement system consisted of a Spectrol 10 KΩ 10-turn potentiometer mounted on a lightweight, 10 mm aluminium tubing that clamps onto the cane stalk. A fishhook was secured to the youngest visible node of stalk and an 80g brass counterweight inside the tubing keeps the non-stretchable dial cord under constant tension. Winding over a pulley on the potentiometer was enough to allow approximately 300 mm travel. The system works such that, as the stalk extends, the hook and the dial cord extends causing the pulley and shaft of the potentiometer to rotate. This rotation in turn alters the position of the variable resistor. Hence as the stalk extends voltage output as a result of varied resistance changes. Hence for a fixed input voltage of 2.5volts, the linear displacement of the cord (stalk extension) can be related to the output voltage of the potentiometer.

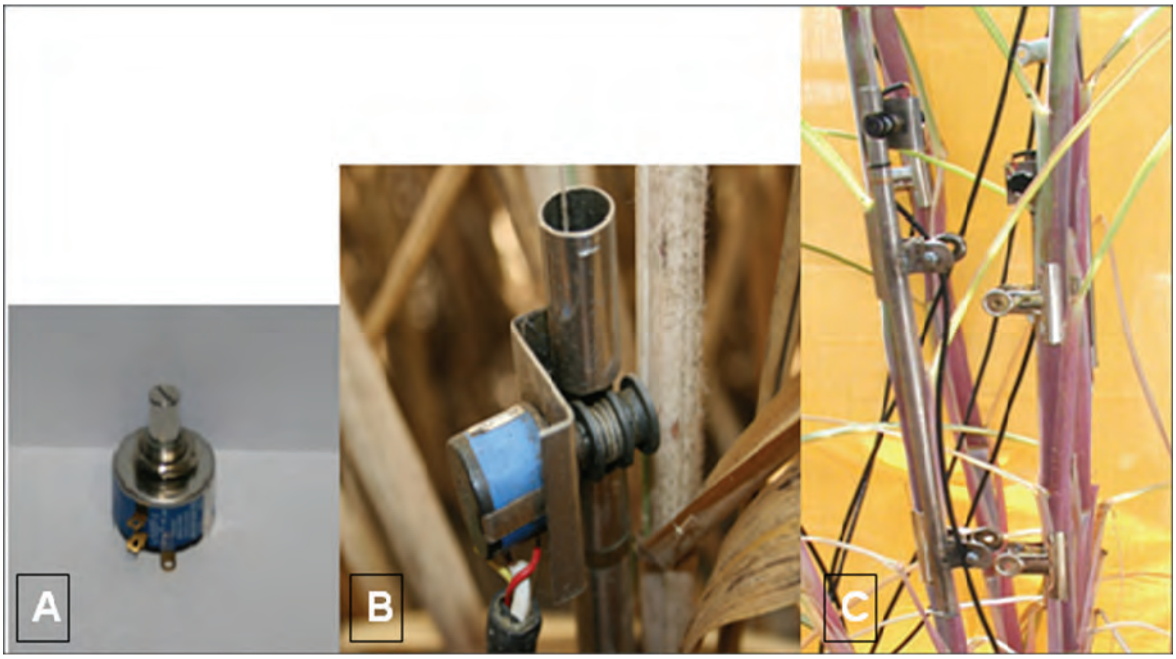

Figure 58: A)Spectrol 10 KΩ potentiometer. B) Non stretch Dial chord mounted on pulley which in turn is mounted on Potentiometer shaft. C) Plant growth measuring device with Alumium tubing mounted on sugarcane stalks (Jumman, 2009).

Limitations of the apparatus include susceptibility to rust. Nevertheless, as will be shown in costing section, the sensor was relatively cheap to replace when required. In addition, there was a need to re-attach the hook on the new node of stalk as the crop grew. This proved a time consuming and laborious exercise and room does exist for improvement. Furthermore, only one stalk was monitored at any given time and questions were posed regarding how representative would a single stalk be of the entire field? Nevertheless, the apparatus still provides valuable data and was to be used until better options were available.

7.4.5.2.4 Soil water

As before, the Watermark sensor was preferred to measure soil water potential. Migration and electrolysis issues were brought back into question with the growth station and the new Alti 4 logger combination. The time period between excitation and logging and hence, the interference due electrolysis and/or migration on data for the Alti 4 logger was unknown. For this reason, the newly launched MPS-1 water potential sensor, illustrated in Figure 59, was used. Similar to the Watermark, the MPS-1 sensor makes use of porous ceramic disks, with a water retention characteristic that wets and dries out as the soil wets and dries out (Decagon, 2008). In the case of the MPS-1, however, the dielectric permittivity of the porous ceramic plates was measured. This was different from the watermark sensor which measured the electrical conductance of the porous material. For this reason, electrolysis, the formation of micro gas bubbles which alters electrical resistance, was not a concern for the MPS-1 sensor. The MPS-1 sensor therefore appears to be better suited to the Alti 4 data logger.

Figure 59: Illustration of the new Dielectric MPS-1 Water Potential Sensor (Decagon, 2008).

"Water content and water potential are related by a relationship unique to a given material. The ceramic used with the MPS-1 has a wide pore size distribution and is consistent between disks. So, if the water content of the ceramic is measured accurately, along with a measurement of actual water potential, then a calibration curve is generated that will give a standard calibration for the MPS-1 in terms of water potential. This calibration is not dependent on the type of soil into which the MPS-1 was installed" (Decagon, 2008). This was attractive to the author bearing in mind the ease of use of the MPs-1 sensor and reduced complexity of data processing for farmers.

In addition, when compared to the Watermark sensor, the MPS-1 measures soil water potential from -10 kPa down to -500 kPa (Decagon, 2008), which is significantly more than the -200 kPa achieved by the Watermark and Hobo logger combination in the pressure plate chamber (Jumman and Lecler 2008). The MPS-1 also appeared fairly robust and accurate with a resolution of 1 kPa from -10 to -100 kPa and 4 kPa from -100 -500 kPa (Decagon, 2008). Furthermore, the MPS-1 sensitivity to temperature and salinity is negligible in the context of irrigation. "The MPS-1 does exhibit some sensitivity to temperature change. This was primarily due to changes in the dielectric permittivity of the ceramic and water due to temperature change. For most field applications (i.e. installation depth >15cm) this sensitivity is negligible. For shallower applications or lab studies over highly variable temperature ranges, a temperature correction may be desirable" (Decagon, 2008). Similarly, MPS-1 sensors demonstrated a, low, 2% sensitivity to changes in salinity ranging from 0.01dS/m to 10dS/m (Decagon, 2008). The MPS-1, therefore, appears to be a better suited sensor to the Alti 4 logger.

7.4.5.2.5 Configuration and cost

The configuration of the Alti 4 Growth Station is shown in Figure 60, below. It was important for the system to be robust and well protected against the environmental elements. These included protection against theft, rodents/pests and climatic factors such as wind and the sun's UV rays. The configuration and attributes are described below.

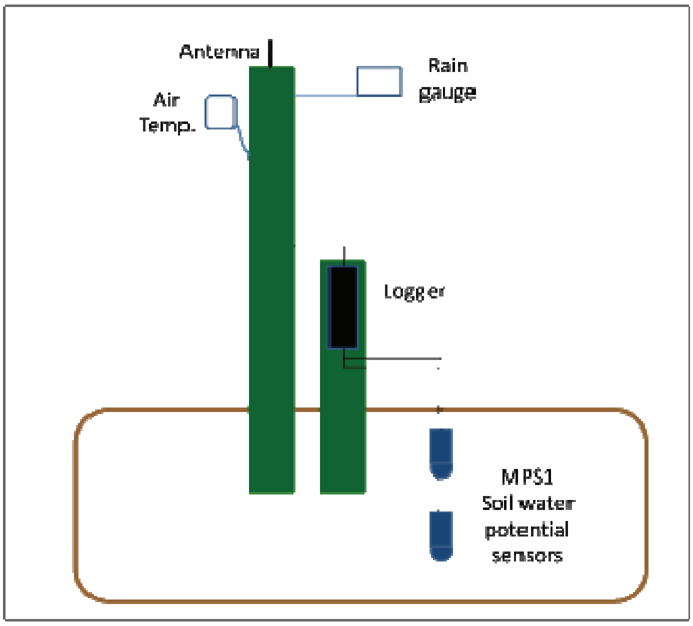

Figure 60: Configuration of the Alti 4 Growth Station (Jumman, 2009).

The growth station was configured such that the logger was housed in a 1.5 m long × 63 mm diameter PVC plumbing vent pipe, which was painted green and planted vertically amongst the sugarcane. This allowed for all cables running from sensors to the logger to be housed within the pipe. A second pipe, 3.5 m long × 63 mm diameter, planted immediately next to the logger, was used to mount the antennae, rain gauge and temperature sensors at canopy level for a fully grown crop. Sensors were fixed on the pipe using hose clamps, thus allowing for easy adjustment of vertical position during different crop growth stages. It was important for the antenna, rain gauge and temperature sensor to be mounted at canopy level. The antenna – to ensure maximum opportunity for cell phone signal, rain gauge – to prevent interception losses and capture rainfall records correctly, and air temperature – to accurately capture the potential energy available for growth and evapotranspiration. The 3.5 m PVC vent pipe was also painted green and proved to be very steady and, for security reasons, blended in well with the environment. The MPS1 soil water potential sensors were installed in the ground as shown in Figure 60. Furthermore, the stalk extension potentiometers were mounted on the sugarcane stalks. This is not shown in Figure 60. The costs of the Alti 4 growth station were broken down as shown in Table 66.

Table 66: Cost break down of Alti 4 Growth Station (Jumman, 2009)

	Description	Unit Price	Quantity	Total
1	Alti4 data logger + Alti two cell battery pack + antenna	R 4, 891.00	1	R 4, 891.00
3	Ech20 air temperature sensor with gill screen	R 1, 891.00	1	R 1, 891.00
4	Panoramic professional 0.2 mm rainfall gauge	R 3, 100.00	1	R 3, 100.00
5	Stalk extension potentiometer	R 200.00	1	R 200.00
6	Decagon MPS1 soil water potential sensors	R 1, 428.00	2	R 2, 856.00
7	Housing (PVC plumbing pipe)	R 193.00	1	R 193.00
	Total (excl. VAT)			R 13, 131.00

As shown in Table 66, the capital investment for the system is R 13, 131. In addition, a monthly subscription fee is payable for the remote transfer of data. This consists of a R50 and R160 sim card and web server hosting fee, respectively. Hence, the operating costs amount to R210 per month. The Alti 4 logger made use of the General Packet Radio Service (GPRS) transmission technology to transfer the data via the cell phone network. In this project, data was logged every hour and only transferred to the website once a day. If GPRS was not available, however, a backup sms system was on hand. The backup system used the Global System for Mobile (GSM) communication where the data was transferred via sms at a charge of 50 cents per sms.

7.4.5.2.6 Installation and preliminary results

The Alti 4 logger, antenna, rain gauge and two MPS-1 sensors together with the upright pipes, as shown in Figure 61, were installed at the Automatic Short Furrow (ASF) trial at Ukulinga in Pietermaritzburg. Installation of the MPS-1 sensor proved to be relatively easy. After digging the hole, with an auger, the soil was simply wetted and packed around the ceramic plates. As described in Section 5.1.4 for the Watermarks, a PVC pipe was fitted around the collar of the sensor and was used to seat the MPS-1 snugly at the bottom of the hole. Sensors were placed in between the furrow and cane row at depths of 20cm and 60cm. A mixture of soil and water was backfilled and lightly compacted into the hole. Preliminary results from the ASF trial in Ukulinga are shown in Figure 61 below.

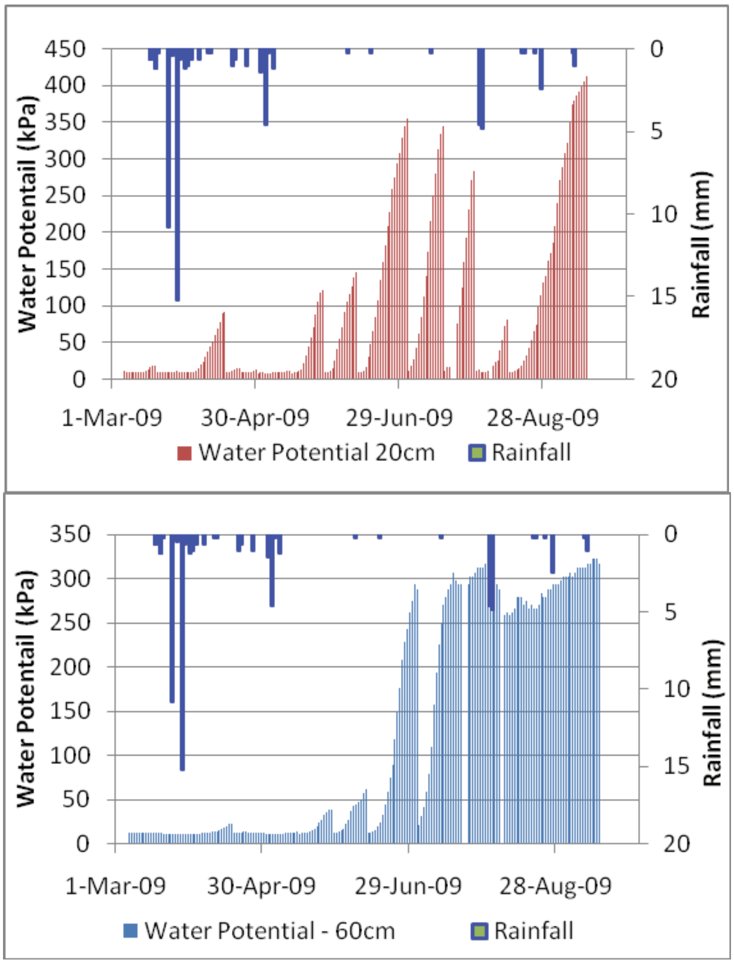

Figure 61: Preliminary results from MPS-1 sensors and rain gauge from the Automatic Short Furrow trial in Pietermaritzburg (Jumman, 2009)

As shown in Figure 61, the MPS-1 sensors responded adequately to both rainfall and irrigation. The sensors also detected the dry off period before harvest in September sufficiently well. In addition the remote transfer of data via the website proved useful and was often used to verify irrigation scheduling as determined by a different scheduling model. For these reasons, the Alti 4 system therefore appears to meet all criteria. The system is relatively easy to install. Remote access to data increases the ease of use for growers and irrigation advisors. The system also proved to be relatively robust and well suited to the harsh agricultural environment.

An alternative Campbell scientific monitoring system was investigated. This is presented in the next section.

7.4.5.3 Campbell Scientific growth station

Campbell Scientific inc., established in 1974 in the United States of America (CS Africa, 2009), was a prominent company that manufactured data loggers, data acquisition systems and monitoring and measuring instruments. In addition to being a well established and reputable company in South Africa, Campbell Scientific Inc. has also demonstrated excellent technical support. Hence, a Campbell Scientific logger was purchased and investigated as an alternative to the Alti 4 logger. The temperature sensor, rain gauge, potentiometer and MPS-1 sensors were all used as in the Alti 4 system. Only the data logger and data transfer mechanisms changed. Below is a description of:

- the characteristics and practical configuration of the selected logger,
- system costs, and
- merits and challenges of the system.

7.4.5.3.1 CR200 Campbell Scientific data logger and sensor configuration

The primary reason for selecting the CR200 logger was that it was the lowest cost data logger from Campbell Scientific (CS Africa, 2009). In addition, the CR200 channel configuration and small size was well suited for this application. The CR200 consisted of 2 excitation channels, 5 individually configured single ended input channels and 2 pulse channels. The excitation channel range was programmable for either 2.5 or 5 volts, while the analogue output voltage range was 0 – 2500 mV. Other specifications included a 12 bit A/D converter, maximum scan rate of once per second, measurement resolution of 0.6 volts, 1 switched battery port and 2 control ports, battery voltage range 7 – 16 Volts DC, an on board 12 Volt DC, 7 amp hour, lead acid battery charger and communications options via RS 232 (CS Africa, 2009). The only limitation of the CR200 was that the 2 excitation channels were not adequate to provide power for exciting all the sensors simultaneously. Figure 5-9 below, illustrates the configuration of the sensors and the CR200 data logger. Due to only two excitation channels being available in this logger, two MPS-1 sensors had to be connected to Excitation channel 1 as indicated in Figure 62.

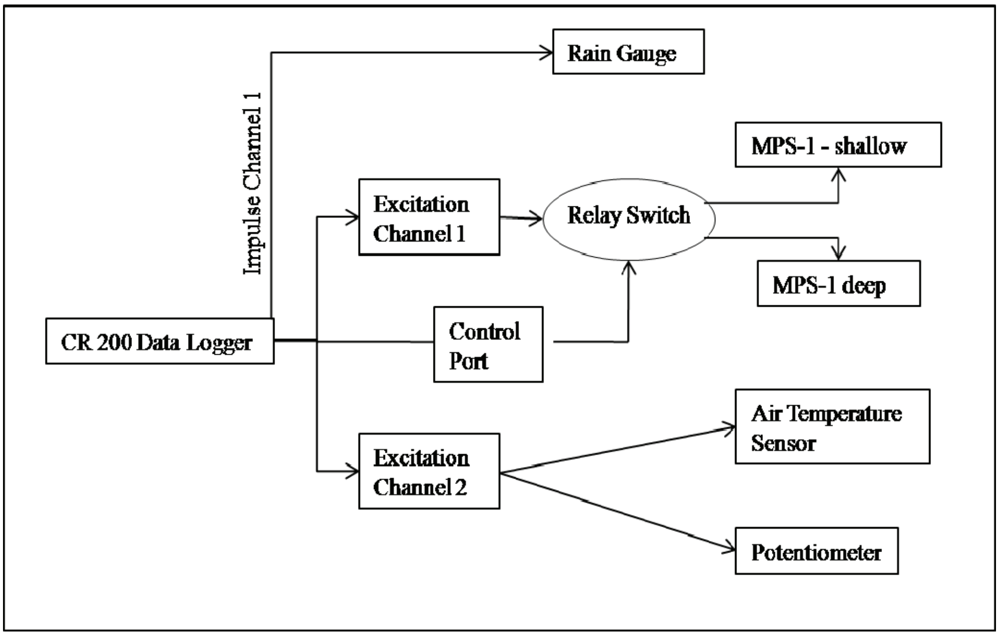

Figure 62: Schematic of CR 200 and Sensor configuration (Jumman, 2009).

For this reason, a relay switch was used. The relay switch allows the data logger to excite one MPS-1 sensor at a time, sequentially. In other words, the relay switch was used to activate and scan, say, the shallow MPS-1 only. On completion of scanning, the shallow MPS-1 was deactivated and the deep MPS-1 activated and scanned. In this way the power requirements of each MPS-1 sensor was met and the limitation dealt with. The remaining excitation channel was used to connect to and excite the air temperature sensor and the potentiometer. The power requirements of the potentiometer and temperature probe were not as high as the MPS-1 sensors and therefore could be excited simultaneously. Finally, the panoramic 0.2 mm rain gauge was connected to the impulse channel. Hence, an impulse channel and a single ended input channel were still available for future additions such as wind speed if required.

The other limitation with the Campbell Scientific system is the relationship between costs, battery life and remote communication of data. The CR200 logger, for this application, made use of a 12 volt rechargeable battery rated at 12 amp hours. Unlike the Alti 4 system, GPRS and GSM options were available independently. For both GPRS and GSM options, two modems were required. A field and an office bound modem. In this case a Meastro 100 GSM/GPRS modem was used as the field unit and a SAMBA 75 GPRS/GSM modem was proposed for the office. Hence, in addition to the powering up the sensors, the battery was also used to power the Meastro 100 GSM/GPRS modem.

The data logger was programmed to scan and log sensor readings every hour and then transfer the data via GSM/GPRS once a day. Operating in this manner implied that the battery would have to be recharged periodically. The battery life before recharging was required was determined theoretically to be 8 months (Hoy, 2009). In terms of “ease of use”, this system was less attractive as maintenance/labour/time requirements to recharge batteries were relatively higher when compared to the Alti 4 system. In addition, the costs of the system as shown in Table 67were also higher when compared to the Alti 4 system.

Table 67: Cost break down of Campbell Scientific Growth Station (Jumman, 2009)

	Description	Unit Price	Quantity	Total
1	CR200 data logger + Antenna	R 5, 083.50	1	R 5, 083.50
2	12V sealed rechargeable battery	R 210.60	1	R 210.60
3	Meastro 100 GSM/GPRS modem	R 2, 011.50	1	R 2, 011.50
4	Ech20 Air Temperature Sensor with Gill Screen	R 2, 266.66	1	R 2, 266.66
5	Panoramic Professional 0.2 mm Rainfall Gauge	R 2, 776.95	1	R 2, 776.95
6	Stalk Extension Potentiometer	R 200.00	1	R 200.00
7	Decagon MPS1 Soil Water Potential Sensors	R 1, 581.25	2	R 3, 162.50
8	Campbell Control Relay	R 95.00	1	R 95.00
9	Housing (PVC plumbing pipe + general purpose electrical box)	R 411.32	1	R 411.32
10	Samba 75 set Falcom modem + sim card set up fee	R 2, 802.09	1	R 2, 802.09
11	LoggerNet Software	R 4, 366.00	1	R 4, 366.00
	Total (excl. VAT)			R 23, 386.12

The capital investment required for this system was R23, 386.12, significantly higher than the Alti 4 system. The difference was largely attributed to the additional costs of the CR 200, the office based Samba modem and the LoggerNet software. It should also be noted that, as in the case of the Alti 4 system, the PVC vent pipe was used as a frame to mount the sensors and/or house the cables. Due to the size of the CR200 logger, however, a general electrical box, mounted onto the PVC pipe, was required to house the data logger, the modem and the battery. The dimensions of the box were 32cm long × 28cm wide × 150cm deep, at a cost of R218.32.

As mentioned previously, remote communication via GSM or GPRS was available. For the GSM option, a fax modem via a landline in the office can be used to communicate to the field unit. The operating costs for GSM, however, were considered too high and therefore only the GPRS option was accounted for in Table 67. In addition to the capital costs for the Samba 75 modem, operating costs for the GPRS system were also allocated. The operating costs consisted of a 24 month cell phone data bundle subscription charged at R 152.62/month. The Campbell Scientific system appears to be a reliable and robust system. The major challenge, however, was the additional capital costs when compared to the Alti 4 system.

7.4.6 Discussion and Conclusions

In the context of the current water shortages, rapidly increasing electricity tariffs and increasing strain on farmers to remain profitable, the primary focus of the work reported in Phase II was to:

- develop a decision support framework with analytical tools to holistically assess the performance of alternative irrigation scenarios, both from a design and operating perspective.
- apply the framework to investigate potential solutions for: over irrigation on shallow soils and increasing electricity tariffs, and to assess the potential benefit of deficit irrigation strategies.
- develop infield monitoring tools to monitor and assist in the implementation of irrigation strategies that require precise management.

7.4.6.1 Framework development

Sugarcane was the target crop and for this reason, the existing *ZIMsched* 2.0 and *Irriecon* V2 models, with the algorithms specific to sugarcane were selected as components of the framework to simulate the water budget and holistically assess the economics, respectively. In terms of water balance and crop yield prediction models, many options such as *ACRUcane*, *SAsched* and CANESIM were available. *ZIMsched* 2.0, however, was selected for its ability to account for different levels of uniformity and the impact of over and under irrigation on yield. An irrigation design and costing tool was then developed in order to prepare irrigation hardware costs that were representative of the irrigation constraints simulated in the *ZIMsched* 2.0 model. Finally, *Irriecon* V2, an economic assessment tool, was used to determine the net margins above allocated costs for the various scenarios and irrigation strategies.

The synthesis of these tools into a decision support framework provided the platform for rapid and efficient generation and assessment of irrigation scenarios, strategies and solutions. The assessment framework followed a holistic approach since interacting parameters were accounted for. These included irrigation system capability in terms of water use and yield and the associated irrigation costs. The irrigation costs included capital costs for systems hardware and operating costs such as labour, maintenance and water and electricity tariffs. A holistic approach was considered important since it allows for sensible assessment of the tradeoffs between system uniformity, watering capability and the associated irrigation system costs versus revenue from yield. In addition the cost for agronomic practices such as planting, herbicide and fertiliser application and harvesting, transport and haulage costs were also accounted for.

All three of the tools were spreadsheet-based allowing for a high degree of transparency and flexibility. This flexibility was vital for the generation of unique scenarios and strategies such as those that were required for the deficit strategies. The *ZIMsched* 2.0 model, in particular, allowed for easy programming to control water applications during peak and off-peak electricity tariff periods and "high" and "low" irrigation demand periods. In addition, the graphic illustration of the soil water budget in the *ZIMsched* 2.0 model, proved to be useful when comparing and understanding the dynamics between strategies. For example, visual representation of the water budget allowed for easy identification of the excess runoff for the 12 hour stand time system in the shallow soils investigation.

Irriecon V2, in contrast required intensive input data from many different disciplines. These include data relating to herbicides and fertiliser application, as well as sugarcane planting, harvesting, haulage and transport in addition to irrigation. For this reason, the tool is relatively complex and potentially limited to only very knowledgeable users. The tool, however, once configured correctly, is valuable and relatively easy to apply.

Finally, the development of the irrigation design and costing tool formed a pivotal component in the framework. Accounting for the cost of irrigation hardware was an essential component in assessing the performance of any irrigation strategy. The tool provided a relatively quick and efficient method to generate alternative irrigation designs and representative costs for these design options. The versatility of a spreadsheet-based tool also allowed for easy modifications to designs. This was particularly useful for the shallow soils investigation, where an additional set of sprinklers and hydrant control valves were incorporated to convert the 12 hour stand-times in an initial design to 8 hour stand times, and the deficit chapter, where cycle length and accordingly lateral length was increased to reduce the peak design capacity.

The irrigation assessment framework provided an ideal platform to research and investigate potential solutions for some of the current and burning issues in the South African irrigated sugarcane industry.

7.4.6.2 Application of the framework

The irrigation performance evaluation framework and associated tools were used to assess potential solutions, for a specific set of conditions, to many issues facing the irrigated sugarcane industry.

7.4.6.2.1 Shallow soils

Considering that a large portion of the industry constitutes shallow soils and in the context of increasing demand for more effective and efficient use of water, poorly matched irrigation systems, even though cheaper, need to be improved upon. Traditionally shallow soils were irrigated with sprinkler systems were labour was required to move sprinklers. Since it was impractical for labour to move sprinklers at night, a 12 hour stand time was typically used. This, however, often results in excess water application per cycle.

The irrigation assessment framework was used to demonstrate that a 28% increase in capital costs in order to modify the system hardware and better match water application to the soil, delivered higher net margins compared to the typically cheaper system. This was primarily the result of reduced runoff from a better matched system and therefore more water infiltrating into the soil to become available to the crop. In this case, the stand time was reduced to 8 hours in order to match water application to the soil profile. The irrigation system was equipped with an additional set of sprinklers and shut-off valves at every lateral allowing for an irrigation supervisor to simply drive along a sub-mainline and activate or deactivate the appropriate sprinklers for the night move. Hence, no labour was required to move sprinklers at night. This highlighted the importance of considering impacts of the water balance on crop yields during the design phase, in order to show the potential value of more "expensive" systems.

It is therefore recommended, that the trade-off between system costs for automation or semi-automation in this case and effective water application be well investigated. A better matched system can increase profitability and, potentially more importantly, reduce the environmental impacts of over irrigation and runoff. The usefulness of the irrigation assessment framework to conduct such investigations was also clearly demonstrated.

7.4.6.2.2 Electricity tariffs

In South Africa, many electricity tariff options are available to farmers. The difference in tariff structures, however, is complex and determining the best option can be difficult for irrigation designers, consultants and farmers. In this study, the *Irriecon* V2 model was used to investigate the differences between the Ruraflex and Landrate options.

The Ruraflex option had higher fixed costs, but also provided opportunity for significant savings if electricity use was shifted into off-peak and standard periods. At the time of the investigation, if the irrigation system was operated continuously for 24 hours, both the Ruraflex and Landrate options incurred similar electricity costs. This however, was only true for the 2009/2010 tariff prices. It appears that in the past, irrigators may have been incorrectly rewarded for operating on the Ruraflex option without shifting use of electricity into off-peak and standard periods.

In addition, tariff increases over the last three years, for this specific scenario would have increased the electricity bill in excess of 70%. This was concerning considering that revenues from cane sales were not increasing. It also highlighted the need for irrigation strategies that reduce electricity use during peak and high demand periods, and therefore take advantage of the incentives provided by the Ruraflex option.

7.4.6.2.3 Deficit irrigation

Typically, generic design procedures deliver irrigation systems with peak design capacities that prevent the crop from experiencing water stress. A deficit approach allowed for deviation from these norms and illustrated how peak system design capacities, associated system costs and system operating rules can be manipulated to reduce costs. The trade-off, however, was reduced water applications, crop stress and therefore reduced revenues from cane sales.

In this study it was shown that the direct cost savings of water and electricity were small in comparison to revenue loss for a range of deficit irrigation strategies. This implied that deficit strategies were only feasible if the opportunity cost of water was realised by using water savings to convert dry land cane into irrigated cane. This was only applicable if land was not limiting. In this study, the increase in relative profitability, after the dry land conversion, ranged from 14 to 28%. In addition, deficit strategies made use of water and electricity resources efficiently. Water application, in some instances, was kept out of the electricity peak periods. Such strategies could prove to be of great benefit to the country, especially in the current context of increasing demands for energy conservation.

Deficit irrigation is precise in nature and implementation of deficit irrigation strategies requires a high level of management and monitoring. Monitoring tools such the growth stations with soil water potential sensors and stalk extension potentiometers should be considered to monitor the soil water budget and crop growth/stress status. In addition, crop production functions and optimum water applications for the specific region, climate and soils should be well understood before irrigation hardware, peak design capacities and deficit strategies are selected. Misinformed designs, in the form of excessive peak system capacities leading to high capital and operating costs, could limit the potential benefit a deficit irrigation strategy can deliver.

At this stage it appears that farmers will require a large amount of support in order to successfully implement a deficit strategy. Investment in innovative methods will be required to communicate and increase the understanding of these concepts and mechanisms. This may also include improving the knowledge and understanding of extension staff as well. In the sugar industry at present, extension officers serve as the channel for dissemination of research to the growers. Extension officers, however, are more focused on advice relating to pest and diseases, variety choices and fertiliser and herbicide requirements in comparison to irrigation. Understanding of irrigation principles and the ability to give irrigation advice is often lacking. Hence, as the primary advisors to farmers, extension officers will play a vital role in the implementation of deficit irrigation strategies.

7.4.6.2.4 Monitoring Systems

Implementation of deficit irrigation strategies requires precise management. Easy to use, robust and relatively cheap monitoring tools were perceived to be vital for the successful implementation and management of deficit irrigation strategies. It was envisaged that monitoring tools will provide data to reassure farmers of the status of their crop. Three monitoring systems were developed and assessed.

The first system was a continuous soil water potential monitoring system which made use of the Watermark sensors and H8 four-channel Hobo data logger. This system proved to be relatively cheap and very robust. The system, however, required the user to travel out to site and download the data manually. This was considered an expensive and tiresome exercise, especially if data was required frequently for decision making. For this reason, this system was considered better suited for long term monitoring. The Watermark system was installed on two farms and provided valuable evidence to affirm predictions of under-irrigation of under-irrigation, at a relatively small cost.

The next two systems were the Alti 4 and Campbell Scientific growth stations. These systems followed a more holistic approach where temperature, rainfall, plant stalk extension and soil water potential were monitored. The only difference between the two systems was the data loggers. The Cr 200 data logger was used for the Campbell Scientific system. Both systems, however, had relatively high capital and operating costs. The Alti 4 system was the cheaper of the two, amounting to a capital investment of R 13 131 and an operating cost of R 210/month. In addition, the Alti 4 appeared to have the competitive advantage by striking the better balance between battery life, remote communication and costs.

In conclusion, the configuration for both the Alti 4 and Campbell system was robust and well suited to the agricultural environment. The PVC pipe installed vertically provided a steady frame for mounting of sensors and housing for the cables. In addition, by painting the pipe green, the system was fairly inconspicuous and, for security reasons, blended in well with the sugarcane. Furthermore, both systems were relatively easy to use since data could be accessed remotely via either GPRS or GSM. Remote access to data was very attractive in terms of easy decision making and irrigation monitoring. These tools are envisaged to encourage more precise management of irrigation systems.

7.4.7 Recommendations

Recommendations for future work that were beyond the scope of this study are as follows:

- modify the irrigation design and costing tool or develop similar tools to design and cost other types of irrigation systems. For example drip systems. In this way, the appropriate design tool could be substituted into the framework when needed. This would allow for easy comparison of strategies for different irrigation systems;
- incorporate the Nightsave electricity tariff option in to the *Irriecon* V2 model. This would then allow for further investigation of the Nightsave option;
- investigate the potential to reduce peak pumping hours by increasing irrigation system capacity. Increasing the system capacity will allow for the required water volumes to be applied in shorter time intervals. In this way, pumping and therefore the use of electricity are restricted to within the off-peak and standard time periods. Concerns with this approach, however, include possibly applying water in excess of the soil infiltration rate resulting in loss through runoff. Furthermore, higher capital costs for the increased system capacity may prove to be a barrier for implementation. It is recommended that these issues be investigated further;
- develop innovative strategies for implementation and use of the infield monitoring tools. For example:

the monitoring system will only be representative of a point in the field. How does one decide where to install the unit and how many units are required for a specified area. One option was to install the unit in a position which was fairly representative of the soils of the entire field. This unit could then be used to increase the understanding of the irrigation strategy taking into account the soils and crop response. This could potentially include calibration of stress and refill points in the soil profile. Once adequate knowledge and understanding is gained, the monitoring unit could be moved to a different part of the field or to a new field altogether. Further work is required to develop a plan of how best these tools can be used;

the crop growth station provides many opportunities to capture growth responses to various treatments in the research environment. For example, relationships between soil types, stalk growth, time of year and irrigation requirements can be developed by monitoring the water balance over a period of time together with crop growth rates. Similar work was completed in Australia, were mini-pans were used to calibrate the evaporation from these pans to the crop water requirements via stalk extension rates for a given soil type and time of year (Attard, 2002). Similarly, the growth stations can be used to gather data in order to develop robust scheduling techniques, for different regions and soil types in South Africa.

Another example could be using the tool to measure the impact on stalk growth rate and water extraction in a compacted soil compared to an un-compacted soil. The applications of these growth stations are far and wide and could prove extremely valuable to the research fraternity for the collection of data and generation of knowledge about crop response to different environments and management.

Concluding, the work reported in this study provides the irrigated sugarcane industry with a platform of computer-based tools and methods to generate and assess potential irrigation solutions for a range of scenarios and contexts. In-field monitoring tools were also developed to allow for easy monitoring, management and assessment of strategies when implemented.

8 Loskop Irrigation Scheme

8.1 Scheme background

Loskop Irrigation Board is located in the Mpumalanga Province. The Scheme manager is Mr Johan van Stryp. The scheme has a total of 16 117 scheduled hectares of irrigation land divided into 702 properties where the majority have an average size of 25,7 ha. The full quota of the scheme is 7 700 m^3 per hectare per year. A further 59 consumers are also attended to by the Board which include all industrial consumers and also private instances.

The main source of water provision is Loskop Dam with a catchment area in the Highveld. The Scheme consists of a network of concrete lined canals and 7 balancing dams. The total length of the ±495 km canal system consists of 2 main canals of 96 km (Left Bank) and 60 km (Right Bank) respectively. The rest consists of canal branches. During peak periods up to 33 000 m^3 per hour can be delivered by the Left Bank main canal.

A network of concrete lined drains as well as earth drains is distributed over the scheme. Crops:

- Cash crops
- Cotton
- Vegetables
- Wheat
- Maize
- Tobacco

Permanent Crops

- Citrus
- Lucerne
- Grapes
- Bananas
- Avocados
- Nuts

8.2 Conveyance system

Loskop Irrigation Board has two main canals, the East canal and the West canal. The scheme is divided into eight water wards. Each water ward has a ward manager who is responsible for the water distribution management of the specific ward. Water is ordered by the farmers on a weekly basis using water order forms. The water orders are posted in a post box in each water ward. The water bailiff empties the post box every Thursday and captures the water orders in the WAS database in the office of each water ward. The distribution is then compiled for each water ward by the responsible water bailiff.

The WAS databases of each ward manager are verified on a regular basis by comparing it with the main WAS database in the water office where all the water orders are captured separately. The release out of the Loskop dam is calculated manually. Water losses are added as a percentage of the flow and lag times are based on previous experience.

Water is delivered to the farmers through pressure regulating sluices that is set on a daily interval. The dam setting is changed on a twelve hourly interval. Water cancellations and additional orders for water are managed on a daily basis depending on the limitations of the system.

8.2.1 Current release calculation method

Loskop Irrigation Board is divided into a number of water wards which is managed by ward managers. Each ward manager runs the WAS program for his/her own water ward. Water orders are captured by each ward manager in the WAS program. Distribution sheets are then compiled using WAS and losses are added.

Sluice gate opening and closing times for the releases into the Left and Right bank main canals at Loskop dam are calculated manually and by using past experience. Farm turnouts are opened beforehand (usually on a Saturday) according to the water requested by the farmers. Sluice settings for branching canals are changed according to past experience and by taking the total water demand into account.

8.2.2 Calculation of losses

The total water loss from the dam wall to the farm edge were calculated using a module in the WAS program which was developed specifically for this purpose. The raw data for the Left and Right bank main canals measuring stations at Loskop dam was imported from datasets supplied by the Hydro Directorate of DWA.

The water orders are historical data which were captured on a weekly basis by the scheme to keep track of each farmer's water quota balance and to calculate dam releases. The water orders are audited externally by an accounting firm on a regular basis. Water delivered is assumed to be equal to the water ordered. The water is delivered to the farm edge through a pressure regulating sluice which is calibrated for fixed gate openings and a constant head in the canal.

The graphs in Figure 63 to Figure 72 show the total water released compared to the total water ordered and a corresponding graph which shows the cumulative values. Both sets of graphs have values for each week for the years 2000 to 2005.

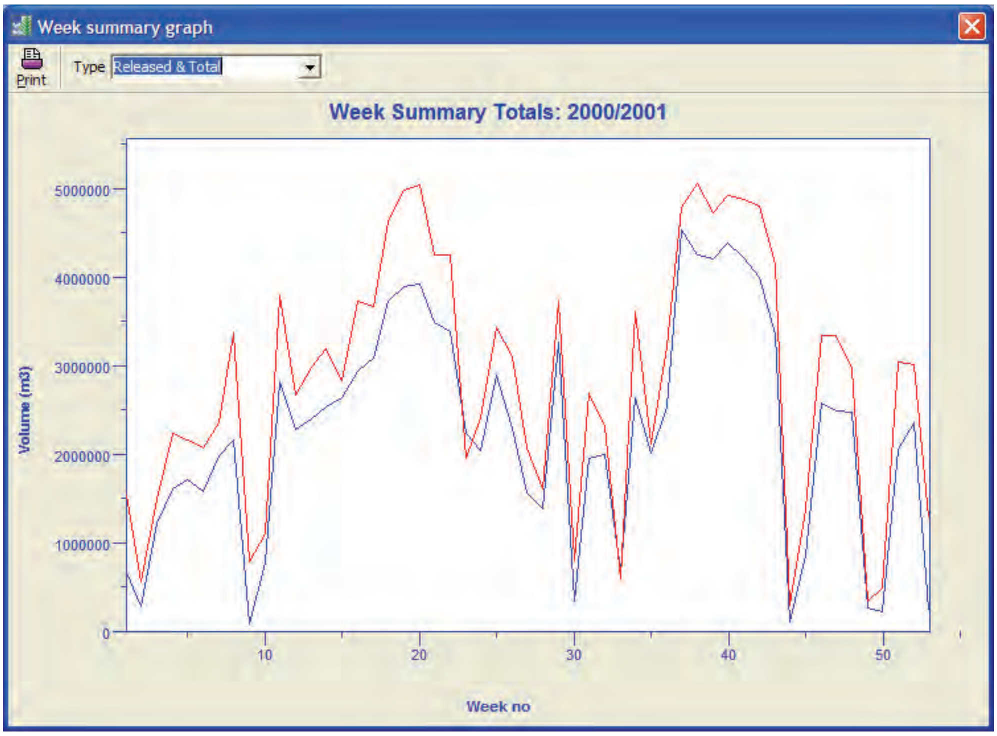

Figure 63: Loskop: Released vs. Ordered for 2000/2001

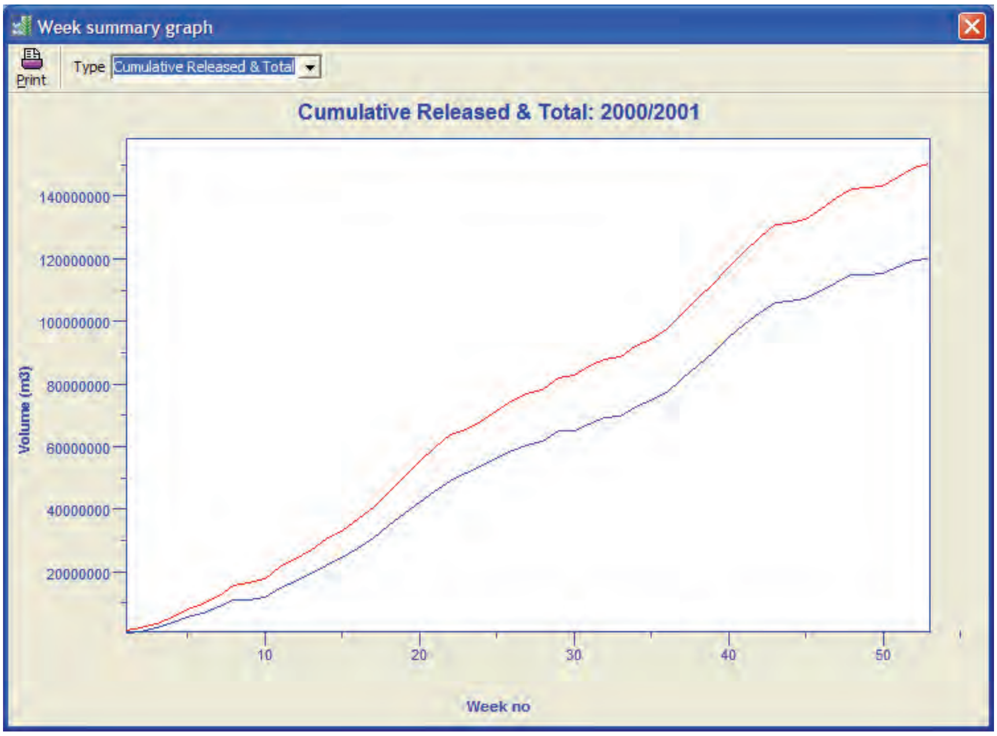

Figure 64: Loskop Cumulative Released vs. Ordered 2000/2001

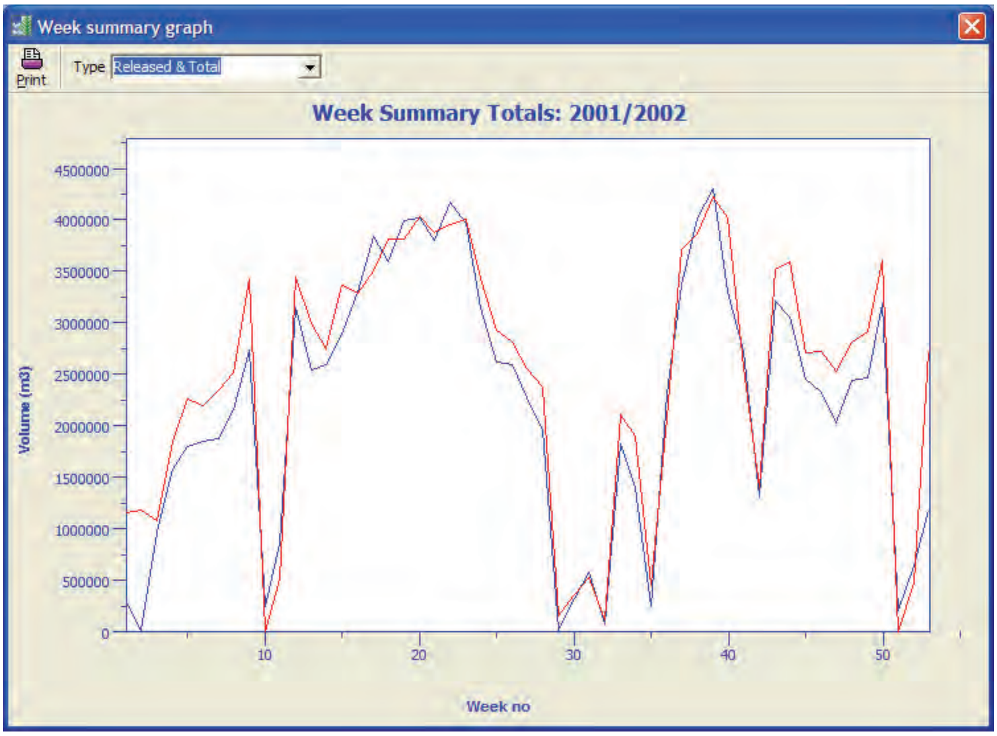

Figure 65: Loskop: Released vs. Ordered for 2001/2002

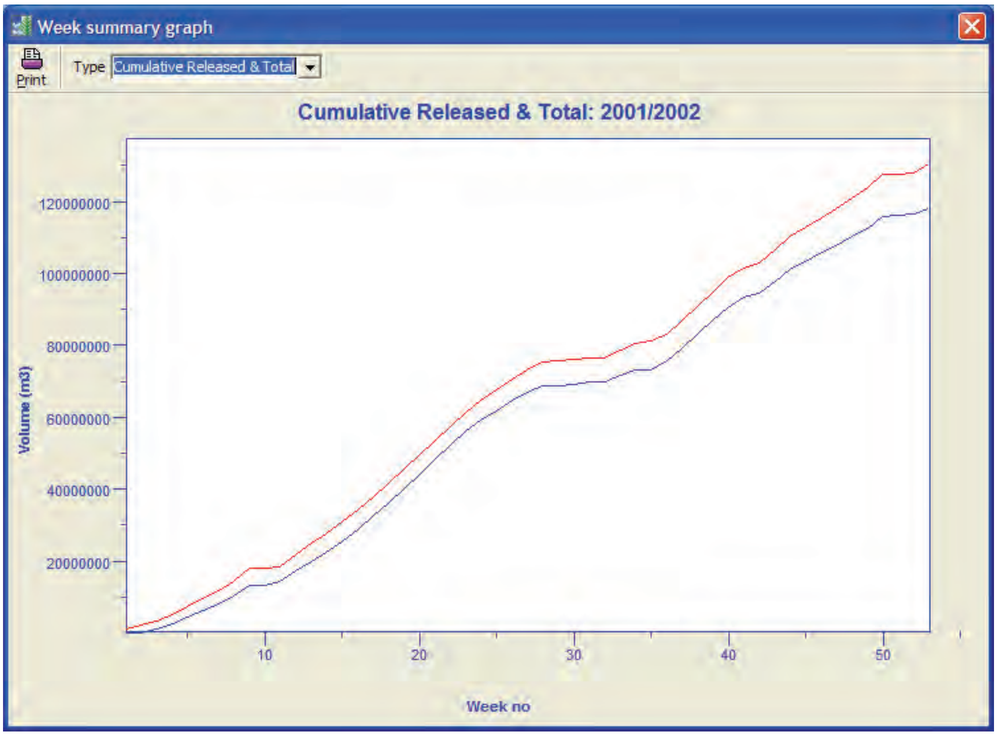

Figure 66: Loskop Cumulative Released vs. Ordered 2001/2002

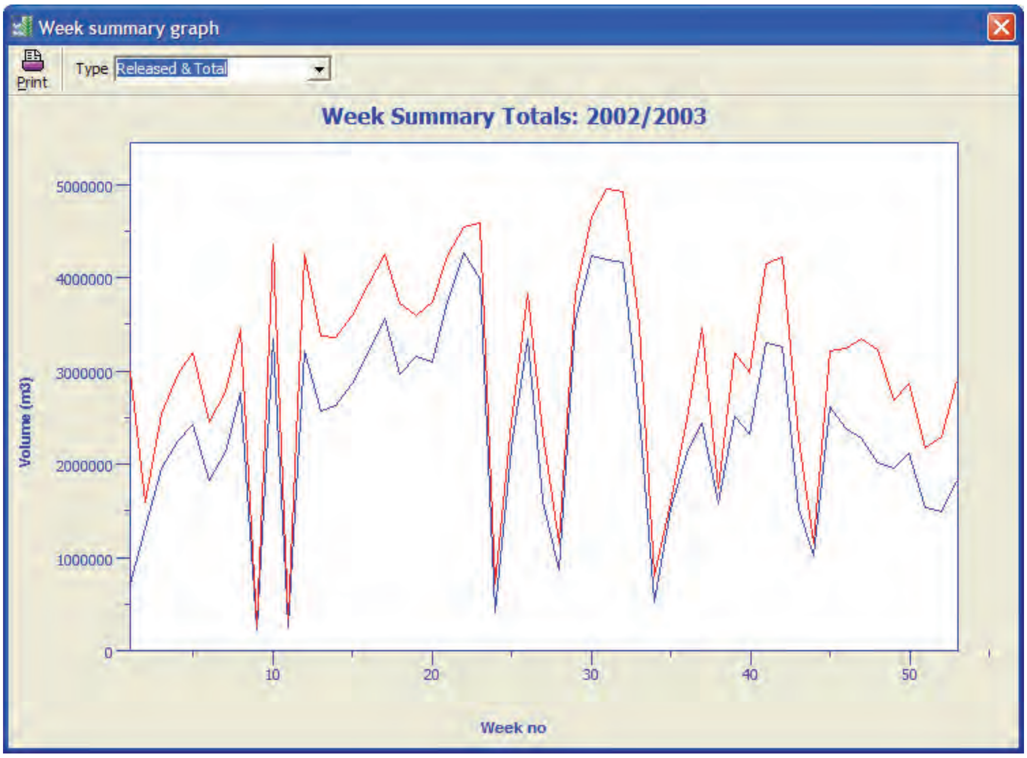

Figure 67: Loskop: Released vs. Ordered for 2002/2003

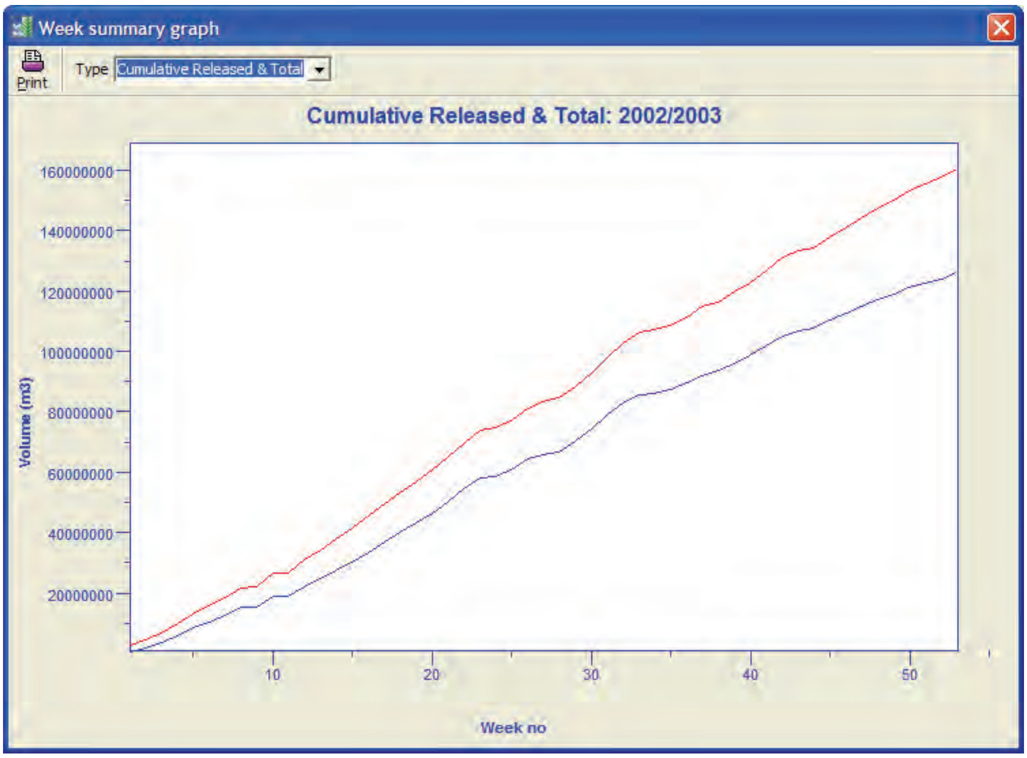

Figure 68: Loskop Cumulative Released vs. Ordered 2002/2003

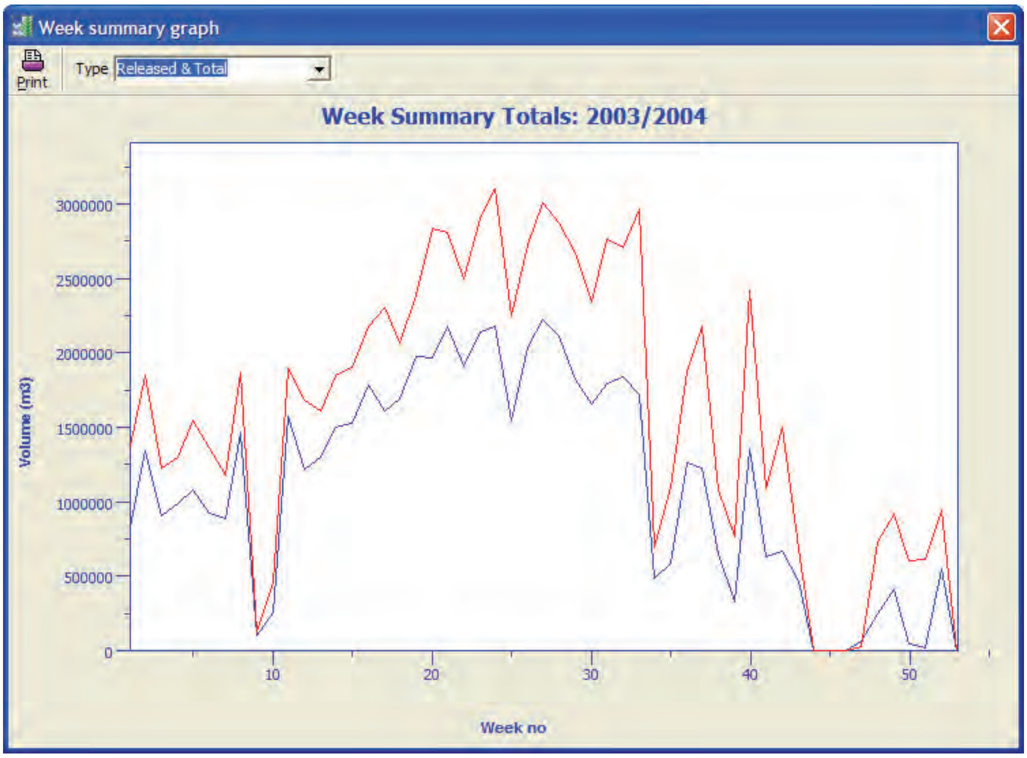

Figure 69: Loskop: Released vs. Ordered for 2003/2004

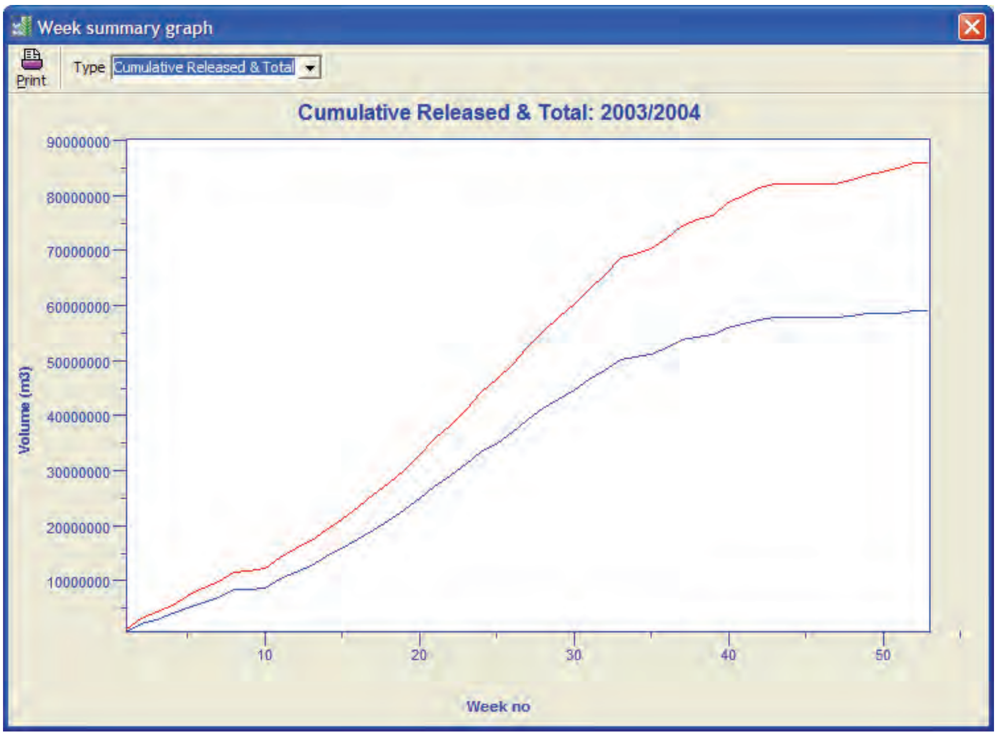

Figure 70: Loskop Cumulative Released vs. Ordered 2003/2004

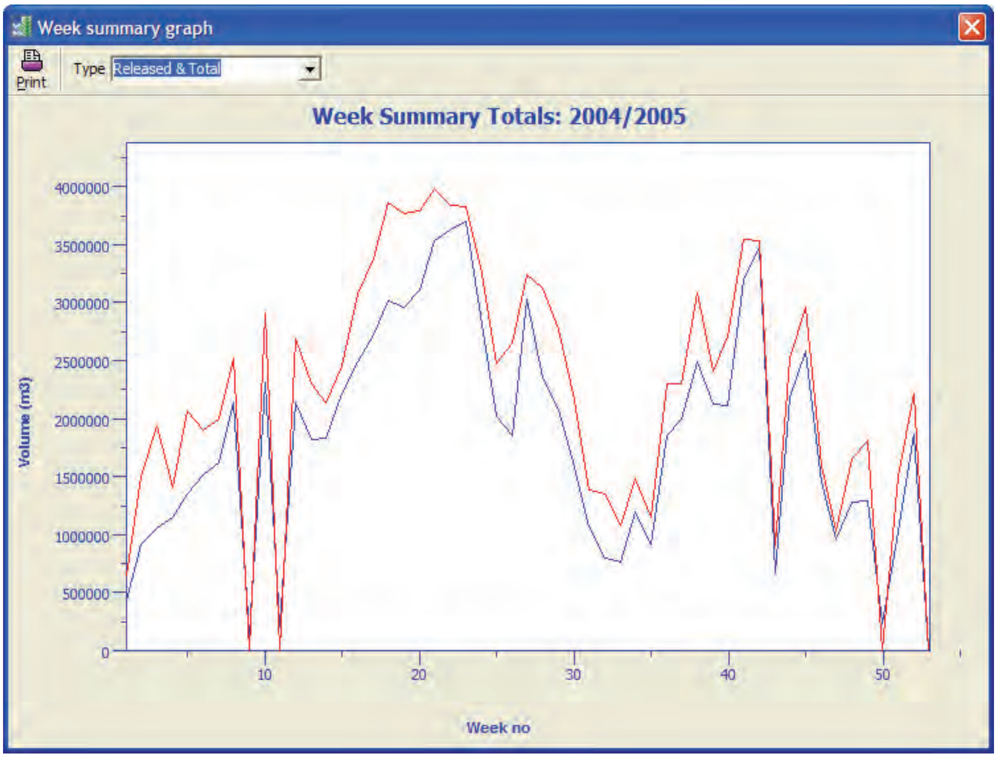

Figure 71: Loskop: Released vs. Ordered for 2004/2005

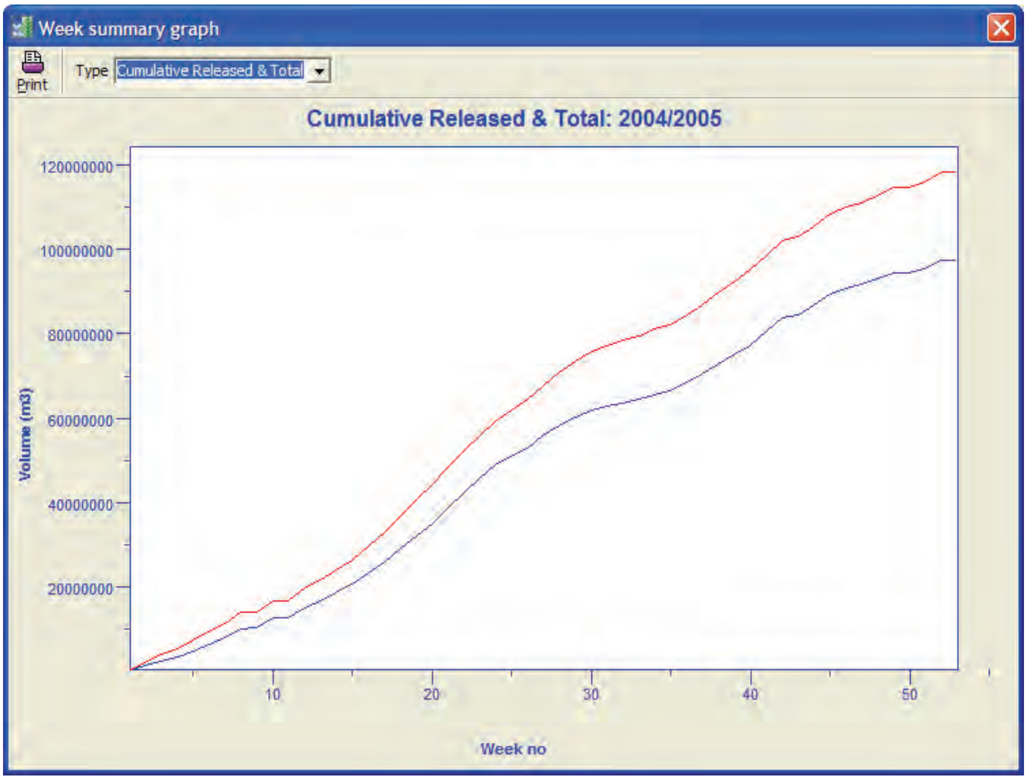

Figure 72: Loskop Cumulative Released vs. Ordered 2004/2005

8.2.3 Results

The total water loss from the dam wall to the farm edge is shown in Table 68, and illustrated in Figure 73 and Figure 74.

Table 68: Loskop Irrigation Board % loss summary period 2000 to 2005

Loskop Irrigation Board					
Year	**Quota (m³/yr)**	**Ordered (m³)**	**Released (m³)**	**Difference (m³)**	**% Loss**
2000/2001	123 346 303	120 066 103	150 635 473	30 569 370	20.3
2001/2002	123 346 303	118 108 993	130 889 884	12 780 891	9.8
2002/2003	124 047 003	126 200 417	160 757 342	34 556 925	21.5
2003/2004	62 122 447	59 307 750	86 055 269	26 747 519	31.1
2004/2005	124 244 893	97 613 397	118 532 099	20 918 702	17.6

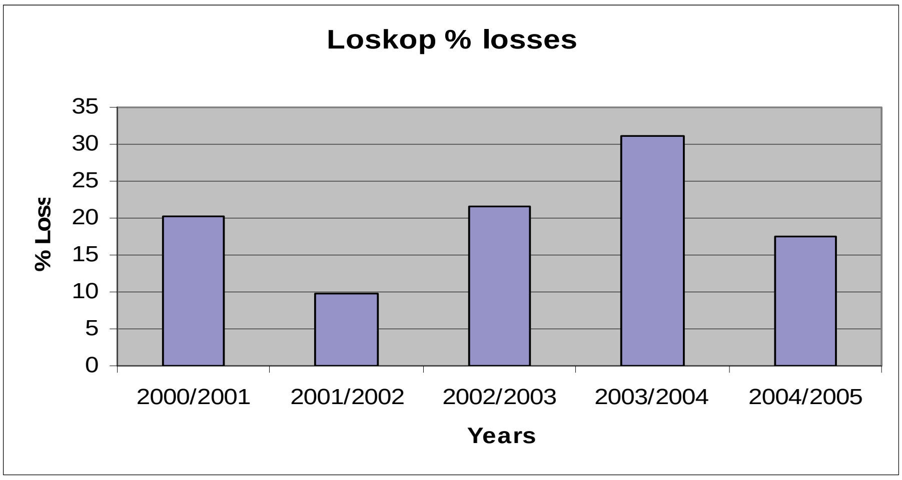

Figure 73: Loskop % loss graph for period 2000 to 2005

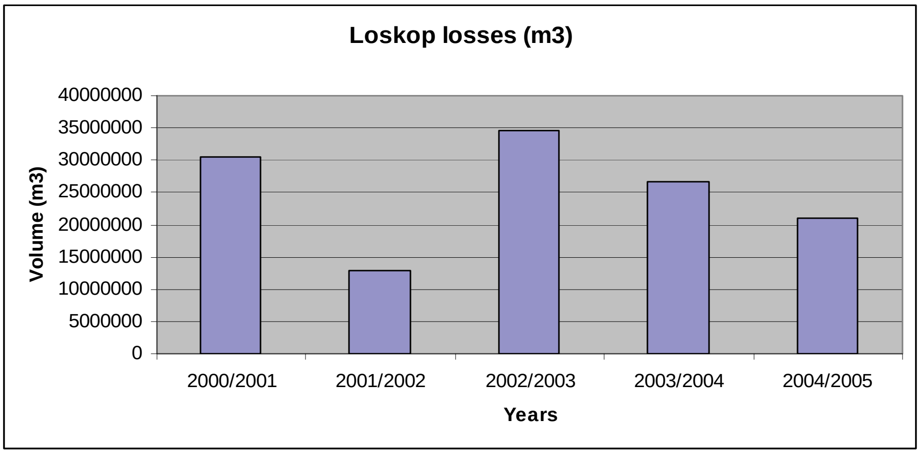

Figure 74: Loskop total losses for period 2000 to 2005

8.3 Irrigation systems

8.3.1 General

The results for the Loskop area are shown in Table 69 to Table 74.

Table 69: Scheme information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
L1	Centre pivot	Pumpkins	Not available	20,5	NA
L2	Micro sprayer	Grapes	18	NA	5,7
L3	Micro sprayer	Nuts	Not available	NA	8,4
L4	Drip	Grapes	22	NA	0,6
L5a	Micro sprayer	Peaches	Not available	NA	4,3
L5b	Micro sprayer	Peaches	Not available	NA	4,2
L5c	Drip	Peaches	Not available	NA	1,3
L5d	Micro sprayer	Peaches	Not available	NA	13,3
L5e	Drip	Peaches	Not available	NA	0,9

The general information gathered showed that all the pumps are in good working condition.

Table 70: Pumps

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
L1	70	Not measured	22	Yes	Yes	Good condition
L2	200	720	55	Yes	Yes	Drainage problems
L3	22	380	7,5	Yes	Yes	Good condition
L4	91	750	55	Yes	Yes	Good condition
L5	76	950	45	Yes	Yes	Drainage problems

8.3.1.1 Centre pivot

Table 71: General information

Test site code	Pressure regulators (Yes/No)	Operating pressure (kPa)	Flow rate (m^3/h)	Speed adjustment (%)		Gross application (mm)	
				Control box	Measured	Control box	Measured
L1	Yes	260	70	20	Not measured	24	20,5

Table 72: Test results

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured
L1	85	87,5	75	81	80	Not measured

8.3.2 Micro irrigation systems

Table 73: General information

Test site code	Type of micro system	Filter type	Emitter spacing (m)	Operating pressure measured (kPa)		Emitter discharge (ℓ/h)	
				Average measured (block)	Hydrant	Average measured (block)	Design
L2	Micro sprayer	Disc	3 x 2	81	140	33,9	Not available
L3	Micro sprayer	Disc	7 x 4	191	180	233,9	Not available
L4	Drip	Sand	3 x 1,8	112	Not measured	3	Not available
L5a	Micro sprayer	Sand	4 x 1,5	59	50	25,7	25
L5b	Micro sprayer	Sand	4 x 1,5	51	62	24,0	25
L5c	Drip	Sand	4 x 0,5	127	210	2,5	2
L5d	Micro sprayer	Sand	4 x 1,5	115	317	79,6	70
L5e	Drip	Sand	4 x 1,5	79	240	5,3	6

.

Table 74: Test results

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s(%)		EU(%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
L2	80	82	85	76	20	54	0,4	Not applicable
L3		96,5		95,4		26		Not applicable
L4		90,6		89,9		49		Not measured
L5a		77,7		64,6		80		Not applicable
L5b		74,1		63,5		101		Not applicable
L5c		84,2		80,1		51		Not measured
L5d		54,6		59,4		144		Not applicable
L5e		82,8		78,9		126		Not measured

8.4 Conclusion

The total water loss from the dam wall to the farm edge at Loskop is well within acceptable limits. The scheme is very well managed with excellent water distribution practices in place. The average water loss for the period from 2000 to 2005 is 20%. The really low loss of 9.8% in 2001/2002 is almost impossible for a manual water distribution system and it would not be surprising if tail end farmers experienced constant water shortages during that year.

It is also interesting to see that the highest water loss of 31.1% in 2003/2004 occurred when the scheme did not receive their full quota. This corresponds with the fact that lower flows in a canal leads to higher water losses.

Although the highest percentage loss occurred in 2003/2004, more water was lost in 2002/2003. This stresses the fact that a percentage loss can be deceiving and in this case it makes more sense to look at the actual volumes.

Loskop don’t use the WAS release module to calculate their water releases from the dam and it would be interesting to see if they could be a little bit more efficient if they did.

9 Northern Cape irrigation schemes

Two irrigations schemes from the Northern Cape were included in the project. These were the Oranje-Riet Water User Association (ORWUA) and the Vaalharts Water User Association (Vaalharts WUA / Vaalharts). This section will provide a brief description of both schemes, and some results of water balances that were completed during the project at a scheme level, as well as a description of some on-farm research that was conducted as part of a collaboration between another WRC project (*K5/1647 – Managing salinity associated with irrigation in selected areas of South Africa*).

9.1 Scheme backgrounds

An introduction and background of both ORWUA and Vaalharts WUA is presented in this section.

9.1.1 Oranje-Riet Water User Association

The ORWUA scheme, which has an irrigated area of 16 700 ha, is situated in South Africa at 24˚ 40'E and 29˚ 10'S and at an altitude of 1 200 m. The climate is semi-arid, annual rainfall is 400 mm and frost occurs regularly in winter. Annual reference ET_0 amounts to 1 556 mm and average daily ET_0 for peak month requirement is 6.8 mm per day.

The Orange-Riet WUA is divided into 5 sub-areas, information on which is summarised in Table 75 and shown in Figure 75.

Table 75: Sub-Areas of ORWUA

Sub-Region*	Developed Area (ha)	Sluices	Irrigators	Length of Canal (km)	Capacity (m^3/s)
Orange-Riet	3 970.00	58	44	112.4	15.6-13.2
Riet River Settlement	8 045.00	254	185	184.5	6.8-0.2
Scholtzburg	637.45	2	16	–	–
Lower Riet	3 937.94	–	51	–	–
Ritchie	96.80		75	10,1	2
Total	16 687.19	314	371	307	

When the scheme was developed during the 1940s, it was developed as a flood irrigation scheme with 25,6 ha farms on the sandy parts of the scheme and 17 ha on the clay parts, to be provided with water out of the Kalkfontein Dam. The water distribution system was lined right through and designed to provide enough water to the irrigators. It was found that the water supply out of the Kalkfontein dam was not secure enough and after many years of farming with only a portion of water, a trans-basin scheme was built which takes water from the Orange River and transfers it to the Riet River irrigation scheme. Further expansion of the scheme took place after this through additional areas where farms of 60 ha were sold. A portion of the area of expansion was also used to allow for the consolidation of smaller units into bigger units with 60 ha as the target size.

Water is supplied from the Orange River through a main canal of 15,6 m³/s capacity and stored in a balancing dam from where it is distributed by lined canals to the irrigators. Measuring devices, mostly crump weirs and some partial flumes are installed in the main canal and at the off takes of secondary canals. Off take at farm level is by means of sunken orifice sluice gates linked to long-crest weirs to stabilise flow height in the canals that serve farmers.

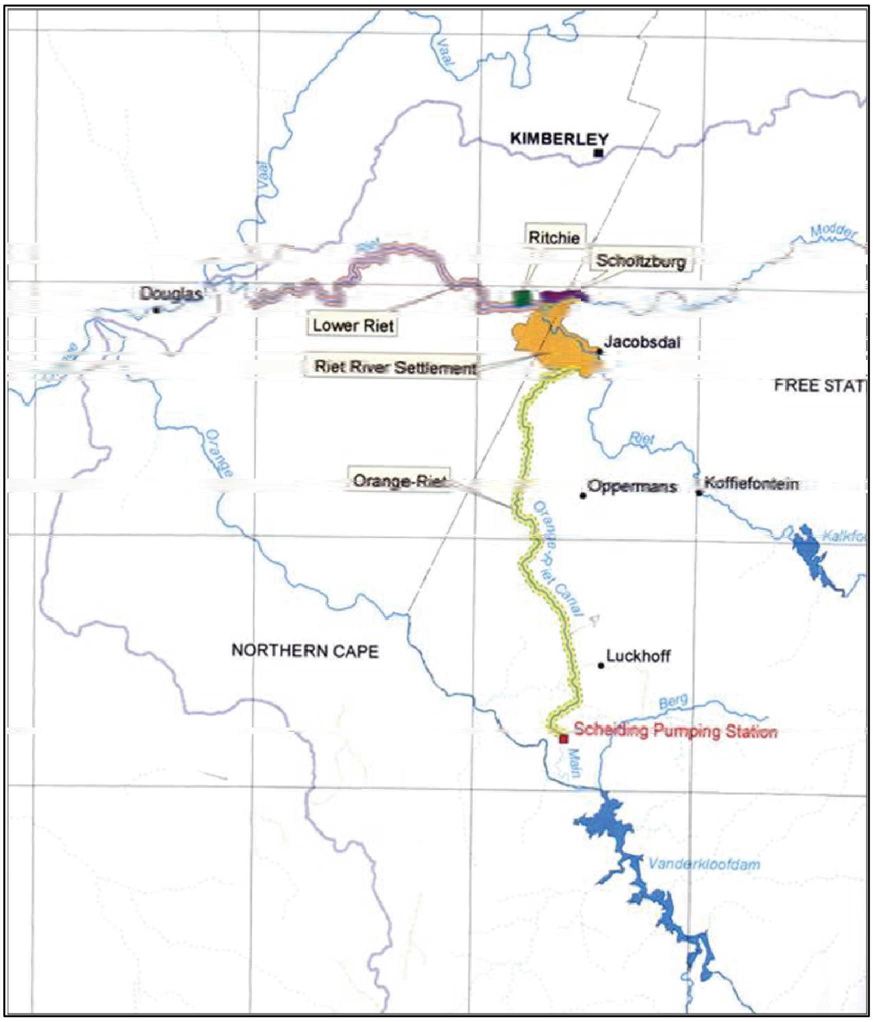

Figure 75: Water Management Areas in the Orange-Riet Region

The scheme has telemetric data capturing in place along the bigger canals, with the result that farmers can order their water as shortly as six to eight hours before they need it. Telemetric control of the sluices on the bigger canals is also used to ensure accurate water distribution and management. The result of this is a saving in manpower because fewer WCOs are required. Required flow rates for the different canals are calculated on the basis of orders and water control officers of the WUA opens and closes sluice gates accordingly. At farm level the farmers are responsible for operating the sluice gates that service their farms. A water balance budget is kept for each user, users pay for water used on a volumetric basis.

On farm the farmers have some leeway in the irrigation of their crops so that irrigation can take place according to crop irrigation requirement. However, controlling water use by irrigators along the Orange-Riet canal and along the Lower Riet River is difficult because water extraction in these areas is not metered.

Crop farming at ORWUA usually consists of wheat and maize that are grown as follow-up crops in a single year. Sometimes potatoes are planted on a smaller scale in the place of maize during this cycle. This cycle of two major crops in one year has a tendency to shift so that every so often the farmers have to leave an area fallow to get the system back on track. Where lucerne is part of the farming system, a cropping cycle is usually followed where the lucerne areas are replaced over time by grain crops and the grain crops areas over time by lucerne.

The soil-climate-water quality combination as well as great distances to bigger fresh produce markets has limited the production pattern to mainly grain crops and lucerne with some groundnuts, potatoes and wine grapes on a smaller scale.

Soils on the flood plains, about 12% of the area, of the Riet River have high clay content. The area outside the flood plain covers about 88% of the total area. The soil is mainly sandy with some calcium carbonate layers below which act as water traps resulting in occasional waterlogging and salinity problems that is found on about 4% of the area. Installing subterranean drains on farms which link up to main drainage channels and improvement in irrigation scheduling over time has contained this problem to some extent. Some of the drains are blocked, but those that flow drains into the Riet River. The scheme itself also supplies water to irrigators who pump water out of the lower reaches of the Riet River. This irrigation water dilutes the drainage water that flows into the river. Irrigation scheduling services are provided and it is estimated that about 5% of the farmers make use of this service. Apart from irrigation scheduling services mainly provided by GWK, the Department of Agriculture also provides information on expected water use that could be used as an aid to irrigation scheduling. It is unknown how many farmers make use of this service.

Flood irrigation on the older parts of the scheme has mostly been replaced by centre pivot irrigation, while all new development was centre pivot. In most cases permanent crops are under micro and drip irrigation systems.

The methods of irrigation are summarised per sub-area in Table 76.

Table 76: Orange-Riet Irrigation Methods Percentage

Sub-Area	Total Developed Area in ha	Centre Pivot %	Flood Irrigation %	Sprinkler Irrigation %	Micro-Jet Irrigation %
Orange-Riet	3 970.0	95	0	5	0
Riet River	8 045.0	60	20	19	1
Scholtzburg	721.6	70	20	10	0
Lower Riet	3 937.9	70	20	10	0
Ritchie	96.8	0	75	25	0

9.1.2 Vaalharts irrigation scheme

This scheme of 34 704 ha irrigated area is situated in South Africa at 24˚ 45'E and 27˚ 45'S and at an altitude of 1 100 m. The climate is semi-arid, annual rainfall is 475 mm and frost occurs regularly in winter. Annual reference ET_0 amounts to 1 545 mm and average daily ET_0 for peak month requirement is 6.3 mm per day.

The soils are mainly sandy with calcium carbonate layers below which act as water traps resulting about 33% of the area experiencing serious water logging and salinity problems. Installing subterranean drains on farm which link up to main drainage channels and improvement in irrigation scheduling over time has contained this problem to some extent. However, the drainage water drains into the Harts River, from where it flows to the Spitskop dam and from where poor quality irrigation water is extracted for 1 663 ha. Upstream of the Spitskop dam another 2 468 ha are irrigated with drainage water pumped out of the Harts River. Irrigation scheduling services are provided and it is estimated that about 5% of the farmers make use of this service. Over time, different variants of evaporation pans have been used as a guide to irrigation scheduling.

The soil-climate-water quality combination as well as great distances to bigger fresh produce markets has limited the production pattern to mainly grain crops, lucerne, groundnuts, cotton and with potatoes, wine grapes and deciduous fruit on a smaller scale. Small areas with suitable microclimate conditions and where soils are suitable are used for farming with citrus fruit. Production of pecan nuts takes place on a small scale and olives have started coming in on a small scale as an alternative crop.

When the scheme was developed in the late 1930s, it was developed as a flood irrigation scheme with 30 morgen (25.7 ha) farms. The water distribution system was lined right through and designed to give water one day per week per farm on the community canals. Most farms had an overnight dam for short-term storage of water, the usual capacity being enough to store the water delivered during the night. A general tendency has developed where financially stronger farmers buy out weaker farmers, so that very few of the original "one-farm" enterprises exist, with the result that the average irrigation enterprise size is now about 68 ha.

Flood irrigation has to some extent been replaced by mainly centre pivot irrigation. Vineyards and orchards are irrigated by micro spray and drip systems. The estimated extent of each is 60% flood, 35% centre pivot and 5% micro and drip systems. Difference of opinion of the extent of the irrigation systems is found, no formal survey has been conducted over the last number of years and some commentators estimate the extent of centre pivot irrigation to be as high as 60%. Farmers who make use of irrigation scheduling services and who have installed irrigation systems where better water control and a better distribution efficiency is easier to attain than with flood irrigation systems, report increases in crop yield of about 30%, however, these claims have not been confirmed through unbiased measurement.

At the bottom end of the scheme and area that was previously part of a homeland area is also irrigated. This area, known as Taung, is 3 750 ha in extent and is farmed by 400 emerging farmers as well as developing commercial farmers. The inclusion of the statistics of this area into the Vaalharts statistics tends to skew the picture regarding benchmark indicators.

Farmers order water at the latest on Thursdays for supply during the next week. They can order additional water during the week for supply during the next day. Required flow rates for the different canals are calculated on the basis of orders and WCOs of the WUA open and close sluice gates accordingly. A water balance budget is kept for each user, although users pay a fee per unit area of the irrigated area and not per unit of water used.

On farm the farmers irrigate when they get their water. The system of getting water once a week, usually on specific days of the week, coupled with limited storage capacity, limits the farmer's management options to those that can be undertaken within the management pattern of the distribution system.

9.2 Conveyance system

The conveyance systems at both ORWUA and Vaalharts are cement lined canals. Both schemes also make extensive use of the WAS database. The approach which was used to assess scheme level performance was based on computing a water balance with data that was captured in the WAS database. All irrigation system performance assessments rely on some form of water balance over the area considered (Small and Svendsen, 1992; Clemmens and Burt, 1997; Burt, 1999) and water balance approaches for assessing irrigation system performance have been widely used. Burt (1999) defines a water balance as a process that accounts for all the water volumes entering and leaving a 3-dimensional space over a specified period of time. This approach also needs to account for internal changes in water storage over the specified period of time. Therefore, it can be concluded that both the spatial and temporal components are important. However, a third element, viz. the functional boundary can also be considered in the interpretation of a water balance. Small and Svendsen (1992) state that performance assessment boundaries can also be defined according to:

i. the functions performed by the irrigation system, and

ii. the processes involved in creating and sustaining the irrigation system during its lifetime.

These two additional criteria have importance in that they are used to differentiate responsibilities for water management in an irrigation scheme. For example, a water user association would be responsible for water management from the scheme off take to the farm boundary. From the farm boundary onwards, the water management responsibility is handed over to the farmer. Often, these functional responsibilities are aligned with the geographical boundaries required for the water balance. For example, when a conveyance system is assessed, it should be noted that the boundary for functional management lies with the water user association and has nothing to do with an individual farmer. The opposite occurs when assessing a specific farm, where the water user association has no input. Therefore, from a geographical and functional perspective, the boundary is very similar.

From a timescale perspective, defining the correct temporal boundaries for an assessment is as important as defining the correct spatial boundaries. All the sources and destinations of water in a water balance change from one year to another (Burt, 1999) and within a year. Therefore, the duration of an assessment, i.e. per irrigation event, per month, per season, or per year, needs to be specified accordingly.

From the classic water balance perspective, it was not possible to accurately determine the conveyance efficiency of the Vaalharts WUA and ORWUA conveyance infrastructure at a small timescale with a water balance approach. This was due to the large size of the schemes coupled with a lack of accurate water meters at individual farm off takes. However, it was possible to determine, with a water balance methodology, the volume of water that could not be reasonably accounted for in the schemes. The manner in which these components were used investigate scheme level performance at the geographical and functional boundary separating scheme from farms at ORWUA and Vaalharts WUA is presented in the next two sub sections.

9.2.1 Vaalharts Sample Results and Discussion

At Vaalharts WUA, individual water orders are captured within the WAS database at a weekly timescale. The inflow to the scheme is also measured at a DWAF gauging weir (DWAF weir number C9H018). Therefore, the difference between the water orders, metered users and tail ends; and the water inflow, can be calculated. This process was completed at a weekly time scale for all the seasons from 2003/2004, to 2008/2009. The annual results of this analysis are provided in Table 77. It must be noted that the results presented in Table 77, and in later figures in this section, are based on data extracted from the WAS database, and as such do not include many aspects of the water balance. The results and the associated water balance trends graphs are an attempt to show potential benefits of interpreting water balances at a fine time scale to identify any patterns that may emerge. *They should not be viewed as absolute results which reflect actual volumes and percentages*.

Table 77: Annual water balance results for Vaalharts WUA based on WAS data

Season	Accountable Water ($m^3 \times 10^3$)	Water Inflow ($m^3 \times 10^3$)	Unaccountable Water ($m^3 \times 10^3$)	Percentage Unaccountable water (%)
2003/2004	325,334.7	443,535.3	118,200.6	26.6
2004/2005	268,883.3	405,587.1	136,703.8	33.7
2005/2006	231,831.7	339,963.8	108,132.1	31.8
2006/2007	326,710.7	433,947.1	107,236.4	24.7
2007/2008	239,245.6	351,412.9	112,167.4	31.9
2008/2009	312,839.5	397,952.2	85,112.7	21.4

The weekly water balance trends graphs are presented in the following figures:

- 2003/2004 season – Figure 76
- 2004/2005 season – Figure 77
- 2005/2006 season – Figure 78
- 2006/2007 season – Figure 79
- 2007/2008 season – Figure 80
- 2008/2009 season – Figure 81

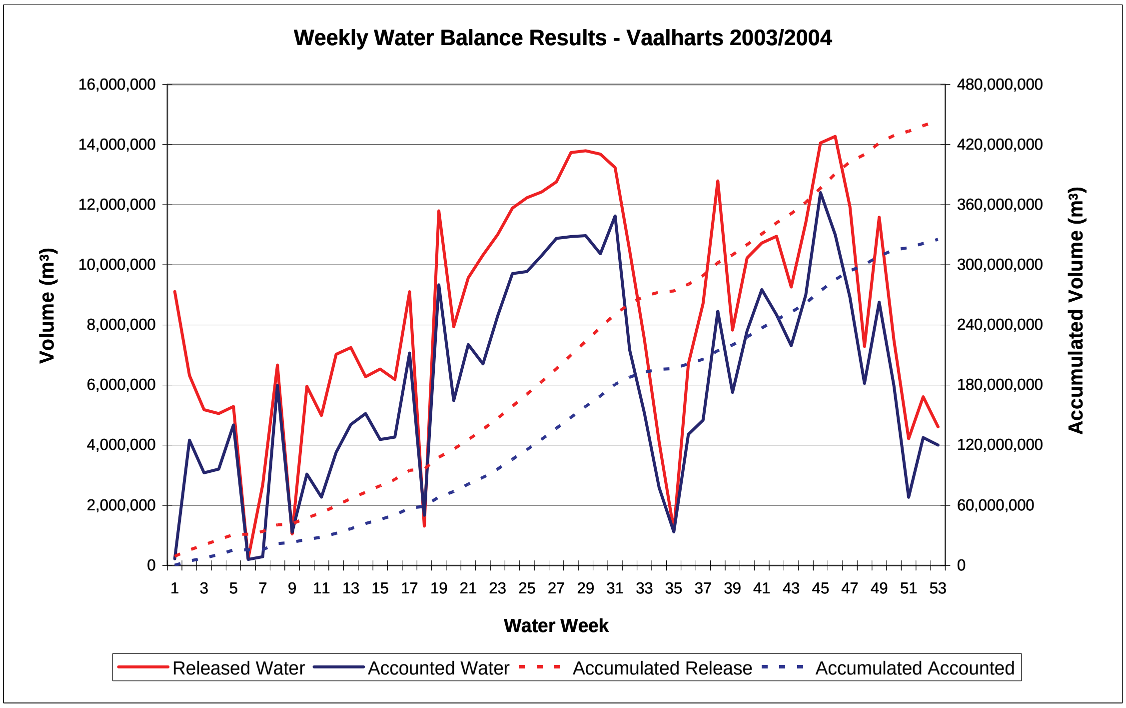

Figure 76: Weekly water balance results for Vaalharts WUA – 2003/2004 (data source: WAS Database)

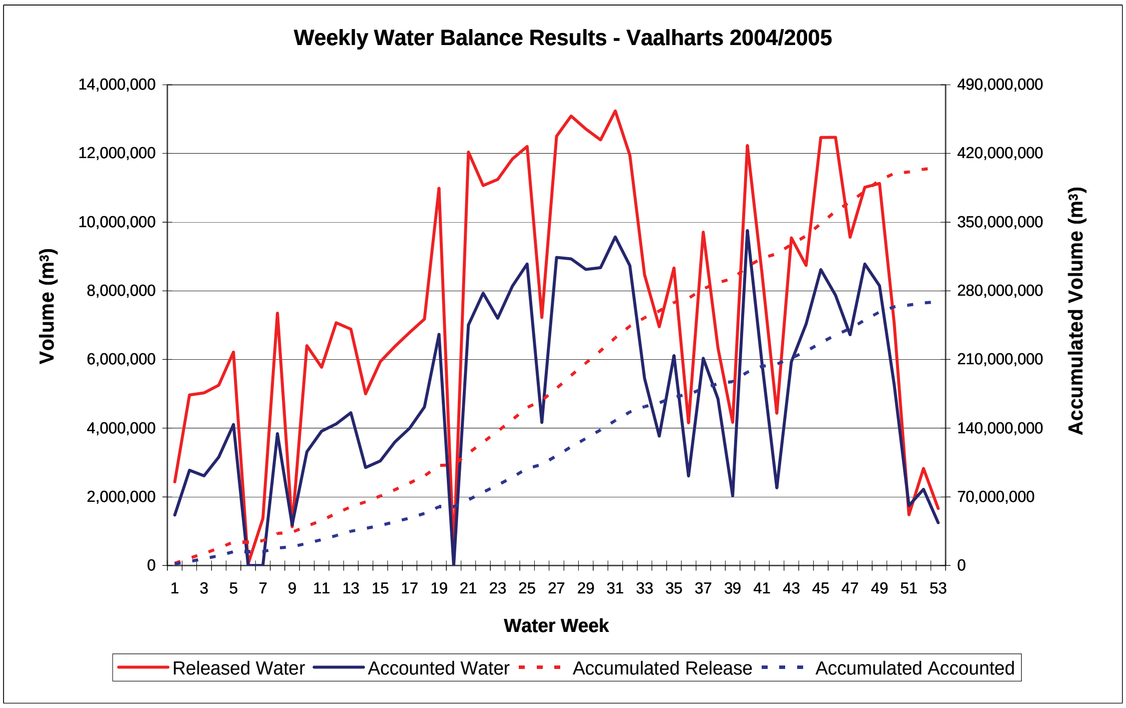

Figure 77: Weekly water balance results for Vaalharts WUA – 2004/2005 (data source: WAS Database)

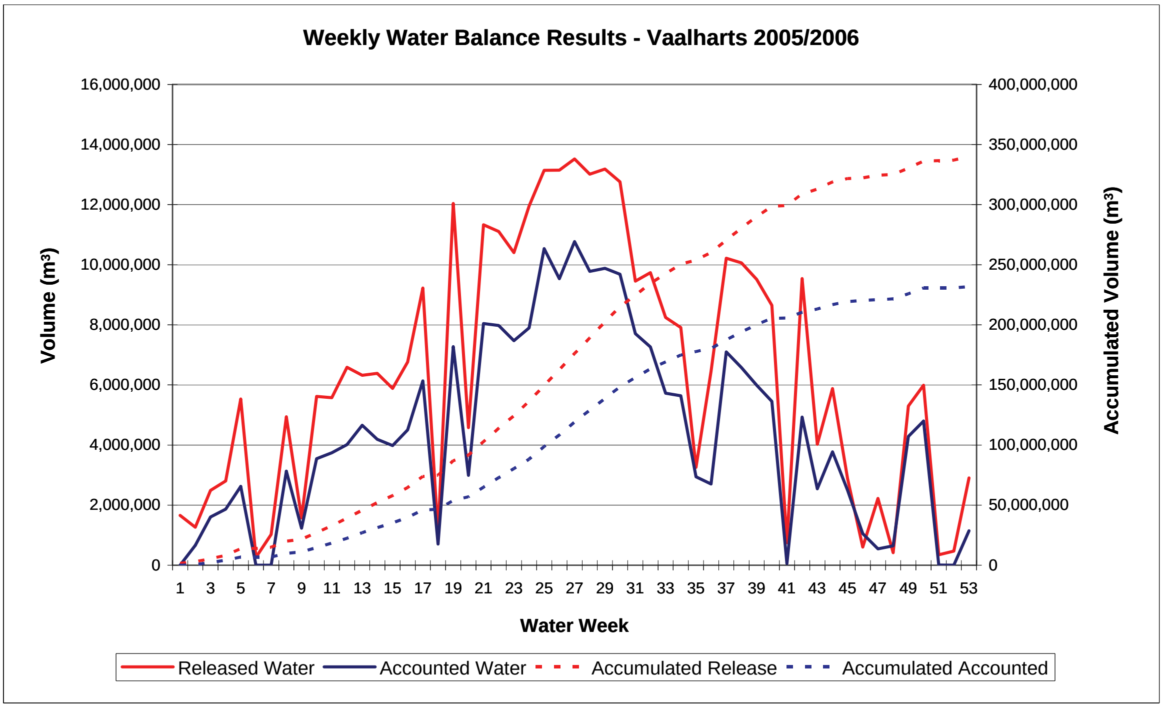

Figure 78: Weekly water balance results for Vaalharts WUA – 2005/2006 (data source: WAS Database)

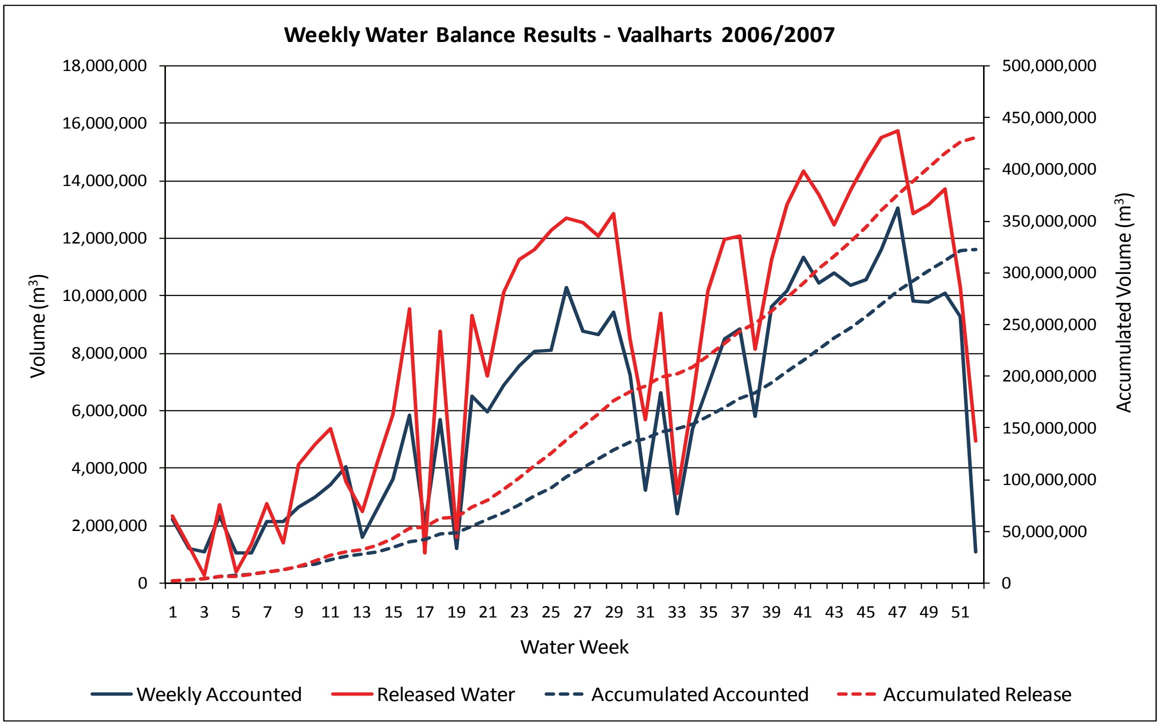

Figure 79: Weekly water balance results for Vaalharts WUA – 2006/2007 (data source: WAS Database)

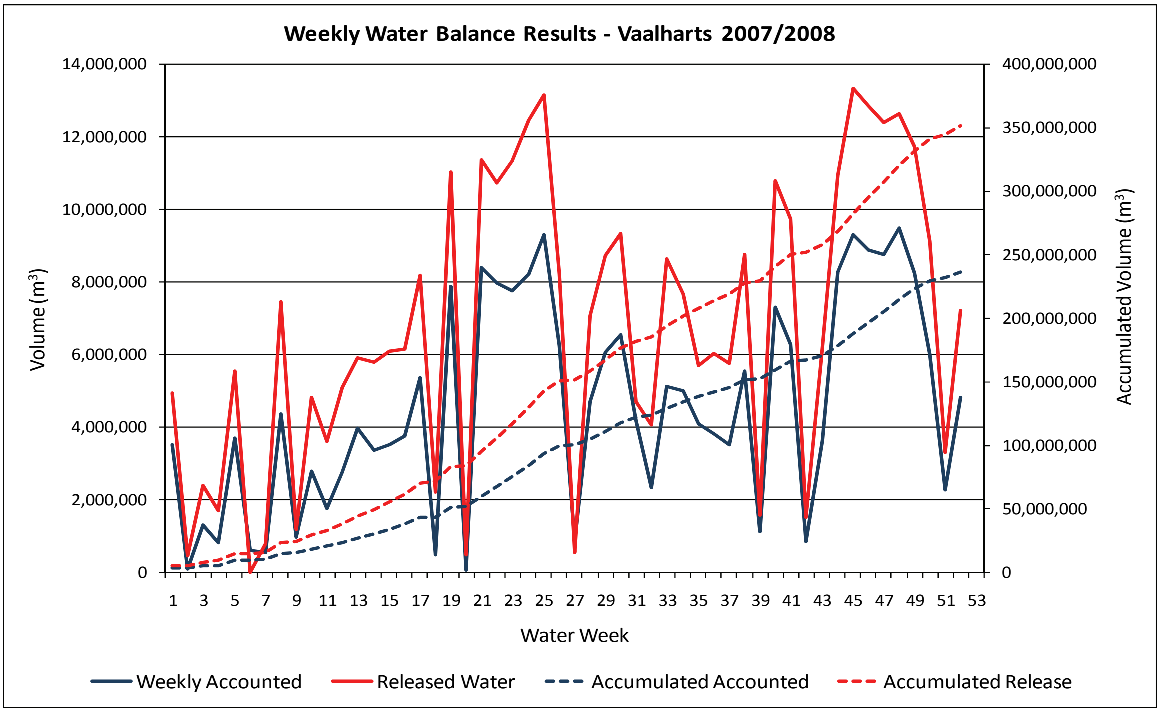

Figure 80 : Weekly water balance results for Vaalharts WUA – 2007/2008 (data source: WAS Database)

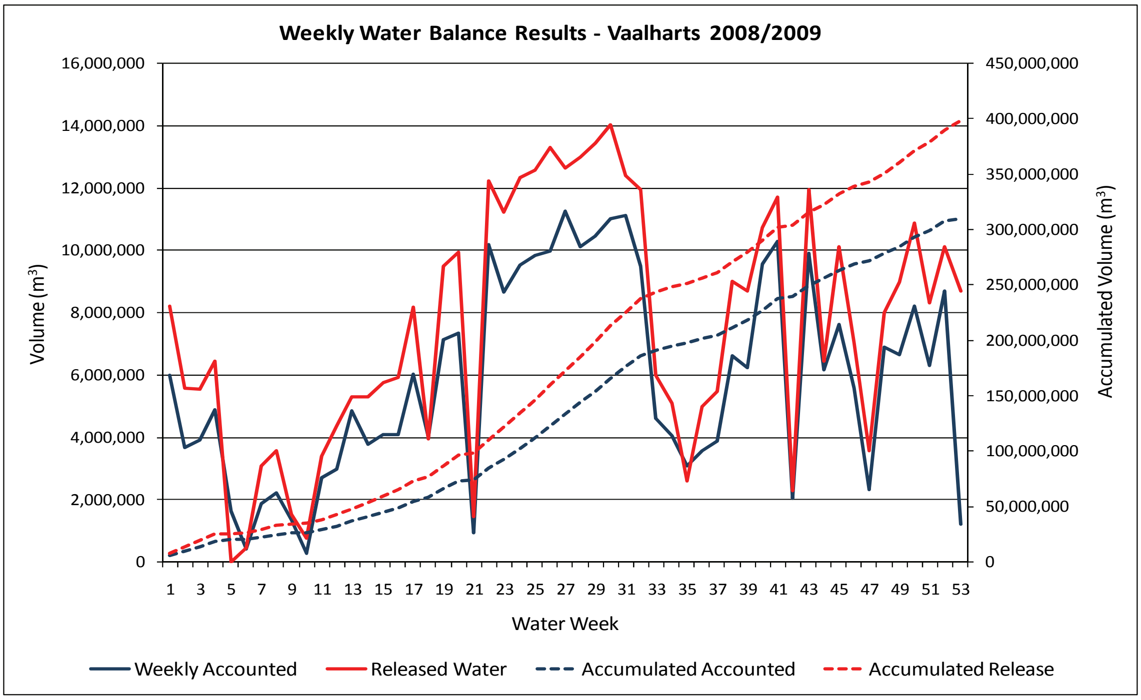

Figure 81: Weekly water balance results for Vaalharts WUA – 2008/2009 (data source: WAS Database)

The weekly water balance results that have been presented show that the trend of water use and water supply at Vaalharts are very similar. Generally the supply was very well matched to the demand. One aspect that is also revealed is the impact of the change in storage on the variability in the unaccounted for water over any one year. As an example to highlight this, Figure 82 is a weekly percentage graph of unaccounted for water for the 2008/2009 year. The variability compared to the annual average result is clearly visible. Scheme managers should therefore remember the impact that the change in storage can have on water balance results, especially at a fine time scale such as a week.

For improved water balances, other components would need to be estimated at Vaalharts, for example balancing dam and canal seepage. However, these two components are the most difficult components of the water balance to quantify (ANCID, 2000). Traditionally, once all the other components have been determined, i.e. pumped inflows and outflows, surface water evaporation, change in storage and addition by rainfall; the remaining water volume is assumed to be lost via seepage from dams and canals.

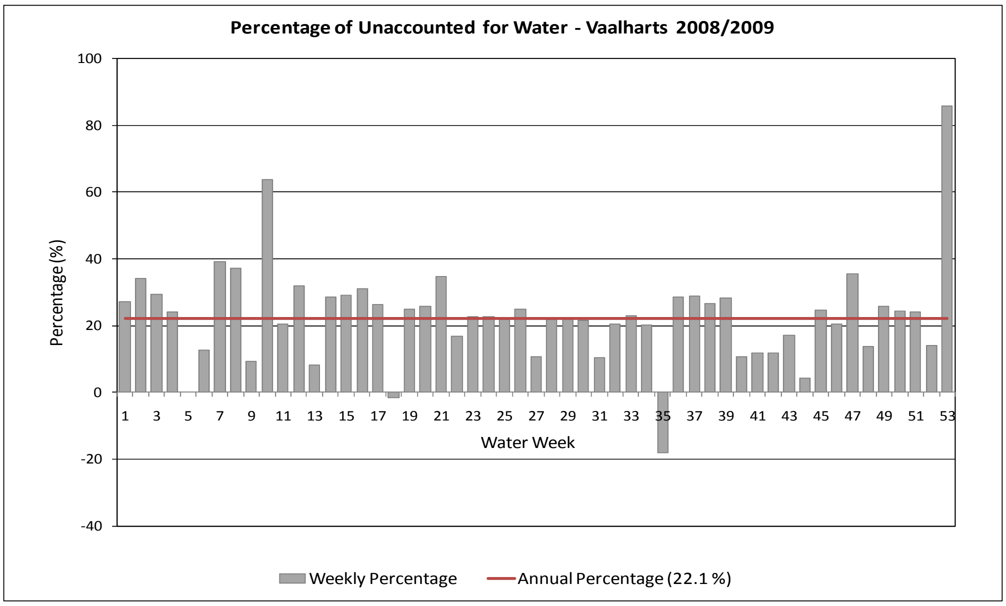

Figure 82: Example – Weekly Unaccounted Water Percentage for Vaalharts WUA – 2008/2009 (data source: WAS Database)

Interactions with stakeholders at the Vaalharts WUA identified the following aspects as potential Best Management Practices (BMPs) that could be used to improve performance at a scheme level:

1. Updated data files on irrigators,
2. More accurate water measurement for water delivery, outflows/overflows and drainage,
3. Reducing water losses out of canals by sealing,
4. Accurate crop information to be used in planning of water supply,

5. Telemetric control of major take-off points in the canal-system, and

6. Water delivery on demand and payment of water on a volumetric basis for water actually delivered.

An improved level of water delivery performance, and an understanding on the rate of water use, will become possible if certain of these potential BMPs are implemented. Accurate monitoring and control of water in the canal network would improve the level of unaccounted for water. However, this could only be achieved together with proper planning and understanding of likely water demand in the short and longer term future. The planning process would need to include a simulated crop water demand based on accurate crop area and planting date information collected from individual users for the forthcoming seasons. Therefore, the implementation of the BMPs that aim to update data files on irrigators and determine accurate crop information to be used for planning purposes are important if water management at Vaalharts WUA is to be improved. A WRC technology transfer project had facilitated a GIS database of the Vaalharts WUA for this purpose. The results of this project could be used to investigate the crop water demand pattern of Vaalharts WUA in the future and assess the likely improvements of this BMP if implemented. At present the level of planning at Vaalharts does not include an analysis of future crop water demands.

A further BMP that is currently being implemented at the scheme is the use of the water release module within the WAS model to improve the timing and magnitude of water releases into the scheme. The impact of this BMP on water losses at the scheme can be was illustrated by comparing the results from the 2003, 2004 and 2005 seasons; with those of the 2006, 2007 and 2008 seasons, where a reduction in the level of unaccounted for water was observed.

9.2.2 ORWUA Sample Results and Discussion

Water for the ORWUA originates from the Vanderkloof Dam. It is pumped at the Scheiding Pumping Station into the Orange-Riet Canal. The canal then flows towards the Riet River Settlement, where it spills into a large balancing dam. There are many irrigators that abstract directly off the Orange-Riet Canal prior to it reaching the balancing dam. From the balancing dam, water is distributed to the irrigators in the Riet River settlement via a complex canal network. Water is also distributed through the canal network and spilt directly into the Riet River to supply the Scholtzburg, Ritchie and Lower Riet Users. Only the users in the Riet River Settlement place a weekly water order with the ORWUA. However, all irrigators in all the different sections supply the ORWUA with crop, area and planting date information.

From this brief description, it can be seen that the same water balance approach that was possible at Vaalharts WUA is not feasible at ORWUA. Not all the water users place an order; therefore the water orders cannot be directly compared to the water pumped at the Scheiding pump station to determine the volume of water that cannot be accounted for. The reason for this is that the scheme management at ORWUA are using crop type, area and planting date information to determine how much extra water to release for the Orange-Riet Canal users, the Scholtzburg and Ritchie users, and the Lower Riet River users. This calculation is achieved in the crop water use module in the WAS program. Table 78 and Table 79 below show the results of some water balances for certain water years between 2003 and 2008 computed with the WAS model. Table 78 shows the results of comparing all water order and meter information to the total volume of water pumped at the Scheiding pump station. Table 79 shows the results from comparing the theoretical crop water use requirement of all the irrigators in the ORWUA to the total volume pumped at Scheiding pump station. It must be noted that the results presented in Table 78 and Table 79, and in later figures in this section, are based on data extracted from the WAS database, and as such do not include many aspects of the water balance. The results and the associated water balance trends graphs are an attempt to show potential benefits of interpreting water balances at a fine time scale to identify any patterns that may emerge. *They should not be viewed as absolute results which reflect actual volumes and percentages.*

Table 78: Annual water balance results for ORWUA based on WAS data

Season	Accountable Water (m^3 x 10^3)	Water Inflow (m^3 x 10^3)	Unaccountable Water (m^3 x 10^3)	Percentage Unaccountable water (%)
2003/2004	84,759.9	236,127.1	151,367.2	64.1
2004/2005	88,404.5	233,085.2	144,680.7	62.1
2005/2006	Not Investigated	Not Investigated	Not Investigated	Not Investigated
2006/2007	Not Investigated	Not Investigated	Not Investigated	Not Investigated
2007/2008	118,354.5	248,280.9	129,926.4	52.3
2008/2009**	119,356.5	234,175.0	114,818.5	49.0

** Water Inflow unreliable due to faulty measuring instrument

The results in Table 78 above seem poor with percentages of unaccounted for water as high as 64.1 for 2003/2004 season. The reasons for this large percentage have already been highlighted because of not all users placing water orders. However, if the crop water use module in WAS is used together with crop type, area and planting date information, better results are obtained when the water use by crops is compared to water inflow. These results are presented in Table 79.

Table 79: Annual water balance results for ORWUA with crop water use data

Season	Crop Water Use (m^3 x 10^3)	Water Inflow (m^3 x 10^3)	Unaccountable Water (m^3 x 10^3)	Percentage Unaccountable water (%)
2003/2004	213,238.4	236,127.1	22,888.7	10.7
2004/2005	199,204.4	233,085.2	33,880.8	14.8
2005/2006	Not Investigated	Not Investigated	Not Investigated	Not Investigated
2006/2007	Not Investigated	Not Investigated	Not Investigated	Not Investigated
2007/2008	Not Investigated	Not Investigated	Not Investigated	Not Investigated
2008/2009	Not Investigated	Not Investigated	Not Investigated	Not Investigated

From Table 79 it can be seen that the volume of unaccounted for water was reduced to 10.7 and 14.8% for the 2003/2004 and the 2004/2005 seasons.

The temporal distributions of both these water balance methodologies for the 2003/2004 and the 2004/2005 seasons are presented on the following two pages. The symbology of the figures is the same as that of Vaalharts WUA.

Figure 83 shows the water balance results using water orders and metered water use. Figure 84 shows water balance results using crop water demand. Both figures are for the 2003/2004 season.

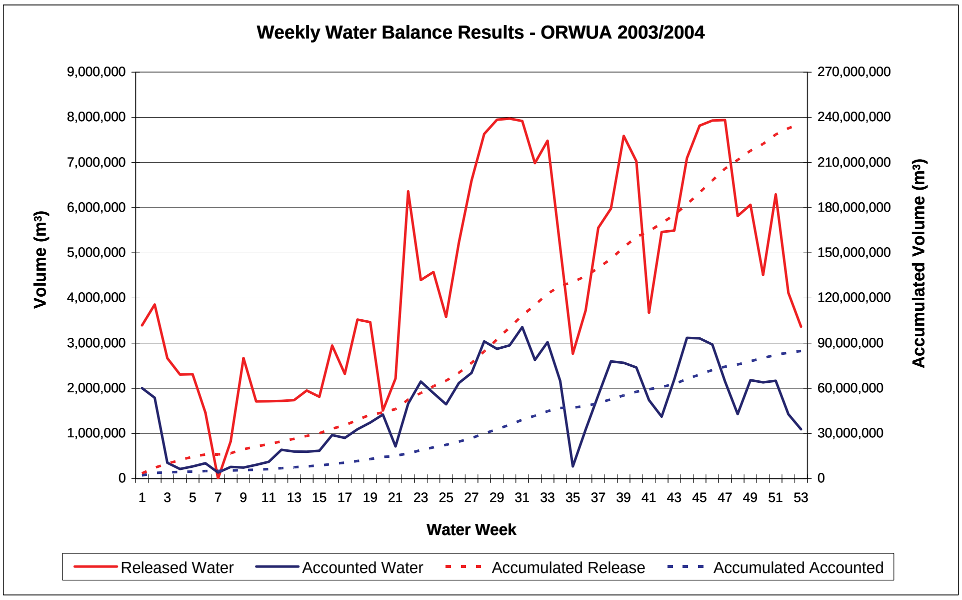

Figure 83: Weekly Water balance results for ORWUA – 2003/2004 (data source: WAS Database)

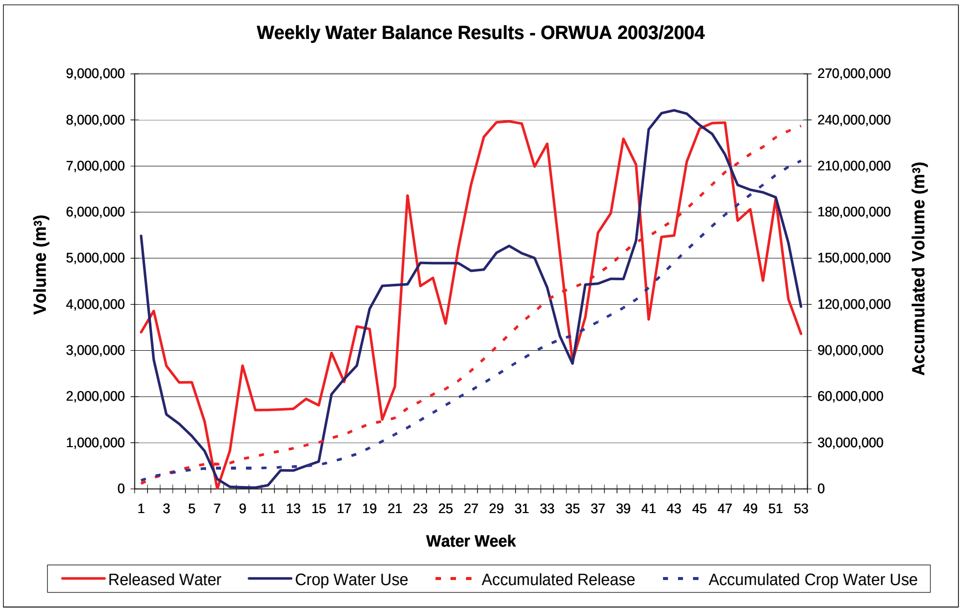

Figure 84: Weekly Water balance results for ORWUA – 2003/2004, comparing theoretical crop water use and released water (data source: WAS Database)

Figure 85 shows the water balance results using water orders and metered water use. Figure 86 shows water balance results using crop water demand. Both figures are for the 2004/2005 season.

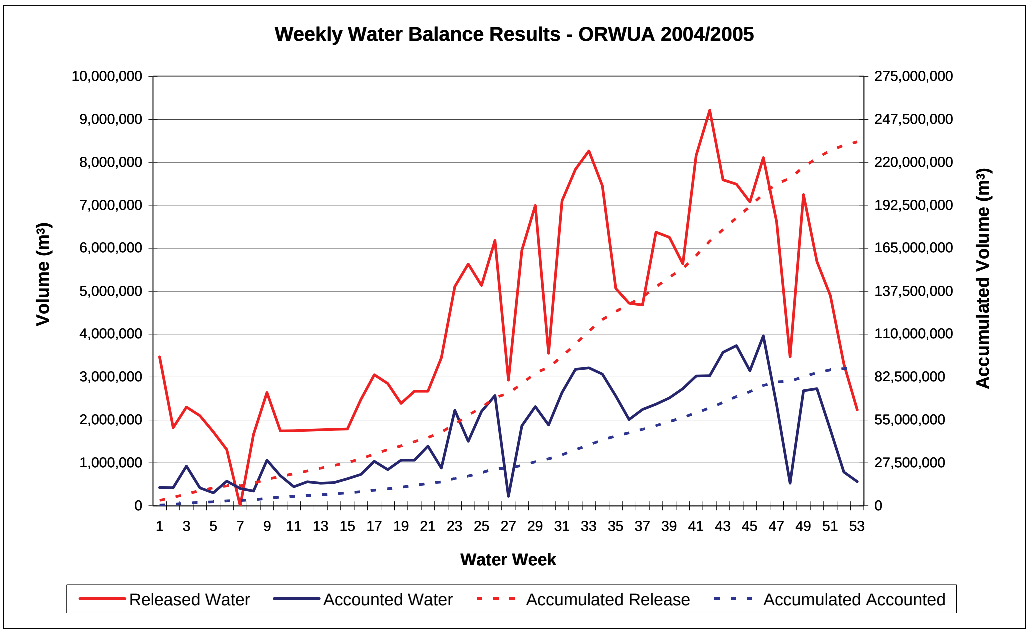

Figure 85: Weekly Water balance results for ORWUA – 2004/2005 (data source: WAS Database)

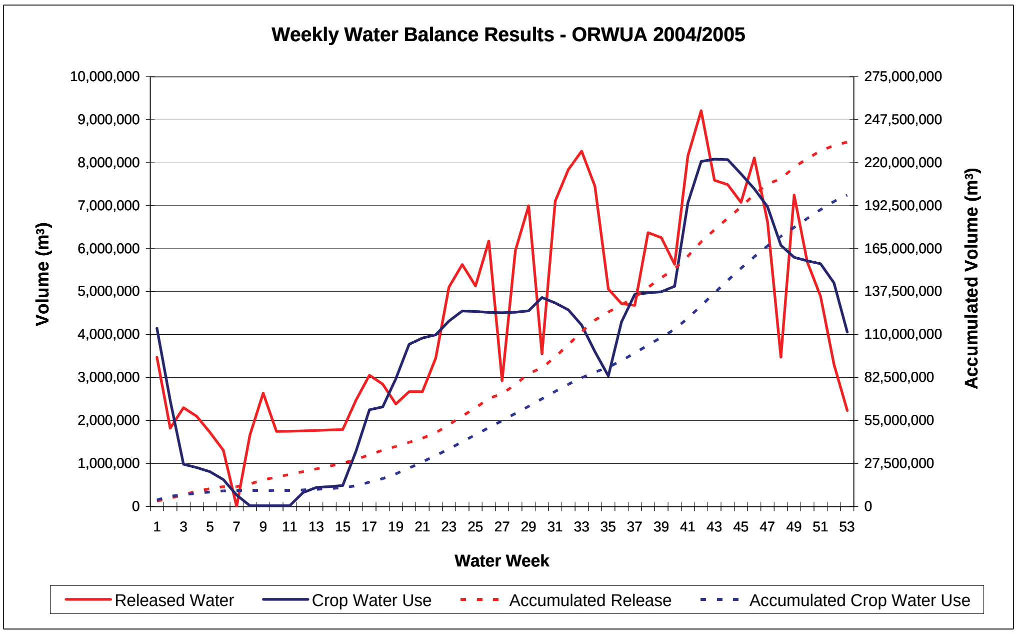

Figure 86: Weekly Water balance results for ORWUA – 2003/2004, comparing theoretical crop water use and released water (data source: WAS Database)

The weekly water balance graphs for types of water balance methodologies are similar for both 2003/2004 and 2004/2005. If just the water orders and water meters are used, it appears that the scheme has large volumes of water that cannot be accounted for. However, when the crop water demand is compared to the water released, the situation improves markedly. Whilst the water released does not follow the crop water demand very closely, the general trend is matched. This is likely to be caused by the model not taking rainfall into account in the crop water demand calculation. This assumption would lead to discrepancies in the calculation and comparison to released data at a weekly scale.

The actual efficiency of water delivery at ORWUA is higher than depicted in this sample exercise.

Table 80 below is a water balance report showing all components of the water balance typically taken into account at the scheme. It can be seen that the weekly water balance approach is not suitable for use at ORWUA due to the large number of components not captured in WAS at the time of the sample exercise.

Table 80: Water Accounting Report 2002/2003 (after DWAF, 2004)

Water Accounting Items:	**Total Year 2002/2003 m^3/a**	**Accuracy 1 to 3***
Inflow to Orange-Riet		
Abstraction: *Scheiding pump station*	226 180 720	3
Supplementary inflows:		
Modder river	31 414 590	3
Kalkfontein WUA	0	1
Groundwater	None	
Abstraction direct from dam *(Not applicable for losses)*	None	
Gross Inflow to Orange-Riet	257 595 310	
Storage change		
Storage change in reservoirs and balancing dams	None	
Net Inflow to Orange-Riet	**257 595 310**	
Consumptive use		
Irrigation	197 810 200	2
Municipalities		3
Industry	1 340 410	3
Domestic and Stock Water	1 278 850	1
Committed to downstream use	None	
Other (specify) *Diggers*	1 100 000	2
TOTAL Consumptive use	201 529 460	
Non-consumptive use (waters used, but not producing outputs for human processes)		
Beneficial		
Ecological uses (e.g. indigenous riverside vegetation)	None	
Non-beneficial		
Alien vegetation	Unknown	
Evaporation	3 594 450	1
Seepage not useful downstream	7 188 900	1
Operational spills (estimated fraction of operational spills not re-usable)	38 093 600	1
Operational loss (leakage and management losses)	7 188 900	1
TOTAL Non-consumptive use	56 065 850	
Total Use	**257 595 310**	
*1 = Estimation, 2 = Inaccurate measurement, 3 = Accurate measurement		

Interactions with stakeholders at the ORWUA identified the following aspects as potential BMPs that could be used to further improve performance at a scheme level and are in the process of being implemented by ORWUA:

1. Additional telemetric control of the sluices at the major take-off points in the canal-system,
2. Improved water measuring in areas where not yet installed, and
3. Calibration of selected farm turnout sluices.

The high level of water management, and in particular the detailed information on crop types, areas and planting dates per individual farmer in the scheme, is a BMP that is being effectively implemented at ORWUA. Improving water measurement in areas where scheme management is relying on simulated crop water demand to determine water use, should improve the level of water management even further. However, the cost benefits of such installations would need to be investigated to determine whether they were warranted or not.

9.3 Irrigation systems

The on farm level investigations into irrigation systems performance was achieved as part of collaboration between this project (K5/1482/4) and another WRC project (*K5/1647 – Managing salinity associated with irrigation in selected areas of South Africa*). In-field irrigation systems performance assessments, which were conducted by the ARC in 2007, were used together with detailed field level water balances to analise irrigation practices and the impact on water, yield and salts at a farm, and thereafter scheme level (via an up scaling process).

Table 81 is a summary of the on farm sites at which equipment was installed in 2007 and for which data has been collected in 2008.

Table 81: Summary of locations with in-field measurement at Vaalharts WUA and ORWUA

Irrigation Scheme	Case study	Case study drained	Crop production	Irrigation system	Irrigation water	Soil type	Mean silt-plus-clay (%)	Number of experimental plots in each land
Vaalharts WUA	V(i)	yes	Lucerne	Flood	Vaal River	SaClL	28	2
	V(ii)	yes	Field crops*	Flood	Vaal River	LSa	13	2
	V(iii)	yes	Field crops*	Flood	Vaal River	LSa	13	2
ORWUA	OR(i)	yes	Field crops*	Centre pivot	Orange River	LSa	13	2
	OR(ii)	no	Field crops*	Centre pivot	Orange River	LSa	10	1

* Field crops are wheat / maize in a winter / summer crop rotation

All data required to complete the mass balance is captured by a variety of measuring equipment at each of the sites. The descriptions of these data elements that are being measured, and are described below, were extracted directly from the progress report submitted to the WRC in September 2007 for the K5/1647 project (Van Rensburg et al., 2007):

1. Irrigation and precipitation are measured with rain gauges wherever possible on a weekly basis. Under centre pivot irrigation systems, in the case of maize, irrigation are calculated from the relationship between running speed (%) of the system and the application rate. The running speed and time are recorded every week. For flood irrigation the water application will be calculated from stream-flow and wetting time.
2. The change in the soil water content of the experimental area is measured with a CPN neutron probe. Two access tubes per area were installed. Measurements are made at 300 mm depth intervals, over the potential rooting depth including at least one soil layer below the rooting depth.
3. One piezometer was installed for each experimental area to a depth of 3000 mm in order to measure the water table height and its salt content. Perforated 63 mm PVC tubes were used for the piezometers. The height and electrical conductivity (EC) of the water tables are measured manually every week by using a measuring tape and EC meter. The water is manually collected with a bailer from the piezometers.

4. The volume of water flowing from the artificial internal drainage systems of the experimental areas are measured weekly with the bucket and time method. Samples of the drainage water are also taken in order to measure the EC weekly. At the beginning and end of every growing season, water samples are again analysed for dissolved cations and anions. Drainage from an experimental area is also calculated from the measured volumetric water content of the soil profile, by using the pre-determined drainage curves. An in situ drainage curve of each case study will be determined.

5. Representative soil samples will be taken at 300 mm depth intervals to if possible a depth of 3000 mm at the beginning and end of each growing season using standard auguring procedures. The soils will be dried at 40°C, crushed to pass through a 2 mm sieve and stored in glass bottles until analysed using standard methods.

6. For determining the yield, viz. biomass and seed, an area of 16 m^2 will be harvested per experimental area at maturity of the crops. The seed yield and total above-ground biomass will be determined separately using standard procedures. Lucerne plots will be harvested at 50% flowering from a 4 m by 4 m area.

In addition to the data being collected on a weekly and seasonal basis by the K5/1647 project, continuous soil moisture monitoring probes were installed in each experimental plot on the 26^{th} September 2007 to complement the soil moisture data collected from the neutron probes. The probes were supplied by DFM Software Solutions and operate on the capacitance principle to measure soil moisture content. Each probe was 1.8 meters long with a sensor every 30cm. Data from all the measuring equipment was been collected during 2008 and 2009. Figure 87 shows the location of the measuring equipment within case study V (i) at Vaalharts WUA. The other plots summarised in Table 82 all contained the same equipment.

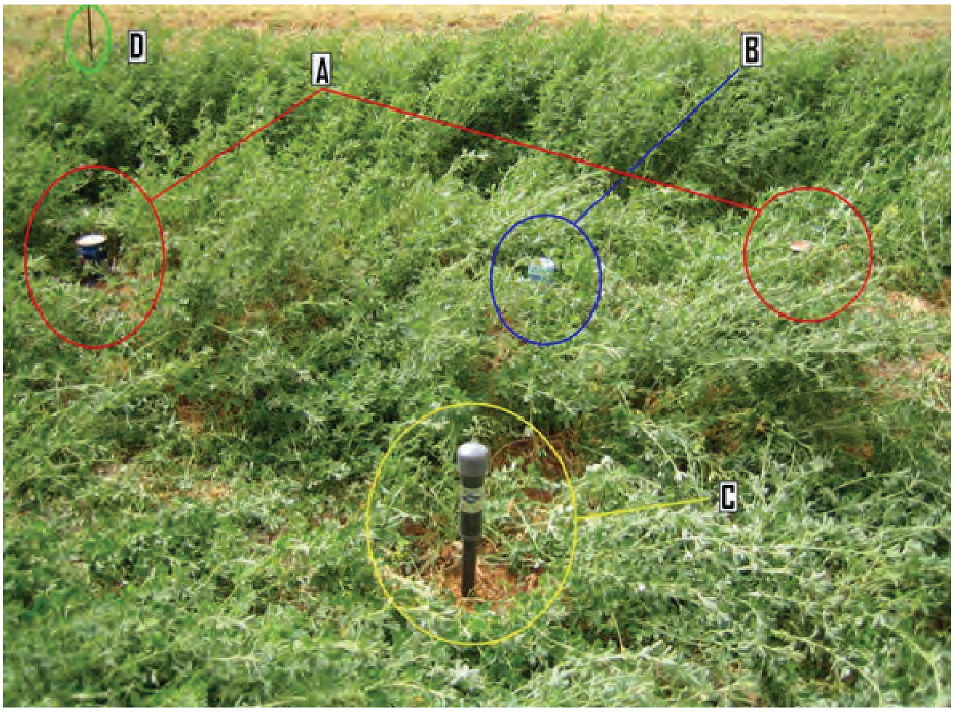

Figure 87: Photo showing equipment installed at Experimental case study V (i) (Table 81).

A: Access tubes for CPN neutron probes

B: Piezometer

C: DFM continuous logging soil moisture probes

D Rain gauge – not fully visible

The results from the irrigations systems evaluations that were previously referred to are presented in Table 82, Table 83 and Table 84. These tables show the large variations in infield irrigation system performance that was encountered. Values highlighted in green reflect situations where measured / calculated performance measures do not meet current norms and standards. This situation is evident in about half of the systems that were evaluated at the two schemes. The team from the ARC who conducted the evaluations was also not able to measure all variables required to calculate certain indices, these are reflected as N/A in the tables.

Table 82: Test Results for Center Pivots evaluated at Vaalharts WUA

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines	Measured	Guidelines	Measured	Guidelines	Measured
V1	85	57	75	82	80	N/A
V2		89		86		65
V3		44		66		82
V4		92		85		53
V5		43,4		53,5		N/A
V6		38,9		71,4		N/A

Table 83: Test Results for Center Pivots evaluated at ORWUA

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines*	Measured	Guidelines*	Measured	Guidelines*	Measured
O2	85	85	75	76	80	76,3
O3		91,2		94		89,5
O4		42,9		72		55,7
O5		84,4		71		85,2

Table 84: Test Results for Floppy System evaluated at ORWUA

Test site code	Uniformity Parameters				Efficiency		Pressure variation (%)		Discharge variation (%)	
	CU(%)		DU_{lq} (%)		SE (%)					
	Guidelines	Measured	Guidelines	Measured	Guidelines	Measured	Guidelines(#)	Measured	Guidelines(#)	Measured
O1	80	N/A	75	N/A	75	N/A	20	24	10	20

9.4 Conclusion

The weekly water balance results that have been presented show that at Vaalharts, the supply was very well matched to the demand. For improved water balances, other components would need to be estimated on the scheme, for example balancing dam and canal seepage. However, these two components are the most difficult components of the water balance to quantify (ANCID, 2000). Traditionally, once all the other components have been determined, i.e. pumped inflows and outflows, surface water evaporation, change in storage and addition by rainfall; the remaining water volume is assumed to be lost via seepage from dams and canals.

At Orange-Riet, if just the water orders and water meter data are used to construct a water balance, it appears that the scheme has large volumes of water that cannot be accounted for. However, when the crop water demand is compared to the water released, the situation improves markedly. Whilst the water released does not follow the crop water demand very closely, the general trend is matched. It was shown that the weekly water balance approach is not suitable for use at ORWUA due to the large number of components not captured in WAS at the time of the sample exercise.

It was therefore highlighted through these water balance exercises that consistent data capture and storage greatly facilitates these analyses. The use of the WAS database made these investigations possible, which would have been difficult were this not the case. Other schemes are encouraged to apply a formal database structure with associated procedures to help account for water within scheme and business function boundaries. It is also suggested that where possible, the application of the water balances, and the water balance trend analysis graphs, should be applied to quantify the extent and nature of any losses occurring within irrigation scheme delivery infrastructures. When used in conjunction with a water balance, it is possible to identify inconsistencies and problems.

10 Steenkoppies Groundwater Area

10.1 Scheme background

As surface water becomes more limited, groundwater sources are increasingly exploited, especially in rural and arid areas. In South Africa there are six major types of aquifers consisting of dolomites, Table Mountain Group sandstones, coastal sand deposits, basement granites, Karoo dolerites, and alluvium along perennial rivers of which karst aquifers, especially in dolomites, are the single most important type of aquifer (Hubert, Wimberely and Pietersen 2006). Exploitation of groundwater occurs mainly in the Western Cape and eastern and north eastern parts of South Africa where aquifers are concentrated (DEAT 2009). It is estimated that 236 x $10^9 m^3$ of groundwater are stored in South African aquifers with an average groundwater exploitation potential (AGEP) of 19 x $10^9 m^3/a$ in average years and 16 x $10^9 m^3/a$ during a drought (Woodford, Rosewarne, and Girman 2006; DWAF 2006). Approximately 6% of the AGEP is currently abstracted, of which 64% is used for irrigation (Woodford et al., 2006). The Steenkoppies dolomitic aquifer, near Tarlton, serves as an example of such an irrigation scheme, where groundwater serves as the source for irrigation.

A groundwater system is a groundwater aquifer in which the water source is shared by individual water users and includes the abstraction points, water distribution network, management structure of the aquifer and automation of any of the components. The exploitation of a shared groundwater system is a typical problem of common property, since the resource is limited and not that visual. If the goal of individual water users (private) is to maximise profit, a private solution to manage the groundwater system is inefficient due to the following reasons (Roseta-Palma 2003):

- Because groundwater supply is limited, each unit extracted by a specific water user is no longer available to other users and the only way to lay claim to a unit of groundwater is to pump it. There is therefore no incentive to save water, since other water users have the same access to the groundwater.
- Pumping costs depend on groundwater depth and extraction costs will increase with the lowering of the groundwater level. Individual water users do not consider the detrimental effect of their pumping on other water users, so again there is little incentive to save water.
- If an aquifer is susceptible to contamination resulting from the users' actions, then additional externalities can occur. For example, groundwater polluted by one user can impose external costs on all other groundwater users.

One of the characteristics of a groundwater irrigation scheme is that farmers have direct access to the water source, with the advantage that water is conveyed in a closed system from the source to the field. The distance of conveyance is usually relatively short and highly efficient if no leakage in the pipe line occurs and even if leakage occurs, it can be argued that this water will eventually drain, as return flow, to the aquifer. However, one of the disadvantages is the limited control over water abstraction from the water source, due to the fact that anybody on the aquifer with a borehole has a direct link to the water source. It is very difficult for a farmer or irrigator to visualise the volume of water available in an aquifer for irrigation purposes and as a result over-abstraction may occur that could be detrimental to the sustainability of such an irrigation scheme. There is also no control of or limitations on the drilling of boreholes. The Water Act of 1956 regarded water abstracted from boreholes as private water and no limitations were placed on the abstraction of water for irrigation purposes. This perception of groundwater "belonging" to the irrigator still exists, although the new National Water Act (NWA) (Act No. 36 of 1998) regards surface and groundwater as one resource, and vests the custodianship of the water resource with the State.

A reliable water balance is therefore necessary to give guidance to a groundwater scheme as to the volume of groundwater available for irrigation in a season. For the Steenkoppies Aquifer a natural spring called Maloney's Eye, serves as a natural outlet for groundwater stored in the Steenkoppies Aquifer, and thus forms part of a simplified water balance as proposed by Barnard (1997) in Equation 2:

$$I - O + Re - Q = S\frac{\Delta V}{\Delta t} = S\frac{dh}{dt}\ \text{Area}$$

Equation 2

where,

I = mean lateral inflow (m^3 d^{-1})

O = mean lateral outflow (m^3 d^{-1}) during Δt

Re = recharge to groundwater (m^3 d^{-1}) from rainfall and runoff during Δt

Q = abstraction

S = storativity

ΔV = change in saturated volume ($V_2 - V_1$)

Δt = time interval ($t_2 - t_1$)

h = hydraulic head.

The following assumptions were made:

Evaporation can be disregarded due to the deep water levels (>60 m).

The base of the system is impervious, preventing any vertical drainage out of the aquifer.

10.1.1 Inflow

Bredenkamp, Van der Westhuizen and Wiegmans (1986) made the assumption that the lateral inflow and outflow are equal and therefore it was eliminated from his water balance equation. Barnard (1997) on the other hand found evidence that artificial recharge from the Randfontein Sewage Works into the Steenkoppies Compartment occurs, which complicates the general water balance equation. However, Holland (2009) obtained the following information from the Randfontein WWTW. The average effluent discharge for the past five years amount to 2.85 m^3/a of which approximately 1.15 m^3/a is discharged into the Upper Rietspruit and 1.71 m^3/a is used by the adjoining mine dumps for dust suppression and also for irrigation of newly planted vegetation for rehabilitation. Therefore it is fair to assume that very little or any of these discharge components reaches the Steenkoppies dolomite compartment.

10.1.2 Outflow

Lateral outflow is represented by the natural flow from Maloney's Eye (Barnard 1997) and measurements of the water flow at Maloney's Eye (m^3/month) have been done since 1908 (Bredenkamp, van der Westhuizen and Wiegmans 1986).

10.1.3 Groundwater recharge

Barnard (1997) and Bredenkamp, van der Westhuizen and Wiegmans (1986) used different methods to determine the recharge of the Steenkoppies Compartment. The methods used were:

i) Recharge from direct rainfall under natural conditions prior to abstraction (Q), thus recharge is estimated from spring flow.

ii) Rainfall-recharge relationship.

iii) Saturated Volume Fluctuation (SVF) method.

iv) Recharge calculated with the chloride method.

v) Employing Darcy's Law when assuming the flow of Maloney's Eye constitutes the full recharge.

vi) Abstraction calculated with the k-factor.

The effectiveness of an aquifer management strategy is dependent on the geohydrological properties, storage coefficient and transmissivity and on community participation for sharing water (Kulkarni, Vijay Shankar, Deolankar et al., 2004). Therefore, for the Steenkoppies Aquifer the socio economics of irrigated agriculture and the existing lawful water use for the different properties were determined. Discharge from Maloney's Eye was related to the influence of abstraction for irrigation and groundwater levels. At field level irrigation system efficiency and amount of irrigation for different irrigation systems and crops were determined. This information was used to propose recommendations to improve management and irrigation efficiency on the Steenkoppies Aquifer.

10.2 Groundwater aquifer

10.2.1 Background

The Steenkoppies Aquifer is situated in the central interior of South Africa, west of Tarlton (26°02' to 26°13' S, 27°29' to 27°39' E) (Figure 88). It covers an area of 213 km^2 with a catchment area of 311 km^2 (Holland 2009). A single representative precipitation time series, similar to the period of discharge records for Maloney's Eye, was compiled from four meteorological stations (Holland 2009). These four stations showed a similar mean annual precipitation (MAP), where the maximum deviation of MAP between stations was below 10%. The time series was compiled by calculating a weighted average (using a squared inverse distance weighting method) of all monthly precipitation records available for a given time period. However, between 1983 and 1985 and from 1990 onwards, data was used from only one meteorological station situated on the aquifer. A simple analysis of the MAP is given In Table 85**.**

Table 85: MAP characteristics for the Steenkoppies Aquifer

Year (record)	MAP	Years above or below long term MAP		Years MAP > 1000 mm	Years MAP < 550 mm	MAP (mm)	
		Below	Above			Min	Max
1908-2008	668	55	46	3	24	348	1081

Precipitation occurs mostly during summer (October to March) as thunderstorms with a mean annual precipitation of 668 mm (Table 85), with 55 years below and 45 years above the mean. The minimum annual precipitation over the period was 348 mm and the maximum 1 081 mm. A MAP of 550 mm was arbitrarily taken as a reference for particularly dry years, and 24 years fell into this category.

The topography consists of undulating plains that vary between 1 550 m above sea level in the east and rise towards the north and west to a height of 1 640 m (Hobbs 1980). The absence of significant surface water drainage features, pans and marshes (**Figure 87**) indicates that most of the natural water supply from precipitation drains directly into the aquifer. It is currently believed that a perennial spring, Maloney's Eye, situated approximately 750 m north of the northern boundary of the aquifer at a height of 1 490 m serves as the only significant natural outlet for the groundwater stored in the aquifer (Hobbs 1980). The discharge from this spring varied over a period of 100 years between 0.05 m^3/s (March 2007) to 1.035 m^3/s (February 1979), with an average of 0.455 m^3/s. It flows into the Magalies River to the north of Maloney's Eye (Figure 88), that feeds the Hartbeespoort Dam, currently a highly polluted impoundment (Oberholster and Ashton 2008)

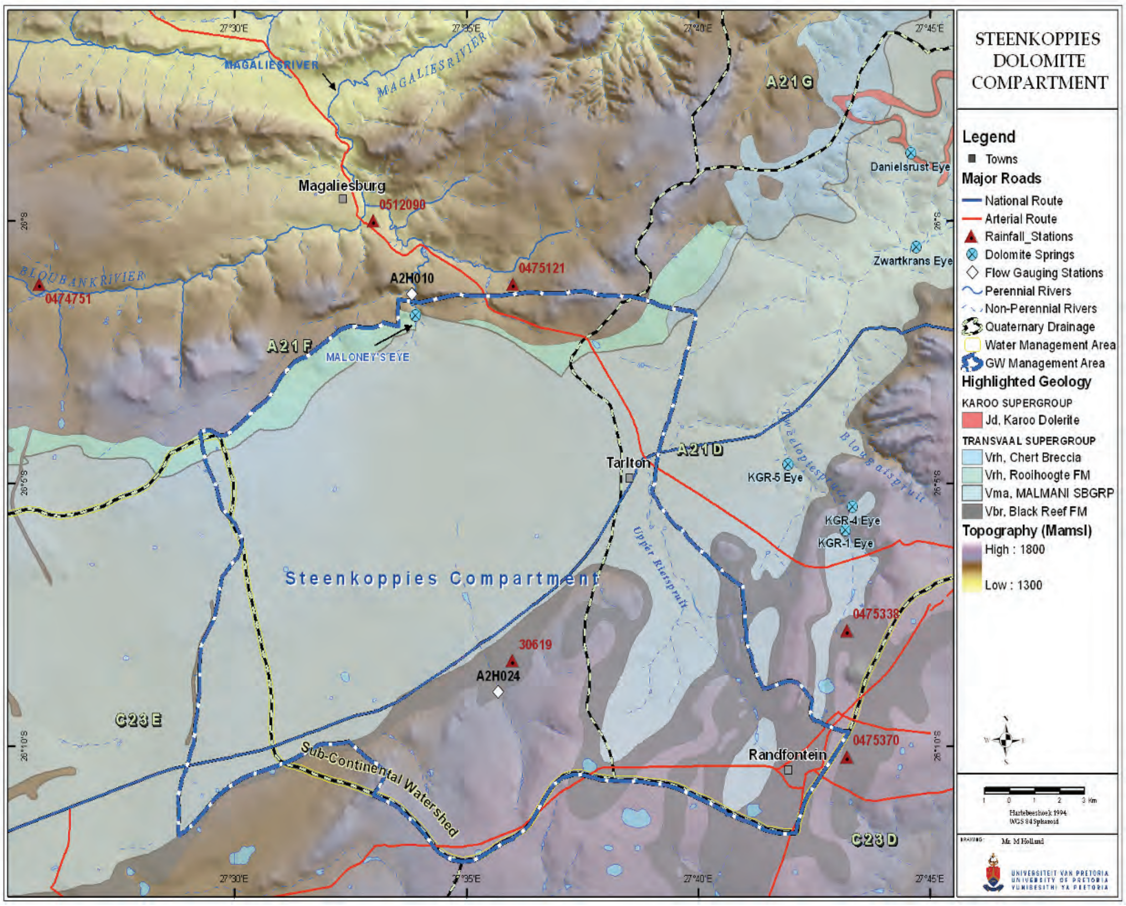

Figure 88: Steenkoppies aquifer

A conceptual model for the Steenkoppies Aquifer is presented in Figure 89. The aquifer is bounded in the east by the Tarlton West Dyke and in the west by the Eigendom Dyke, with both striking north-south. The area is underlain by dolomitic limestone, which, together with interbedded chert lenses form the Malmani Subgroup of the Chuniespoort Group, dipping to the northwest at 5-20° (Bredenkamp, van der Westhuizen, Wiegmans et al., 1986). The outcropping quartzites of the underlying Black Reef Quartzite Formation, form the southern boundary of the compartment, while to the north an unconformity separates the Chuniespoort Group from overlying quartzite and shale of the Pretoria Group, effectively forming the northern boundary of the compartment (Foster 1984). Maloney's Eye is situated above the groundwater level of the dolomite drainage area at the intersection of the Maloney's Eye dyke and the east-west striking fault zone within the shales/quartzites of the Rooihoogte/Timeball Hill Formations (Pretoria group); therefore the existence of the Eye could be attributed to a dyke of low permeability and the cross cutting of the fault zone representing the main water conduit from the dolomite into the shales and quartzites (Figure 89) (Holland 2009).

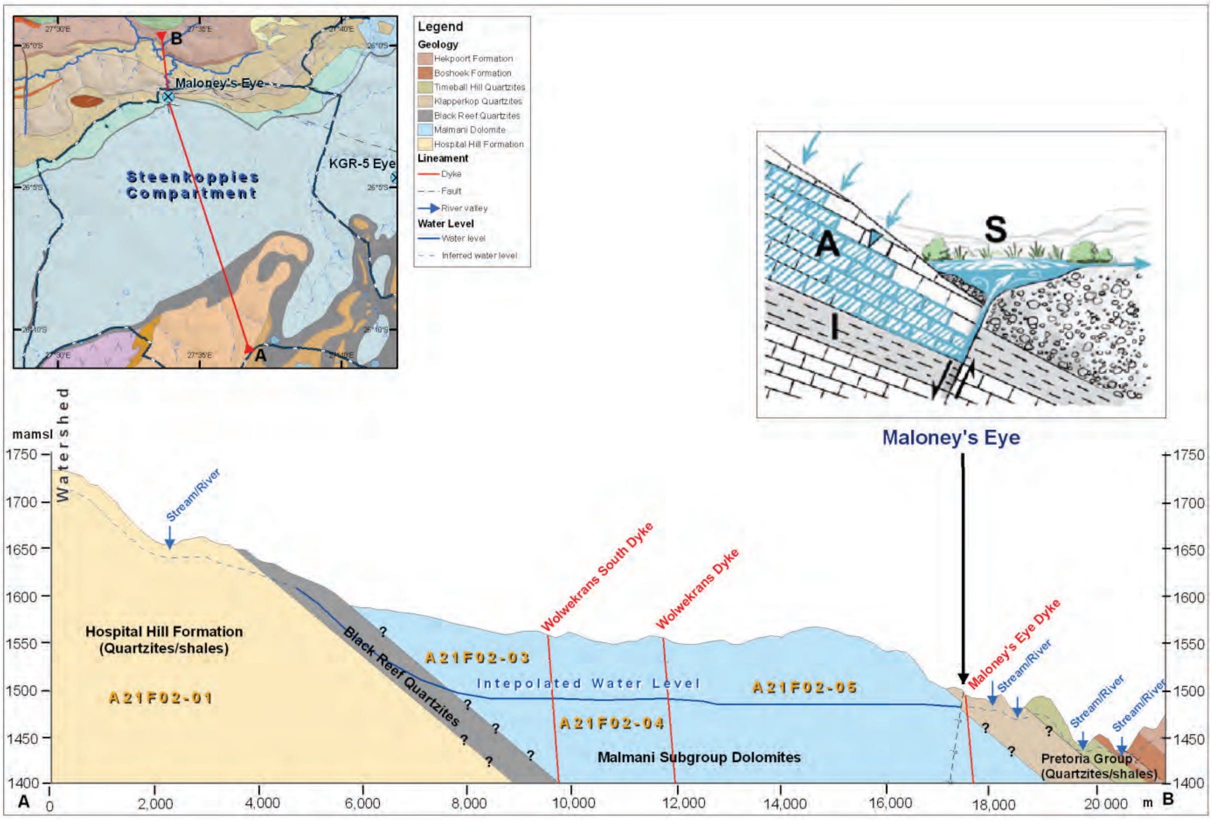

Figure 89: Conceptual model for the discharge at Maloney's Eye (Holland 2009)

The main agricultural activity is cultivation under irrigation, and water for households and irrigation is abstracted from the Steenkoppies aquifer. Abstraction from more than 200 boreholes and a network of pipe lines, developed and maintained by each water user, supply the water for irrigation. Irrigation systems consist primarily of centre pivots and quick coupling pipes to a lesser degree, with drip and micro emitters restricted to crops grown under plastic and shade cloth covered structures. No restrictions on drilling, size of boreholes and pumps or compulsory measuring of water abstraction or monitoring of groundwater levels exist. However, a limited number of flow meters were installed recently as part of a pilot study initiated by famers on the aquifer. The water is of exceptional quality with a maximum total dissolved salts (TDS) concentration of 240 mg/l (Kuhn 1988), and the possibility to use the aquifer as a water supply source for Rustenburg and as part of an emergency groundwater pumping scheme was investigated by DWA. However, the capital investment and running cost made the project unviable (Bredenkamp et al., 1986; Kuhn 1988).

10.2.2 Socio economics

Data on the socio economics of irrigated agriculture based on the Steenkoppies Aquifer was collected by means of a semi-structured personal interview (Stevens, Düvel, Steyn et al., 2005) with each farmer in 2007/08.

A summary of the data is presented in Table 86. Highly productive soils, high quality irrigation water and close proximity to major cities and airports render the Steenkoppies Aquifer ideal for intensive irrigated agriculture. The largest producers of carrots in Africa, mushrooms in South Africa and the single largest grower of chrysanthemums in the world, are all drawing on the Steenkoppies Aquifer. The area is characterised by intensive farming with vegetables and flowers as the main crops grown on approximately 3 786 ha (Table 2). Work is provided to more than 4 000 people with more than R7.2 million paid in monthly salaries, which contributes greatly to the local economy. Capital investments are in the order of R780 million, with an annual turnover of approximately R500 million (Table 86). Social programmes such as accredited skills development and HIV awareness programmes have been implemented, and on site medical clinics with full time nurses and crèche facilities are also supported and funded by growers dependent on the aquifer.

Table 86: Socio-economic data for the Steenkoppies Aquifer

Type of crops grown	Vegetables, maize, wheat and flowers
Permanent workers	2945
Temporary workers	1072
Managers	177
Living on farm	1475
Monthly salaries	R 7 200 000
Turnover	R 500 600 000
Capital investment	R 773 900 000

Until recently, farmers on the Steenkoppies Aquifer responded well to their social responsibility, but did not fully comprehend and adequately manage their most important natural resource, water. Being irrigation farmers, they depend on the sustainability of the groundwater resource and until as recently as 2008, no management structure, monitoring of groundwater levels, measuring of abstraction or scientific based irrigation scheduling took place. However, the pressure of possible further legal action against groundwater users have forced the farmers to establish the Steenkoppies Aquifer Management Association (SAMA) in 2008, to facilitate the institutionalisation of a water users association as required by the NWA.

10.2.3 Validation

It becomes increasingly more difficult to determine the existing lawful water use for irrigation through the current process of validation because of the elapsed period of time gone by from 1996/1998 (the period in which lawful water had to be exercised) to now. Farmers do not keep records of seed and seedling purchases for this length of time and therefore the detailed information on the quantity and type of vegetables planted is lost.

The following processes and data sources were used and/or consulted to determine and classify the water use;

- Landsat satellite images (170-078) taken on 24 September 1998,

  11 January 2001 and 23 August 2004. By combining certain spectral bands of the images, composite scenes were generated to highlight irrigation. The satellite images were then overlaid with the property boundaries and the identified irrigated areas on the different dates were digitised to determine the extent thereof.
- Topo-cadastral maps.
- Title Deed information obtained from the Registrar of Title Deeds.
- Input from property owners.
- Proof of seedling purchases (cultivar and quantity).
- Proof of seed purchases (cultivar and quantity).
- Market and fresh produce buyers' reports.
- Affidavits from neighbours, chemical and fertiliser representatives.
- Detailed field survey information obtained from "Optoit Opmetings".
- Registration information received from DWAF.
- SAPWAT (Version 2.6.1 – April 2003) calculations.

Satellite images were used to confirm the surface area planted during the qualifying period. Information regarding the cultivar and quantity of seedlings and seed planted can be used to calculate the crop area planted. SAPWAT was used to determine the amount of water used by the crop during the qualifying period. The surface area planted and the millimetres of water used by the different crops were then used to calculate the volume of water used for irrigation during the qualifying period.

In terms of the NWA existing lawful water use is water use that was lawfully exercised within the two years prior to promulgation, i.e. 1 October 1996 to 30 September 1998. Under the previous Water Act (1956), water abstracted from boreholes was regarded as private water and since the study area is not included in a Subterranean Government Water Control Area, no limitations were placed on the abstraction of water from boreholes for irrigation purposes. The Steenkoppies Aquifer is also excluded from the General Authorisation (GA) published on 26 March 2004, meaning that any new use from boreholes after 1 October 1998 is subject to a licensing process and that no new abstraction from boreholes is allowed unless a license for such use has been issued.

In order to determine the efficiency of an irrigation scheme, the lawful water use must first be determined. However, very limited records of water use during the qualifying period for groundwater schemes exist. No records of direct measurements for water abstraction on the Steenkoppies Aquifer during the qualifying period could be found. Therefore, an alternative method for determining the volume of water used during the qualifying period must be used. An effective procedure to determine the current and historic water usage of irrigation farmers is by a process of validation, which entails analysing satellite images over a time span to determine the surface area under irrigation. The area planted with a specific crop can be verified by comparing seed and seedling purchases to the actual surface area under irrigation for each farming unit. This process was completed for all water users on the Steenkoppies.

Water for irrigation purposes on the Steenkoppies Aquifer is abstracted from boreholes situated within quaternary drainage region A21F. Currently, 269 properties with a total area of 11 077 hectares have water rights for an estimated 3 786 ha (Table 87). Groundwater abstracted for irrigation is between 27.4 x $10^6 m^3/a$ (registered WUA and Water Registration Management System (WARMS) users) and 22.4 x $10^6 m^3/a$ (preliminary validation volume) with vegetables and flowers as the main crops Table 86). A total of 46 farms and 133 properties were verified and a summary of these results are presented in Table 87.

Table 87: Summary of the results from the validation process

Property extent	Field area		Crop area		Lawful water use	Registered water use
	Verified	Registered	Verified	Registered		
ha	ha	ha	ha	ha	m^3/a	m^3/a
11077	2472	2821	3786	3545	22.4 x 10^6	27.3 x 10^6

From Table 87 it can be seen that only 22% of the total surface area is used for irrigation. Of the registered surface area, 88% of the area was found to be lawful with an average cultivation of 1.5 crops per year in this area. It was also found that 82% of the irrigation water registered was lawful.

On average 906 mm of water per year is allocated to the verified area which results in an average of 604 mm per crop area.

10.2.4 The influence of groundwater abstraction on discharge

The relationship between precipitation and spring discharge was evaluated with the Cumulative Rainfall Departure (CRD) method. The CRD method is based on the premise that equilibrium conditions develop in an aquifer over time and that the average rate of loss relates to the average rate of recharge of the system (Xu and van Tonder 2001). The natural groundwater level fluctuation is related to that of the departure of rainfall from the mean rainfall of the preceding period. If the departure is positive, the water level will rise and vice versa (Bredenkamp, van Tonder and Lukas 1995). Therefore, the CRD method can be used to determine if an external factor e.g. abstraction, influences the equilibrium conditions.

The CRD method is represented mathematically as Equation 3:

$$ {}_{av}^{1}CRD_i = \sum_{n=1}^{i} Rn - k\sum_{n=1}^{i} R_{av} \quad (i = 0,1,2,3....N)$$

Equation 3

Where:

R = monthly precipitation with subscript "i" indicating the i-th month and "av" the average.

The exploitation factor k is defined as:

$$k = 1+(Q_p+Q_{out})/(A.R_{av})$$

Where:
Q_p = abstraction
Q_{out} = discharge
A = area
R_{av} = mean rainfall
If k > 1 then abstraction and/or natural discharge take place, if k = 1 then no abstraction occurs (Xu and van Tonder 2001).

The equation was adjusted to consider the long-term groundwater fluctuations and short-term delay from precipitation to groundwater recharge.

Generally the CRD-graph mimics the spring discharge reasonably well with a short-term moving average of 9 months and a long-term moving average of 60 months, except for the extremely high discharge obtained during the period 1976 to 1985. Since 1987, however, a clear discrepancy exists between expected discharge and precipitation, with actual discharge lower than the simulated discharge (Figure 90). This discrepancy can be explained by excessive abstraction from the aquifer, especially during the drought periods 1990 – 1994 and 2002 – 2005 and 2007 when farmers relied heavily on groundwater for growing their crops.

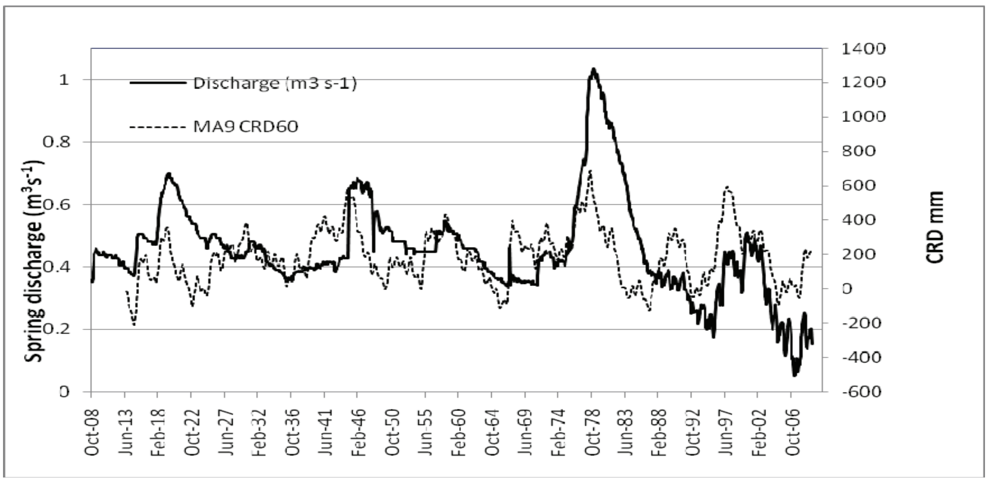

Figure 90: Spring (Maloney's Eye) discharge compared with simulated discharge

A cumulative plot of precipitation versus spring discharge reveals the distinct increase in spring discharges for the period 1976 to 1985 (Figure 91). This can be attributed to a 10 year (1971 – 1981) period of above average precipitation, indicating a cumulative effect on discharge. This occurrence can be explained by the duality of the recharge process in karst aquifers where an early immediate response is possible due to intake via fissures and fractures (conduit type karst), and a late delayed phase which consists of water percolating slowly through soil and rock of lower permeability (diffuse karst type) and greater thickness, also known as the "Epikarst" zone (Fiorillo and Guadagno 2009).

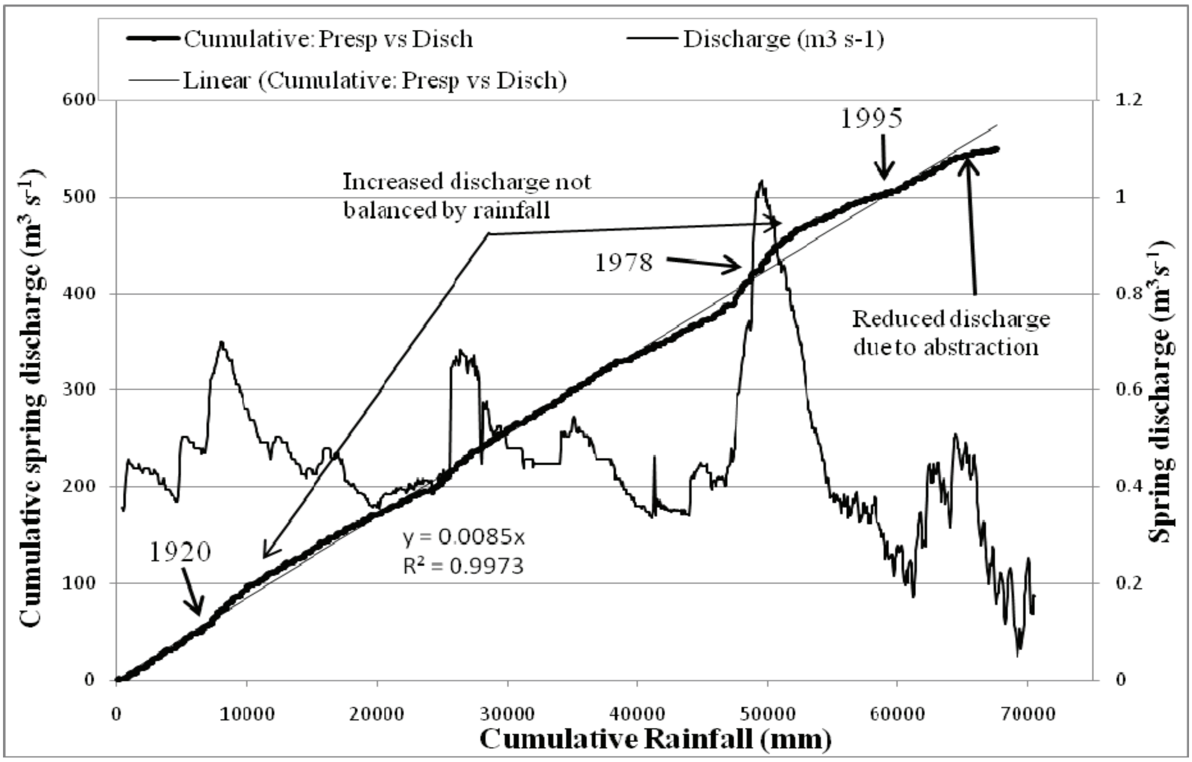

Figure 91: Cumulative precipitation versus cumulative spring (Maloney's Eye) discharge

A direct relationship between spring discharge and groundwater levels also exists (Figure 92). The lowest groundwater levels recorded in the area correspond closely to the lowest spring flow recorded in March 2007 (0.05 m^3 s^{-1}). The mean groundwater elevation in this area ranges from 1488 to 1491 meter above mean sea level and confirms the flat hydraulic gradient of this system, which are attributed to high transmissivities and low topographic gradients. The sensitivity of the groundwater level to the discharge at Maloney's Eye is evident, with groundwater table depths fluctuating only between 2.3 and 5.5 m over the last 24 years.

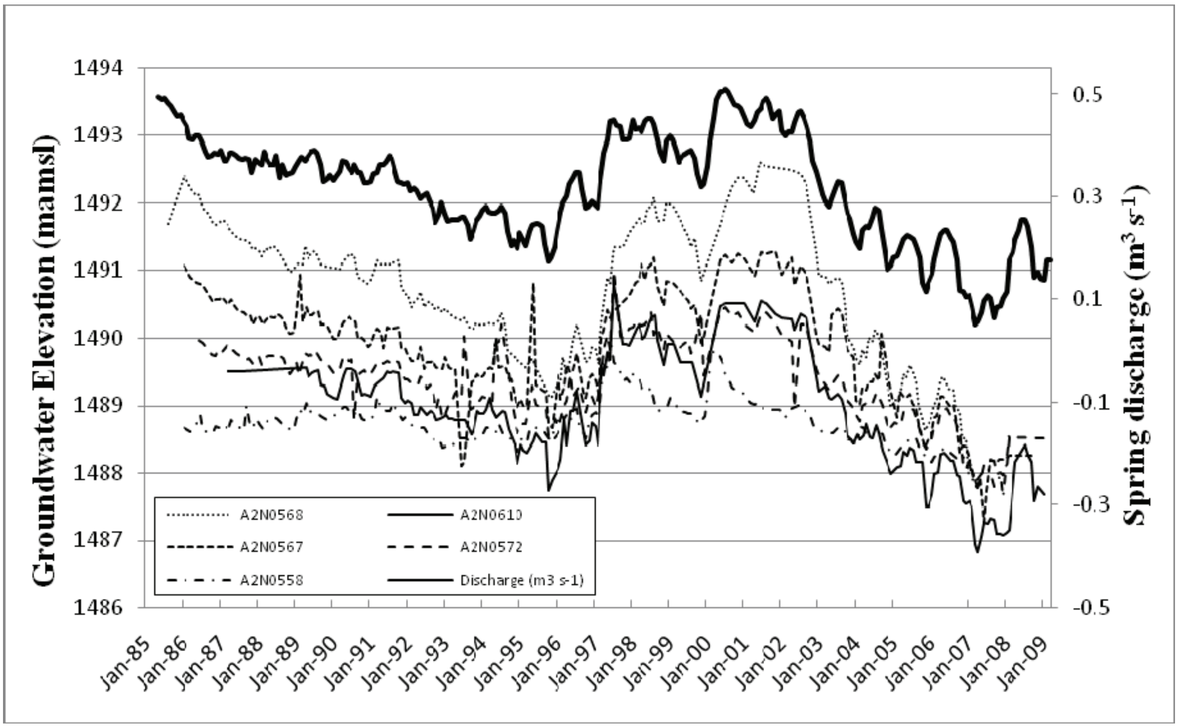

Figure 92: Spring (Maloney's Eye) discharge versus hydrographs for 6 different boreholes

An understanding of the geohydrology and the interaction between surface and groundwater is essential for the sustainable management of a groundwater scheme so that excessive abstraction does not take place. It is also important for groundwater schemes with natural occurring springs to maintain a minimum discharge, the so called Reserve, as provided for in the NWA. The Reserve consists of two parts, the Basic Human Needs Reserve, and the Ecological Reserve (NWA 1998). In the case of the Steenkoppies Aquifer this means that a minimum discharge from Maloney's Eye must be maintained, both for the essential needs of individuals such as water for drinking, for food preparation and for personal hygiene, as well as to maintain the ecology of the downstream river system. Calculation of the Reserve needs to take into consideration both the current and future needs.

10.3 Irrigation systems

10.3.1 System Evaluation

The system evaluations were all done by the same team of technicians from the ARC-Institute for Agricultural Engineering (ARC-IAE), to reduce the change of measurement errors caused by variation in technique. The names of the farmers and the identified systems were given to the evaluation team by each scheme leader from the project team, and the technicians then made appointments with the farmers. In general, the farmers were willing to co-operate and supported the team well, although there were some exceptions. The field evaluation of an irrigation scheme consists of an investigation into the operation of the pump station, the supply system and the irrigation system on the land. This information was used to determine efficiency values and was also used to compare it with the different irrigation systems guidelines according to the manual for the Evaluation of Irrigation Systems (Koegelenberg et al., 2002). It was not possible to measure at all the different positions mainly due to limited space in the pump house. Most of the measurements were done at the valve, emitter and the soil surface, depending on the irrigation system.

The results for the Steenkoppies area are shown in Table 88 to Table 93.

Table 88: General information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
T1	Sprinkler	Lettuce	Not available	NA	6,3
T2	Centre pivot	Beetroot	40	21,3	NA
T3	Centre pivot	Cabbage	70	10,71	NA
T4	Sprinkler	Turnip	55	NA	7,1
T5	Sprinkler	Carrots	Not available	NA	4,5
T6	Centre pivot	Carrots	55	10,3	NA
T7	Centre pivot	Carrots	70	16,2	NA
T8	Centre pivot	Cauliflower	Not available	25,4	NA
T9	Sprinkler	Beans	Not available	NA	11,5
T10	Centre pivot	Cauliflower	30	15,9	NA
T11	Sprinkler	Lilies	7 000 bulbs/ha	NA	3,9
T12	Sprinkler	Carrots	Not available	NA	1,9
T13	Centre pivot	Carrots	Not available	2,5	NA
T14	Sprinkler	Cabbage	Not available	NA	5,1

Table 89: General information of pump

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
T1	Not measured	Not measured	Not measured	Yes	Yes	No screens over couplings
T2	Not measured	Not measured	22	No	No	Electricity unsave
T3	Not measured	Not measured	55	No	No	Bad condition
T4	Not measured	Not measured	55	No	No	No screens over couplings
T5	Not measured	580	37	Yes	Yes	Good condition
T6	Not measured	580	37	Yes	Yes	Good condition
T7	Not measured	620	45	Yes	Yes	Good condition
T8	Not measured	Not measured	45	Yes	Yes	Drainage problems
T9	Not measured	Not measured	Not measured	Yes	Yes	Drainage problems
T10	Not measured	250	5,5	No	Yes	No screens over couplings
T11	Not measured	590	25	No	No	No screens over couplings
T12	Not measured	Not measured	45	Yes	Yes	No screens over couplings
T13	Not measured	Not measured	55	Yes	Yes	Bad condition
T14	Not measured	Not measured	55	Yes	Yes	Bad condition

10.3.2 Centre pivot

Table 90: General information

Test site code	Pressure regulators (Yes/No)	Operating pressure (kPa)	Flow rate (m^3/h)	Speed adjustment (%)		Gross application (mm)	
				Control box	Measured	Control box	Measured
T2	Yes	290	52	20	17,1	17,5	21,8
T3	Yes	672	38	25	30	10	7,3
T6	Yes	255	36	15	15,2	11,9	9,0
T7	Yes	370	80	25	23,8	15	14,9
T8	No	310	Not measured	25	20	15	Not measured
T10	Yes	200	Not measured	25	18	15	Not measured
T13	Yes	380	Not measured	100	Not measured	3	Not measured

Table 91: Test results

Test site code	Uniformity Parameters				Efficiency	
	CU_H (%)		DU_{lq} (%)		SE (%)	
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured
T2	85	93,7	75	81,7	80	Not measured
T3*		74,6		65		Not measured
T6**		81,8		85,6		Not measured
T7		94,1		90		Not measured
T8		76,3		72,3		Not measured
T10		81,7		76,9		Not measured
T13		73,9		65		Not measured

*T3 – One sprinkler did not rotate;

**T6 – Drainage valve leaked

10.3.3 Sprinkler irrigation system

Table 92: General information

Test site code	Type of sprinkler system	Sprinkler spacing (m)	Nozzle size (mm)	Operating pressure (kPa)			Sprinkler discharge measured (ℓ/h)
				Hydrant (measured)	Nozzle pressure calculated	Average nozzle pressure measured	
T1	Quick-coupling	15 x 12	4,5	Not measured	262-306	245	1136
T4	Quick-coupling	18 x 12	4,5	Not measured	262-306	303	1675
T5	Quick-coupling	19 x 12	4	Not measured	238-278	255	1046
T9	Quick-coupling	12 x 16,8	4	Not measured	238-278	348	1668
T11	Quick-coupling	12 x 17	Variable	Not measured	-	308	2086
T12	Quick-coupling	12 x 17,2	4,5	Not measured	262-306	198	995
T14	Movable	12 x 19,3	Variable	Not measured	-	235	1405

Table 93: Test Results

Test site code	Uniformity Parameters				Efficiency		Pressure variation (%)		Discharge variation (%)	
	CU(%)		DU_{lq} (%)		SE (%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (max)	Measured
T1	80	79,8	74	65	75	99,23	20	33	10	27
T4		71,7		68		76		96		94
T5		72,2		55,2		97,3		31		15
T9*		77,3		69,8		-		23		4
T11		71,3		61		37		52		72
T12		40		64,3		38		25		22

T14		73		53,5		82		17		10

*T9 – Leakages

10.3.4 Irrigation monitoring on the Steenkoppies Aquifer

Rain meters were installed at 9 different farms in different vegetable crops (lettuce, cabbage, broccoli, carrots and beetroot) commonly grown on the Steenkoppies Compartment. The total water application (irrigation and rainfall) was measured weekly for the different crops. At the end of the crop cycle, dry and fresh weight was measured. This information was then used to determine the marketable yield per unit of water used for vegetables commonly grown on the Steenkoppies Compartment.

In Tbale 94 a summary of the amount of irrigation water used to produce vegetables under different irrigation systems are given.

Table 94: Summary of infield irrigation measurements of vegetables as grown on different farms and under different irrigation systems

		Unit	Summer		Winter	
			Centre pivot	Quick coupling	Centre pivot	Quick coupling
Lettuce	Growing days	days	58	61	77	80
	Fresh fruit weight	g	585	510	417	386
	Irrigation	mm	193	153	135	206
	Rainfall	mm	150	186	23	30
	Fresh fruit weight / irrigation	g/mm	3.0	3.3	3.1	1.9
	Irrigation / growing day	mm/d	3.3	2.5	1.8	2.6
Cabbage	Growing days	days	111	96	134	132
	Fresh fruit weight	g	1445	1246	1744	1571
	Irrigation	mm	282	220	261	323
	Rainfall	mm	463	253	63	67
	Fresh fruit weight / irrigation	g/mm	5.1	5.7	6.7	4.9
	Irrigation / growing day	Mm/d	2.5	2.3	1.9	2.4
Broccoli	Growing days	days	102		105	136
	Fresh fruit weight	g	385		196	230
	Irrigation	mm	148		194	457
	Rainfall	mm	308		28	78
	Fresh fruit weight / irrigation	g/mm	1.2		1.0	0.5
	Irrigation / growing day	mm/d	1.5		1.9	3.4
Carrots	Growing days	days	130	149	179	146
	Fresh fruit weight	g	104	86	80	87
	Irrigation	mm	282	350	449	369
	Rainfall	mm	208	215	73	63
	Fresh fruit weight / irrigation	g/mm	0.37	0.25	0.18	0.24
	Irrigation / growing day	mm/d	2.2	2.3	2.5	2.5
Beetroot	Growing days	days	72	113	138	122
	Fresh fruit weight	g	205	56	362	118
	Irrigation	mm	229	179	350	351
	Rainfall	mm	215	253	31	68
	Fresh fruit weight / irrigation	g/mm	0.90	0.31	1.04	0.34
	Irrigation / growing day	mm/d	3.2	1.6	2.5	2.9

The irrigation of vegetables is complex, depending not only on plant water requirements that is influenced by climate, soil type, seasonal change and cultivar, but also on marketing forces. Thus, it is possible that although vegetables are market ready, vegetables will not be harvested due to unfavourable prices or quality issues.

In general the vegetables grown under centre pivots have a shorter growing period, higher fresh fruit weight, less irrigation water and a higher yield per unit irrigated water efficiency (Table 94)), especially if the growing days and rainfall are of the same order.

However, this is not true for all the data. For lettuce production during the summer more water was irrigated for production under the centre pivot than the quick coupling pipes. This can be explained by the fact that the rainfall was higher (36 mm) for the lettuce grown under quick coupling pipes which resulted in a higher yield per unit irrigated water efficiency.

The summer production of cabbage also resulted in longer growing days and more irrigation water used than for the cabbage grown under quick coupling pipes. However, it is clear that the amount of rainfall for the cabbage grown under the centre pivot is significantly higher than that for the quick coupling pipes. This high rainfall contributed to a higher incidence of disease (Downey mildew) in the cabbage that resulted in a longer growing period. The winter production for carrots resulted in significant longer growing days, and thus more irrigation water used, due to unfavourable market prices.

10.4 Conclusion and recommendations

Optimisation of the performance of any component of the system requires careful consideration of the implications of decisions made during both development (planning and design) and management (operation and maintenance) of the component. Optimisation through management alone will be severely limited in its potential if the infrastructure was not developed with technical, economical and environmental efficiency in mind.

The most efficient groundwater system will therefore be one that:

- Combines all water users into a voluntary association, with the different sectors being represented in a management committee,
- Is planned and designed to accommodate the requirements of the users and the hydrology of the aquifer, which includes the planning of borehole sizes, depth and distribution network on the aquifer,
- The abstraction of groundwater needs to be controlled and monitored,
- Groundwater levels need to be measured and recorded.
- Has accurate and reliable measuring devices installed at identified strategic points in the system,
- Is operated and maintained according to a suitable hydrological model and sound operational rules, as captured in a regularly updated water management plan, and
- Is regularly evaluated to assess the level of performance and detect problems as early as possible,

- Irrigation scheduling must be implemented,
- Farmers need to be trained to have a better understanding of the hydrology of the groundwater.

10.5 Future Research needs

The NWA makes provision for a Reserve. The Reserve consists of two parts, the Basic Human Needs Reserve and the Ecological Reserve (NWA 1998). In the case of the Steenkoppies Aquifer this means that a minimum discharge from Maloney's Eye must be maintained both for the essential needs of individuals (such as water for drinking, for food preparation and for personal hygiene) as well as to maintain the ecology of the downstream river system. Calculation of the Reserve needs to take into consideration both the current and future needs. There are several areas that need to be researched to improve management of the Steenkoppies Aquifer to ensure adequate environmental flows through wet and dry periods. These include:

i) The possibility to guarantee the reserve by abstracting water from a sub compartment within the aquifer and pump it to Maloneye's Eye during periods with low discharge must be investigated.

ii) An accurate water balance for the Steenkoppies Aquifer needs to be developed before compulsory licensing of water use can take place and to provide a basis for a groundwater management plan.

iii) A model that relates meteorological data to groundwater recharge must therefore be developed to help improve management of the groundwater system.

iv) If competition between stakeholders for access to a water resource exists, the priority to use water needs to be defined and determined. In the case of the Steenkoppies Aquifer, the priority for water use between the environment, groundwater users and surface water users needs to be determined and implemented.

v) The possibility to use water pricing and water trading to encourage the allocation of water to either redress inequities or for higher value uses must be investigated.

11 Worcester East Irrigation Scheme

11.1 Scheme background

Worcester-East Water User Association (WEWUA) is one of the sub-schemes of the Central Breede River WUA. The scheduled area of the scheme is 1799 ha. A total of 70 farmers benefits from the scheme.

The Worcester East Irrigation Board is a fairly complicated umbrella board that oversees a scheme that pumps from the Breede River, as well as a number of smaller boards that lie to the east of Worcester.

The Worcester East Irrigation Board manages a pumping scheme that pumps water from the Breede River to augment the supply to farmers in the area, who may also receive water from the smaller boards. This water is partly compensation water for river water rights lost to the Hex Valley Irrigation Board.

The smaller boards managed by the Worcester East Board are the Hex River, Nooitgedacht, Nonnarivier, and Nuyrivier Irrigation Boards. These smaller boards can be considered wards of the Worcester East Board. These wards tend to overlap to a large extent, with some properties receiving water from four of the boards. The area served by the Worcester East Board lies directly to the east of Worcester, and is bordered by the Kwadouws Mountains on the north, the Breede River to the south, and extends as far as the upper reaches to the Vink River in the west.

The Board has a total scheduled area of 6 066 ha, which is divided up between the various sources as follows:

Breede River :	1 701,2 ha (651,4 ha compensation water from Hex River)
Hex River :	2 055,6 ha
Nuy River (Keerom Dam):	1 379,9 ha
Overhex/surplus canal:	1 285,2 ha
Nonna River:	274,3 ha

11.2 Conveyance system

The Board has a pump station on the Breede River (33º 41' 50" 19º 27' 25") just below the confluence with the Hex River. This rising main runs in a north-easterly direction to the farm Nooitgedacht, where the line splits in to two branches. One branch head north to the farm Rooiwal, to Pump Station 2. The second branch heads in an easterly direction to Pump Station 3, and then swings north east to Pump Station 6 and stops on the farm Leipzig on the right bank of the Nuy River. From Pump Station 2, one branch heads into the Hex River

Valley where it stops on the farm Louzaan, and another branch heads east to Pump Station 4 before reaching the end line on the farm Patryskloof. From Pump Station 6 (near the farm Werda) a branch heads out in the direction of the farm Kloppersbosch, where it stops. The scheme started delivering water in 1989.

The scheme consists of a pumping station at the river, 53 km of distribution pipe network and four balancing dams. Users can withdraw water on demand from the system.

The irrigation manager reads meters weekly and regularly give feedback to farmers on the status of their water use.

A telemetry system is in place to assist with water supply and balancing.

The irrigation manager is not too concerned about water losses; he has good methods in place to manage the system well. A weak link in the system was the absence of a water meter at the main pump station, but this has been addressed earlier this year when an ultrasonic water meter was installed.

The only water not measured is the discharge and abstraction from the 4 balancing dams. However, management does not expect significant losses from it since these dams are lined.

Supply and withdrawal figures for the 2006/2007 season were received for this scheme and a summary thereof appears in Table 95. (Before 2006 the scheme supply water was not measured. There is a remarkably small difference in the supply and withdrawal figures (keep in mind that balancing dams were not monitored and this may account for differences as well).

Table 95: Water supply and withdrawal figures for WEWUA scheme

Dates	Scheme supply		Users withdraw		Difference (Withdraw – Supply)			
	Month	Accumulative	Month	Accumulative	Month		Accumulative	
	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(%)	(m^3)	(%)
15 Oct-15 Nov	505,836	505,836	569,307	569,307	63,471	12.5%	63,471	12.5%
15 Nov-15 Des	1,397,815	1,903,651	1,313,289	1,882,596	-84,526	-6.0%	-21,055	-1.1%
15 Dec-15 Jan	2,116,679	4,020,329	2,159,029	4,041,625	42,351	2.0%	21,296	0.5%
15 Jan-15 Feb	2,393,272	6,413,601	2,341,973	6,383,598	-51,299	-2.1%	-30,003	-0.5%
15 Feb-15 Mar	1,881,251	8,294,852	1,955,000	8,338,598	73,749	3.9%	43,746	0.5%
15 Mar-15 Apr	1,622,779	9,917,631	1,676,051	10,014,649	53,272	3.3%	97,018	1.0%
15 Apr-15 May	834,090	10,751,721	821,385	10,836,034	-12,705	-1.5%	84,313	0.8%
15 May-15 Jun	238,594	10,990,315	281,000	11,117,034	42,406	17.8%	126,719	1.2%
15 Jun-15 Oct	971,213	11,961,528	328,000	11,445,034	Receive water from other source			
Total	11,961,528		11,445,034				516,494	4.3%
Volume of Dams	80,000							

11.3 Irrigation systems

11.3.1 System evaluations

The results for the Worcester East area are shown in Table 96 to Table 101. The relative low values for the gross irrigation requirement (test site W5 and W9) could be attributed to the fact that the values supplied were not for the peak irrigation period. From Table 96, it can be concluded that the gross irrigation requirement ranged from 1.5 to 6 mm/day for grapes.

Table 96: General Information

Test site code	Irrigation system	Crop	Expected yield (ton/ha)	Nett application measured (mm)	Nett application rate measured (mm/h)
W1	Drip PC	Grapes	16	NA	2,0
W2	Drip PC	Grapes	30	NA	0,8
W3	Micro sprayer	Grapes	40	NA	13.9
W4	Drip PC	Grapes	30	NA	0,6
W5	Drip PC	Grapes	14	NA	0,8
W6	Drip	Grapes	30	NA	0,8
W7	Sprinkler	Grapes	35	NA	Not measured
W8	Drip	Grapes	30	NA	1,2
W9	Drip	Olives	6	NA	1,0
W10	Drip	Grapes	35	NA	1,0

NA = Not applicable

The general information regarding for the pump revealed that most of the pumps are in good working condition but there are a few that have drainage and safety problems. The reason for not measuring the flow rate and operating pressure are due to the fact that limited space is available for measurements in the pump house.

Table 97: General Information of Pump

Test site code	Flow rate (m^3/h)	Operating pressure (kPa)	Power rating (kW)	Eccentric inlet (Yes/No)	Concentric outlet (Yes/No)	General pump station appearance
W1	Not measured	Not measured	18,5	Yes	Yes	Limited space and no screens over couplings
W2	Not measured	350	18,5	No	Yes	Good condition
W3	No pump	-	-	-	-	-
W4	Not measured	700	22,5	Yes	Yes	Good condition
W5	Not measured	500	15	Yes	Yes	Drainage problems and limited space
W6	Not measured	Not measured	11	Yes	Yes	Drainage problems and no screens over couplings
W7	Not measured	Not measured	18,5	Yes	Yes	Drainage problems and no screens over couplings
W8	Not measured	240	8,5	No	No	Drainage problems and no screens over couplings
W9	No pump	-	-	-	-	-
W10	No pump	-	-	-	-	-

11.3.2 Sprinkler irrigation system

The hydrant pressure of block W7 was not measured because there was limited space available.

Table 98: General Information

Test site code	Type of sprinkler system	Sprinkler spacing (m)	Nozzle size (mm)	Operating pressure (kPa)			Sprinkler discharge measured (ℓ/h)
				Hydrant (measured)	Nozzle pressure calculated	Average nozzle pressure measured	
W7	Permanent	2,5 × 9,8	4	Not measured	238-278	80	586

Table 99: Test results

Test site code	Uniformity Parameters				Efficiency		Pressure variation (%)		Discharge variation (%)	
	CU (%)		DU_{lq} (%)		SE (%)		Guidelines (max)	Measured	Guidelines (max)	Measured
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (min)	Measured				
W7	80	Not measured	75	Not measured	75	Not measured	20	38	10	34

11.3.3 Micro irrigation systems

The hydrant pressure of blocks W3 and W8 were not measured, because there was limited space available. Most of the systems are using sand/disc filters for the drip irrigation systems.

Table 100: General information

Test site code	Type of micro system	Filter type	Emitter spacing (m)	Operating pressure measured (kPa)		Emitter discharge (ℓ/h)	
				Average measured (block)	Hydrant	Average measured (block)	Design
W1	Drip PC	Sand / Disc	$2,44 \times 0,75$	77	160	3,6	3,5
W2	Drip PC	Disc	4×1	35	110	3,3	3,5
W3	Micro sprayer	Disc	$2,44 \times 4$	131	Not measured	135,6	Not available
W4	Drip PC	Disc	$2,5 \times 1$	114	140	2,4	2,2
W5	Drip PC	Sand / Disc	$2,44 \times 0,75$	189	300	2,3	3,5
W6	Drip	Sand / Disc	$2,44 \times 1$	157	260	2,3	2
W8	Drip	Sand / Disc	$2,5 \times 1$	66	Not measured	3,6	4
W9	Drip	Disc	$5 \times 0,5$	223	275	2,5	2
W10	Drip	Sand / Disc	$2,4 \times 0,6$	49	75	1,5	2

The low EU, U_s and CV values are due to the fact that the systems operates at too low and in other cases too high pressure which can be attributed to, too many blocks that irrigate together, or in the other cases only one block operates. The high measured pressure in the blocks is due to the fact that no pressure regulating is done at the block inlet. The low flushing velocity can also be due to the above mentioned reasons.

Table 101: Test results

Test site code	Uniformity Parameters				Pressure variation (%)		Flushing velocity (m/s)	
	U_s (%)		EU (%)					
	Guidelines (min)	Measured	Guidelines (min)	Measured	Guidelines (max)	Measured	Guidelines (min)	Measured
W1	80	89,5	85	88,1	20	129	0,4	Not measured
W2		84,3		80,2		271		0,2
W3		89,3		85,5		34		NA
W4		93,3		91,4		22		1,35
W5		76		73,2		132		0,74
W6		60,5		61,8		29		0,6
W8		51		55		128		0,33
W9		87,5		85,9		31		1,26
W10		73,7		69		51		0,53

11.3.4 Irrigation requirements – On-farm water balances

The irrigation supply and demand for 84 farms in this scheme were analysed in as much detail as possible. The common factor between these farms is that all have enlistments from the Worcester East Irrigation Scheme. Most farms also have other water sources, e.g. water from other smaller schemes and ground water. The total area of irrigated crops is 6 335 ha.

The analysis required that a lot of data had to be acquired, and in this regard the personnel of the WEWUA, including the (retired) former CEO of the scheme provided invaluable input. The following (on farm level) were important for the analyses:

- Existing lawful water use rights registered, per water resource
- Water use for the 2007/2008 irrigation season, per water resource
- Present area per crop irrigated
- Applicable local automatic weather station data

Only the water supplied from the WEWUA is measured (per farm) and considerable effort was put in to determine the water supplied from the other resources.

The results of the analyses appear in Table 102 below. It should be noted that irrigation requirements for the average years were used, while the water use was for a specific year. Since the major part of the rainfall occurs during winter when almost no irrigation is required, the inaccuracy should not be too significant. However, it will be possible to use also the weather station data for the specific year to improve the accuracy.

Table 102: Water Uses in Worcester East Irrigation Scheme

Farm	Registered water use right	Area irrigated	Agricultural water requirement	Agricultural water use (07/08)	Irrigated vs. requirement	Water use vs. water use right
	(m^3)	(ha)	(m^3)	(m^3)		
Farm 1	862,899	56.9	460,781	322,797	70%	37%
Farm 2	635,700	107.9	809,996	478,354	59%	75%
Farm 3	434,475	47.8	349,835	316,836	91%	73%
Farm 4	52,895	10.0	76,200	40,030	53%	76%
Farm 5	859,179	322.2	851,900	668,753	79%	78%
Farm 6	319,555	39.0	315,217	233,650	74%	73%
Farm 7	626,610	72.7	617,538	701,952	114%	112%
Farm 8	1,063,569	163.4	1,126,601	518,286	46%	49%
Farm 9	509,310	127.1	502,420	476,677	95%	94%
Farm 10	393,062	51.1	347,582	377,942	109%	96%

Farm	Registered water use right	Area irrigated	Agricultural water requirement	Agricultural water use (07/08)	Irrigated vs. requirement	Water use vs. water use right
	(m^3)	(ha)	(m^3)	(m^3)		
Farm 11	387,102	45.6	295,808	395,553	134%	102%
Farm 12	426,526	90.5	1,055,595	534,232	51%	125%
Farm 13	474,960	80.3	604,410	481,416	80%	101%
Farm 14	577,450	86.5	656,134	403,354	61%	70%
Farm 15	533,421	61.7	456,088	396,160	87%	74%
Farm 16	577,450	78.6	600,058	427,515	71%	74%
Farm 17	860,935	128.5	833,864	827,328	99%	96%
Farm 18	27,500	2.0	14,965	12,740	85%	46%
Farm 19	585,804	90.4	613,043	613,178	100%	105%
Farm 20	770,330	72.8	781,616	826,925	106%	107%
Farm 21	241,520	41.1	195,680	302,019	154%	125%
Farm 22	550,650	72.4	602,768	512,278	85%	93%
Farm 23	27,380	2.3	18,078	6,120	34%	22%
Farm 24	511,631	53.1	457,284	551,394	121%	108%
Farm 25	421,400	42.1	369,014	604,668	164%	143%
Farm 26	251,202	32.9	259,364	232,156	90%	92%
Farm 27	39,411	1.5	34,851	26,338	76%	67%
Farm 28	376,162	32.8	284,818	606,327	213%	161%
Farm 29	240,480	26.7	233,983	295,399	126%	123%
Farm 30	542,760	93.1	569,420	583,043	102%	107%
Farm 31	1,147,920	168.3	1,331,426	981,708	74%	86%
Farm 32	1,905,910	159.4	1,041,887	816,381	78%	43%
Farm 33	23,215	3.2	37,437	20,709	55%	89%
Farm 34	12,760	2.2	26,592	9,640	36%	76%
Farm 35	293,225	22.7	198,781	151,418	76%	52%
Farm 36	71,340	9.4	80,574	61,994	77%	87%
Farm 37	417,660	67.6	623,133	436,945	70%	105%
Farm 38	112,565	27.6	143,408	112,566	78%	100%
Farm 39	808,040	133.9	826,185	824,991	100%	102%
Farm 40	212,030	27.3	238,800	281,216	118%	133%
Farm 41	273,840	32.0	279,018	714,789	256%	261%
Farm 42	202,500	19.8	173,649	212,892	123%	105%
Farm 43	335,480	52.3	405,702	156,004	38%	47%

Farm	Registered water use right	Area irrigated	Agricultural water requirement	Agricultural water use (07/08)	Irrigated vs. requirement	Water use vs. water use right
	(m³)	(ha)	(m³)	(m³)		
Farm 44	249,405	37.4	285,331	150,026	53%	60%
Farm 45	146,100	28.9	253,600	189,239	75%	130%
Farm 46	721,000	123.2	743,703	798,751	107%	111%
Farm 47	519,240	89.9	670,306	326,303	49%	63%
Farm 48	334,680	47.9	408,521	209,672	51%	63%
Farm 49	947,020	165.0	1,055,191	684,556	65%	72%
Farm 50	654,765	73.4	720,164	669,277	93%	102%
Farm 51	664,722	102.3	823,084	1,283,898	156%	193%
Farm 52	1,084,220	173.0	1,064,837	1,001,218	94%	92%
Farm 53	696,520	107.3	812,106	1,846,267	227%	265%
Farm 54	971,860	96.3	832,105	22,217	3%	2%
Farm 55	761,400	63.5	828,831	532,436	64%	70%
Farm 56	836,400	101.6	907,553	600,661	66%	72%
Farm 57	3,211,700	322.5	3,121,520	3,414,100	109%	106%
Farm 58	642,040	82.1	743,098	881,828	119%	137%
Farm 59	916,860	148.4	1,149,807	929,238	81%	101%
Farm 60	548,740	87.2	638,654	526,921	83%	96%
Farm 61	695,780	101.0	778,145	605,739	78%	87%
Farm 62	34,140	3.8	35,338	35,440	100%	104%
Farm 63	938,880	154.1	1,176,599	720,227	61%	77%
Farm 64	878,500	109.1	967,375	695,451	72%	79%
Farm 65	512,880	61.9	592,334	236,025	40%	46%
Farm 66	225,480	23.7	194,624	249,719	128%	111%
Farm 67	515,280	84.8	621,198	261,808	42%	51%
Farm 68	15,900	1.5	17,494	3,973	23%	25%
Farm 69	648,680	95.1	758,674	565,726	75%	87%
Farm 70	483,960	72.9	592,173	350,218	59%	72%
Farm 71	164,480	25.4	196,788	140,841	72%	86%
Farm 72	192,980	18.4	161,214	192,140	119%	100%
Farm 73	237,900	40.3	285,655	280,769	98%	118%
Farm 74	156,450	17.2	148,714	184,421	124%	118%
Farm 75	1,779,397	189.7	1,640,429	1,865,306	114%	105%
Farm 76	208,000	20.4	178,990	238,552	133%	115%

Farm	Registered water use right	Area irrigated	Agricultural water requirement	Agricultural water use (07/08)	Irrigated vs. requirement	Water use vs. water use right
	(m^3)	(ha)	(m^3)	(m^3)		
Farm 77	163,420	18.2	153,215	153,041	100%	94%
Farm 78	565,090	132.5	829,988	602,464	73%	107%
Farm 79	370,500	29.1	254,474	315,947	124%	85%
Farm 80	884,275	191.2	1,111,645	772,524	69%	87%
Farm 81	596,240	88.2	595,101	509,783	86%	85%
Farm 82	378,375	42.2	375,678	412,828	110%	109%
Farm 83	313,960	53.8	368,531	287,889	78%	92%
Farm 84	335,480	52.3	405,702	106,210	26%	32%
Total	45,200,510	6,335	47,299,990	41,408,322		
Average					89%	93%

11.4 Conclusion

The following are some concluding remarks are based on outcome of the analyses:

- There are relative few cases where farms use more than their lawful water use rights. For the region as a whole the usage is 7% below the lawful rights
- In general, farmers irrigate less than the theoretical irrigation requirement of the crops on the farm. For the region as a whole the usage is 11% below the irrigation requirement. Probable reasons for this are:

  A certain percentage (between 10% and 15%) of crops are still not mature, and therefore requires less irrigation

  The climate for the particular year vary from average conditions

  Irrigation management

- It appears if bigger differences (especially under-irrigation) takes place on the smaller farms, but in general it does not appear if there is a definite pattern with regards to the size of the farms

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