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An evaluation of irrigation water supply infrastructure to improve conveyance efficiency and water availability at Dzindi Irrigation Scheme, Limpopo Province

by

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Declaration

I, Mukovhe Maureen Nthai, hereby declare that the dissertation/thesis, which I hereby submit for the degree, M Inst Argrar (Rural Engineering Technology) at the University of Pretoria, is my own work and has not previously been submitted by me for the degree at this institution or any other tertiary institution.

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Title: An evaluation of irrigation water supply infrastructure to improve conveyance efficiency and water availability at Dzindi Irrigation Scheme.

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Abstract

A water use and availability study was conducted at the Dzindi Irrigation Scheme in Limpopo Province. The problems experienced at Dzindi Irrigation Scheme regarding water allocation, concern water availability at a field level. Although water is continuously being diverted into the main canal, farmers at the bottom end of the system claim not to receive adequate water supplies, forcing them to practice dry land irrigation (farming). Water losses occur between the source and the point of application, and the causes of loss need to be identified so that water availability can be improved.

The study focused on water released to Block 2, and an analysis was made of all losses which occur from the weir where water is released to the point of application in the fields. An estimation of water supplies that return to the river as an unused delivery, and conveyance losses that occur along the distribution channels, were determined through a water balance drawn up from measured canal inflows, such as seepage and evaporation.

A total volume of 371096 m^3 was supplied to Block 2 during a 45 day monitoring period. For a planted area of 16.52 ha, this works out to 22463 m^3 /ha supplied, or a relative irrigation supply of 14.2 times the irrigation requirement.

Losses originate from a number of sources. Results indicated that losses that occurred in the main canal were very low, with a conveyance efficiency of 96% recorded. Knowledge of irrigation water management and practical irrigation scheduling at a scheme level is weak. The biggest immediate need is to improve the management of the infrastructure. The main system capacity is adequate, and losses due to seepage, evaporation and return flows are within acceptable limits. The return flows are mostly caused by the farmers' lack of understanding that led to them removing the entire sluice gates at the head of the secondary canals of Block 2. This results in water running to the first two secondary canals only, and not reaching the rest of the Block.

Based on the requirements identified by all the stakeholders, training should be provided to the water bailiffs and farmers to implement management practices that are both effective and sustainable. Together with prioritised infrastructure upgrading, more acceptable water delivery should be possible.

The challenge lies in making the technical and the social aspects converge in such a way that the result is acceptable to both systems and can be sustained over time. The opportunities for capacity building by equipping the stakeholders with new skills are considerable, but the time and effort required to achieve this should not be underestimated.

Dedication

In memory of my father, Muravha Benjamin Nthai, who regretfully did not live to see this work.

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Chapter 1 Introduction

1.1 Background

1.1.1 Irrigation water management in South Africa

Since 1994, the South African Government has undertaken massive reforms aimed at addressing rural poverty and inequalities inherited from the past apartheid regime. Amongst other programmes, it has adopted ambitious new water legislation, which culminated in the acceptance of a new National Water Act; Act 36 of 1998. The National Water Act (Act 36 of 1998) provides for water to be protected, utilised, developed, conserved, managed and controlled, in a sustainable and equitable manner (Perret and Touchain, 2002).

South Africa is in the process of implementing a new water management policy. The policy considers water as a common asset, and users are going to be granted the rights to use that water. It will require that most of them must be registered and licensed, and they must pay for this right. The Act promotes equity, sustainability, representativity and efficiency. Its key objectives are social development, economic growth, ecological integrity, and equal access to water. The Act distinguishes between national areas of water management and regional and local areas. New water management entities (Catchment Management Agencies and Water Users Associations) will be established in order to achieve the aims of the Act (Perret and Touchain, 2002).

Water Users Associations (WUAs) will operate at the local level. These WUAs are in effect co-operative associations of individual water users who wish to undertake water related activities for their mutual benefit. The role of the WUA is to enable a community to pool financial and human resources in order to carry out more effective water related activities. Irrigation management forms one of the key activities to be performed by WUAs

(DWAF, 1999).

South Africa is a semi-arid country where water is of critical strategic importance to all development, in any sector of the economy. Recognising the potential limiting effect that water could have on future economic expansion in this country, it is of utmost importance that this resource be optimally utilised to the benefit of all current and future users (Water Conservation and Demand Management Strategy for the Agricultural Sector, Draft 2000).

The efficient management of increasingly scarce water resources is becoming a crucial issue for the future in many countries. This is bringing about a shift in conceptions of “water management”; particularly with respect to water used in agriculture (Huppert, 1999).

The irrigated agriculture sector, which currently accounts for two thirds of the world’s water use, is increasingly required to produce more food from a limited land area using less water (Cornish, 1998). Water resources are increasingly being exhausted, and competition for the available water between agriculture and the municipal and industrial sectors is increasing each year.

As competition with other users of water increases dramatically, the challenge for irrigation is to produce more with less water. This goal can only be the result of a high level of performance. It will not be possible without considerable changes in the way water is managed throughout the basin; from the sources down to the end users. The increase of water productivity in the agricultural sector and the cost effectiveness of irrigation require changes (or adaptation) of the institutional set up, as well as of the physical infrastructure. In many situations the first crucial improvement is to enhance the reliability of water supply to the farmers. In other situations where the reliability is already high, further improvement will result in increased flexibility of delivery. (ITIS 5, 1999).

The purpose of an irrigation system is to deliver water in a specified quantity for irrigation. Considerable emphasis should be placed on measurement and control of water, both in storage and in transit through the system, to minimise losses. So the conservation of water must be practiced at any cost.

To conserve water, meaningful losses should be identified. This can only be achieved by measuring discharge at critical locations (Water Conservation and Demand Management Strategy for the Agricultural sector, Draft, 2000).

Improved irrigation water management is needed, but without water measurements it is impossible to determine current usage and what management should accomplish (Rogers and Black, 1993). Water should ideally be measured at the entrance and exit of the WUAs borders, as well as at the beginning of every secondary and tertiary canal or pipeline, along the main, secondary and tertiary conduits, at inlets and outlets of every balancing dam, at the end of every conduit, and at the farm turnout. (DWAF, 2000).

1.1.2 Water management at the Dzindi Irrigation Scheme

The Dzindi Irrigation Scheme is situated in the Limpopo Province of South Africa. The scheme is situated about 6 km south west of Thohoyandou, in the Thulamela Local Municipality. Thulamela Municipality forms part of Vhembe District Municipality.

The total irrigated area in Dzindi amounts to 136 ha. Dzindi consists of four irrigation Blocks, which combined comprise 106 plots of 1.28 ha each. Of these 25 are in Block 1, 35 in Block 2, 13 in Block 3, and 33 in Block 4. Spatially, the four Blocks are separated from each other (Figure 3.1).

Water to the scheme is supplied by a diversion of the Dzindi River, a perennial river that flows south of Itsani Village (Figure 3.1), by means of a concrete weir. A concrete canal distributes the water to the four irrigation Blocks. Concrete furrows bring the water to the farmer’s plots. The distribution of furrows has been designed to allow water to enter the fields at regular intervals. In three of the four irrigation Blocks, the main canal directly supplies the secondary distribution furrows, which bring the irrigation water to the plot edge. In Block 1, the canal supplies water to an earthen dam, from where it is transferred to the distribution furrows and the plots.

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, where 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.

The previous study involved the measurement of flow rates at various points in the distribution system, but since all of these measurements were not made simultaneously, it cannot present a true picture of water losses in the system since adjustments to regulating structures may have occurred between measurements. A more acceptable way to quantify water losses, or determine distribution efficiency, is through a water balance, which can be defined as an accounting of all water volumes entering and leaving a three-dimensional space over a period of time (Burt, 1999). This implies that spatial and temporal boundaries have to be defined, and that water crossing the boundaries needs to be measured volumetrically. This is best achieved through measuring flow rates at selected points in the distribution system over a known period of time.

A proposal was drawn up to obtain additional funding for the investigation, which broadly consisted 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.

1.1.3 Socio-economic importance

The Dzindi Irrigation Scheme is very important for the Itsani community and the surrounding areas. The farmers in the Dzindi Irrigation Scheme produce enough food for their families and sell the excess to the local communities and to hawkers. Some of the farmers plant only maize in the summer. In the winter they do not use their plots to plant vegetables. It was observed that some of the plots have been lying there for more than two years.

The scheme creates part-time jobs for the local communities during planting, weeding and harvesting time. Those who have fulltime labourers rely on Zimbabweans and Mozambicans because farmers say they are cheaper. The majority of the farmers rely on family labour.

1.1.4 Water availability

In the Dzindi Irrigation Scheme, there is no water conservation or management. Water always runs in the canals at full capacity everyday. According to the Water Conservation and Demand Management Strategy for the Agricultural Sector, Draft 2000; water conservation is defined as the minimisation of loss or waste, care and protection of water resources and the efficient and effective use of water. There are two water bailiffs at the scheme but they do not perform any water management duties in terms of control, except for the canal section serving Block 1, where the inlet sluice is apparently closed every night to allow the balancing dam to fill. In Block 2, farmers have indicated that there is no water available for irrigation, especially the last part of plot 25 and other plots towards Muladane. Most of the farmers in these plots are practicing dry land farming.

The Dzindi River, which the scheme uses for irrigation, is also used by the community for domestic purposes. Next to the main road before Block 4, they use the canal to wash their cars. On the other side towards Block 3, they use the canal to wash their clothes; others use the canal as the rubbish tip, and sometimes dead dogs etc. are thrown in. In the evenings, towards Block 2, others use the canal for bathing, especially in summer.

1.1.5 Benefits of improved management

The Dzindi Irrigation Scheme has competing uses of water in terms of irrigation management, including agriculture and local communities etc. The benefits of water management rely on the better use and protection of the water (a natural resource) which must be sustainable. Irrigation can have an impact on local communities and other users of water in river basins, and these consequences have often been neglected when irrigation is being developed and managed.

In the Dzindi Irrigation Scheme, the canal was only meant for irrigation. Some community members who live close to the canals, far from street taps, use the canal for domestic purposes, like washing their clothes. Some go to the extent of using it as a rubbish bin.

There is a need to better understand these linkages and influences, and to evaluate options for developing and managing water more productively for the benefit of all users in a river basin.

1.1.6 Dangers of not improving

They are destroying the natural water resource that they need to sustain for the future generation. Protecting the water resource ensures its continuing availability for human use. The scheme is their only source of income and it provides food for their families.

1.2 Problem statement

Scarcity of water has become a major issue in the world. Not only does the unwise use of water resulting in wastage make it an important issue, but so is the need to use it for other sectors, and to protect the resource. The purpose of an irrigation system is to deliver water in a specified quantity for irrigation. Considerable emphasis should be placed on measurement and control of water, both in storage and in transit through the system, to minimise losses.

To conserve water, meaningful losses should be identified. This can only be achieved by measuring discharge at critical locations. Loss of water occurs at different points of the system like canals, storages and applications (Final Draft paper for Water Conservation and Demand Management Strategy for the Agricultural Sector (DWAF, 2000).

The problems experienced at Dzindi Irrigation Scheme regarding water allocation concern water availability at the field level. Although water is continuously being diverted into the main canal, the farmers at the bottom end of the system claim not to receive adequate water, forcing them to practice dry land irrigation (farming). Water losses occur between the source and the point of application, and the causes of loss need to be identified so that water availability can be improved.

1.3 Objectives

1.3.1 General objectives

The overall objective of the study is to quantify losses in the canals of Block 2 in the Dzindi Irrigation Scheme, and recommend water conservation measures to reduce losses and improve water availability.

1.3.2 Specific objectives

- To determine typical irrigation efficiency and uniformity values of the short-furrow system through in-field evaluation.
- To prepare a volumetric water balance of the water distribution system, focusing on Block 2.
- To evaluate the efficiency of the different components of the water distribution system by calculating performance indicators.
- To evaluate the results and make recommendations to improve water

availability.

1.4 Scope of the study

The study focused on the water that was released to Block 2. It comprises an analysis of all losses which take place from the division where water is released to the water that will be used by the plant, and the estimation of water that finally returns to the river as unused deliveries. Conveyance losses occur along the distribution channels. Conveyance water balances were performed by considering canal inflows and outflows, such as seepage and evaporation.

1.5 Methodology

The scheme was visited for the first time in August 2004 to inspect the distribution infrastructure. Towards the end of August measuring devices were installed. Monitoring of the equipment and the planted areas took place during October and November 2004.

In summary, the following activities were undertaken:

- The water distribution infrastructure was inspected during a field visit.
- Suitable indicators for evaluating water distribution efficiency were identified.
- The spatial and temporal boundaries of the water balance and its components, as well as the required level of accuracy, were defined.
- The available and required measuring infrastructure was identified.
- The necessary measuring devices were installed or repaired.
- The measuring process was monitored and data collected for the specified period.

- An evaluation of typical in-field irrigation practices.
- Data was analysed and the water balance completed.
- The results were evaluated using the chosen indicators.
- Benchmarks were calculated.
- Recommendations were made for improved water management.

1.6 Conclusion

In South Africa there is no data for water balances or any water measurements undertaken for small-scale schemes which are mostly in the former homelands. This is the first of such kind. It is very important to have the water measurement data, because most of the schemes will be rehabilitated. If data like these are available it makes it easier for those who will be rehabilitating the scheme to consider the challenges faced when collecting the data.

Chapter 2 Literature review

2.1 Introduction

Rainfall is highly variable in the province, ranging from 400 mm in the west and increasing to about 800 mm in the extreme east. The Northern Province is generally characterised by water scarcity. As a result there is competition between established water users (commercial farmers, mines etc.) and emerging farmers who have limited or no access to surface water. The resource therefore has to be conserved.

2.2 Access to water

2.2.1 The right to use water

According to Vermillion and Sagardoy (1999), there may be lack of clarity about how the right is measured, criteria of allocation, and means of distinguishing among different types of users. An important area in which legal action may need to be taken is in relation to water rights.

Water rights specify expectations about the amount, share and/or duration of flow of water to which particular kinds of water users, groups of water users, or an entire irrigation system is entitled. Increasingly, water laws also involve rights and obligations and water quality. Water rights may need to be created or existing ones need to be updated for modern conditions.

According to Vermillion and Sagardoy (1999), in many countries modern statutory laws back up customary water rights. There are a number of developing countries, particularly Asia and Africa, where there are no water rights recognised by the state, and where instead all water resources in the country are considered to be owned and controlled by the state. In these circumstances, the state is responsible for allocating water according to administrative regulations, and tends to see water allocation as a social welfare benefit rather than as a legal entitlement. The water user is a supplicant, not a holder of a right. Where water is scarce relative to the demand, considerable uncertainty and competition for water may exist.

The social welfare conception of water tends to work against a primary objective of irrigation management transfer, which is to eliminate farmer dependence on the government and to create locally self reliant organisations which can extract, distribute and dispose of water according to local needs. Without water rights, farmers cannot predict or define how much water they will receive, and when conflicts or competition over water arise, there is no clear legal basis for setting disputes. This weakens their motivation to invest intensively in agriculture or water management. Any government that has adopted a policy to transfer management should first put in place a basic system of water rights, which defines the principles according to which water will be allocated among different users (Vermillion and Sagardoy, 1999).

Water rights may be granted to collective entities such as water user associations, or may be granted to individuals and public corporations. The Mexican water law of 1992 established a basis for WUAs to obtain formal water rights, whereas Chile granted absolute, tradable water rights to individual users. Individual users may lack control over infrastructure, which diverts water from the resource base (the river), and since the WUA does not hold a right, difficulties may arise in managing water transfers between individuals. In most countries, water rights are allocated and distributed to water user associations, which in turn allocate rights to their individual members (Vermillion and Sagardoy, 1999).

2.3 Irrigation water use in South Africa

Rights to use water in South Africa were subjected to successive water legislations, the principles of which had their roots in the Roman, Dutch, then English laws (Thompson et al, 2001).

The South African New National Water Act (Act 36 of 1998) broke drastically with the previous water laws in the sense that past key concepts were discarded. These include the individual right to use water for riparian users.

Water is now considered a common asset (DWAF, 1999).

2.4 An overview of water use rights, as determined by the National Water Act of 1998

2.4.1 License

A license is a legal entitlement to use water, granted for a period of 40 years (users must be registered). It does not guarantee water availability or quality to the licensed users. It may be surrendered, withdrawn, or transferred totally, partially, temporarily or permanently. It may be inherited by a successor to the title holder (licensed water user). Transfer of license is possible (water rights market). A use is regulated by a license when there is a high risk of unacceptable impact if not controlled (overuse, degradation, etc.).

DWAF may call for compulsory licensing of water usage (decide on license allocation, terms and conditions for all prospective users) in a stressed resource areas where there may be problems experienced from over utilisation, competing water users, or very inequitable allocation. Such calls for compulsory licensing will apply to all water users and rights, including general authorisations and existing lawful uses. An allocation schedule will be proposed in such instances.

2.4.2 General authorisation

A general authorisation is an authorisation to use water without a license, with certain limits and conditions, and is valid for 3-5 years. It may be reviewed at intervals of not less than 2 years. It only applies to new water usage that has taken place since October 1999, when the Act was fully promulgated.

It applies to any water user anywhere in the country, unless areas are specifically excluded. It may also apply to a particular water resource, and is generally issued in an area with relatively sufficient water.

It allows certain water use, which has a small or insignificant impact on water resource (i.e. limited abstraction and storage, irrigation with waste water, discharge of waste water, etc.). General authorisation users are not usually required to apply for a license (except in water stressed situations), but may also be registered in most cases.

2.4.3 Existing lawful use

Existing lawful uses corresponds with authorisations that were granted from October 1996 to September 1998, just before the application of the National Water Act. Existing lawful users are usually not required to apply for licenses (except in water stressed situations), but they must be registered.

2.4.4 Schedule 1

Schedule 1 uses of water have minimal or insignificant impact on water resources. They include, amongst others uses, “reasonable” garden watering and rain water storage. Schedule 1 users are nor required to register, or to apply for license.

2.4.5 Reserve

The reserve is the only right to use water in law. Most small scale irrigation draws very little water, and most fall under Schedule 1 use, for which no registration or license is required. Smallholders should be made aware of the advantages of belonging to a WUA. Under the water law, only WUAs may apply for a license to use more water. Failure to become a member would limit an individual farmer’s use of water to that under general authorisation (Schedule 1) and prevent him or her expanding to operate more commercially.

According to Malano & Burton (2001), farmers should be encouraged to form WUAs early and put in license applications before all the water is committed elsewhere.

2.4.6 Water Conservation and Demand Management Strategy

Water conservation and water demand management are often used as synonymous terms. Although the meaning and implications of these terms is very similar, it is important to recognise the difference. Brief explanations of both terms and their definitions are described below (DWAF, 2000).

Water conservation

Over time, both in South Africa and internationally, the meaning of water conservation has varied. From the beginning of the industrial revolution, water conservation meant dams to capture and store water so it could be distributed as needed. These systems were designed to conserve water by preventing the waste of water to the ocean. Over the last two decades the meaning of water conservation became restricted to "use less water" and "protect the environment".

The definition of water conservation proposed is:

"The minimisation of loss or waste, the preservation, care and protection of water resources and the efficient and effective use of water."

It is important to recognise that water conservation should be both an objective in water resource management and water services management, as well as a strategy.

Demand management

The definition of demand management proposed is:

"The adaptation and implementation of a strategy (policies and initiatives) by a water institution to influence the water demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services, and political acceptability."

Demand management should not be regarded as the objective but rather a strategy to meet a number of objectives. One reason why the full potential of demand management is often not recognised is because it is often perceived or understood in a limited context. It is common for people to equate demand management only to programmes such as communications campaigns or tariff increases.

Demand management should equate to the development and implementation of strategies and initiatives associated to managing water usage.

A useful comparison on the philosophy of demand management is a comparison with the role of marketing in the commercial corporate environment. In the past, marketing in the commercial environment meant simply advertising. Currently marketing has a much wider meaning which involves understanding the clients and their needs, understanding the market forces and then deriving a strategy in order to set and achieve target sales, market share and profits.

The principles of demand management are very similar to that of marketing, where the water supply institutions should set water demand goals and targets by managing the distribution systems and consumer demands in order to achieve the objectives of economic efficiency, social development, social equity, affordability and sustainability. The water supply industry can gain much by adopting marketing principles to the demand management strategies.

South Africa is a semi-arid country, where water is a key strategic resource in the development of all sectors of the economy. Efficient management of our limited resource is therefore an essential element of that development (DWAF, 2000).

Water has to be conserved at all levels, from the source, right through to the points of use. However, the focus at this early stage of the process is on the activities of WUAs and how these are aimed at the following : reducing water losses related to the WUAs storage and water distribution systems and management, and enabling farmers to use water more efficiently on-farm.

In a water management plan, a WUA describes its current irrigation water use and conservation measures and sets out how to implement Best Management Practices (BMPs) to improve its irrigation water supply services and to achieve water conservation and water demand management. BMP is not some distant idealistic vision, but a generally accepted practice that has every chance of being attained. A BMP (also called an Effective Water Management Practice) is a policy, programme, practice, rule and/or regulation, or the use of devices, equipment or facilities which is:

- An established and generally accepted practice that results in more efficient use, conservation or management of water

- A practice which makes progress towards insuring sufficient data is available from existing water management projects to indicate:

    - That significant efficiency improvements or management related benefits could be achieved.

    - That the practice is technically and economically reasonable and not socially or environmentally unacceptable, and

    - That the practice is not otherwise unreasonable for most WUAs to carry out.

The primary benchmarks for irrigation water use are firstly, the crop water requirement of a specific crop (ET_{crop}) in a specific area at a specific time of year. ET_{crop} does not take irrigation efficiency factors into account.

Secondly, the ET_{crop} benchmark can be used to calculate the irrigation water requirements for a specific crop in a specific area and at a specific time of year by adjusting the crop water requirement for appropriate irrigation efficiency factors such as leaching requirements, irrigation application efficiency, effective rainfall and reasonable transmission losses (mainly evaporation). This benchmark is not the "quota" or water allocation for irrigation, but rather a management tool for decision-making within a WUA.

In future, the WUAs will be expected to develop water management plans on a regular basis. The impact of irrigation practices and strategies of water budgeting demands the evaluation of the impact of crops on irrigation requirements. This is one of the functions for which SAPWAT was developed.

2.4.7 Irrigation management

According to Vermillion and Sagardoy (1999), water can be managed at the level of river basin, the main, branch and distribution canal network of an irrigation system, along field channels and in the drainage system.

Management may be transferred for an entire irrigation system or only for certain levels. A single system may be managed by multiple organisations. An example is the so called "jointly managed" irrigation system, where a government agency manages the main and branch canals, and farmer associations manage the distribution and field channels.

At the scheme level, management (between government and farmer associations) is the approach followed in some states in India, Sri Lanka and Indonesia, where a government agency and farmer organisations are responsible for managing irrigation systems at different levels. Important decisions, such as cropping patterns or rotational irrigation, are, in principle, made jointly by government officials and farmer representatives. In medium to large-scale systems in Sri Lanka, "joint management committees meet at distributor and main levels to make key management decisions. In large irrigation systems in Mexico, the government commonly manages the intake and main canal, while water user associations manage the distribution and field channels. Representatives from both sides coordinate between main and distributor levels.

At the farm level, irrigation management is based on scheduling, which involves adjusting the quantity or the frequency of irrigation to suit crop water requirements at different stages of the growing season. Scheduling is a complicated process, even for the best farmers, although it is standard practice to design irrigation with the expectation that farmers will schedule (Crosby *et al*, 2000).

2.5 Water use efficiency evaluation methods

2.5.1 Water balance approach

According to Burt (1999), a water balance can be defined as an accounting of all water volumes entering and leaving a three dimensional space over a period of time. This implies that spatial boundaries have to be defined, and that the water crossing the boundaries needs to be measured volumetrically. This is best achieved through measuring flow rates at selected points in the distribution system over a known period of time. A complete water balance is not limited to only irrigation water, rainwater or ground water, etc., but includes all water that enters and leaves the spatial boundaries.

Spatial boundaries for the conveyance system can be defined as follows: for the upper boundary it can be the water surface, and for the lower boundary it can be the canal bottom. The horizontal boundaries can be all diversions, spills, and discharge points.

A water balance has temporal (time) boundaries as well as physical boundaries. All of the values of water balances (rain, irrigation water supply, ET, etc.) change from one year to another.

The elements of the water balance that are usually measured in evaluating a delivery system include discharge or pressure at various delivery points within the system, duration of the delivery, timing of the delivery, total volume of water supplied, and how often water delivered at a given off-take.

According to Fairweather *et al*, 2003, water balance calculations require that vertical and horizontal boundaries of the system be investigated and precisely defined. The water balance quantifies the volume of water moving into the defined boundaries of the area under consideration, the change in the volume of water within the boundaries, and the volume that moves outside the boundaries.

According to the Water Conservation and Demand Management Strategy for the Agricultural Sector, water balance can be represented by the following equation (DWAF, 2000).

Inflow to irrigation scheme + Storages changes= Consumptive uses + Outflows

Inflows

- Gross inflow is the total amount of water flowing into the domain from rainfall, surface and ground water sources.

- Net inflow is the gross inflow plus or minus any changes in storage.

Consumptive uses

Consumptive use is a use or removal of water from a domain that renders it unavailable for further use.

- Process consumption (productive use) is that amount of water diverted to produce an intended good, and is therefore considered a beneficial use.

- Non-process consumption (non-productive use) occurs when diverted water is “consumed” or depleted, but not by the process (or for the production) intended. This could still be a beneficial use (e.g. indigenous riverine vegetation), but it is mostly non-beneficial (e.g. evaporation, or deep percolation that cannot be retrieved for productive uses).

Outflow

Water flowing out of the system can be either committed or non-committed:

- Committed water is that part of flow that is committed to other uses.
- Uncommitted outflow is water that is not depleted nor committed; and is thus available for use within a basin or for export to other basins, but flows out due to lack of storage or operational measures (e.g. storm water). Water that leaks from a canal and returns to the river may also be considered as uncommitted outflow.

Other definitions:

- Available water is the net inflow less the amount of water set aside for committed use and represents the amount of water available for use at the basin, service, or use level.
- Non-consumptive uses of water are uses where benefits are derived without depleting water (e.g. fishing).

2.6 Estimating the water balance components

2.6.1 Water measurements

According to the Water Demand Management Strategy (2002), water should be measured at the entrance and exit of the WUAs borders, as well as at the beginning of every secondary and tertiary canal or pipeline, along the main, secondary and tertiary conduits, at the inlets and outlets of every balancing dam, at the end of every conduit, and at farm turn out (National Water Resource Strategy DWAF, 2002). Apart from the legal requirements regarding water measurement, it can also be used to quantify various components of the water balance.

A wide range of measuring devices is available. For the measurement of impure irrigation water in pipelines, the expensive high technology meters which are designed to provide high sensitivity and accurate measurement of clean, potable water, cannot be used, because maintenance for the devices will be a problem for small scale farmers and most of the small scale farmers are irrigating with untreated water. The measurement of the flow of water from dams, rivers and canals requires less sophisticated and less expensive types of water meters.

Water measurements provide the data necessary for:

- Determining irrigation efficiency.
- Improving water management.
- Monitoring pumping plant performance.
- Detecting well problems.
- Completing annual water use reports.

2.6.2 Benefits of better water measurement

Besides proper billing for water usage, many benefits are derived by upgrading water measurement programs and systems. Good water management requires accurate water measurement (Water Measurement Manual, 1997).

- Accurate accounting and good records help allocate equitable shares of water between competitive uses, both on and off the farm.
- Good water measurement practices facilitate the accurate and equitable distribution of water within district or farm, resulting in fewer problems and easier operation.
- Accurate water measurement provides the on-farm irrigation decision makers with information needed to achieve the best use of irrigation water applied while typically minimising negative environmental impacts.

- Installing canal flow measuring structures reduces the need for time consuming current metering. Without these structures, current metering is frequently needed after making changes of delivery and to make seasonal corrections for changes of boundary resistance caused by weed growths or changes of sectional shape by bank slumping and sediment deposits.

- Instituting accurate and convenient water measurement methods improves the evaluation of seepage losses in unlined channels. Thus, better determination of the cost benefits of proposed canal and ditch improvements are possible.

- Permanent water measurement devices can also form the basis for future improvements, such as remote flow monitoring and canal operation automation.

- Good water measurement and management practice prevents excess runoff and deep percolation, which can damage crops, pollute ground water with chemicals and pesticides, and result in project farm drainage flows containing contaminants.

- Accounting for individual water use combined with pricing policies that penalise excessive use.

2.6.3 Units of water measurements

Units of water measurement are considered in two classes: First, those expressing a specific volume of water at rest, and second, those expressing time flow. The commonly used units of volume at rest are the liter or cubic meter. The commonly used units of flow are liters per second, cubic meters per second.

According to Subramanya (1997), effective use of water for crop irrigation requires that flow rates and volumes be measured and expressed quantitatively. Measurement of flow rates in open channels is difficult because of non-uniform channel dimensions and variations in velocities across the channel. Water measurement systems include a primary device, which have some physical contact with the water, and a secondary device, which condition the output of the primary device and display this output in a desired form. The primary measurement devices include flumes, weir, Pitot tube and the like, whereas secondary devices for meters which read water levels include manometer, point gauges, weir stick, and float operated chart recorders, submerged pressure transducers, and float operated optical scanners.

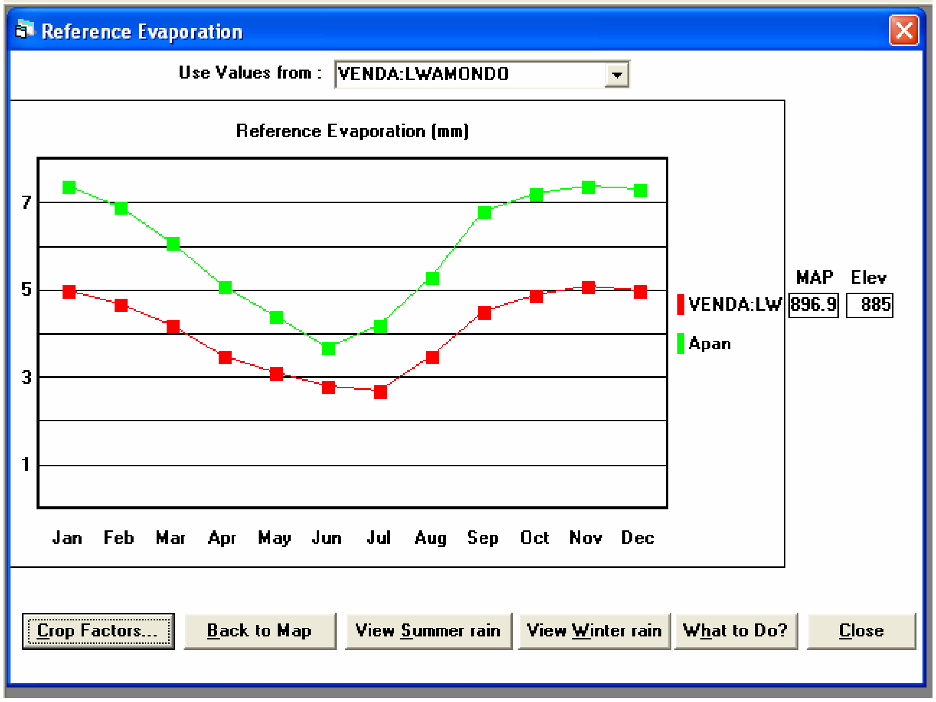
It is beyond the scope of this study to discuss the primary and secondary measuring devices in detail. However, a more in-depth discussion will be presented only for pressure transducers and data loggers.

2.7 Crop water requirements

2.7.1 Overview of SAPWAT

SAPWAT is a planning and management tool incorporating extensive South African climate and crop databases. It is general in applicability in that the same procedure is utilised for vegetable and field crops, annual and perennial crops, and pasture and tree crops. It is possible to simulate wide bed planting, intercropping and different irrigation methods. In addition, the effect of soil water management options, such as deficit irrigation, can be evaluated and alternative irrigation strategies developed (Crosby *et al*, 2000).

SAPWAT allows the user to specify such items as frequency of irrigation, planting density and canopy cover, wetted area, and to select for favourable, normal and severe seasons. There is a scheduling mode that enables the sensitivity of and scheduling strategy to be assessed in minutes so that alterations can be made to the irrigation programme (Improving Agricultural Water Management, 2000).



Use Values from : VENDA:LWAMONDO

MAP 896.9
Elev 885

Figure 2:1 Reference evaporation

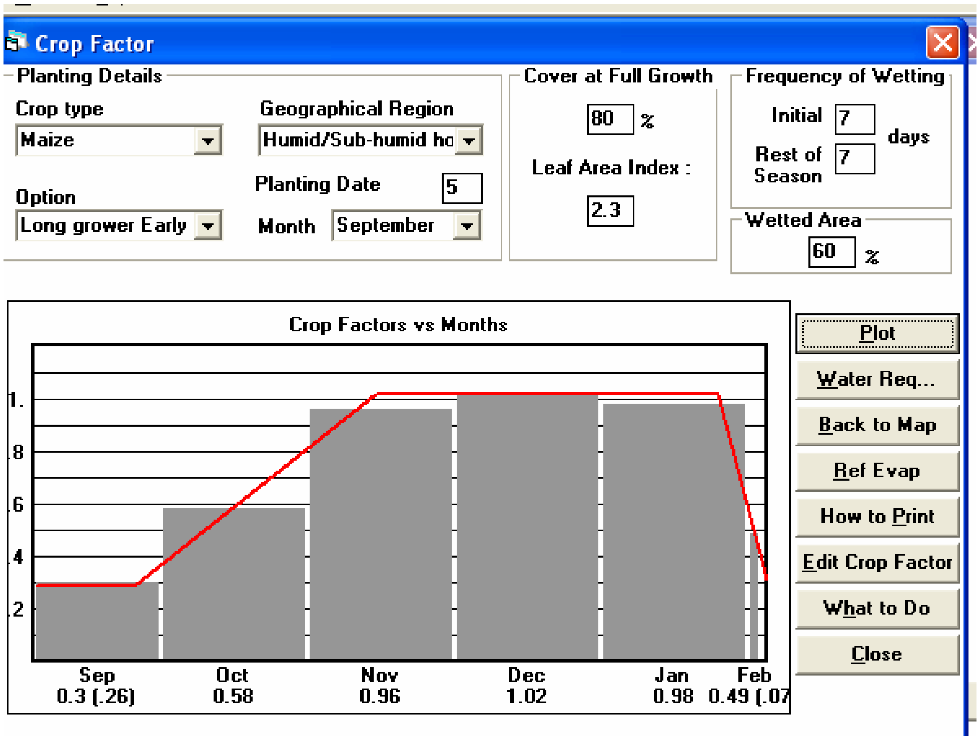
2.7.2   SAPWAT and crop factors

Smith (1994) strongly recommended that the four stages FAO procedure for the determination of crop factors be applied in SAPWAT to ensure a transparent and internationally comparable methodology. Crop factors have to be adjusted to provide for the climatic conditions of regions, new cultivars and deviations in planting density, as well as for the full range of irrigation methods (Van Heerden *et al*, 2001).

The SAPWAT procedure has the advantage that it is independent of soil texture. If the soil evaporation and plant transpiration are considered, it becomes possible to manipulate the basic crop factors to provide for ground cover, wetted area, and frequency of irrigation cover crops, fruit trees, and different irrigation systems. SAPWAT is the first program that applies this possibility in a user orientated crop irrigation program.

During the development of SAPWAT, specific attention was given to crop factors. The ideal would have been to let the crop grow, similar to growth models, so that stage length will react to planting date and climate. The use of short grass evaporation reduces the impact of climatic change on crop water use, but has no influence on the length of growth stages (Van Heerden *et al*, 2001).

The solution was to subdivide South Africa into seven agro-climatic regions and to develop default crop factors for each of these regions. Where planting dates have a noticeable influence on growth sages, individual crop files were developed according to planting month per region. Where noticeable differences between cultivars (e.g. early and late) are found, each is handled as a separate crop. The crop factor file was developed according to "rules" derived with the help of crop scientists (Van Heerden *et al*, 2001).



Crop Factor

Planting Details
Crop type: Maize
Geographical Region: Humid/Sub-humid ho
Option: Long grower Early
Planting Date: 5
Month: September

Cover at Full Growth: 80 %
Leaf Area Index : 2.3

Frequency of Wetting
Initial: 7 days
Rest of Season: 7

Wetted Area: 60 %

Figure 2:2 SAPWAT Crop factors

2.7.3 Application of SAPWAT in practice

Tariff policy in terms of the water pricing strategy

In terms of the National Water Act, users of irrigation water must register for purposes of charging water use. DWAF indicated that the SAPWAT computer program would be the accepted method for the estimation of annual water requirements. In the absence of water measurements, SAPWAT enables a water authority to evenly quantify planned water use so that cost recovery can be done systematically.

Setting charges

The responsible authority will set charges and collect revenue. Charges may differ between water management areas, depending on the socio-economic circumstances and physical and demographic characteristics of each area. After budgets have been prepared and proposed charges determined, they will be announced and made known to users prior to the beginning of the financial year during which they will be imposed.

All charges will be specific to each of the four end-user sectors: municipal (water services authorities); industrial, mining and energy; agriculture; and stream flow reduction activities (e.g. commercial forestry). Charges may be different for each user sector (DWAF, August 2002). The National Water Act now makes it possible for WUAs to use innovative pricing structures when they calculate tariffs for their members that promote the efficient use of water, rather than a flat rate (DWAF, July 2002).

Water charges

To achieve an incentive for efficient water use, the price of water must be directly related to the volume delivered. This is identical to an electricity meter where the farmer can decide to switch off or on a particular device, and experience a directly proportional response in the electricity bill (Perry, 2001).

Measurement and charging at the farm level will require substantial investments in equipment, and an associated administrative bureaucracy to collect data on farm level deliveries and undertake the billing process (Perry, 2001).

2.7.4 Irrigation planning

Irrigation uses more water than the other user sectors; therefore the irrigation component is important in catchments planning. SAPWAT principles are recognised by the DWAF and are incorporated in the irrigation inputs of the national water balance model.

The planning of how much water is needed when, is a prerequisite for irrigation farmers, designers, WUAs, irrigation schemes and reservoir management. The power of SAPWAT lies in the extensive database, which saves the user the task of hunting for figures, as well as the built in routines for undertaking of sensitivity analyses for different stages.

2.7.5 Scheduling and planning outputs

The water balance model of SAPWAT utilises average monthly inputs, but the processing is on a daily basis. The output from simulation runs can be exported to spreadsheets and further processed by the user to provide for specialised applications. The main output file can be exported with graphics to Excel and other compatible spreadsheets, and can be used for a daily or weekly based real-time scheduling with provision for Eto and profile water contents. This facility is rough and ready, but can complement the specialised real time scheduling programmes (Van Heerden *et al*, 2001).

SAPWAT can be utilised to develop a pre-season programme for irrigation similar to some aspects of BEWAB. There is, however, the additional benefit that the forecast programme can be modified in the course of the year as the season develops. This is of particular value were organisations issue farmers with weekly information on atmospheric demand and crop water use for the preceding week (Van Heerden *et al,* 2001).

2.7.6 Short furrow irrigation system

The irrigation method used at Dzindi is called short-furrow irrigation, which is an indigenous modification to long furrow irrigation. It is highly manageable and requires comparatively little in terms of permanent infrastructure and maintenance. However, this simplicity of operation is only possible by correct system design, requiring a balance between water flow rates, furrow slope and length for the specific soil.

The farmer prepares his plot by first ploughing then disking the soil on the contour. Ridges are then made to form a strip of three to six furrows, about 1 m wide and 200 mm deep. These long strips, between 50 and 150 m long, are subdivided into sets of furrow basins approximately 8 to 10 m long, by constructing cross furrows with a hoe at right angles across the strip. Each set of basins should be as level as possible so that the water infiltrates evenly into the soil, ensuring uniformity of irrigation application (Van der Stoep *et al*, 2001).

The top furrow is used as a supply furrow to convey water to each of the cross furrows. Water is diverted into the supply furrow from a secondary canal (concrete) by placing an obstacle in this canal just downstream of the supply furrow inlet. The flow rate into the supply furrow is regulated by the size of the obstacle, which can be a large stone, a sandbag or a metal plate. It should not completely stop the flow of water, otherwise farmers further along the secondary canal cannot irrigate at the same time. This is an obvious vulnerability: If several farmers irrigate at the same time, it is unlikely to achieve equitable distribution.

The secondary canal is fed from the main concrete canal, which brings water to the top of the lands from a dam or river, often over several kilometres. Thus, water is carried from the river to each short furrow via a main canal, a secondary canal, a supply furrow and a cross furrow. See Figure 2.3 for a sketch of the lay-out.

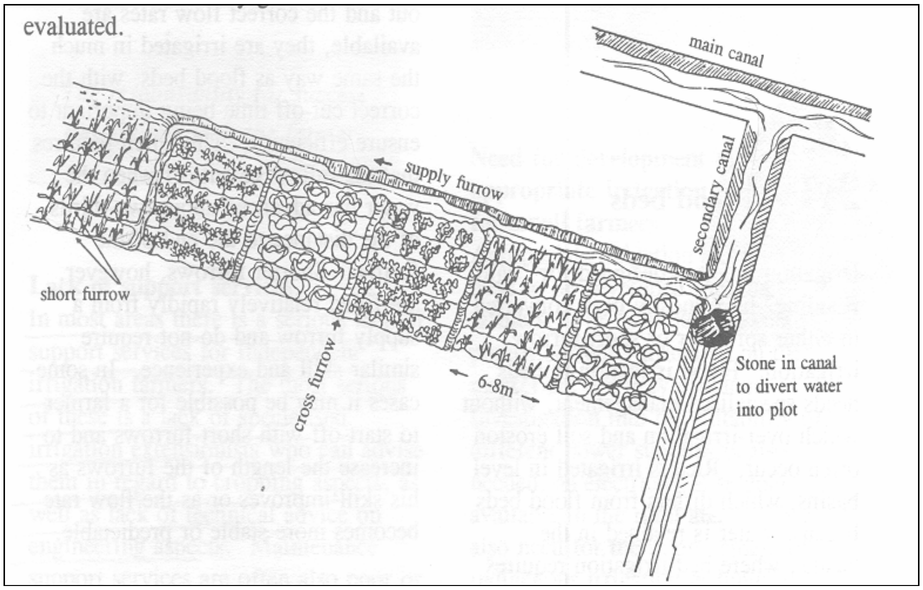


Figure 2:3 Typical lay out of short furrow irrigation system

The irrigation process is as follows:

The farmer diverts water from the secondary canal into the supply furrow. He walks along the ridge beside the water as it flows along the supply furrow and makes sure all cross furrows are closed and that the supply furrow is open, until the water reaches the last cross furrow into which the water is then diverted.

He diverts the stream into the furthest short furrow and allows each subsequent short furrow to be filled in succession from the cross furrow, working back to the supply furrow.

He can choose how much water to allow into a furrow before pushing a hoe full of earth into the top end of the furrow to block it, thus very effectively controlling the amount of water applied. Sometimes, particularly when the plants are still young, he blocks the furrow when the water has not quite reached the end of the furrow. At other times, particularly when the plants are bigger or need more water, he lets the water dam up from the ridge at the bottom end of the furrow to fill along its full length before he blocks it. Then he can start weeding the next short furrow while water runs into it.

Immediately after the irrigator has opened the last short furrow of a set, he diverts the water from the supply furrow into the set that is to be irrigated next. The water left over in the cut-off section of supply furrow is enough to fill that last short furrow of the set below. This avoids water wastage. In this way, the farmer works his way back to the secondary canal, making the most efficient use of water all the way.

During research conducted by the ARC-IAE in 1997, it was found that the application efficiency in short furrows is generally relatively high. This means that most of the water in the short furrows actually reaches the roots of the plants being irrigated. Distribution uniformity in the short furrows can achieve 80–90%. This is a property of small-basin and short-furrow irrigation, provided the basins/furrows have a fall of less than 1:300. On a steep gradient of 1:100, the uniformity of distribution was below 40%, largely due to unequal damming in the short furrow. Self-scheduling (controlled depth of application) occurs in flood irrigation to some extent because dry soil absorbs more water than wet soil, so the same plot will take longer to irrigate after a dry, hot week than after a cool week and this results in a heavier irrigation application.

The efficiency of water use in the system as a whole, that is, irrigation efficiency may not be as high, if significant losses occur in the supply furrow. In order to determine losses in the supply furrow during irrigation, the decrease in flow rate along the furrow (due to infiltration) must be known. However, this is very difficult to measure in practice but can be calculated fairly accurately using the information that was gathered during the tests. A computer program called Furrow, developed by Charles Crosby in the 1990's, was used to simulate and analyse the field test.

2.7.7 Water losses

According to Fairweather *et al,* (2003)**,** conveyance losses are defined as those that occur from the time water is released from the reservoir to when it is delivered to the farm gate. It includes evaporation, transpiration, seepage losses and other leakages such as filling losses.

According to Schulze, 1995, canal conveyance losses are defined as the fraction of irrigation water lost between water released at a canal head works and the water delivered to the farm off takes. These losses can be divided into unavoidable losses and avoidable losses. Unavoidable losses are made up of the major system losses in open farm water distribution systems: evaporation and seepage. These losses occur on a continual basis and depending on the local evaporation potential, soil types and design parameters, these losses may be as high as 50% of total volume available. Avoidable losses include operational losses or wastage resulting from improper management with one of the most critical faults being incorrect run times varying climatic and demand conditions, which can account up to 9-17% Reid et al.,1986 in DWAF 2000), but are also dependant on variations of water delivery rates, project size and algae growth.

Seepage losses

According to Holland 1997 in DWAF (2000), seepage is simply defined as the loss of water due to infiltration through the bed or banks of an irrigation channel. Seepage losses have presented considerable problems in many farm storages and distribution channel networks. The range of variables affecting seepage rates include:

- Characteristics of the soil at the soil water interface and below the channel bed;
- Percentage of entrapped air in the soil;

- Chemistry of the water and the soil;
- Amount of sediment carried and deposited by the water;
- Length of time that water has been in the channel;
- Channel water depth;
- Velocity of channel flow;
- Temperature of the water and soil;
- Soil capillary tension;
- Position of the water table and water table gradient;
- Barometric pressure; and
- Channel shape and wetted perimeter.

An estimate of the magnitude of the seepage loss for a channel can be obtained either by direct or indirect measurements. Indirect techniques involve the measurement of the groundwater profile. Direct measurement technique may be made using inflow-outflow or ponding techniques for measuring seepage loss for relatively long sections of the channel. Point measurements may be obtained using either seepage meters or salt penetration methods (Smith, 1973).

Seepage losses are normally expressed in l/s per 1000m^2 wetted areas of the canal lining. According to Reid, Davidson and Kotze (1986) in (Implementation Guidelines for Water Conservation and Water Demand Management in Agriculture, 2000), the seepage in concrete canals are between 0.35 to 1.9l/s per 1000m^2.

The ponding technique is the most accurate means of measuring seepage. According to Smith, this technique is used during static periods of storage or channel operation with the seepage rate calculated from the rate of fall in the water level after correction for evaporation and rainfall. This technique can be used over shorter channel lengths than the inflow-outflow technique. However, it should be noted that errors in the measurement of the change in water volume, the evaporation losses, or rainfall would be reflected in the seepage term.

Evaporative losses

Water is mainly lost from storage through evaporation. Apart from a water source, evaporation requires an energy source, which is largely provided by sunlight, as well as a transport mechanism for water vapour. The transport is related to wind speed and humidity (Fairweather *et al*, 2003). The surrounding land and air have a big impact on evaporation.

Evaporative losses are normally expressed in l/s per 1000 m^2 water surface that is exposed to the atmosphere. According to Reid, Davidson and Kotze (1986) in Implementation Guidelines for Water Conservation and Water Demand Management in Agriculture, 2000), approximately 0.3% of the total stream is lost due to evaporation.

The traditional approach for monitoring the evaporation losses from a free water surface such as a water storage or distribution channel is to use an evaporation monitoring pan (evaporimeter) and relate evaporation from the pan to the free water surface evaporation via coefficient. The most commonly used evaporimeter is the U.S. Class A evaporation pan which consists of an unpainted galvanized iron container 1.22m in diameter by 0.25m deep.

SAPWAT can also be used to determine evaporation values.

2.7.8 Assessing the water balance

Benchmarking

Benchmarking can be defined as “A systematic process for securing continual improvement through comparison with relevant and achievable internal and external norms and standards (FAO, 2001).

Malano and Burton (2001) gave the following definition for benchmarking: “Benchmarking may be defined as the identification and application of organization specific best practices with the goal of improving competitiveness, performance and efficiency.”

The overall aim of benchmarking is to improve the performance of an organisation as measured against its mission and objectives. Benchmarking implies comparison - either internally with previous performance and desired future targets, or externally against similar organisations performing similar functions. Benchmarking is a management tool already in use in both the public and private sector organizations (FAO, 2001).

Benchmarking is about change, moving from one position to a better position. It originated in the corporate business sector as a means for companies to gauge, and subsequently improve, their performance relative to key competitors. The scope of the benchmarking activity is determined by the objectives and scale pursued in finding “best management practices”.

Some of the reasons that an irrigation organisation may be interested in benchmarking:

- Increasing demand on the irrigation sector to produce more food for growing populations.
- Growing pressure to effect cost savings whilst increasing the productivity and efficiency of water resource.
- Turnover and privatisation of irrigation schemes to water users and water

user associations.

- Increased interest by the wider community for productive and efficient water use and the protection of natural environments.
- Increasing need for accountability to both government and water users in respect of water resource use and price paid for water.

Water supply performance indicators

Levine, Burt &Styles, Molden et al. (1982) first presented the external indicator Relative Water Supply, as shown in Table 2.1 below. Relative Irrigation Supply (RIS) was developed by Perry (1996). In these indicators, the crop demand is defined as the potential crop ET, or the ET under well-watered conditions. The total water supply of the scheme is the sum of the volume of all surface diversions, net groundwater draft and rainfall, but excludes reticulation of internal drainage within the scheme. The irrigation demand is the crop demand, less effective rainfall, and the irrigation supply is the volume of surface diversions and net groundwater draft.

Burt and Styles (1998) state that the American Society of Civil Engineers (ASCE) Irrigation Efficiency (IE), shown as Indicator 4, gives a much more in-depth description of water destinations than either RIS and RWS.

The Water Delivery Capacity (WDC) ratio, Indicator 5, gives an indication of the extent to which the irrigation infrastructure has constrained the cropping intensity in the command area (Molden *et al*, 1998). This is achieved by comparing the canal conveyance capacity to the peak consumptive demands. Values greater than 1 indicate that the canal capacity is not a constraint to meeting crop water demands.

Burt and Styles (1998) did not agree with this definition of peak demand because it included the rainfall component of the ET and therefore does not give an indication of the actual irrigation requirements. Therefore, they suggest the denominator be changed to "Peak *irrigation water* consumptive demand”. Malano and Burton (2001) agree with Burt and Styles (1998) in the peak consumptive demand from irrigation water only.

Other researchers have also developed indicators to assess performance. A summary of indicators is shown in Table 2.1.

Table 2-1 Summary of water supply indicators

No	Indicator Name	Indicator Equation	IWMI	ITRC	IPTRID	RAP*
1	Total annual volume of irrigation water delivery (M^3)	Total annual volume of irrigation water delivery			X	
2	Relative Water Supply (RWS)	Total water supply Crop demand	X	X	X	X
3	Relative Irrigation Supply (RIS)	Irrigation Supply Irrigation demand	X	X	X	X
4	Irrigation Efficiency % IE	Volume of irrigation water beneficially used Volume of irrigation. water applied-storage of irrigation water		X		X
5	Water delivery capacity ratio (WDC)	Canal capacity to deliver water at system head Peak consumptive demand	X	X	X	X
6	Annual irrigation water supply per unit irrigated area (m^3/ha)	Total annual volume of irrigation supply Command Area			X	
7	Annual irrigation water supply per unit irrigated area (m^3/ha)	Total annual volume of irrigation supply Total annual irrigated crop area			X	
8	Security of entitlement supply	System water entitlement 10 yr min water availability flow pattern			X	X

*Molden *et al* (1998) (IWMI), Burt and Styles (1998) (ITRC), Malano and Burton (2001), (IPTRID) and Burt (2002).

Chapter 3 Materials and methods

3.1 Introduction

The research work addressed the following five main tasks:

- Evaluation of in field irrigation systems.
- Survey of planted (irrigated) areas in Block 2.
- Collecting weather data for the study period.
- Obtaining data regarding canal dimensions.
- Measuring and recording flow rates.

A number of different tools were used to collect the water balance data, as described in Chapter 2. These include real time measurements and computer modelling methods, of which more detail of input parameters are provided below where relevant.

3.2 Scheme description

3.2.1 General description of the water supply to the scheme

Water to the scheme is supplied by a diversion of the Dzindi River, a perennial river that flows south of Itsani Village by means of a concrete weir. A concrete canal distributes the water to the four irrigation Blocks. Concrete furrows have been designed to allow water to enter the fields at regular intervals. In three of the four irrigation Blocks, the main canal directly supplies the secondary distribution canals, which bring the irrigation water to plot edge (Van Averbeke *et al*, 2004).

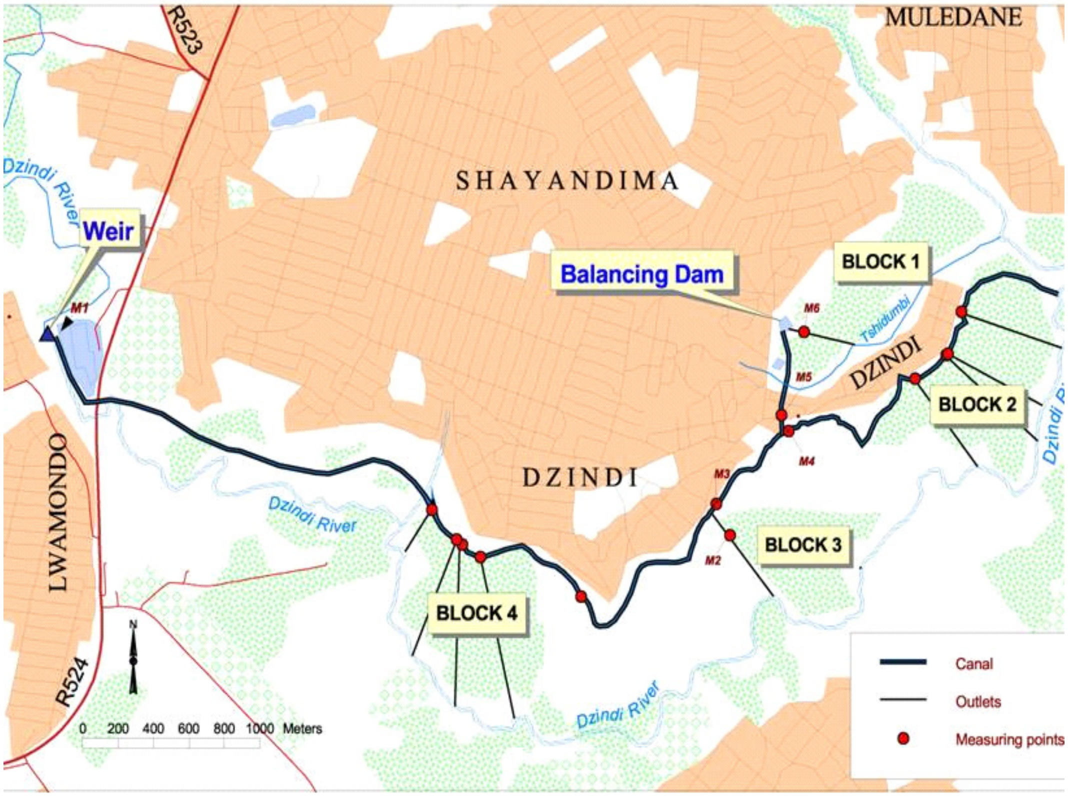


Figure 3:1 Schematic representation of Dzindi Irrigation Scheme

All the major diversion points on the canal system were fitted with measuring devices (cipoletti and v-notch weirs). The control mechanisms have mostly been removed. Unused deliveries return to the river.

3.2.2 Operation of the water supply to the irrigation scheme

In the Dzindi Irrigation Scheme, the water runs twenty-four hours a day, everyday, from the weir (River) to the scheme even if the farmers are not irrigating.

The farmers have a timetable to use for irrigation purposes during the day, but if a farmer is not available to irrigate according to the time table, he/she can arrange with another farmer to irrigate instead, and he/she can then irrigate during that person's turn. After five in the afternoon, farmers can irrigate for as long as they like because the time table is not in use.

According to the timetable for Block 2, two farmers are allowed to irrigate in the morning and in the afternoon before five at the same time if time table is in use. Conflict arises when the farmer who is in the first plot closer to the canal won't let water to pass so that the other farmer can irrigate, especially when the water is not sufficient. In times of drought (water shortage) they change the timetable so that all the farmers can irrigate water. Only one farmer is supposed to irrigate in each Block and it rotates until all the farmers have irrigated their fields.

3.3 Estimating the water balance components

In order to calculate losses along the canal, the inflow at the entrance of the secondary canal to Block 2 was measured. Irrigation water was estimated by examining the planted area, crops planted, growth stage. These measurements will be used to construct a water balance that will finally yield an estimation of the total loss of the system.

The water balance components relevant to Block 2, based on the theory presented in Chapter 2, are presented in the table below:

Table 3-1 Components of the water balance for Block 2

Component	**Data collection method**
Inflows Gross inflow to Block 2	Measure at the Cipolletti weir
Consumptive uses Process consumption Gross irrigation requirement	Calculate based on planted areas
Non process consumption Non beneficial: Seepage Evaporation Other losses	Calculate based on weather data and estimate.
Outflows Return flows	Calculate the result of the water balance

For a water balance to be constructed, all the spatial boundaries have to be defined (Burt, 1999). In this case, it will be as follows (see Table 3.2).

Table 3-2 Spatial boundaries of water balance

Space:	**Conveyance system (main and secondary Canals)**
Upper boundary	Water surface
Lower boundary	Canal / dam bottom
Horizontal boundaries	All inlets, diversions, spills and discharge points

3.3.1 Inflow

For the purpose of this study, water will only be measured at the main canal to Block 2. In the secondary canals, water will not be measured and return flows will be estimated or calculated theoretically.

Pressure transducers and a data logger will be used to measure the inflow to Block 2.

Flow measurements

Inflow was measured at the Cipolleti weir for the main canal to Block 2. The Cipolleti weir to Block 2 was 72 cm long above water, with 60 cm at the bottom and 22.5 cm in width. The flow data was collected after the sluice gate before the Cipolleti weir for a period of 45 days (15 October to 30 November 2004) at 30-minute intervals.

One pressure transducer was installed and was connected to the data logger and the 12V battery, which is the source of power. The battery was checked every week using the tester and changed when the voltage fell below 12 Volts. The logger and the battery were placed in a “Trunk tin/ Metal box” and a padlock was used for safe protection of the battery and data logger. The pressure transducer was placed inside the PVC pipe with holes to guide and protect the sensor.

Originally all major diversions points on the canal system were fitted with V-Notch and Cipolletti. Most of these devices are still in place but the control mechanisms have mostly been removed or 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.

The primary devices that were used were Cipolletti (Trapezoidal) and V-notch (Triangular) weir.

Cipolletti (Trapezoidal) weir

In the Trapezoidal weir the sides are inclined to produce a trapezoidal opening. When the side's slopes one horizontal to four vertical the weir is known as a Cipolletti weir and its discharge equation is:

$$q= k\ L\ h^{1.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.1)$$

Where:

q= flow rate, m^3 /s

k= constant

L= Length of trapezium base, m.

h= the head, m

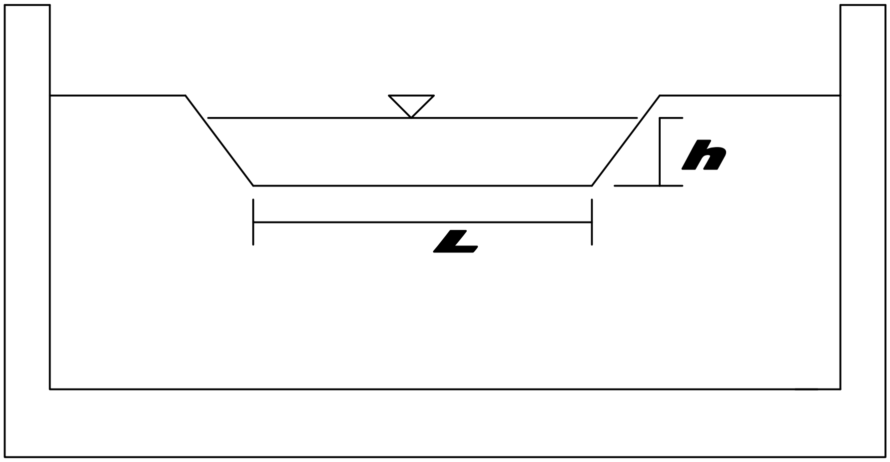


Figure 3:2 Trapezoidal or Cipolletti weir

V-notch (Triangular) weir

The V-notch weir comprises an angular v-shaped notch usually of 90° and is well suited to low flows. A major problem with both the rectangular and the trapezoidal type weirs is that at low flow rates the nappe clings to the crest and reduces the accuracy of the measurement.

The discharge equation of the V-notch weir is given by:

$$q=k\,h^{2.5} \quad \text{(3.2)}$$

where:
q= flow rate, m^3/s
k= constant
h=the head, m

V-notch weirs are suitable for flow rates between 2 and 100l/s and, provide an accuracy of 2-3%. High flow rates can be obtained by placing a number of triangular weirs in parallel. The main problem with the V-notch is that it is easily blocked by debris (Crabtree, 2000). For the purpose of this study it was used for in field short furrow evaluation.

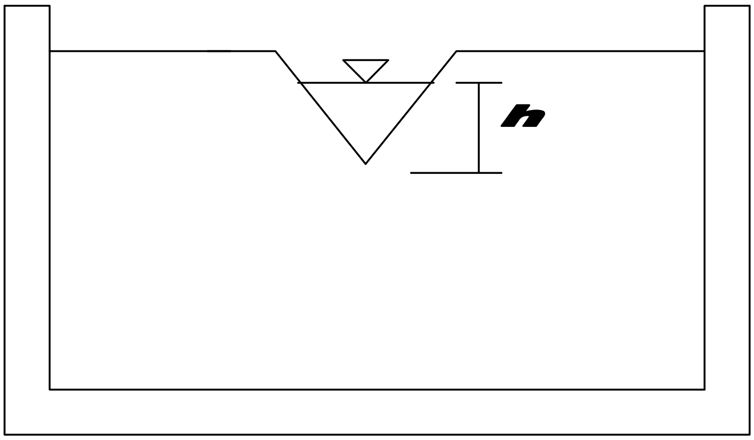


Figure 3:3 The triangular or V-notch weir

3.3.2 Equipment installation

Table 3-3 Materials used for inflow measurement

Item	**Description**	**Quantity**
1	Hobo RH/ Temp/ 2 * External Data Logger	1
2	HD 2004 Pressure Transducer	1
3	12 V Battery	1
4	Trunk Tin	1
5	Cables	1

The HOBO RH/ Temp/ 2 x External Data Logger

The HOBO RH/ Temp/ 2 x External Data Logger has 4- Channels: one for temperature, one for relative humidity, and two that will accept external input. It can measure and record up to 7.943 readings. Its reading rate is user selectable with sampling intervals being 0.5 seconds to 9 hours, recording times for up to one year. Additional features include programmable start time/date, non volatile EEPROM memory that retains data even if battery fails, and an extendable internal temperature sensor. It has the dimension of 68 x 48x 19 mm.

The HD2004 Pressure Transducer

The level probe model LS-10 has been designed for simple, inexpensive level measurements. The output signal is 4 – 20 mA with an accuracy of 0.25%. It measures pressure from 0.5 to 16 bar based on user requirement. An important advantage of this level transmitter is the longitudinal water resistance, supplied as standard, which guarantees that liquid cannot get into the transmitter even if the cable is damaged.

In the case of cable damage, the transmitter will remain completely functional and only the cable needs to be exchanged. The probe offers a hermetically sealed, durable stainless steel case. For hydrostatic pressure measurements the pressure compensation towards the atmosphere is done via the internally vented cable.

3.3.3 Consumptive uses

Process consumption

Process consumption is defined as the amount of water that has been used productively for the intended use. In this case it is water that has been used by the crop (Gross Irrigation Requirement).

Due to the nature of the distribution system, the actual amounts of irrigation water applied at each plot could not be monitored manually or automatically, so a modelling approach was taken to estimate the irrigation requirements.

Information was gathered on the size of the plots, the crops being irrigated, their growth stages, and climatic data as well as the typical irrigation durations and intervals. In order to estimate the gross irrigation requirements of Block 2 for the monitoring period, the computer model, SAPWAT, was used to determine the theoretical net irrigation requirements for the period per crop in mm. By combining this information with the planted areas, the volumetric net irrigation requirement with the planted areas, the volumetric net irrigation could be calculated.

The crop and field size information was used to estimate the crop water requirements, while the other information was used to estimate the amount of irrigation water required. By combining the two sets of information, the total required volume of water could be estimated.

The results of the in-field short furrow evaluation were used to determine typical efficiencies and distribution uniformities, which could then be taken into consideration to calculate the gross irrigation requirement. Therefore:

$$GIR = \frac{\sum (ET_c - R_e) \times A_c \times 10}{DU \times \eta_a} \quad \text{...(3.3)}$$

Where:

GIR = Gross Irrigation Requirement, m^3 for the study period.

Et_c = Crop evapotranspiration, mm for the study period.

R_e = Effective Rainfall, mm for the study period.

A_c = Irrigated area for a specific crop during the study period, hectares.

DU= Distribution Uniformity (typical), fraction.

η_a = Application Efficiency, fraction.

A list was compiled of the plots being cultivated in Block 2 during the monitoring period (15 October to 30 November 2004). Information that was gathered included the size of the plots, the crop being irrigated, its growth stage, and climatic data as well as the typical irrigation durations and intervals. Actual irrigation taking place at each plot could not be monitored manually or automatically but general practices were observed.

Non-process consumption

Non-process beneficial consumption, as defined in Chapter 2, is not applicable to Block 2 because there is no vegetation or other uses that the canal water for, other than irrigation. Only non-process non-beneficial is applicable.

Non beneficial

Seepage is simply defined as the loss of water due to infiltration through the bed or banks of an irrigation channel. Guidelines by the Department of Water Affairs and Forestry indicate that seepage losses in concrete canals should be in the order of 1.9 l/s per 1000 m^2 wetted canal lining. It is suspected that the losses at Dzindi are arguably higher than this due to the poor condition of the concrete, and a value of 2.2 l/s per 1000 m^2 was used together with wetted lining based on the flow depths and canal cross sections at the measuring locations.

$$\text{Seepage} = \frac{\text{Seepage rate (l/s)}}{1000} \times \text{time} \times \frac{\text{wetted area}}{1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where:
Seepage = Seepage rate of 2, 2 l/s was used.
Time = Seconds in monitoring period.
Wetted area = $\left(\frac{W + 8y}{3W}\right)$ x Length.

Evaporation losses were estimated using available real time weather data, and average water surface areas exposed to the atmosphere. The surface areas were determined in a similar method as the wetted lining, making use of the canal cross-sections (depth and width) and the recorded flow depths at the measuring points.

$$\text{Evaporation (l/Sec)} = \frac{\text{Evaporation rate (mm/day)}}{1000} \times \text{(no of days)} \times \text{Surface area} \ldots \quad (3.5)$$

Where:
Evaporation rate = mm/day within the monitoring period.
No of Days = 45 days monitoring period.
Surface area = Length of the canal X width of the canal.

3.3.3. Outflows

Return flows

The main outflow from the system was the return flow from the secondary canals. Return flows in this case can be defined as water that was not used by the crops. The water that flows back to Dzindi River is committed for other uses, e.g. livestock drink from the river; and some community members wash their clothes in the river. In this study return flows were not measured.

3.4 Benchmarking

3.4.1 Introduction

The quantification of certain water use components and the water balance will make it possible to assess the situation at Dzindi according to internationally accepted indices or performance criteria, and make recommendations for improvement. This process is called benchmarking, and requires the determination of current performance levels and the identification of practices that can be implemented to improve the current situation. The application of benchmarking in irrigation water management has been researched by amongst others, the International Water Management Institute (IWMI), the Irrigation Training and Research Center (ITRC) at Cal Poly, and the FAO's International Programme for Technology and Research in Irrigation and Drainage (IPTRID).

Performance indicators have been developed to assess agricultural, water supply, financial and environmental performance. For the purpose of this study only the water supply indicators will be applied. These indicators will address the situation at different water supply levels at Dzindi, as illustrated in the schematic representation shown in Table 3-4. The table shows where the information used in the calculations originates. Some of the performance indicators will be calculated for the purpose of this study.

3.4.2 Scheme level

Table 3-4 Summary of benchmarking indicators

Scheme Level	**Indicator**
Total seepage losses	Seepage Rate x Wetted canal Lining x time
Total evaporative losses	Evaporation rate x water surface area x time
Total volume delivered to farms	Inflow – Seepage –Evaporation- Return flows
Conveyance efficiency	Total volume delivered to farm /Inflow
Relative water supply	(Inflow + Gross precipitation)/Crop ET for Scheme
Relative irrigation supply	Inflow/(Crop ET-Effective Rainfall)
Command area Irrigation Eff.	100x (Crop ET – Effective Rainfall)/Inflow
Relative gross canal capacity	Peak monthly Nett Irrig.Req/Main Canal Capacity
Relative actual canal capacity	Peak monthly NIR/Peak main canal flow rate
Irrigation supply/command area	Inflow/total scheme area
Irrigation supply/Irrigated area	Inflow/actual irrigated area
Electrical conductivity of irrigation water	
Total dissolved solids in the irrigation water	

3.4.3 Farm level (Blocks)

Table 3-5 Farm level (Blocks)

Distribution efficiency	**Volume delivered to fields/ Volume delivered to Block**
Water use per irrigation area	Volume delivered to fields/ irrigated crop area
Field irrigation efficiency	(Crop ET-Eff. Rainfall)/Volume delivered to fields

3.4.4 Field level (short furrow)

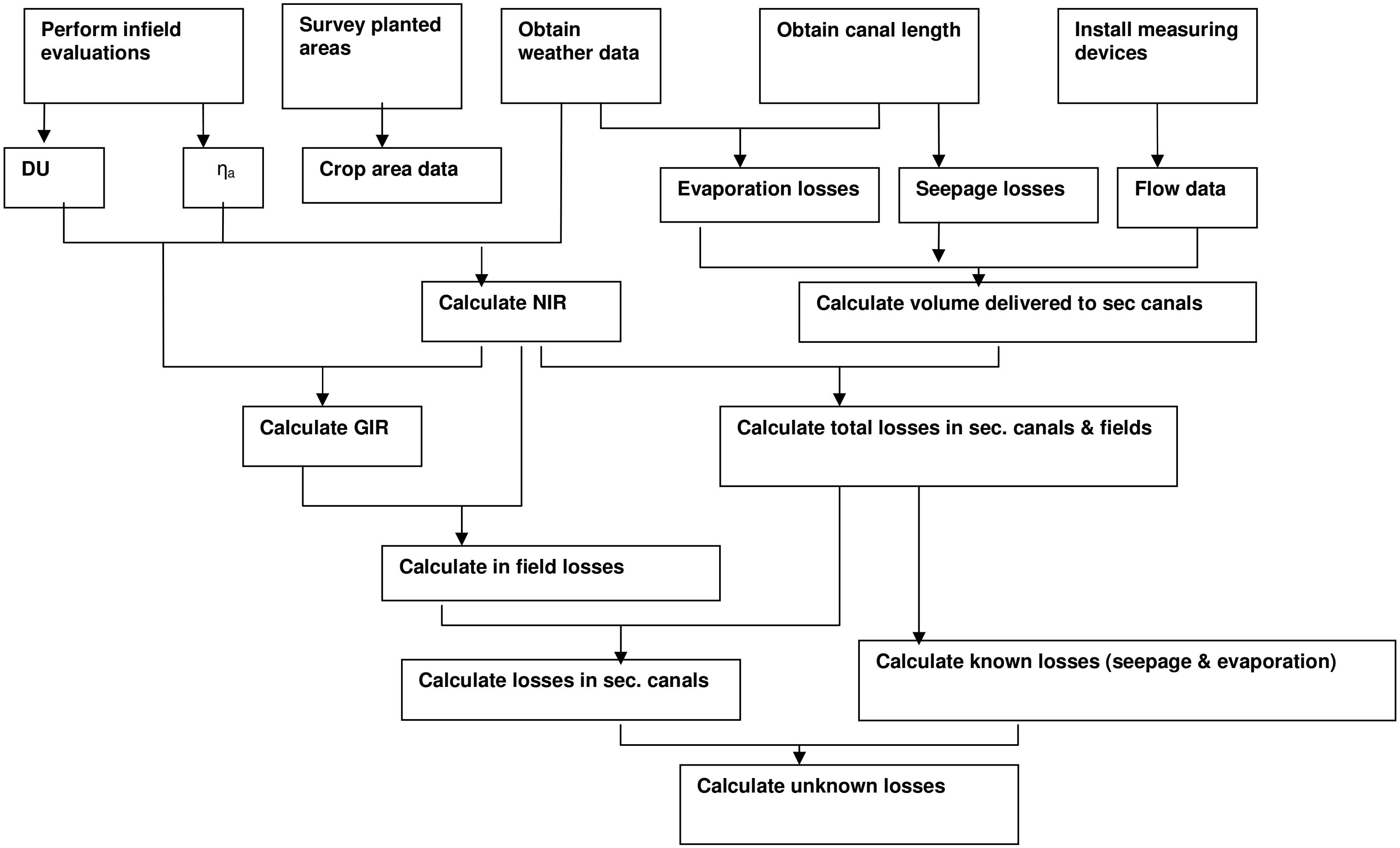
Table 3-6 Field level (short furrow)

Average application	**(Supply Furrow Flow Rate x Time)/Area of beds**
Application efficiency	Ave.depth of water infil. In root zone /Ave. applic.
Distribution uniformity (CU)	Lower quarter aver. depth infiltr ./Aver. depth infiltr.
Soil:	Bulk density, water retention curve

3.5 Conclusion

As already discussed in Chapter 3, 3.1 – what the research work would address, the scope of the study, and the activities that would be taken. All the major activities that were taken are summarised below in figure 3.4. The figure represents all the activities taken to meet the objectives that were set in Chapter 1 of this study. The study focused on the water that was released and measured, crops planted under irrigation, canal length and weather data during the study period for Block 2.

Figure 3:4 Activities undertaken to meet the objectives stated in Chapter 1



Chapter 4 Results and discussion

4.1 Introduction

In order to address the objectives as set out in Chapter 1, the various components of the water balance were quantified through field evaluations and the results of these evaluations are discussed per component in this chapter.

4.2 In-field evaluation of short furrow irrigation

Actual irrigation taking place at each plot could not be monitored manually or automatically, but general practices were observed. In order to quantify the typical flow rates and volumes used for irrigating crops with the short furrow system, a representative plot was evaluated. The evaluation method entailed measuring the amount of water diverted into one plot of short furrows, recording the advance time of the stream along the supply furrow (to calculate distribution losses), and the time taken to irrigate each bed of furrows (to calculate application efficiency).

The plot that was evaluated was 139 m long and consisted of 13 beds, each bed containing 5 rows of maize between 8 and 12 m long, and irrigated with furrows spaced about 1 m apart.

The short furrow irrigation system on of the plots in Block 2 was evaluated to determine typical efficiencies and uniformities. The set of furrows selected was laid out in the typical manner of the scheme, with a 124 m long supply furrow conveying water to 13 groups of 5 short furrows each (total area = 556 m^2). The set had been planted with maize on 1 August 2004 and had last been irrigated one week prior to the evaluation. The evaluation took place on 27 October 2004, two days after a short rainstorm, in fine and hot conditions.

The procedure that was followed included the following:

- Install the v-notch at the beginning of the supply furrow to measure all the water diverted from the secondary canal.

- Start irrigation and record the advance time of the water along the supply furrow to the last bed outlet.
- Record the time taken to irrigate each bed in the set.

4.2.1 Advance front

The irrigator opened the water from the secondary canal into the supply furrow and allowed it to advance quickly to the last outlet, at an average flow rate of 24 m^3/h, which is higher than the rate used during irrigation. The advance front's movement down the supply furrow is presented graphically in Figure 4.1. It took 7 minutes and 45 seconds for the front to reach the outlet at the last bed where irrigation was to commence.

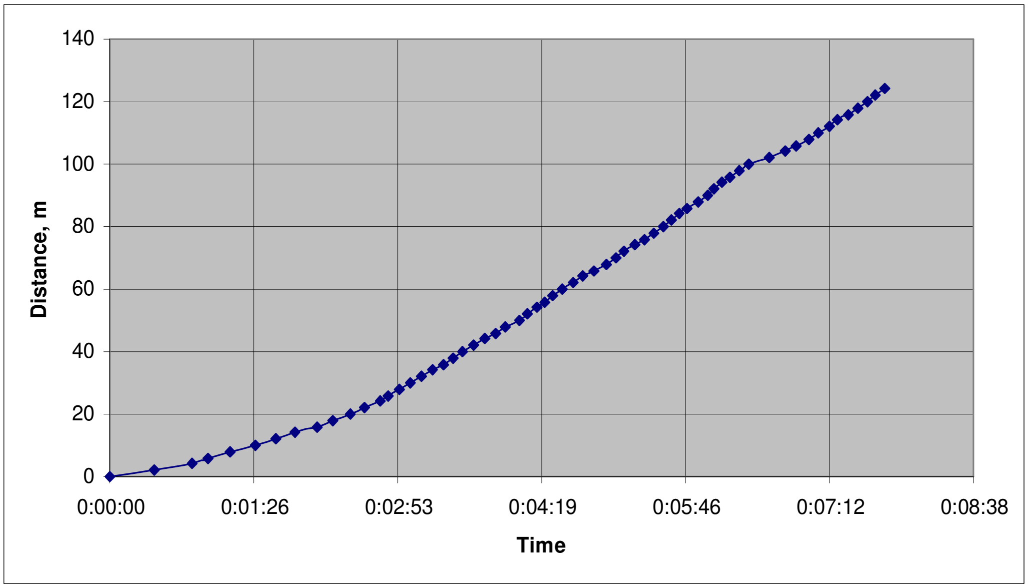


Figure 4:1 Advance front of water along the supply furrow

4.2.2 Inflow rate

Once the front had reached the last outlet, 124 m from the v-notch, the irrigator asked for the flow rate to be reduced since the initial stream was too big to handle comfortably during irrigation. The stream was adjusted twice more in the course of the irrigation process and the variation can be seen in Figure 4.2, which shows the flow rate as measured at the v-notch in during the irrigation process, which took about 1 hour to complete. The average flow rate was 16.1 m^3/h.

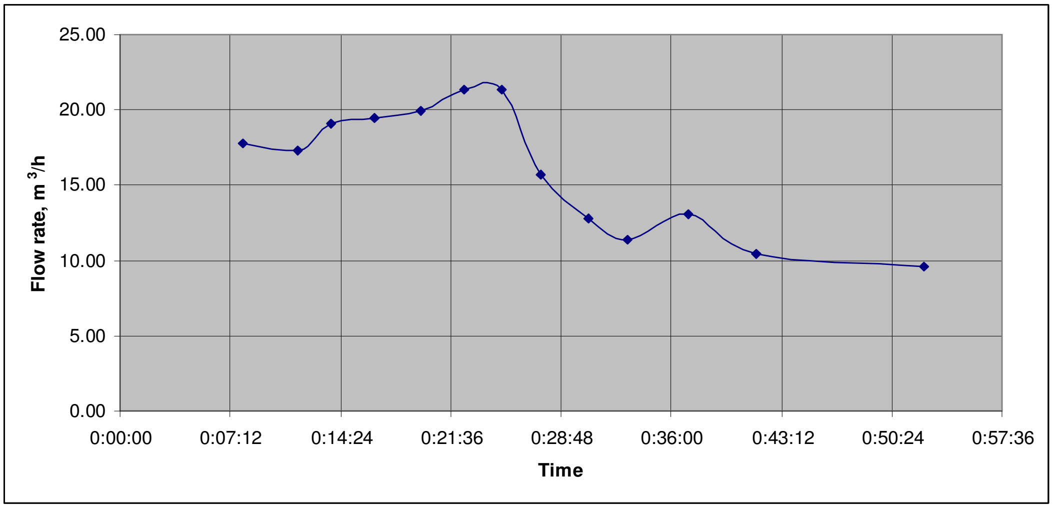


Figure 4:2 Flow rate at the supply furrow inlet during irrigation

The flow rate at the supply furrow inlet is adjusted so that the flow rate at the point of irrigation, which varies due to infiltration taking place along the supply furrow, can stay within a practical range (10-15 m^3/h). The variation in flow rate along the supply furrow was determined using a simple analysis programme called “Furrow” which was developed by Charles Crosby during the 1990’s, and the variation for this specific case for an inflow rate of 16.1 m^3/h is shown in Figure 4.3.

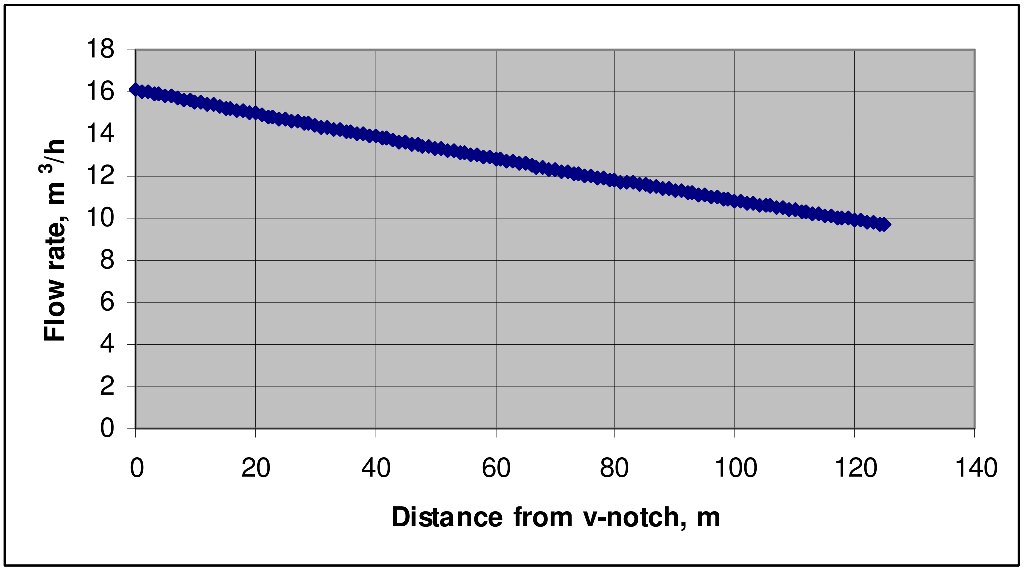
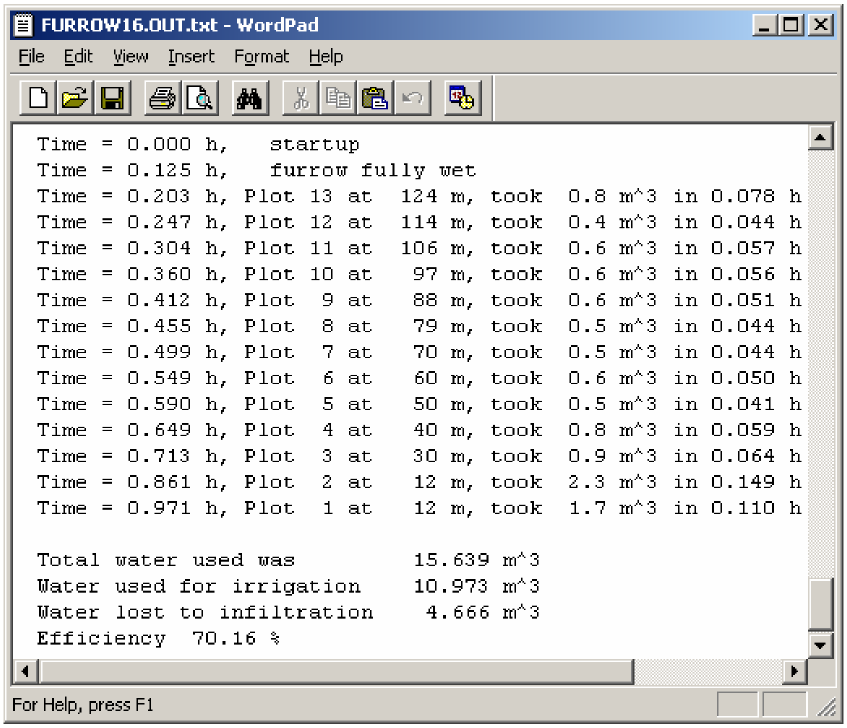


Figure 4:3 Flow rate variation along the supply furrow due to infiltration losses

This explains why the inflow rate is decreased when working with the water in the furrows closer to the v-notch – the flow rate is too high too handle with ease, resulting in water spilling over the sides of the furrows.

4.2.3 Application

The results of the data analysis with the “Furrow” program are shown in Figure 4.4.



```
Time = 0.000 h,   startup
Time = 0.125 h,   furrow fully wet
Time = 0.203 h, Plot 13 at  124 m, took  0.8 m^3 in 0.078 h
Time = 0.247 h, Plot 12 at  114 m, took  0.4 m^3 in 0.044 h
Time = 0.304 h, Plot 11 at  106 m, took  0.6 m^3 in 0.057 h
Time = 0.360 h, Plot 10 at   97 m, took  0.6 m^3 in 0.056 h
Time = 0.412 h, Plot  9 at   88 m, took  0.6 m^3 in 0.051 h
Time = 0.455 h, Plot  8 at   79 m, took  0.5 m^3 in 0.044 h
Time = 0.499 h, Plot  7 at   70 m, took  0.5 m^3 in 0.044 h
Time = 0.549 h, Plot  6 at   60 m, took  0.6 m^3 in 0.050 h
Time = 0.590 h, Plot  5 at   50 m, took  0.5 m^3 in 0.041 h
Time = 0.649 h, Plot  4 at   40 m, took  0.8 m^3 in 0.059 h
Time = 0.713 h, Plot  3 at   30 m, took  0.9 m^3 in 0.064 h
Time = 0.861 h, Plot  2 at   12 m, took  2.3 m^3 in 0.149 h
Time = 0.971 h, Plot  1 at   12 m, took  1.7 m^3 in 0.110 h

Total water used was         15.639 m^3
Water used for irrigation    10.973 m^3
Water lost to infiltration    4.666 m^3
Efficiency  70.16 %
```

Figure 4:4 Results from the Furrow program for data analysis

The program takes the flow rate variation explained above into consideration to calculate what percentage of the water was put to beneficial use in-field, and what was lost due to infiltration in the supply furrow.

The results compared well with the actual measured times taken to irrigate each bed (called "plot" in the program) and the total volume of water measured at the v-notch (15.77 m^3). An on-farm efficiency of 70.16 % was achieved.

Further analysis of the program output made it possible to calculate the distribution uniformity in the beds. It was based on a comparison of the volumes of water delivered to each bed, as shown in Figure 4.4., taking into consideration the surface areas of the different beds.

The method does not make provision for infiltration variations between the different furrows in one bed since this would be very difficult to measure or verify, but experience has shown that a great degree of re-distribution takes place in the soil under and next to the furrows so that high distribution uniformity can be achieved with this irrigation system. If distribution uniformity is poor, it would be due to variations in the amount of water diverted into each bed, and that is taken into account.

The results of the DU calculation are shown in Table 4.1. It can also be seen that an average application of 18.9 mm was given during this irrigation event.

Table 4-1 Distribution uniformity in short furrow beds

Bed nr	Volume	Bed area	Depth infiltrated
	m^3	m^2	mm
13	0.76	60	12.62
12	0.45	40	11.20
11	0.60	32	18.77
10	0.62	36	17.17
9	0.59	36	16.30
8	0.52	36	14.37
7	0.54	36	15.05
6	0.64	40	15.89
5	0.54	40	13.54
4	0.82	40	20.40
3	0.92	40	23.09
2	2.29	72	31.83
1	1.69	48	35.30
Average application			18.89
Lower Quarter average application			12.45
Distribution Uniformity			65.93%

4.3 Water balance

Water balance discussion requires the determination of spatial and temporal boundaries as mentioned in the literature review. From Table 3.2 of this paper it can be concluded that the spatial boundaries are the upper boundary which is the water surface, the lower boundary which is the canal bottom, and the horizontal boundary which is all diversions, spills, and discharge points. The temporal boundary is the time or period when all the components of water balance were measured, i.e. 15 October to 30 November 2004.

The different data of the distribution system are presented graphically and in table format under different headings.

4.3.1 Gross inflow to Block 2

The results showed that water is diverted into the canal continuously and confirmed that no adjustments were ever made to the inlet sluice to regulate the flow rate according to demand. The average inlet flow rate was 0.094 m^3/s for Block 2 and the variations on the graph were 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 371096 m^3 for Block 2. A graph of the data collected at the canal inlet to Block 2 is shown in Figure 4.5.

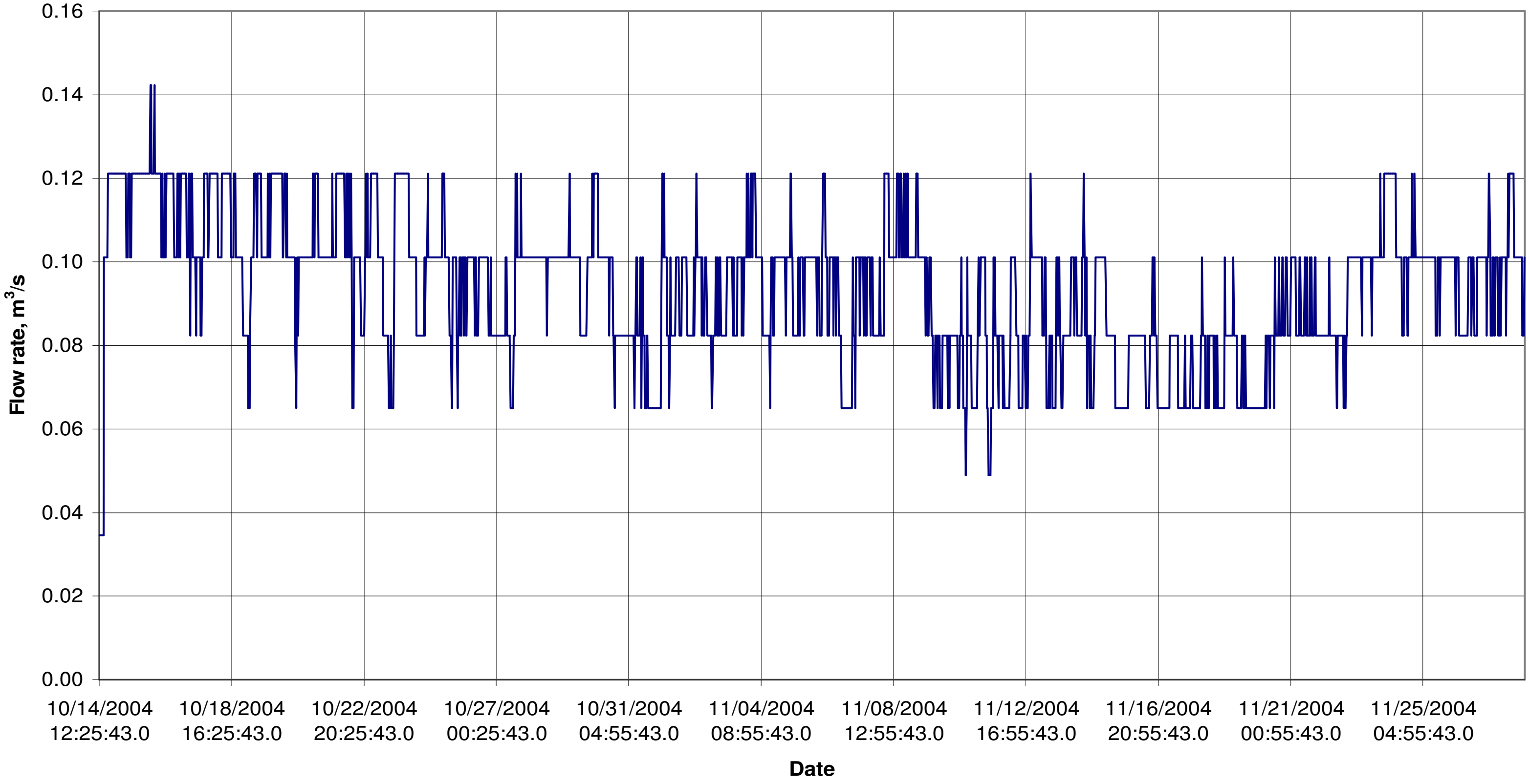


Figure 4:5 Data collected at the canal inlet to Block 2

4.3.2 Block 2 main canal losses

Evaporation

As discussed in Chapter 3 evaporation was calculated as follows:

$$\text{Evaporation} = \frac{\text{Evaporation (mm)}}{1000} \times \text{No of days} \times \text{Surface area} \qquad (3.5)$$

The evaporation was determined from SAPWAT, and the results are calculated on a weekly basis and are presented in Table 4.2. The surface area was taken as the average flow width of the water in the supply canal in Block 2, multiplied by the canal length.

$$\text{Therefore} = \frac{E_o}{1000} \times \text{Length} \times \text{Width}$$

$$= \frac{339}{1000} \times 1946 \times 0,54$$

$$= 356 \text{ m}^3$$

Table 4-2 Evaporation rate values calculated in weeks using SAPWAT

Week	**Date**	**E_o / Day**	**E_o / week**
1	15 – 22 October	7.1 mm	49.7 mm
2	23 – 29 October	7.2 mm	50.4 mm
3	30 – 5 November	7.4 mm	51.8 mm
4	6 – 12 November	7.5 mm	52.5 mm
5	13 – 19 November	7.5 mm	52.5 mm
6	20 -26 November	7.5 mm	52.5 mm
7	27- 30 November	7.4 mm	29.6 mm
			339 mm

Seepage

As discussed in Chapter 3 seepage was calculated as follows:

$$\text{Seepage} = \frac{\text{Seepage rate (l/s)}}{1000} \times \text{seconds in monitoring period} \times \text{wetted area}$$

The seepage rate of 2, 2 l/s per 1000 m^2 of wetted area was used. The wetted area was calculated based on an average canal flow width and depth, and multiplied with the length.

$$\text{Seepage} = \frac{\text{Seepage rate (l/s)}}{1000} \text{ x sec in monitoring period x } \frac{(W + 8y^2)}{3W} \text{ x Length}$$

$$= \frac{2,2}{1000} \text{ x } 45 \text{x } 24 \text{ x } 60 \text{ x } 60 \text{ x } 1.498$$

$$= 0.0022 \text{ x } 3\,888\,000 \text{ x } 1.498$$

$$= 12817 \text{ m}^3$$

Leaks

Accurate measuring and accounting can only detect leaks. By measuring a specific canal it is sometimes possible to identify and quantify leaks. Leaks occur in broken sections of the main canal to Block 2, caused by poor maintenance and a general deterioration of the infrastructure due to age. It is difficult to quantify the amount of water that is lost due to leaks.

4.3.3 Volume of water delivered to fields

Volume delivered to fields is the difference between the gross inflow to Block 2 and the main canal losses. Therefore it can be calculated as follows:

Volume delivered to fields=Gross inflow – Evaporation- Seepage

$$= 371096 - 356 - 12817$$

$$= 357923 \text{ m}^3$$

4.3.4 Gross irrigation requirement in Block 2

$$GIR = \frac{\sum (ET_c - R_e) \times A_c \times 10}{DU \times \eta_a} \qquad (3.5)$$

Where:

GIR = Gross Irrigation Requirement, m^3 for the study period.

ET_c = Crop evapotranspiration, mm for the study period.

R_e = Effective Rainfall, mm for the study period.

A_c = Irrigated area for a specific crop during the study period, hectares.

DU= Distribution Uniformity (typical), fraction.

η_a = Application Efficiency, fraction.

A variety of crops were planted and irrigated but the majority crop was maize, planted on various dates from 1 August to 3 November 2004 (Table 4.3). Crops were grouped together according to type and planting date and the growth modelled using SAPWAT. The settings that were used in the programme made provision for the following:

- Canopy cover at full growth of 70% of vegetables and 80% for maize.
- Wetted area of 60% (short furrow method).
- 1 irrigation event per week.

ETo and Etc values were taken and multiplied with the actual planted area for each crop to calculate the Net Irrigation Requirement (NIR) values.

The application efficiency of 70% and the distribution uniformity of 65% values were determined using short furrow evaluation (see Figure 4.1) to calculate the Gross Irrigation Requirement. The results are shown in Table 4.3.

Application efficiency of 70% (based on field trials- see Figure 4.4).

Distribution uniformity of 65% (based on field trials – see Figure 4.1).

Table 4-3 Actual crops and planted areas during the monitoring period

Block 2	**44.8 ha**					
Crops	Planting date	Irrigation area	ETo	ETc	NIR	GIR
			mm	mm	m^3	m^3
Beans	1 Aug	0.06	0	0	0.00	0.00
Beans	08 Sep	0.06	156	118.2	71.49	155.13
Cabbages	20 June	0.31	0	0	0.00	0.00
Cabbages	20 Jul	0.72	13.8	11	79.12	171.70
Cabbages	01 Aug	0.80	217	165.7	1333.22	2893.09
Cabbages	30 Aug	0.53	221	152.7	804.29	1745.30
Cabbages	06 Sep	0.11	161	121.7	132.09	286.64
Cabbages	14 Sep	0.51	198	145	737.04	1599.37
Groundnuts	01 Aug	0.17	217	166.7	287.81	624.54
Maize	01 Aug	1.31	217	218	2846.47	6176.84
Maize	06 Aug	0.70	217	217.9	1530.31	3320.78
Maize	15 Aug	0.71	217	217.9	1546.68	3356.29
Maize	19 Aug	1.43	217	217.3	3097.12	6720.76
Maize	28 Aug	3.70	217	210.8	7805.82	16938.63
Maize	05 Sep	1.06	217	194.9	2066.91	4485.20
Maize	08 Sep	0.81	217	187.6	1524.17	3307.46
Maize	12 Sep	1.47	217	169.9	2505.46	5436.86
Maize	20 Sep	0.78	217	146.6	1146.37	2487.62
Maize	27 Sep	0.41	217	121.7	497.21	1078.94
Maize	06 Oct	0.53	217	114.1	607.74	1318.80
Onions	1 Aug	0.13	217	137.4	175.10	379.97
Onions	28 Aug	0.02	217	87.1	13.94	30.24
Spinach	20 Jul	0.07	217	148.8	101.84	219.57
Tomatoes	15 Aug	0.12	217	176	213.84	464.03
TOTAL		**16.52**		**158.5**	**29123**	**63198**

Therefore the total GIR for the 45-day monitoring period was calculated as 63198 m^3 and the NIR as 29123 m^3.

4.3.5 Total losses in secondary canals and fields

This value is the difference between the volume of water delivered to the fields at the secondary canal off takes and the NIR for the Block.

Total losses in sec canals = Volume delivered to sec canals – NIR

= 357923 – 29123
= 328800 m^3.

4.3.6 Total in-field losses

The total losses at field level could be calculated as the difference between the volume of water delivered to fields and the gross irrigation requirement in Block 2.

The infield losses can be calculated as the difference between GIR and NIR

Infield losses = 63198 – 29123
= 34075 m^3

4.3.7 Total losses in secondary canals

The losses can originate from a number of sources, including seepage, evaporation and leaks from the secondary canals, return flows to the river, or over-irrigation in the fields.

In order to get an estimate of the magnitude of the different losses, theoretical values were calculated based on field observations, for the two known losses, evaporation and seepage.

The total losses in the secondary canals can now be calculated as follows:

Total losses in sec. canals= Total losses in sec. canals – Total in field losses
= 328800 – 34075
= 294725 m^3

Evaporation

As discussed in chapter 3 evaporation was calculated as follows:

$$\text{Evaporation} = \frac{\text{Evaporation (mm)}}{1000} \times \text{Surface area}$$

The evaporation was determined from SAPWAT, and the results, calculated weekly are presented in Table 4.1. The surface area was taken as the average flow width of the water in the supply canal in Block 2, multiplied by the canal length.

Therefore:

$$\text{Evaporation} = \frac{E_o}{1000} \times \text{Length} \times \text{Width}$$

$$= \frac{339}{1000} \times 3288 \times 0.54$$

$$= 602 \text{ m}^3$$

Seepage

As discussed in Chapter 3, seepage was calculated as follows:

$$\text{Seepage} = \frac{\text{Seepage rate (l/s)}}{1000} \times \text{seconds in monitoring period} \times \frac{\text{wetted area}}{1000}$$

The seepage rate of 2, 2 l/s per 1000 m^2 of wetted area was used. The wetted area was calculated based on an average canal flow width and depth, and multiplied with the length.

$$= \frac{\text{Seepage rate (l/s)}}{1000} \times \text{sec in monitoring period} \times \frac{(W + 8y^2)}{3\,W}$$

$$= \frac{2,\ 2}{1000} \times 45 \times 24 \times 60 \times 60 \times 0.77$$

$$= 0.0022 \times 3\ 888\ 000 \times 0.77$$

$$= 6586 \text{ m}^3$$

Unaccountable losses

Since only seepage and evaporation losses could be determined for the secondary canals to an acceptable degree of accuracy, a considerable volume of water seems to be unaccountable losses. This volume can be calculated as follows:

Unaccountable losses = Total losses in sec. canals – Evaporation – Seepage

$$= L_s - E_s - S_s$$
$$= 294725 - 602 - 6586$$
$$= 287537 \text{ m}^3$$

Return flows

This value is also difficult to determine. Water runs continuously through the Block and no control of water is exercised. All the gates to the secondary canals have been removed. Together with leaks, return flows probably make up most of the in field losses in Block 2.

Leaks

Accurate measuring and accounting can only detect leaks. By doing an accounting on a specific canal it is sometimes possible to identify and quantify leaks. Leaks occur in broken sections of the main canal to Block 2. In the secondary canals there were leaks due to broken canals, caused by poor maintenance and the general deterioration of the infrastructure due to age. It is difficult to quantify the amount of water lost due to leaks.

Over irrigation

Due to the labour intensive nature of short furrow irrigation, farmers are unlikely to irrigate unnecessarily. Based on the field evaluations and the time table that the farmers use to irrigate they are only allowed to irrigate once per week, usually applying 10 to 20 mm (Table 4.1), which does not exceed the nett irrigation requirement (NIR) any time during the year.

4.3.8 Summary of water balance values

The final water balance for Block 2 is shown in Table 4.4. Based on the values described in this chapter, a total of 2947525 m^3 of water was lost in a 45-day period on the secondary canals, probably due to leaks, return flows and possibly over irrigation. From observations, a considerable amount of water is lost through return flows.

It was observed that water diverted to the canal for Block 2 is enough for all the farmers in Block 2 to irrigate. On the other hand, other farmers are complaining that they are not getting any water. They are practicing dry land farming because they cannot get water from the canal next to their plots. Water does not get to the canal next to their plots because the control sluice gates for all the secondary canals in Block 2 have been removed. Water only runs in full capacity in the first secondary canals, even if they are not irrigating, and flows back to the river as return flows.

However provision should be made for losses that occur in the distribution system and that all the water diverted for Block 2 will not reach the irrigation field.

Dzindi farmers don’t see the necessity of the control sluice gate. That is why they removed all of them in Block 2. Only the sluice gate supporting the water to the main canal of Block 2 close to the extension officer’s house was not removed.

In fact, the amount of return flows seen during the field visit is so great that there are probably a number of downstream users that depend on it (such as riverine vegetation and other water users), and if the management approach changed, it could affect the water situation of these users. The return flows probably contribute significantly to groundwater levels in the area too. The system has a large number of secondary canals from which water flows back to the river almost constantly and these ends could not all be monitored.

Table 4-4 Water balance for Block 2 of Dzindi Irrigation Scheme

		Scheme				CI
		%	%	m^3	m^3	%
Gross inflow to Block 2		100		371096		10
Consumptive uses and outflows						
Main canal losses						
Seepage		3,5		12817		10
Evaporation		0,5		356		5
	Volume delivered to secondary canals		96,5		357923	
Nett Irrigation requirement		7,8		29123		15
	Total losses in secondary canals and fields		88.6		328800	
In-field losses		9,2		34075		15
	Total losses secondary canals		79,4		294725	
Secondary canal losses						
Calculated values:						
Seepage		1,7		6586		5
Evaporation		0,04		602		10
	Total unknown losses in secondary canals		77,6		287537	
Unknown values:		77,6		287537		
Leaks						
Return flows						
Over-irrigation						
		100.0		371096		

4.4 Performance indicators

4.4.1 Field level

$$\text{Average application} = \frac{\text{Sum of (Water diverted to bed x Irrigated area of beds}}{\text{Number of beds}}$$

= 245.5 mm / 13

= 18.9 mm

The evaporation rate per week ranged from 49.7 to 52.5 - see Table 4.2.

This indicator is based on the volume of water applied to each bed from the supply furrow and the result is in line with typical weekly short furrow applications observed at other schemes in the Limpopo Province (Crosby *et al*, 2000).

Application efficiency = 100 x Water applied to field / Water delivered to field edge

(In-field system efficiency) = 100 x 10.97 m^3 / 15.64 m^3
= 70.1 %

This value is realistic and shows that 70.1% of the water that was diverted into the set of beds from the secondary canal reached the furrows where the crops are planted.

To improve Application Efficiency, the distribution furrow can be lined or a lay flat pipe can be used. The SABI norm is 60% for application efficiency. From the calculations that were made, the value was 70.1 %. The calculated value is more than the SABI norm of 60%. It can be concluded that Block 2 of the Dzindi Irrigation Scheme is doing well.

Distribution uniformity=100 x Lower quarter ave. depth infiltrated / Ave. infil.
= 100 x 12.5 mm / 18.9 mm
= 66.1 %

This value gives an indication of the uniformity with which water delivered to the beds is varies between beds. The lower quarter average depth infiltrated value is the average of the lowest 25% of values calculated for the beds.

The SABI norm is 65% for distribution uniformity. From the calculations that were made, the value was 70.1%. The calculated value is more than the norm. It can be concluded that Block 2 of the Dzindi Irrigation Scheme is doing well.

Norm 65% for Distribution Uniformity. The calculated value is 66.1%.

4.4.2 Secondary canal level

Benchmarking at secondary canal level could not be done effectively due to the lack of return flow data and actual in-field water use for all the plots in Block 2.

Secondary canal efficiency =100 x (GIR) / Volume delivered to secondary canal
= 100 x (63197 m^3) / 1201690 m^3
= 20.7 %

In this case the two input parameters are both calculated values and can only give an indication of the efficiency of the secondary canals. Most of the losses are probably made up from return flows from the bottom of the secondary canals to the river.

This can be improved by releasing water that is sufficient to irrigate crops planted in Block 2. Water must be measured; planting dates recorded, crop variety and planted areas known. Canals must not run at full capacity everyday even if the farmers are not irrigating.

4.4.3 Block level

Irrigation supply / command area = Inflow / total Block area:
= 371096 m^3 / 44.8 ha
= 8283.39 m^3/ha for 45 days

This value converts to 828 mm of irrigation per year, which should be adequate in the climatic area.

Irrigation supply / irrigated area = Inflow / actual irrigated area:
= 371096 m^3 / 16.52 ha
= 22490.7 m^3/ha for 45 days

This indication shows gross supply of water to the Block – water allocations of commercial irrigation farmers are typically around 10000 m^3 per irrigated hectare per YEAR.

Relative water supply = (Inflow + gross precipitation) / Crop ET for Block:
= (371096 m^3 + (13.3 mm x 44.8 ha)) / 248977 m^3
= 14.3

This indicates that 14.3 times more water was supplied to the whole Block through irrigation and rain than actually required.

Relative irrigation supply =Inflow / (Crop ET – Effective Rainfall):
= 371096 m^3 / (26152.5 - 0)
= 14.2

This indicates that 14.2 times more water was delivered to Block 2 with the irrigation supply system than what was required by the crops grown.

Command area irrigation efficiency=100 x (Crop ET–Effective rainfall)/inflow:
= 100 x (26152.5 m^3 – 0) / 371096 m^3
= 7.05 %

This indicates that only 7.05% of the water diverted into the Block 2 was required by the crops planted during the monitoring period.

Main canal conveyance efficiency =100 x Water delivered to secondary canals/inflow:

= 100 x 357923 m^3 / 371096 m^3

= 96.5 %

This value is very good considering the state of the infrastructure. This may indicate that the other efficiency indicators are low due to excessive return flows rather than leakages and spills. The value considered is a theoretical value.

Volume delivered to secondary canals = Inflow – Seepage – Evaporation:

= 371096 – 6586 – 602

= 363908 m^3

These indicators should be interpreted carefully since seepage and evaporation were estimated as described above, and could not be verified. However, even if it is subject to a low confidence interval, it gives some indication of the situation.

There are no return flows directly from the main canal since it ends at the last secondary canal.

4.5 Conclusion

Water that was supplied to Block 2 was enough for all the farmers in Block 2 to irrigate. The irrigation supply per command area that was calculated, i.e. 828 mm was enough for all the farmers to irrigate. The irrigation supply per irrigated area (calculated at 22490.7) was more than the value allocated to commercial farmers per year to irrigate the hectare. The calculated value of the relative water supply of 12.7 indicates that 12.7 more water was released for the farmers in Block 2.

Losses originate from a number of sources. Results indicated that the losses that occurred in the main canal were not bad considering the value that was calculated (Table 4.2). Most of the losses occurred in the secondary canals, and the problems that resulted in the losses were due to the fact that all the control mechanisms to the secondary canals had been removed, resulting in too much water entering the first two secondary canals and returning to the river if farmers were not irrigating at the time.

From the water balance table (Table 4.2) it can be concluded that most of the losses that occurred resulted from the return flows.

Chapter 5 Conclusions and recommendations

5.1 Water balance and performance indicators for Block 2

A water balance was compiled for Block 2 in the Dzindi Irrigation Scheme, i.e. a water distribution system based on actual field measurements and some modelled outputs for a period of 45 days. The following section details the conclusions.

Approximately 96.5% of the water diverted to Block 2 reached the secondary canals, but only accurate measuring and accounting can detect leaks. By doing an accounting on a specific canal it is sometimes possible to identify and quantify leaks of the irrigated areas (therefore the losses were 88.6% of the inflow).

The losses in the secondary canal were more than acceptable. In total, 88.6% of the water that was diverted to Block 2 was not used for irrigation and it is assumed that the water returned to the river as return flows because the sluice gates has been removed, Water runs to the first secondary canal in large volumes even when the farmers are not irrigating**.** Due to the labour intensive nature of short furrow irrigation, farmers are unlikely to irrigate unnecessarily.

Of the loss, 9.2% are infield losses, and 1.74 % can be directly linked to evaporation and seepage in the secondary canals, leaving 77.6% unaccounted for. This can be classified as the total unknown loss.

Only about 16.5% of the surface area in Block 2 of the Dzindi Irrigation Scheme was planted with crops requiring irrigation during the monitoring period.

Only 8% of the water diverted to Block 2 was required at field level by the actual planted crops based on climatic requirements.

For the situation that was assessed, where 16.5% of Block 2 of the Dzindi

Irrigation Scheme area was planted with crops requiring irrigation, it was found that almost six times the required amount of water (based on ET_c) was diverted into the main canal to Block 2. However, since this was done on a 24 hour basis, most of the water (more than 50%) probably flowed through the system unutilised.

As far as the Block 2 is concerned, the canal capacity makes it possible to divert the equivalent of 22.9 mm per day gross application for the whole 136 ha. At a conveyance efficiency of 85%, it means that the equivalent of 19.5 mm can reach the Block off-takes. If 50% of the water is then lost between the Block off-take and the field, there should still be 9.7 mm per day for a farmer to divert into his plot. If he then applies it at an application efficiency of 70.1%, he can still give an average application of 6.8 mm on the soil. At a distribution uniformity of 66%, this means that a minimum of 4.5 mm will be applied in all the beds. For comparison's sake, the peak daily reference evapo-transpiration is 4.9 mm in January (SAPWAT).

This of course is all theoretical, and based on a 24 hour schedule. If only 12 hours per 24 hours are considered, losses between the Block off-take and the field should be reduced to make the 4.5 mm nett application possible. Other practicalities include the capacity of the secondary canals, operational losses and flow times to the different off-take points.

From the calculated results of DU, it can be concluded that an average application of 18.9 mm was given during irrigation. The short furrow irrigation system that was evaluated had an application efficiency of 70.1% and a distribution uniformity of 66%. This value gives an indication of the uniformity with which water delivered to the beds varies between the beds.

The factors that influence water availability can be summarised as follows:

- Management and improvement of infrastructure.
- Training.

Van Averbeke *et al* (2004) report that the open channel water distribution system used at Dzindi is "considered the least complex technology to manage"; this does not however mean that it is simple to manage! Even commercial irrigation schemes with more resources where water is conveyed in this way struggle to manage canals effectively and have to continuously evaluate their practices, adapt and maintain the infrastructure to ensure acceptable service delivery to their water users, who are paying for their share of the water.

This is not to say that the same approach should be rigidly applied to a emerging farmer scheme, but it should be understood that the infrastructure was originally designed to be operated successfully in a certain manner and unless major infrastructural changes are made it still has to be operated within these design parameters to be effective.

5.2 Recommendations

Knowledge on irrigation water management and practical irrigation scheduling at scheme level is weak. The biggest immediate need is to improve the management of the infrastructure. The main system capacity is adequate and losses due to seepage, evaporation and return flows are within acceptable limits. The return flows are mostly caused by the farmers' lack of understanding resulting in them removing the entire sluice gates at the head of the secondary canals of Block 2, which leads to water running to the first two secondary canals only and not reaching the rest of the Block.

Some improvement of the infrastructure is required (replacement of sluices and fixing of leakages, mainly). Farmers must be made aware through workshops that it is their responsibility to make sure that the infrastructure is in a good condition. Training of the water bailiffs and irrigators to manage the distribution system more effectively is of the utmost importance. Water bailiffs must always make sure that all the sluice gates are closed in the evening to avoid water running in the canals when farmers are not irrigating. Farmers must stick to their timetable when it comes to irrigating and avoid irrigating in the evenings. By implementing a few simple management practices that will fit in with the water requirements of the irrigators, better water delivery can be achieved. An example of such a practice is closing the off-takes to Block 2 if the farmers are not irrigating (no irrigation in the evening).

Maintenance of infrastructure is also required. It is recommended that the following activities be practiced as frequently as possible:

- All mud and debris should be removed from the canal and farmers must be able to do that on a rotational basis because it's for their own benefit.
- The canal should be inspected on a regular basis and damaged sections should be removed and the canal relined.
- All vegetation should be removed from the banks of the canal.
- Cracks or damage on the canal can be patched with a cement and sand mix.

Through a participatory consultation process, it should be possible to develop a water management plan for the scheme that points out which planning actions have to be taken every year (or season or month or week) to ensure that water is distributed fairly in a way that suits all the stakeholders. The following are some of the questions that will need to be addressed:

- Why was the inlet sluice gate removed for all secondary canals in Block 2? Farmers must be made aware of the necessity of having the sluice gate in the canals.
- Why is the inlet flow rate never adjusted?
- Which plots are planted, when and with which crops? (This should be recorded the beginning of every season.)
- When do the different irrigators prefer to irrigate? (Do they stick to the

time table?)

- Who irrigates at night? (Is this an acceptable practice?)
- When is the canal cleaned (is there a fixed routine) and who is responsible for doing it?

The return flows are mostly caused by the farmers because they have removed the entire sluice gates into the secondary canals of Block 2, which leads to water running to the first two secondary canals.

Based on the requirements identified by all the stakeholders, training should be provided to the water bailiffs and farmers to implement management practices that are both effective and sustainable. Together with prioritised infrastructure upgrading, more acceptable water delivery should be possible.

The challenge lies in making the technical and the social aspects meet in such a way that the result is acceptable to both systems and can be sustained over time. The opportunities for capacity building by equipping the stakeholders with new skills are considerable, but the time and effort required to achieve this should not be underestimated.

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