ASSESSING THE PERFORMANCE OF SMALLHOLDER IRRIGATION IN SOUTH AFRICA AND OPPORTUNITIES FOR DERIVING BEST MANAGEMENT PRACTICES

Taziva Gomo

Submitted in fulfilment of the requirements
for the degree of Master of Science in Engineering

School of Engineering
University of KwaZulu-Natal
Pietermaritzburg
South Africa

February 2012

As the candidate`s supervisors we have approved this dissertation for submission.

Supervisor: ______________________________ Date: _____________

Dr. A. Senzanje

Co-Supervisor:____________________________ Date: ______________

Dr. M. Mudhara

ABSTRACT

South Africa is a water scarce country. With the increasing demand of water from other users, irrigation, as the largest water user, has to find ways to produce more per drop and meet the food demands of the growing population. Enhancing the performance of smallholder irrigation schemes (SHI) is one way of saving water since they are fast becoming the largest water users in South Africa and the world over. Performance in the smallholder sub-sector is reportedly below the expectations of stakeholders. However, performance in smallholder irrigation schemes is multi-dimensional and can be looked at from different perspectives. This study assessed the technical performance of the Mooi River Irrigation Scheme (MRIS) from the technical managers` and the farmers` points of view and integrated them into one to derive a comprehensive set of best management practices (BMPs) for the scheme. This was done acknowledging that the farmer is now the water manager in line with Participatory Irrigation Management (PIM) and Irrigation Management Transfer (IMT).

Three performance indicators related to water supply and delivery: conveyance efficiency, dependability of irrigation intervals between water applications and relative irrigation supply, and two agricultural performance indicators namely, output per unit irrigation supply and output per unit water consumed, were assessed during the spring and summer of the 2010/11 season. The field measurement method was used for the assessment of these indicators as opposed to the faster and more encompassing remote sensing method, due to resource constraints. The Velocity-area method was used to measure flow-rates in canals and crop water demands were estimated from FAO Cropwat 8.0 and Aquacrop 3.1. The results show an overall scheme conveyance efficiency of 86.4%, a maximum dependability of irrigation intervals between water applications of 2.57 in spring and a scheme relative irrigation supply of 1.48. Agricultural performance indicators, output per unit irrigation supply and water productivity per unit crop evapotranspiration (ET), were found to be 0.64 kg/m^3 and 5.37 kg/m^3 on average for cabbage, respectively.

Farmers` satisfaction with taking an irrigation service can be used as a measure of the scheme`s performance. A questionnaire was administered among farmers to gather their views on the performance and to determine the factors that significantly influence their satisfaction status with taking the irrigation service at MRIS. Information collected from the questionnaire include age, gender, irrigation training, timeliness of water delivery, water distribution among the blocks, farming experience, farmer involvement in inspection of irrigation infrastructure and maintenance, among others. Farmers` were also asked for suggestions on improving the performance of their scheme. Their responses were analysed using a multinomial logit model. Results showed that 57% of the farmers are satisfied with using the irrigation service at MRIS, 30% are not satisfied, while 13% are neutral. Eight factors were found to be statistically significant in influencing the farmers` satisfaction status namely: location with respect to the water diversion point, location within a block from the main canal, age of the farmer, education level attained by the farmer, farming experience, the number of plots a farmer owns, fairness of water distribution across the blocks and the number of days a farmer accesses water

The technical performance indicators assessed and the suggestions from the farmers on the way to improve performance of MRIS allowed the selection of the BMPs for the scheme. A set of seven BMPs based on farmer suggestions was derived. BMPs used as a guideline. The farmers were also tasked with the ranking of the derived BMPs according to their preference. The collected data was then ranked through an Analytic Hierarchy Process (AHP). The results show that establishment of and adherence to an irrigation schedule was the most preferred BMP by the farmers, while volumetric measurement of irrigation water used by each block was the least preferred.

This study concludes that the performance of MRIS is comparable to other schemes and that farmers are aware of the problems bedevilling their scheme. It is also concluded that the performance of the scheme meets the farmers`, the key stakeholders, expectations and that irrigation scheduling is the most preferred BMP. The study recommends that farmers be more involved in performance assessments and management of their schemes. It is crucial to ensure that the recommended BMPs are acceptable to the farmers in the scheme.

The best way to achieve this is by allowing farmers to participate in policy formulation and decision making.

Table of Contents

DECLARATION 1 - PLAGIARISM

I, ……………………………………………..… declare that:

1. The research reported in this dissertation, except where otherwise indicated, is my original work.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

    a. Their words have been re-written but the general information attributed to them has been referenced.

    b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.

5. This thesis does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the dissertation and References sections.

Signed: ………………………………………

DECLARATION 2 – PUBLICATIONS

Details of contribution to publications that form part this dissertation, which include papers in preparation, are given in each paper.

Publication 1 – Chapter 2 of this dissertation

Gomo T and Senzanje A. 2011. Water management in communally-managed smallholder irrigation schemes: Technical performance of Mooi-River Irrigation Scheme. *Paper in preparation*

Publication 2 – Chapter 3 of this dissertation

Gomo T., Mudhara M., and Senzanje A. 2011. Performance of smallholder schemes: Farmers` perspectives. *Paper in preparation*.

Publication 3 – Chapter 4 of this dissertation

Gomo T., Senzanje A and Dhavu K. 2011. Deriving best management practices for smallholder irrigation schemes in South Africa from the farmers` perspective. *Paper in preparation*.

Signed: ………………………………………

ACKNOWLEDGEMENTS

Firstly I would want to thank God the Almighty for His grace, mercy and protection during the course of this study. May His glory be forever.

I want to express my gratitude to the following people for their different roles during the 24 month period of this study:

Dr. A. Senzanje and Dr. M. Mudhara. This study would not have come to a successful conclusion without your supervision and guidance. You taught me a great lesson of openness and team work. May God bless you.

Prof. Jeff Smithers and all members of the former School of Bioresources Engineering and Environmental Hydrology for ensuring that resources are available for this study to go ahead. Prof., you have done a commendable job of running the school smoothly.

My late father (May his soul rest in peace), mother, brothers and sisters for the support you were always willing to provide, even when things were tough for you too. Special thanks to Mr. Trust Gomo for always being there when needed and for your unwavering support and trusting me.

Department of Agriculture (Tugela Ferry Offices): Mr. T. Ngubane, Mr. M.C. Zulu, Thembelihle Mzimela, Sphindile Mdunge, Nompumelelo Mthethwa and all the staff at the offices for making sure that I carry out my studies smoothly and always offering to help. Thank you very much and may that spirit continue among you.

Mooi River Scheme farmers for your cooperation during the study.

Michael P Malinga for introducing me to Msinga community and the support you offered. To other FSG staff, Lindelwa, Zanele and Gina, please keep up the good work.

My collegues Phesheya, Ernest, Mphatso, Craig, Charmaine, Shaame, Sylver and all other postgraduate students in the school. It was marvellous to work with you.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BMPs	Best Management Practices
CWR	Crop Water Requirements
DAEA	Department of Agriculture and Environmental Affairs (KwaZulu Natal)
FAO	Food and Agriculture Organisation of the United Nations
IMT	Irrigation Management Transfer
MRIS	Mooi River Irrigation Scheme
RIS	Relative Irrigation Supply
SABI	South African Irrigation Institute
SHI	Smallholder Irrigation
TFIS	Tugela Ferry Irrigation Scheme
WRC	Water Research Commission

1. INTRODUCTION

Water for irrigation is increasingly becoming limited owing to increased demand from other uses such as domestic water, industries and the environment (Perry, 2005) which give higher economic and social returns. This is the case despite that irrigation remains one of the best options to meet future food demands. To meet the increasing demands for food with an increasingly limited water supply, water resources management must be improved.

The realisation of the need to carefully manage scarce and further dwindling water resources forced governments across the world to embark on various management interventions, such as injection of financial aid to smallholder irrigation schemes, introduction of Participatory Irrigation Management (PIM) and Irrigation Management Transfer (IMT). In PIM participation by all irrigation stakeholders, such as farmers in irrigation management was increased while in IMT responsibilities were completely transferred from government to farmers. In South Africa, the government invested financial resources in the range of R30, 000 to R60, 000 per hectare towards the revitalization of smallholder irrigation schemes (Denison and Manona, 2007). The revitalization programme included capacity development among the farmers, improvement of extension services, establishment of water user associations and repair and maintenance of infrastructure in the schemes. These schemes are used as engines of growth in the poor rural areas in developing countries such as South Africa where 30, 000 families rely on them for employment and food security (Denison and Manona, 2007).

To evaluate the effectiveness of management strategies employed to improve the performance of irrigation schemes, various authors proposed several performance indicators (Bos and Nugteren, 1974; Levine, 1992; Abernethy, 1986; Seckler *et al.,* 1988; Molden and Gates, 1990; Sakthivadivel *et al.,* 1993; Perry, 1996, Molden *et al.,* 1998). Most of these indicators are applicable to all types of irrigation schemes ranging from simple gravity-fed to highly technical computer-controlled systems. Rao (1993) summarized the various performance indicators proposed by the different authors for measuring irrigation system performance and explained their use. Only a few of these indicators allow comparisons between schemes. In the past the focus was mainly on the irrigation systems, as seen in the summary by Rao (1993), but an irrigation scheme as a whole requires a holistic performance evaluation in order to recommend comprehensive best management practices. The difference between an irrigation system and an irrigation scheme is that an irrigation system is the part of the scheme which deals with water conveyance structures while an irrigation scheme encompasses socio-economic and institutional sub-systems such as road networks, temporary storage facilities, human resources, management structures, irrigated land and villages (Bos *et al*., 2005). These various sub-systems within the scheme have different effects on each other and on the general performance of the scheme, hence the need to consider the scheme holistically when carrying out performance assessment.

The proposed performance indicators have been widely used to evaluate if the performance of various schemes across the world satisfy different objectives such as helping irrigation managers to improve water delivery service to users or for providing information for policy implementation (Kuscu *et al.,* 2009). The performance assessments have been done from different perspectives – researchers, donors, farmers, irrigation managers and government. Sam-Amoah and Gowing (2001) and Kuscu *et al.,* (2009), however, highlighted that the least attention has been paid to the perspectives of the consumer of irrigation services and the fundamental stakeholder – farmers. With farmers as managers and users after PIM and IMT, it is possible to combine the performance assessments from different points of view into one and develop the best management practices (BMPs) acceptable in smallholder irrigation schemes. The introduction of PIM and IMT indicates that farmers can no longer be relegated to mere spectators in technical and management decision making processes; and their views have to be taken into account.

However, a cause for concern has been the performance of the various irrigation schemes under the management of farmers (Garces-Restrepo *et al*., 2007). Several studies carried out in various countries across the world have shown mixed results. In some countries, the performance improved after IMT while in others the performance deteriorated (Shah *et al*., 2002). Svendsen *et al*. (2009) noted the general performance of smallholder irrigation schemes across the world has been below expectations before and after PIM and IMT. The causes of low performance have varied among countries but have relatively been similar within countries. In South Africa, Bembridge (2000) and Oosthuizen, (2002), mentioned sub-optimal water management, especially in communally-managed smallholder schemes, as one of the drivers of low performance.

1.1 Objectives

The aim of this study was to assess the performance of a communally-managed smallholder irrigation scheme from both technical and farmers` points of view and derive best management practices for smallholder irrigation schemes in South Africa. This study integrated a wide spectrum of research aspects; from engineering to partly socio-institutional factors. The specific objectives were to:

- assess the technical performance of Mooi River Irrigation Scheme (MRIS) using selected and appropriate indicators,
- determine the farmers` subjective assessment of performance and the factors underlying their assessment at MRIS, and
- derive the best management practices for smallholder irrigation from the key factors identified above.

1.2 Outline of the Dissertation

This dissertation is comprised of five chapters. Chapter 1 consists of a brief introduction to the whole document. Chapters 2 – 4 address the aforementioned objectives in 'draft paper format'. All the field work, selection of research methods, data analysis techniques, data analysis, results interpretation, discussion and other aspects to do with thesis was done by the student while the supervisors and co-authors provided academic guidance. The final chapter is a summary of conclusions and recommendations from the whole document. A brief description of what to expect in each chapter is given below.

Chapter 2 addresses the technical performance assessment aspects of the research. Five performance indicators – conveyance efficiency, dependability of irrigation interval between water applications, relative irrigation supply, water productivity with respect to irrigation water supply and water productivity with respect to water consumed, were assessed. Flow rates, irrigation schedules and depths and yields were measured in the field while crop water requirements were estimated using FAO software. In Chapter 3, farmers` perceptions, satisfaction levels and factors underlying their assessment of irrigation performance were investigated through a semi-structured questionnaire. A Logit model was used to analyse their responses.

A set of seven BMPs derived from both the technical and farmers` perspectives, and guided by the Texas State Soil and Water Conservation Board (TSSWCB, 2005) BMPs, were ranked using Analytic Hierarchy Process (AHP) and the results are presented in Chapter 4.

1.3 Scientific Relevance and Contribution of the Study

In the past, performance assessments in irrigation have been from one stakeholder`s or the other`s point of view that is from the irrigation manager`s perspective, from the donors` point of view or from a farmer`s point of view (Ghosh *et al.*, 2005, Kuscu *et al.,* 2008; Kuscu *et al*., 2009). This study has integrated the technical performance assessment with the farmers` assessment in view of the reality that under PIM and IMT the farmer is now the water manager. A set of BMPs is derived, and then ranked using AHP (Saaty, 1994), the first time it has been used in ranking smallholder BMPs in South Africa.

A pictorial view of the study structure is shown in Figure 1.1.

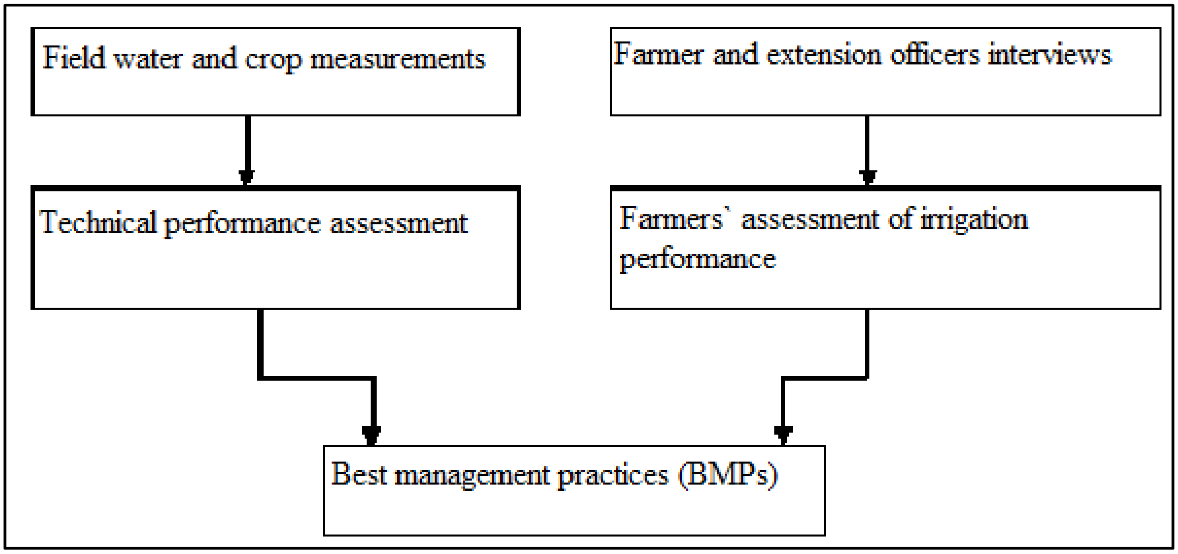

Figure 1.1 Structure of study

1.4 References

Abernethy, CL. 1986. Performance Measurement in Canal Water Management. ODI-IIMI Irrigation Management Network paper 86/2d.

Bembridge, TJ. 2000. Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa. Water Research Commission report number 891/1/00. Pretoria, South Africa.

Bos, MG and Nugteren, J. 1974. On Irrigation Efficiencies. International Institute for Land Reclamation and Improvement Publication 19. Wageningen, The Netherlands. Revised. 1990.

Bos, MG, Burton MA, and Molden, DJ. 2005. Irrigation and Drainage Performance Assessment: Practical Guidelines. CABI Publishing, London, UK.

Denison J, and Manona, S. 2007. Principles, Approaches and Guidelines for the Participatory Revitalisation of Smallholder Irrigation Schemes Volumes 1 & 2. Water Research Commission Report No TT 309/07. Pretoria, South Africa

Garces-Restrepo, C., Vermillion, D., and Muñoz, G. 2007. Irrigation Management Transfer: Worldwide efforts and results. FAO Water Report 32. FAO Publications, Rome, Italy

Ghosh, S, Singh, R., and Kundu, DK. 2005. Evaluation of Irrigation-Service Utility from the Perspective of Farmers. *Water Research Management Journal 19: 467 – 482.*

Kuscu, H, Demir, AO, Korukcu, A, 2008. An assessment of the irrigation management transfer programme: case study in the Mustafakemalpasa irrigation scheme in Turkey. *Irrigation and Drainage Journal 57: 15 – 22*

Kuscu, H, Boluktepe, FE, Demir, AO. 2009. Performance assessment for irrigation water Management: A case study in Karacabey Irrigation Scheme in Turkey. *African Journal of Agricultural Research 4(2), 124 - 132*

Levine G. 1992. Relative Water Supply: An Explanatory Variable for Irrigation Systems. Technical Report No. 6. Cornell University, Ithaca, New York, USA.

Molden, DJ and Gates T. 1990. Performance measures for evaluation of irrigation water delivery systems. *Journal of Irrigation and Drainage Engineering, ASCE 116(6): 804 - 823.*

Molden, DJ, Sakthivadivel, R, Perry, C.J. and de Fraiture, C. 1998. Indicators for Comparing Performance of Irrigated Agricultural Systems Research Report 20. IWMI Publications, Colombo, Sri Lanka

Oosthuizen, LK. 2002. Land and water resources management in South Africa. Integrated Land and Water Resources Management (WG-ILWRM), 18th ICID Congress, Montreal, Canada

Perry, CJ. 1996. Quantification and measurement of a minimum set of indicators of the performance of irrigation systems. International Irrigation Management Institute, Colombo Sri Lanka

Perry C. 2005. Irrigation reliability and the productivity of water: A proposed methodology using evapotranspiration mapping. *Irrigation and Drainage Systems 19: 211 - 221*

Rao, PS. 1993. Review of selected literature on indicators of irrigation performance. International Irrigation Management Institute. IIMI Publications. Colombo, Sri Lanka

Saaty, TL. (1994). Fundamentals of Decision Making and Priority Theory with the AHP.

RWS Publications, Pittsburgh, PA, U.S.A.

Sakthivadivel, RD, Merrey, DJ. and Fernando, N. 1993. Cumulative relative water supply: A methodology for assessing irrigation system performance. *Irrigation and Drainage Systems 7: 43–67.*

Sam-Amoah, LK, and Gowing JW. 2001. Assessing the performance of irrigation schemes with minimum data on water deliveries. *Irrigation and Drainage. 50: 31 - 39*

Seckler, D, Sampath, RK. and Raheja, SK. 1988. An index for measuring the performance of irrigation management systems with an application. *Water Resources Bulletin 24(4): 855 – 860*

Shah, T, van Koppen, B., Merrey, D., de Lange, M. and Samad, M. 2002. Institutional Alternatives in African Smallholder Irrigation: Lessons from International Experience with Irrigation Management Transfer Research Report 60. IWMI Publications, Colombo, Sri Lanka

Svendsen, M, Ewing, M. and Msangi, S. 2009. Measuring Irrigation Performance in Africa. International Food Policy research Institute Discussion Paper 00894. Washington DC, USA

TSSWCB (Texas State Soil and Water Conservation Board). 2005. Water Conservation Best Management Practices BMP Guide for Agriculture in Texas Report 362. Texas, USA

2. WATER MANAGEMENT IN COMMUNALLY-MANAGED SMALLHOLDER IRRIGATION SCHEMES: TECHNICAL PERFORMANCE OF MOOI-RIVER IRRIGATION SCHEMES

[a] T. Gomo, [a] A. Senzanje and [b] M. Mudhara
[a] School of Engineering, [b] Farmer Support Group,
University of KwaZulu-Natal, Pietermaritzburg, RSA

Abstract

Performance assessment of irrigation has become the central issue in water management with the unprecedented development of smallholder irrigation. Smallholder irrigation (SHI) farmers still rely on more affordable and simple field measurement methods, despite the advent of new and more encompassing methods such as use of remote sensing. This study assessed three water supply and delivery and two agricultural performance indicators through physical measurements in a communally-managed Mooi-River Irrigation scheme (MRIS) in KwaZulu-Natal, South Africa, during the spring and summer of the 2010/11 season. The Velocity-area method was used to measure flow-rates in canals and crop water demands were estimated using FAO Cropwat 8.0 and Aquacrop 3.1. The results showed overall scheme conveyance efficiency of 86.4%, a maximum dependability of irrigation interval between water applications of 2.57 in spring and a scheme relative irrigation supply of 1.48. These results are comparable to results from other international studies around the world and previous studies in South Africa. Agricultural performance indicators, which are, output per irrigation supply and water productivity (ET), were found to be, on average 0.64 kg/m^3 and 5.37 kg/m^3, respectively for cabbage and are similar to other results in studies carried out in Botswana and Malawi. It was concluded in this study that the performance of MRIS is comparable to other schemes around the world. This study recommends that farmers be more involved in all performance assessments and management in order to improve the performance levels since the farmers are responsible

for operation and maintenance after the introduction of Participatory Irrigation Management (PIM) at the scheme.

Keywords: Participatory irrigation management, performance, water management, water balance approach, smallholder irrigation, water use efficiency

2.1 Introduction

Water is a critical agricultural resource which is increasingly becoming limited owing to the increasing demands for domestic water supply, industries and manufacturing as well as the environment (Perry, 2005, Garces-Restrepo *et al.,* 2007). The increasing demand for water has led the irrigation sector to review its water use efficiency and policy, and to seek an in-depth understanding of when and how much water to apply (Akbari *et al.,* 2007). As the sector continues to lose water to other users and its water-use comes under international scrutiny (Garces-Restrepo *et al.,* 2007), efficient conveyance and field application in smallholder irrigation, which is fast becoming the largest water user (Svendsen *et al.,* 2009), has become imperative. To this end, several irrigation performance indicators, applicable to any type of irrigation scheme, have been developed. Some of these performance indicators can be assessed using either field measurement method or remote sensing.

Performance indicators have been used in assessing levels of service pertaining to operation, strategy (Gorantiwar and Smout, 2005), for comparison of different schemes with respect to management environments (Molden *et al.,* 1998), and to evaluate the impacts of management interventions such as Participatory Irrigation Management (PIM) and Irrigation Management Transfer (IMT) (Svendsen and Murray-Rust, 2001; Latif and Tariq, 2009). The indicators have also been used to monitor trends in water management performance of specific schemes over time (Mateos *et al*., 2010) and for the purpose of benchmarking with other schemes exhibiting efficient water management systems (Chivate, 2010).

Rao (1993) summarized the various indicators proposed by different authors for measuring irrigation system performance and explained their use. Molden *et al.* (1998); Malano and Burton (2001) and Bos *et al*. (2005) developed other indicators which included socio-economic and institutional factors, that provided the basis for holistic scheme performance assessments when they developed indicators for use at irrigation project level. These indicators have been used internationally to fulfil different performance objectives. In South Africa, Ntsonto (2005) and Yokwe (2009) evaluated the economic performance of the Zanyokwe irrigation scheme, while on-going research work at Tugela Ferry irrigation scheme (TFIS) seeks to address socio-institutional practices (Cousins, 2011), but technical performance assessment has been lagging behind. Shongwe (2007) evaluated water distribution only in a section of TFIS.

Perry (2007), however, highlighted that most of the indicators currently being used are just theoretical ratios which are difficult to interpret for an ordinary smallholder farmer and, in some cases, to policy makers, yet the performance evaluations are done mainly to advise them. In technical evaluations related to water supply, delivery and water-use in water scarce countries such as South Africa, Reinders *et al*., (2010) encourages the water balance approach which does not involve complex mathematical ratios. The approach identifies and minimises losses and non-beneficial water uses, from the conveyance system to field application.

The main objective of this study was to assess the technical performance in relation to water supply and delivery and agricultural performance of the MRIS using performance indictors based on a water balance approach. The performance indicators are briefly discussed below.

The technical performance indicators assessed in this research include conveyance efficiency (E_c), dependability of irrigation interval between water applications (D_{int}) and relative irrigation supply (RIS). Agricultural performance indicators were water productivity with respect to irrigation water supply (WP_I) and water productivity with respect to crop evapotranspiration (WP_{ET}) as explained by Bos *et al.*, (2005). These performance indicators were selected basing on the fact that water is more constrained (Molden *et al.,* 1998) and are representative of the problems faced by farmers after a pilot survey at MRIS, TFIS and other smallholder gardens in the study area, as part of this research. The indicators also help in identifying non-beneficial water uses, in line with the water balance approach (Reinders *et al.* 2010; Van der Stoep, 2010) and they have not been widely used in South Africa. More research work has been done on socio-economic indicators (Ntsonto, 2005; Yokwe, 2009)

2.1.1 Conveyance efficiency (E_c)

Conveyance efficiency refers to the ratio of volumes of water leaving a canal section to that introduced into the section. As a performance indicator, E_c is assessed by measuring inflow and outflow of selected canal reaches and calculated using Equation 2.1 developed by Bos *et al*. (2005)

$$E_c = \frac{Q_{out}}{Q_{in}} \qquad (2.1)$$

where E_c is the conveyance efficiency,

Q_{in} is the total water flowing into a specific section of the canal [$m^3.s^{-1}$], and

Q_{out} is the total water flowing out of a specific section of the canal [$m^3.s^{-1}$].

This indicator can be analysed either as a trend in time to quantify the need for system maintenance or spatially to identify sections of the canal sections that need maintenance. The temporal variation of the conveyance efficiency over the same section shows that either the system has deteriorated or has been rehabilitated, depending on whether the variation is positive or negative. A value >1 implies more water leaves a specific canal reach than that which enters it, while a value equal to 1 implies there is no water loss over the section under consideration. A value < 1 indicates that there was water loss in the section and therefore a need for maintenance of the system. The extent of water loss will determine the need for maintenance of the system. It is recommended that the conveyance efficiency of concrete lined-canal should be above 85% (Brouwer *et al.,* 1989, Gungor *et* *al.,* 1996; cited by Korkmaz *et al.,* 2009). The indicator has been used in various performance assessment studies in water scarce regions and recently Awulachew and Ayana (2011) used it in Ethiopia.

To allow comparison of actual water losses to permissible limits, a water conveyance loss ratio can be calculated for each section of the primary canal using Equation 2.2 (Ucar *et al.*, 2010).

$$W_{LR} = \frac{Q_{in} - Q_{out}}{Q_{in}} \times 100 \qquad (2.2)$$

where W_{LR} is the water conveyance loss ratio expressed as a percentage[%], and Q_{in} and Q_{out} are as previously defined.

2.1.2 Dependability of irrigation interval between water application

Dependability addresses the reliability of timeliness of water delivery to the edge of the plots. Renault and Vehmeyer (1999) noted this indicator can be used to address dependability of duration of water application or assesses the dependability of water delivery. To show how dependable water supplies are in an irrigation scheme, Bos *et al.*, (2005) proposed the indicator given as Equation 2.3:

$$D_{int} = \frac{A_{int}}{I_{int}} \qquad (2.3)$$

where D_{int} = dependability of irrigation interval between water applications,
A_{int} = actual irrigation interval [days], and
I_{int} = intended or design irrigation interval [days].

This indicator, when given as a trend in time, shows changes in service to farmers (timing only) while it illustrates the equity of water delivery service to farmers when analysed in space (Bos *et al*., 2005). D_{int} equals 1 if water is delivered as scheduled, less than 1 if water is delivered more often than planned and greater than 1 if farmers wait longer than scheduled to receive water.

2.1.3 Relative irrigation supply

Molden *et al.*, (1998) described relative irrigation supply (RIS) as giving an indication of how well crop water requirements are met or satisfied in a scheme as calculated using Equation 2.4:

$$RIS = \frac{S_{irr}}{D_{irr}} \tag{2.4}$$

where RIS is the relative irrigation supply,
S_{irr} is the irrigation supply [$m^3.s^{-1}$], and
D_{irr} [$m^3.s^{-1}$] is the irrigation demand.

Molden *et al.* (1998) also state that RIS is an inverse of the irrigation efficiency proposed by Bos and Nugteren (1974). If the water requirements are met, the value of RIS is unity while a value greater than 1 would indicate more water is supplied than required, and a value less than 1would show the crops are not getting enough water.

2.1.4 Output per unit irrigation supply

This indicator relates the crop yield to the amount of water diverted into a specific field. It provides information on water use in the field or plot, and is expressed in kg/m^3. It is calculated using Equation 2.5(Molden *et al.,* 1998).

$$WP_I = \frac{P}{Q_d} \tag{2.5}$$

where WP_I is the water productivity with respect to irrigation water supply [kg/m^3],
P is the crop yield [kg], and

Q_d is the diverted irrigation water into a specific plot [m^3].

It must however be noted that water productivity can only be compared in terms of mass if the same crop is considered (Molden *et al.,* 1998), otherwise they have to be compared in terms of their market values. This indicator is important to water managers and farmers. Water managers are usually concerned with water use, and farmers who want to realise maximum returns from their investment.

2.1.5 Output per unit water consumed (WP_{ET})

This indicator focuses only on crop evapotranspiration (ET); water evaporated from soil surface and transpired by crops, and therefore focusing on crop behaviour; that is the changes in crop water demands with time. It excludes water that may have been used for leaching of salts or drained away through deep percolation or surface flow as this is included in the calculation of WP_I. It is calculated using Equation 2.6 (Molden *et al.,* 1998):

$$WP_{ET} = \frac{P}{Q_{ET}} \quad (2.6)$$

where WP_{ET} is the output per unit water consumed [kg/m^3],
P is the yield [kg], and
Q_{ET} is the volume of water consumed by crop ET [m^3].

The indicator provides information on yield production to those more concerned with crop behaviour such as crop physiologists and agronomists

2.2 Irrigation Performance Assessment in Smallholder Irrigation (SHI)

Performance assessments in smallholder irrigation rely more on affordable and understandable field measurement methods, despite the advent of new and more accurate methods of evaluating performance, such as remote sensing (Perry, 2005). The field measurement method involves physical measurement of parameters, such as flow rates, irrigation schedules, irrigation depths and crop yields.

2.2.1 Field measurement of flow rate

Flow rate measurements in the canals can be done using various methods. Yoder (1999) discussed the various methods which included hydraulic structures, slope-hydraulic radius, dilution method, water collection at the downstream end of the open channels and velocity-area method. The Velocity-area method is recommended for temporary flow measurements such as research studies and in the absence of hydraulic structures (Yoder 1999).

The velocity-area method involves measuring of mean velocity at various cross-sections along a channel. Yoder (1999) explained several increasingly accurate technologies, such as Doppler, electromagnetic, transit time as well as radar, which can be used to measure velocity in open channels. The selection of the method is however dependent on several factors which include cost, geometry of the canal, water quality, required accuracy (Martin, 2009) and duration as well as ergonomics.

The flow cross-sectional area is determined at each cross-section to allow for computation of flow rates from the continuity Equation 2.7:

$$Q = V \times A \tag{2.7}$$

where Q = discharge [$m^3.s^{-1}$],
V = average velocity [$m.s^{-1}$], and
A = flow cross-sectional area [m^2].

Other than that the velocity-area method is complex compared to using hydraulic structures; it has several advantages over other methods, such as:

- it can be used where there are no weirs or flumes constructed,

- the method can be used with a variety of channel shapes,
- the method is more accurate than hydraulic-radius method, and
- there is minimal flow obstruction when using this method

Cross-sectional areas of the channels are calculated differently depending on the variations in geometry of the channels. For parabolic channels, Equation 2.8 is used for calculation of area (Sarkar 2008)

$$A = \frac{2}{3}Ty \tag{2.8}$$

where A is the area [m^2],
T is the top width of flow[m], and
y is flow depth [m].

2.2.2 Crop-water requirements, irrigation schedules and depths

Despite the fact that the physical determination of crop-water requirements (CWR), irrigation schedules and depths, is complicated and time-consuming, they remain vital to irrigation water management and planning (Abdelhadi *et al*., 1999).

The introduction of computer models has made it easier and possible to schedule irrigation and supply the exact amounts of water required by crops at every physiological stage in their growth cycle. Examples of such models include CropWat (Clarke *et al.,* 1998), SapWat (Crosby and Crosby 1999, 2010) and more recently AquaCrop (FAO 2010). The models are based on work done by Doorenbos and Pruitt (1977), Doorenbos and Kassam (1979) and Allen *et al.,* (1998) and they require information on crop environment (climate and soil) and physiological behaviour of the crops to estimate reliable CWR (Smajstrla and Zazueta, 1995). Their estimation is based on statistical methods or physical laws that govern water uptake and use. The main advantage of the models is that they produce very accurate estimates once they have been calibrated for a specific area.

2.3 Materials and Methods

Field measurements were used to assess irrigation performance in this study. Flow rates, irrigation schedules and depths and yields within the scheme were physically measured. Although there are new faster, accurate and more encompassing technologies such as remote sensing (Perry, 2005), field measurements were used in this study due to resource constraints and the small size of individual irrigated plots which measure approximately 0.1 ha per plot.

Crop water requirements in the scheme were estimated using Cropwat 8.0 (Clarke *et al.*, 1998), and Aqua-Crop 3.1 (FAO 2010). The estimation of CWR was calculated because of the significant changes in cropping patterns from the time the scheme was designed. The scheme was originally meant for maize to provide food security to the rural poor in that area of South Africa, but now the farmers are more into horticulture, thus effecting a change in water demand.

2.3.1 Study site

The MRIS is located in the uMsinga District in the Midlands region of KwaZulu-Natal province in South Africa. The scheme is located between 28º 56` longitude, latitude 30º 22` (diversion point) and. 28º 56` S, 30º 29` (lower end of scheme). Water is diverted from a weir constructed across the Mooi River into a parabolic canal which runs for 20.8 km from the diversion point to the end of the scheme (DAEA, 2001). The concrete-lined canal with a top width of 2.0 m and a depth of 1 m is designed to convey approximately 0.36 $m^3.s^{-1}$ (DAEA, 2001). The scheme is divided into 15 blocks of different sizes for management and ease of water distribution. The scheme layout is depicted in Figure 2.1.

The actual year the scheme was established is not clear but farmers highlighted that the scheme started in the early 20th century with earthen canals and concrete-lined in 1973. The scheme was intended to provide food and jobs to the local people. It covers 600 hectares and consists of distinctly demarcated plots, approximately 0.1 ha each in size. However, some farmers own or use more than one plot with most of them using about 0.5 ha on average. There are 824 farmers in the scheme.

The scheme is managed through block committees which are responsible for water distribution within each specific block, among other responsibilities. The overall scheme is managed by an irrigation management committee (IMR) which is comprised of the chairpersons and secretaries of all blocks. The irrigation management committee ensures equitable water distribution among the blocks, inspection of irrigation infrastructure and sourcing funds for repairs and conflict resolutions.

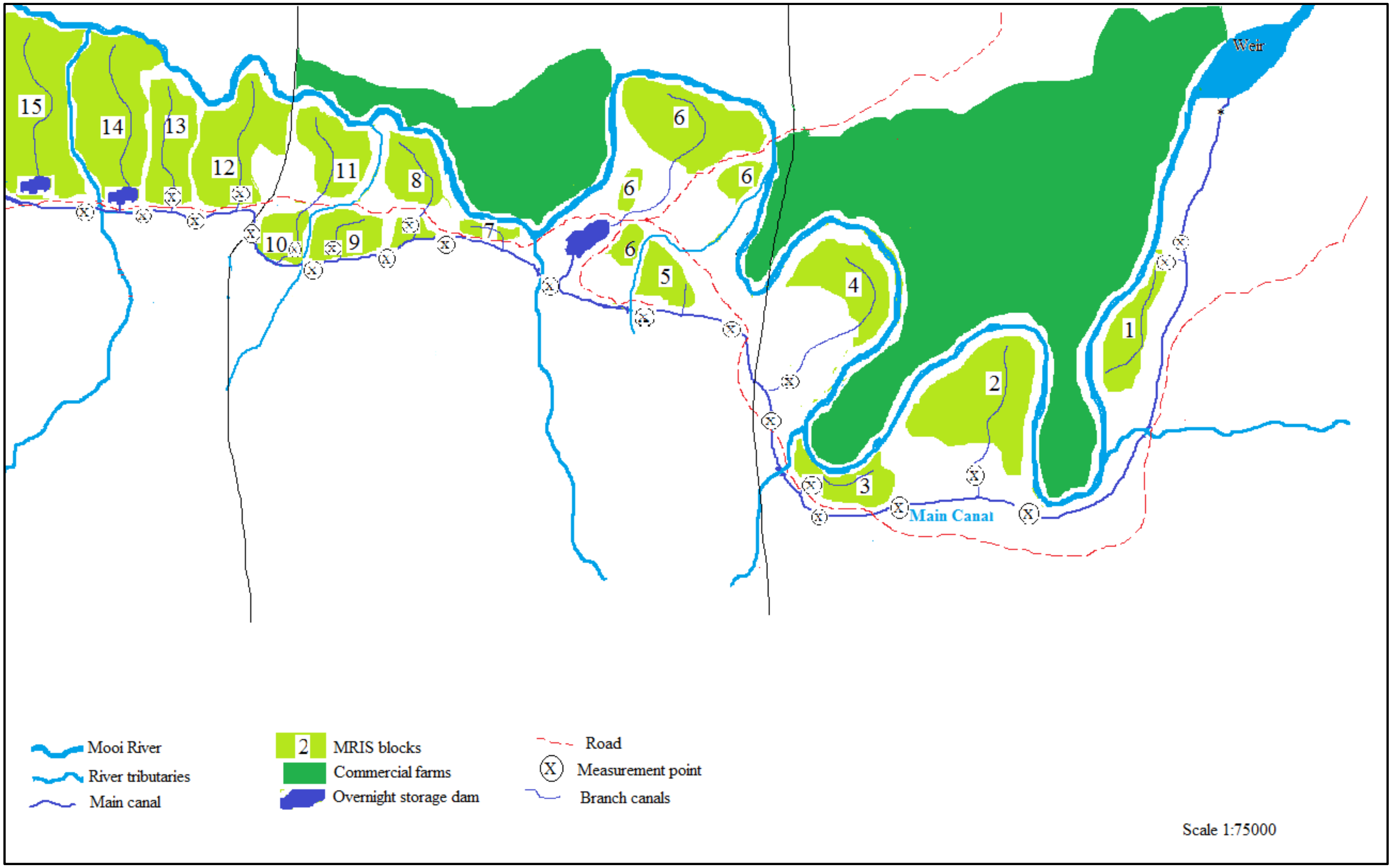

Figure 2.1. The scheme layout showing blocks and main canal (after DAEA 2001)

Water is distributed into the various plots through parabolic distributary canals of varying size depending on the area to be irrigated in the block. The sizes of the blocks and number of plot-holders in each block are shown in Table 2.1

Table 2.1 The sizes of the different blocks and the number of plot-holders in each block

Block	Total hectares per block	Number of plots	Number of farmers
1	5.0	44.0	15.0
2	15.0	152.0	26.0
3	9.0	90.0	29.0
4	26.0	253.0	76.0
5	2.5	25.0	2.0
6	64.8	648.0	113.0
7	4.4	44.0	16.0
8	33.8	338.0	35.0
9	14.0	140.0	31.0
10	50.4	504.0	91.0
11	39.2	392.0	68.0
12	62.0	620.0	76.0
13	71.0	710.0	86.0
14	58.0	580.0	103.0
15	146.0	1460.0	57.0
Total	**601.1**	**6000**	**824**

2.3.2 Data collection

2.3.2.1 Flow rates measurement

The Velocity-Area method, as described in sub-section 2.2.1, was used for flow-rate measurement in this study. The main canal was divided into 15 sections, each section covering a block. This was done to determine the total water being delivered into and leaving a specific section of the canal for each block, except Blocks 10 and 11 which share the distributary canals. As a result, 15 measurement points were selected along the main canal. Measurements were taken at points where water enters a section of the main canal, at the off take from the main canal and as it leaves that section of the canal.

Flow velocity, top width of flow and depth of flow were measured at each point three times a day, in the morning (at 08:00 hours), afternoon (12:00 hours) and evening (16:00 hours) from July 2010 to February 2011. Based on preliminary measurements taken for two weeks prior to commencement of actual data collection, it was assumed that:

(i) The flow rates are constant between 06:00 hours – 10:00 hours, 10:00 hours – 14:00 hours and 14:00 hours – 18:00 hours for both the main canal and branch canals. This was the basis for selection of measuring times, 08:00 hours, 12:00 hours and 16:00hours. Regular cross checks to ensure the assumption holds were also done at the main canal and branch canals

(ii) The flow rates in the branch canals within each block are the same. The branch canals in this case are defined as those canals that distribute water from the main canal into the blocks. Regular cross checks were also carried out to ensure the assumption holds at all times.

The flow rate measurements were done early, mid and late in the cropping season throughout the scheme.

The flow velocity of water in the canal was measured using the Global Water Flow Probe (Global Water Instrumentation, 2009). The flow probe is described as a highly accurate instrument for water velocity measurements in irrigation canals, with an accuracy of 0.1 $m.s^{-1}$. The probe consists of a propeller and bearing for measuring water velocity, coupled with a graduated telescoping probe handle ending with a flow display computer, as shown in Figure 2.2.

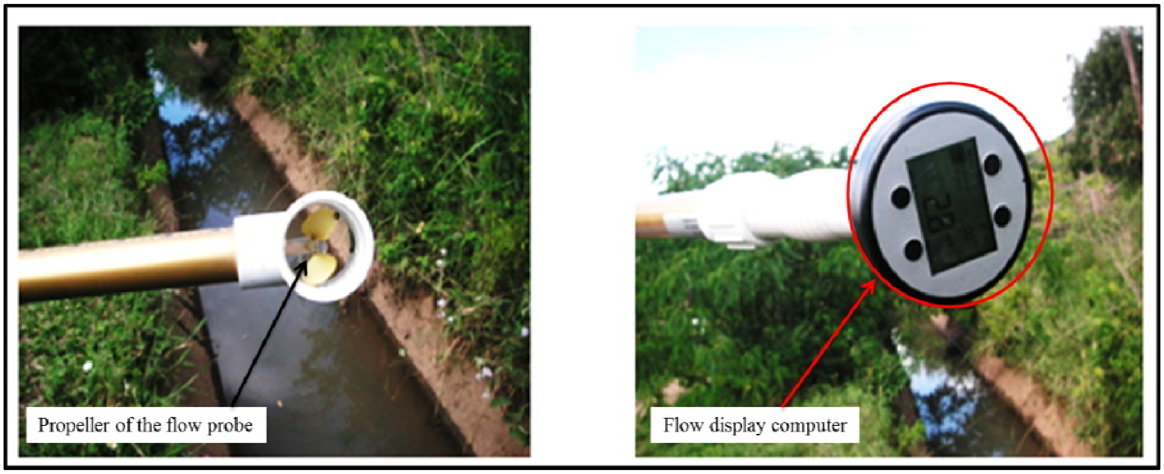

Figure 2.2 The FP111 Global Water Flow Probe

When taking flow velocity measurement at a point, the probe was dipped in water as shown in Figure 2.3 below, and gently moved three times across the section of channels at different depths of 0.3y, 0.6y and 0.9y, where y is the flow depth. This was repeated three times at a time and the 3 readings averaged to reduce errors. Moreover, the reading recorded is an average of several values averaged by the probe since it records the velocity every second. Global Water Instrumentation (2009) gives a detailed discussion of how the probe operates.

Figure 2.3 The use of Global Water Flow Probe FP111

Within each block, a distributary canal was selected along which three measurement points were chosen in the upper, middle and lower parts of the canal, as shown in Figure 2.4.

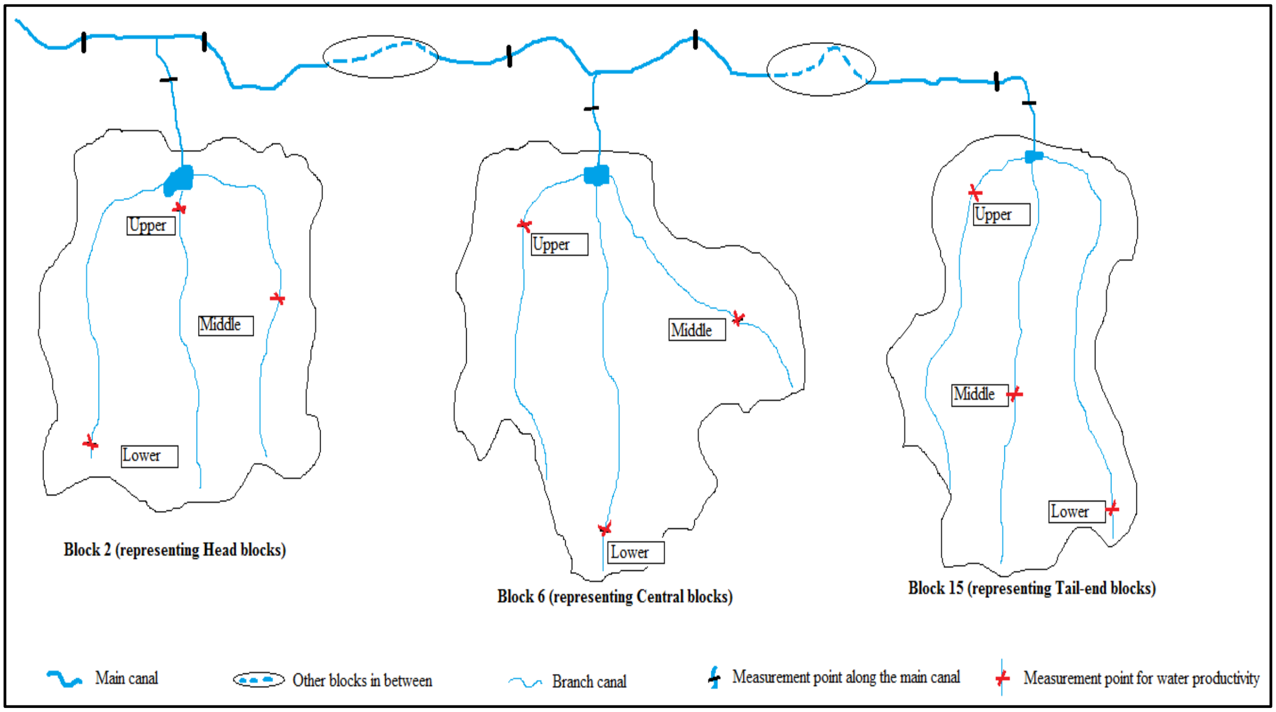

Figure 2.4 Measurement points and location of plots used in the study

Water supplied into selected plots was also measured. A total of 9 plots with cabbage were used in the study. Three plots were chosen in each of the head, central and tail-end sections of the scheme for the measurement of water supplied and yields. Blocks 2, 6 and 15 were chosen to represent the three sections of the scheme respectively. The plots within each section were located in the upper, middle and lower regions in each block. The locations of the plots can be seen in Figure 2.4.

2.3.2.2 Crops grown, estimation of crop water requirements, irrigation schedules and depths

The crop water demands, schedules and water depths for each block were estimated using Cropwat 8.0 (FAO, 2009). This was done because the cropping patterns have changed since the design and lining of the scheme in the 1970s.The estimation was done to allow evaluation of how much of the crop water demands had been met during the growth cycle.

A physical inspection of the cropped plots revealed three main crops: cabbage, potato and tomato, which were found in all blocks in the scheme. Cabbage was selected for comparison of water productivity in the head, central and tail-end sections of the scheme. The percentage area occupied by each crop between July and end of October 2010 can be seen in Table 2.2.

Table 2.2 The percentage area occupied by crops in each block at the time of study

Block	Percentage area occupied by crop						
	Cabbage	Beans (gr)	Tomato	Small Vegetables	Potato	Maize	Pepper
1	-	-	-	-	-	-	-
2	70	10	10	-	10	-	-
3	40	20	30	-	10	-	-
4	60	10	5	10	15	-	-
5	5	-	50	20	20	-	5
6	40	-	10	15	10	20	5
7	70	-	20	-	10	-	-
8	50	-	20	5	10	10	5
9	20	10	20	15	25	10	-
10	30	10	10	20	20	10	-
11	30	10	25	5	15	10	5
12	20	10	15	10	25	20	-
13	15	10	20	20	15	15	5
14	60	-	15	5	20	-	-
15	20	-	30	10	20	20	-

The information in Table 2.2 was used as input into Cropwat 8.0 for determination of water requirements. Block 1 was excluded because there were no crops during spring of 2010.

2.3.2.3 Yield measurements

Crop yields were measured from farmers in the upper, middle and lower location in all the 9 plots. Individual cabbages were weighed and an average mass calculated for each plot. The total harvest per plot was calculated from the average weight of individual cabbages and number of cabbage heads per plot. The yield measurements were done just before the produce was taken to the market.

2.3.3 Data analysis

The flow velocity and depths and cross sectional area data were used for calculation of flow rates. For agricultural performance indicators, analysis of variance (ANOVA) was used to test the significance of variation, at $p = 0.05$, in water productivity in and across the blocks.

2.4 Results

2.4.1 Conveyance efficiency (E_c)

The results presented show both the temporal and spatial conveyance efficiency values. The variation of conveyance efficiency at the beginning, middle and end of the season at 08:00, 12:00 and 16:00 hours for each block can be seen in Figures 2.5 – 2.7, while the variation of overall E_c per round per block in the scheme is depicted in Figure 2.8. Block 6, 14 and 15 have been excluded from most graphical presentations because they are mainly supplied from balancing dams which usually fill at night, with no water delivered during the day. In some cases, the conveyance efficiency was not calculated because there was no water delivered at the time of measurement, hence some missing values such as in Blocks 10 -13.

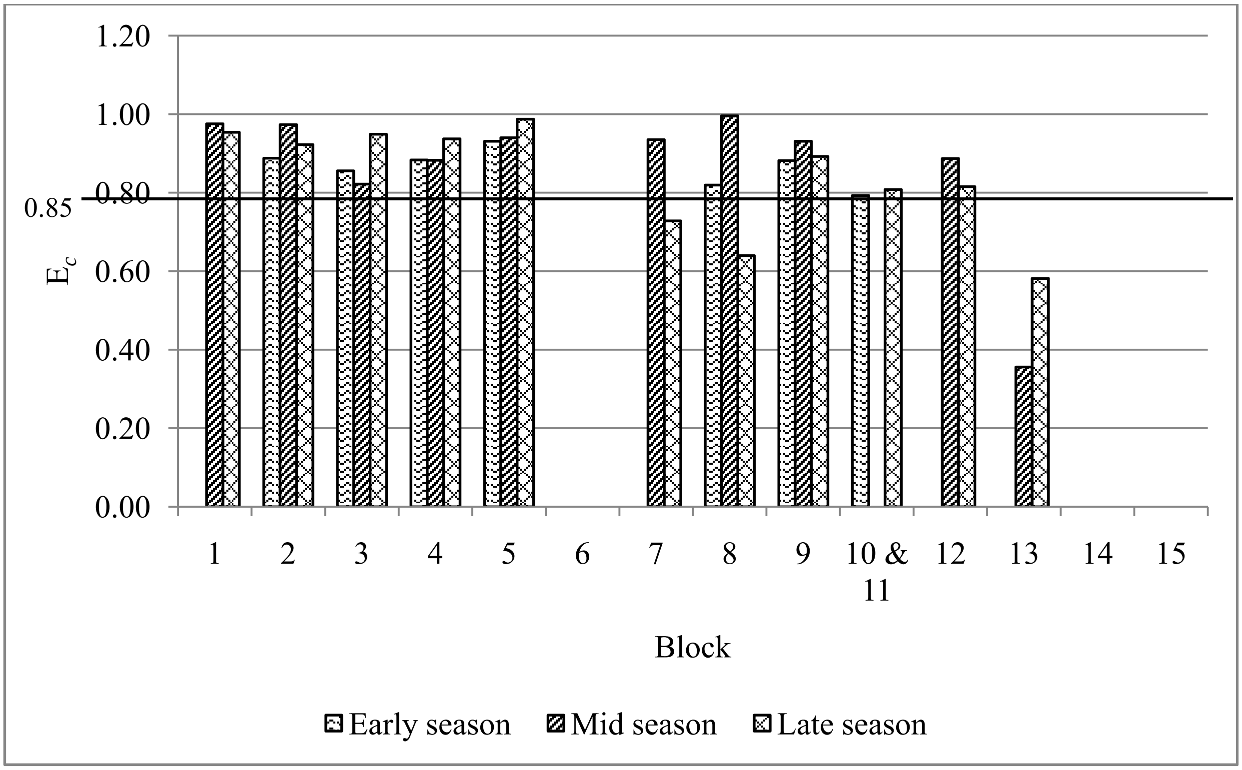

Figure 2.5 Seasonal variation of conveyance efficiency (E_c) among blocks at 08:00 hours

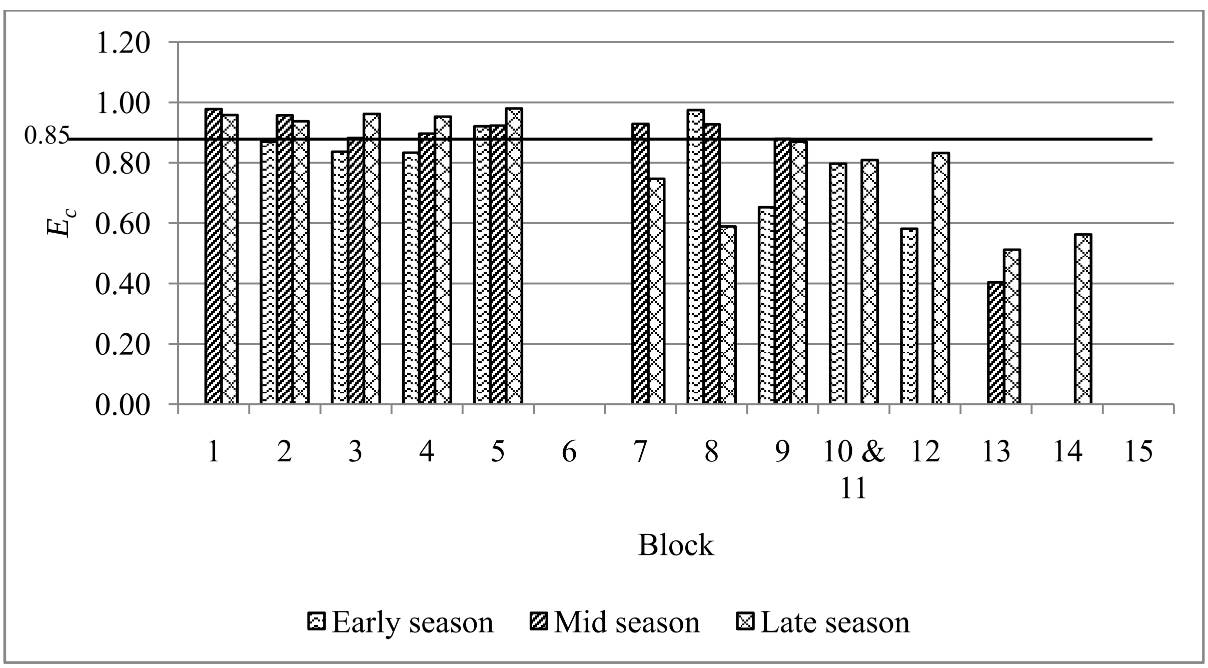

Figure 2.6 Seasonal variation of conveyance efficiency (E_c) among blocks at 12:00 hours

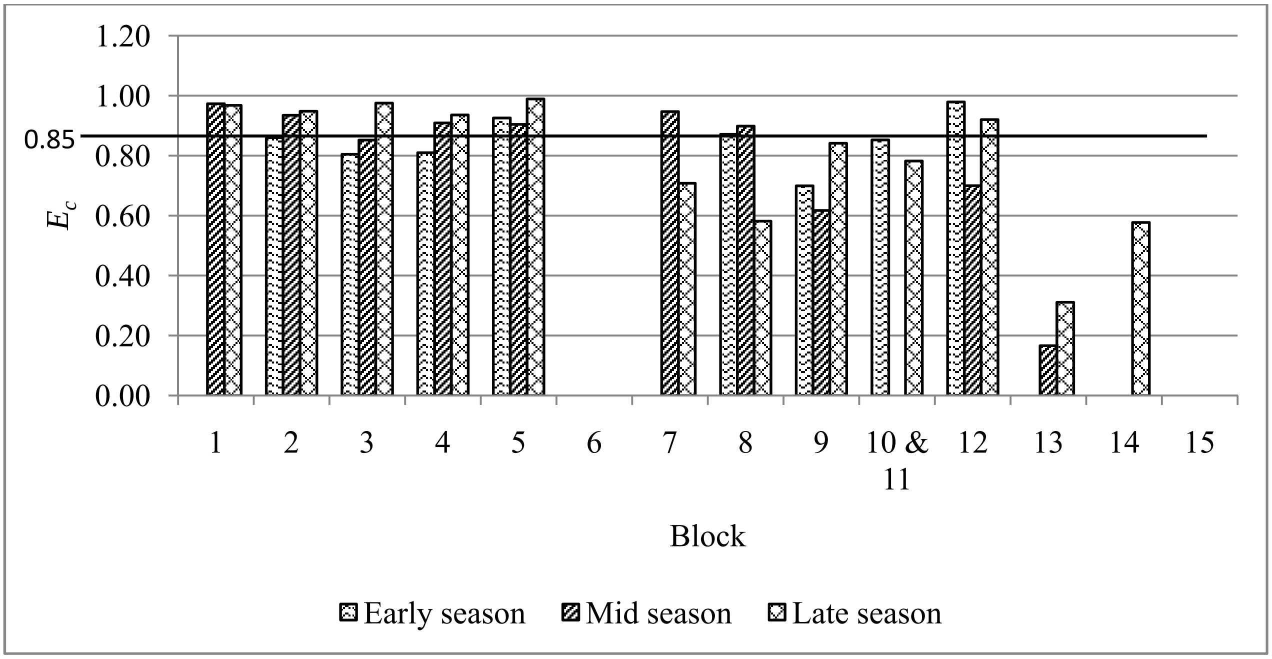

Figure 2.7 Seasonal variation of conveyance efficiency (E_c) among blocks at 1600 hours

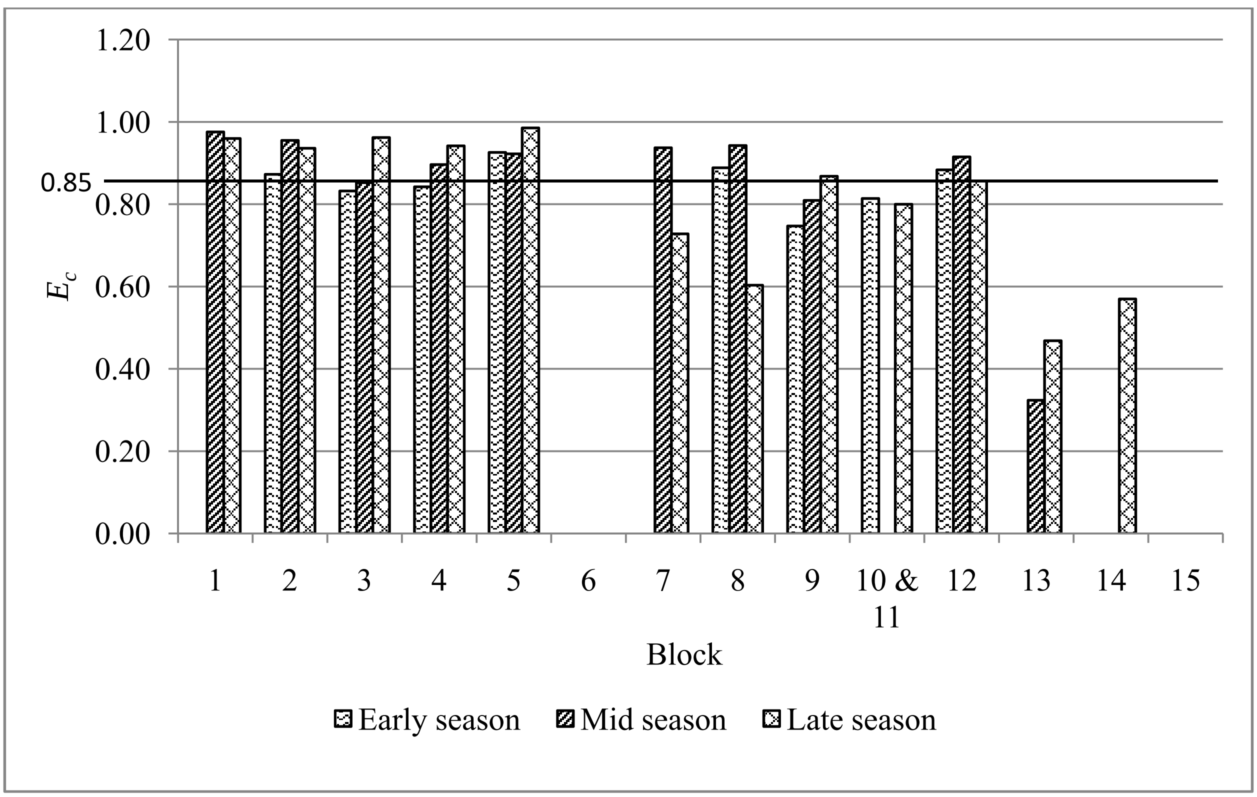

Figure 2.8 Variation of mean conveyance efficiency (E_c) per block throughout the season

The water conveyance loss ratio for the main canal sections shows a high of 61.2% in Block 13, as shown in Figure 2.9. In some blocks, the water conveyance loss ratios were not calculated since there were no water deliveries at the time of measurement such as early season in Blocks 1and 7, and mid-season in Blocks 10 and 11.

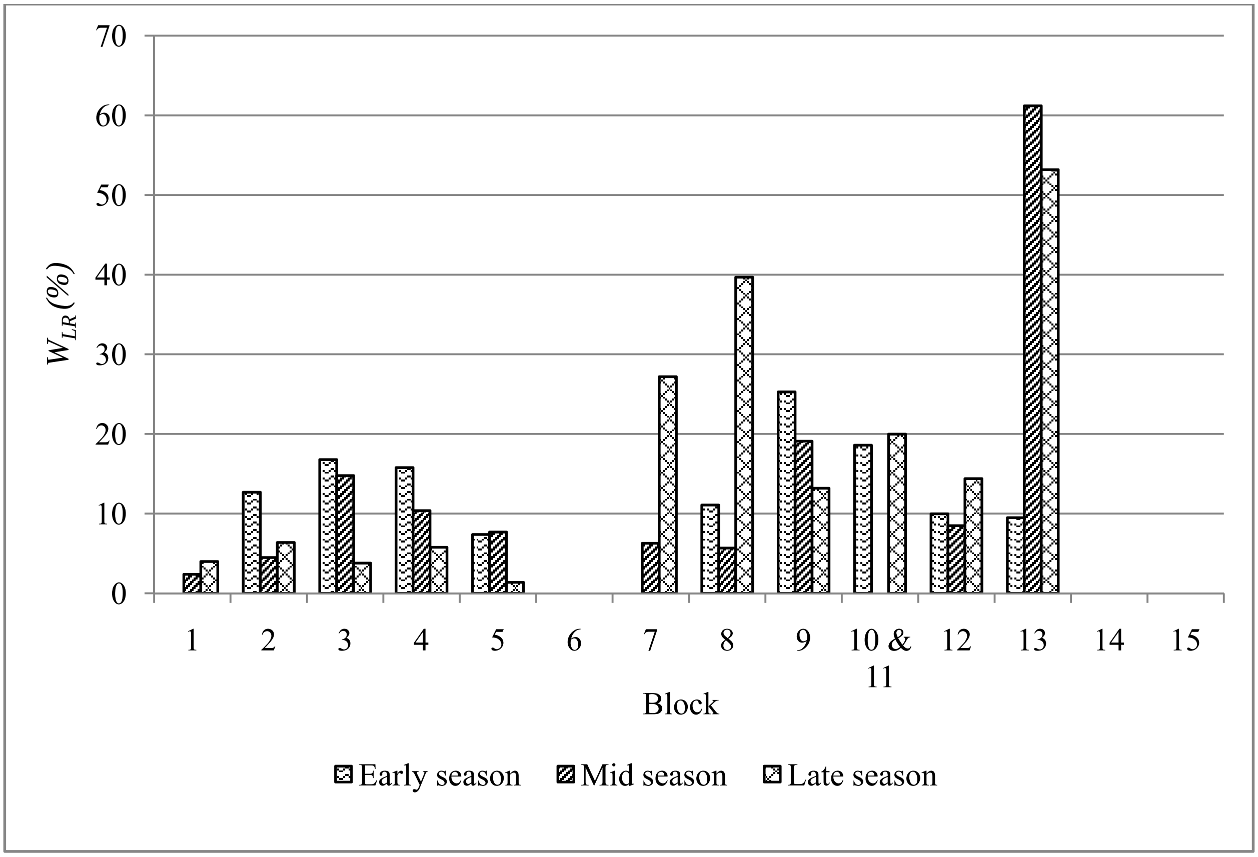

Figure 2.9 Water conveyance loss ratio (W_{LR}) variations in time and space among the different blocks

2.4.2 Dependability of irrigation interval between water applications

The dependability of consecutive water deliveries to the edge of plots varied within each block and along the canal from head to tail-end between 0.34 – 2.48 and 1.14 – 2.81 for spring and summer respectively as can be seen in Figures 2.10 and 2.11.

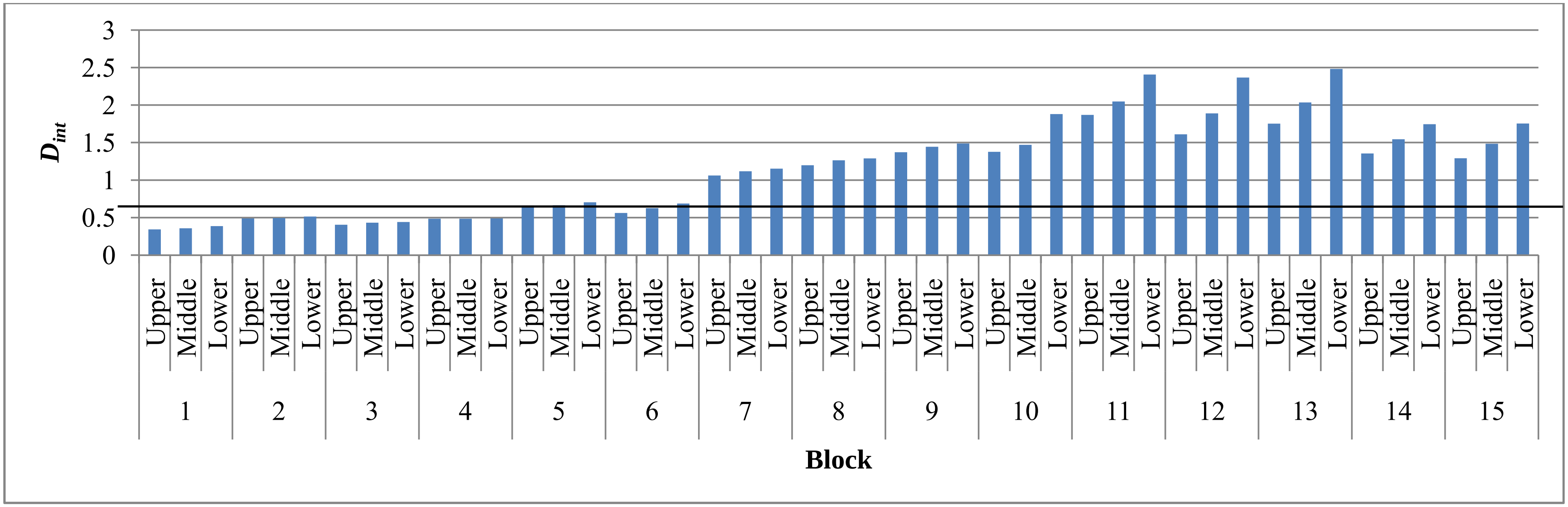

Figure 2.10 The average dependability of irrigation interval between water applications in spring 2010 irrigation season

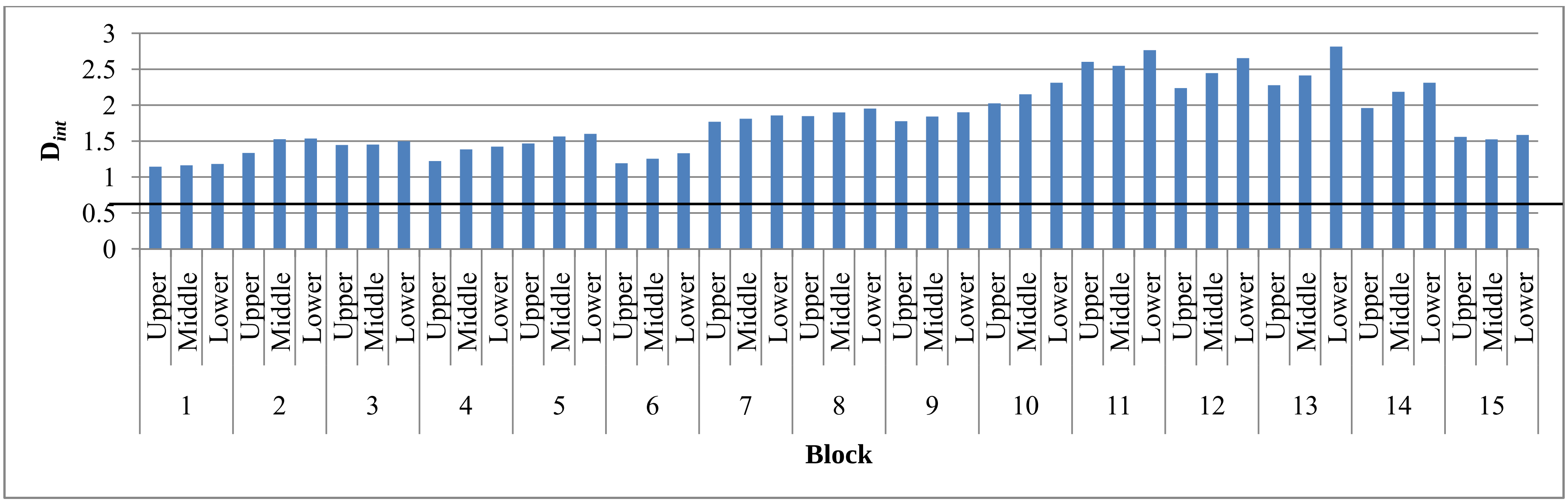

Figure 2.11 The average dependability of irrigation interval between water applications in summer of 2010/11 irrigation season

In spring, the values of D_{int} are < 1 for Blocks1 – 4 indicating that water is being delivered to the edge of the plots more often than planned; while D_{int} values are around 1 in the middle blocks, 7 – 10, showing that water is delivered at around the planned time. D_{int} values are > 1 for tail-end blocks, 11 – 13 meaning that the farmers wait for a longer time to get water on the edge of their plots than promised. In summer however, the D_{int} values are all greater than 1.

2.4.3 Relative irrigation supply

The level to which crop water demands were met varied at the beginning, middle and end of the season. At the onset of the season, RIS varied among the blocks between 2.1 – 0.1, increasing in the middle of the season to vary between 6.4 – 0.1 from head to tail-end blocks respectively, as can be seen in Figure 2.12. The measured values of water supply towards the end of the season were not reliable due to some rainfall being received which would overflow into the damaged branch canals, thus giving distorted measurements. Some of the blocks such as Blocks 7 and 8 were not irrigating towards the end of the irrigation season because the rainfall was enough for the crops water requirements.

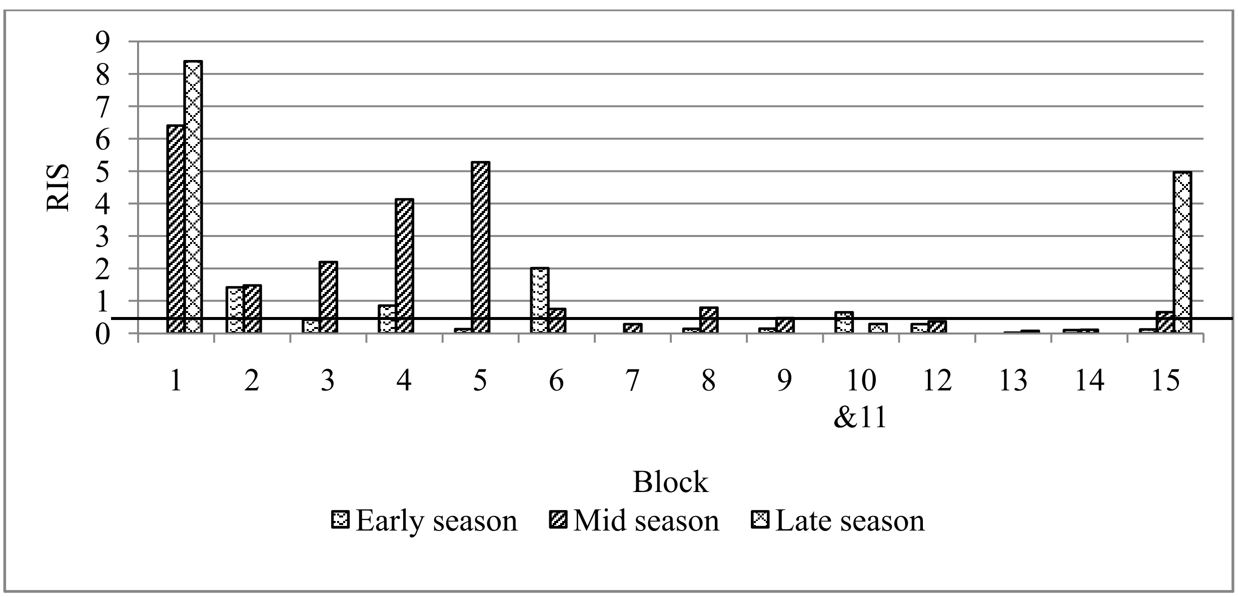

Figure 2.12 Variation of relative irrigation supply throughout the season at MRIS

Results of RIS complement D_{int} since the upper part of the scheme shows that RIS >1, and RIS <1 for the tail-end blocks.

2.4.4 Output per unit irrigation supply

The trend in the results shows that plots close to the main canal have a lower output to water delivered than those further away from it each block within a block. The output per unit irrigation for cabbage shows variations of 0.38 – 1.10 kg/m^3 as shown in Figure 2.13. The highest productivity was in the tail-end block. It should be noted that Blocks 6 and 15 are included in the results of water productivity, unlike in the conveyance efficiency, because the flow rate measurements taken were of water delivered into individual plots.

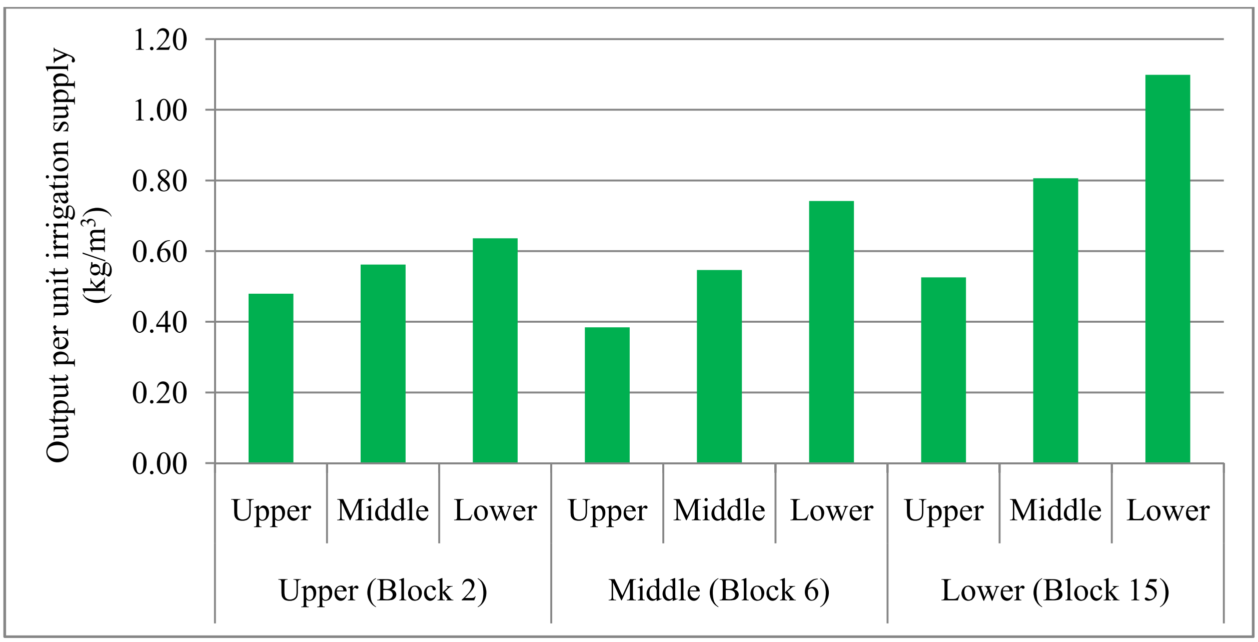

Figure 2.13 Cabbage output per unit delivered irrigation water at MRIS

2.4.5 Output per unit water consumed by crop (ET)

The average values of output per unit of water consumed by the cabbage for the head, middle and tail end 5.5, 6.8 and 3.8 respectively. The results show that the water productivity increases as we move from the main canal further away for central and tail end parts of the scheme, while the head of the scheme shows a different pattern as can be seen in Figure 2.14.

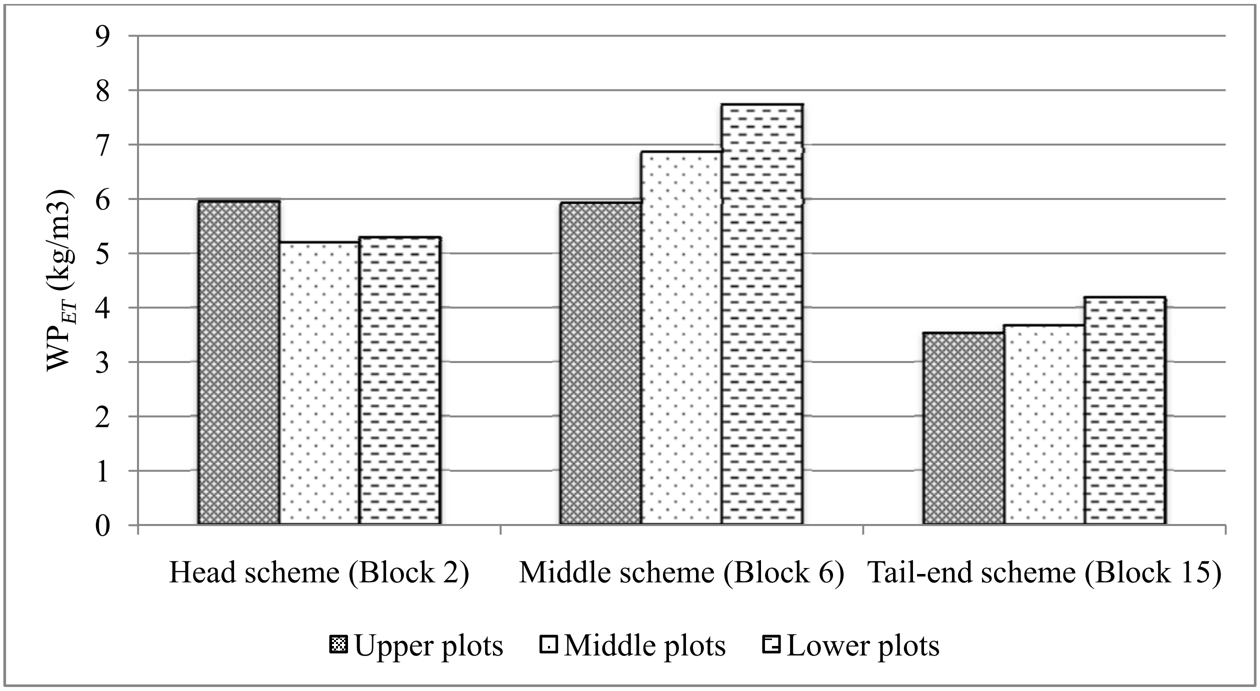

Figure 2.14 Water productivity with respect to crop evapotranspiration

2.5 Discussion

2.5.1 Conveyance efficiency

The conveyance efficiency varied within a day, at the beginning, middle and end of season and among the blocks throughout the scheme as can be seen in Figures 2.5 -2.8. The average conveyance efficiency of the concrete-lined parabolic main canal was 86.4%, above 60% SABI norms and slightly above 85% which Gungor *et al.,* (1996) in Korkmaz *et al.,* (2009) stated should be the minimum for concrete-lined canals but lower than 95% recommended by Brouwer *et al.,* (1989) in properly maintained canals in FAO training manual.

The conveyance efficiencies at 08:00, 12:00 and16:00 hours at the beginning, middle and end of the season was almost constant in each block, as shown in Figures 2.6 – 2.8, for upstream Blocks 1 – 5, ranging above 85% , indicating that there was no significant deterioration of the system nor increased illegal water withdrawals throughout the season. This was because the upstream farmers have access to adequate irrigation water and there are proper maintenance practices. The slight variations can be explained in SHI water supply being multiple-use system with domestic and other minor water uses from the canal, such as those shown in Figure 2.15 taken in Block 3.

Figure 2.15 Domestic and other water uses in the head blocks of MRIS (a) Washing (b) Animals drink from the canal, (c) community fetches water from the canal.(d) brick moulding with water from the canal

For middle and tail end blocks, 7 – 13, there were significant variations in the conveyance efficiencies as can be seen in Figures 2.5 – 2.8 due to increased illegal withdrawals of water as farmers jostle for the inadequate water to irrigate even plots outside the demarcated scheme boundaries. This was evident particularly in Blocks 9 and 10 where pumps with a combined capacity 1800 litres per minute (0.03 $m^3.s^{-1}$) were used to irrigate gardens outside the scheme, larger than individual plots in the scheme. One such illegal water withdrawal is shown in Figure 2.16, where a pump is housed and the suction is in the canal.

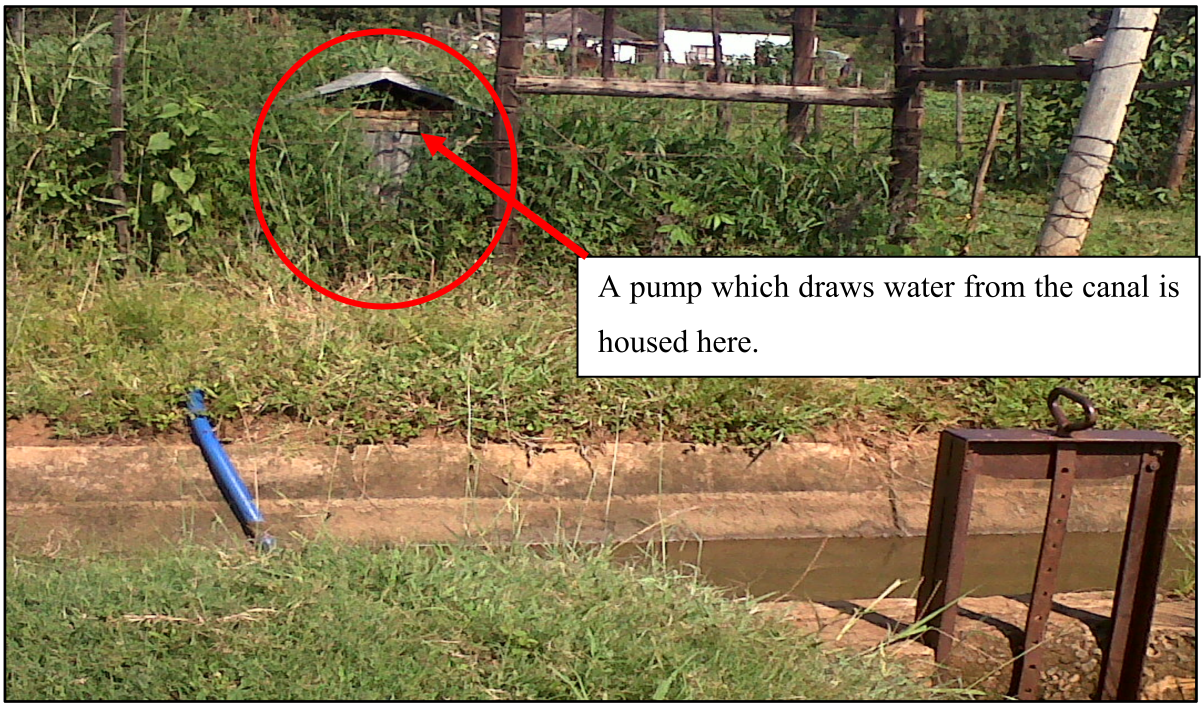

Figure 2.16 One of the pumps drawing water from the main canal in Blocks 9 & 10

In Blocks 12 and 13 which have the lowest average conveyance efficiency of 40%, far below that recommended for concrete-lined canal of 85%, there were pronounced leaks due to damaged canal walls, reduced canal capacity due to deposition causing water to flow over canal banks, illegal withdrawal of water with pipes drilled on the canal base and there were signs of continuous tempering with the canal, as shown in Figure 2.17.

Figure 2.17 Condition of the main canal in blocks with lowest conveyance efficiency (a) Leaking canal; (b) damaged canal wall; (c) & (d) canal filled with grass and blocking, (e) distribution gate blocked with rocks; (f), (g) & (h) vandalism of canal walls to 'steal' water

The water conveyance loss ratio in Figure 2.9 supports the fact that much water is lost in Blocks 8, 9, 10 and 13 where the lowest conveyance efficiency is found. The conveyance efficiency for Blocks 6, 14 and 15 were excluded since they are supplied from balancing dams.

The values of conveyance efficiency found in this study show an improvement in conveyance efficiency compared to 76% found by Reid *et al.,* (1986) when the same scheme was government-managed. The improvement could be explained in terms of transfer of responsibilities from government to farmers through PIM post-1994.

The conveyance efficiency values found in this study are comparable to other results found in various irrigation canals in Africa, Asia and Latin America which ranged between 61 and 93% (Plusquellec *et al.,* (1990) in Korkmaz *et al.,* 2009). Korkmaz *et al.,* (2009) also found an average of 86% in concrete-lined trapezoidal canal in Turkey, while Awulachew and Ayana (2011) found a conveyance efficiency of 88.7% in Bilate irrigation scheme in Ethiopia. The research results from this study showed a scheme average of 86.4% which is not so different from those found in Turkey and Ethiopia.

2.5.2 Dependability of irrigation interval between water applications

The dependability of intervals between water deliveries was low in the upstream indicating greater access to water by farmers in Blocks 1 – 5. The waiting period between two consecutive water applications within and among these blocks ranged between 1 - 5 days, averaging 3 days for spring of 2010. This is less than the intended interval of 7 days between water applications. The farmers have access to water at any time of the day hence they do not wait for the planned day of delivery at the expense of those further downstream. Bos *et al.,* (2005) noted that pattern of water delivery over time is directly proportional to the overall water that is consumed with a direct impact on crop production. However it should be noted that frequent access does not transform directly into adequacy of water unless the supply meets demand over a given period.

The values of dependability of intervals between water applications shown in Figure 2.10 steadily increase along the scheme within and among the blocks in the middle to the tail end blocks up to 2.5. The results show that the farmers in the lower blocks waited for longer periods of up to 17.5 days before water was delivered. The farmers would not be sure of the actual time the water would be delivered and as such tend to temper with the infrastructure for them to be able to access the little water that reaches them, as can be seen in Figure 2.17. The farmers would also not use other inputs such as fertilizers in optimal quantities faced with unpredictable variation in timing of water delivery, instead they would be concerned with the survival of the crop (Bos *et al.*, 2005).

Block 11 was the worst affected both in spring and summer because it shares the distributary canal with Block 10, hence is further away from the main canal. Lower plots in Block 13 were also affected because the little water that reaches Block 13 is used up by upper plotholders in the block. In some cases the waiting period was longer because of repairs and maintenance of the canal. The waiting period reduced slightly for the Blocks 14 and 15 because of the balancing dams which provide relief to crop earlier, although the waiting period is still above the intended.

A comparison between spring and summer values shows similar trends although all D_{int} values are greater than 1 for summer. This was probably because more frequent rain events are received in summer. Farmers also grow maize during summer for subsistence and only irrigate after a relatively longer period without rainfall.

The results found in this study are comparable to those found in other studies, for example Bos *et al.,* (2001) found the dependability of irrigation interval between water application in Chivilcoy canal in Argentina ranging between 0.1 and 1.15, where the water distribution was controlled by the government.

2.5.3 Relative Irrigation Supply

In this study, the average RIS values were found to be 0.52 at the beginning of the season, 1.64 in the middle of the season and 2.29 at the end of the season. The calculation of this indicator were however based on measurements of water diverted through official distributary canals, hence there is a possibility of over-estimation of the RIS since illegal water withdrawals were evident.

The values of RIS per block in this study were found to vary significantly both at the beginning and the middle of the season. The upper blocks had the higher values, as can be seen in Figure 2.12, indicating that they may be over irrigating. This might be because the farmers have access to water at any time of the day since they are responsible for water distribution. The trend in the results shows that there was an increase in the RIS values as summer approached from 2.1 to 6.4. This can be attributed to the farmers increasing their water application because the soil surface quickly looks dry in the scotching heat usually just before the onset of the rains in the study area. The farmers always wanted to see the surface wet despite that there might have been enough water in the soil for their crops, so they tended to irrigate more than required.

The tail-end blocks have extremely low RIS values of around 0.1 throughout the season, indicating a large mismatch between the supplied irrigation water and the crop demand. This may be explained in terms of the higher RIS values upstream which imply more water is used upstream and there is not enough water for downstream blocks. In some instances, blocks 14 and 15 would not receive water during the day, but rely on balancing dams like that shown in Figure 2.18, which fill at night The dams are however small, considering that the areas of the blocks add upto 204 hectares constituting 34% of the scheme, and sometimes they run dry as can be seen in Figure 2.18(b).

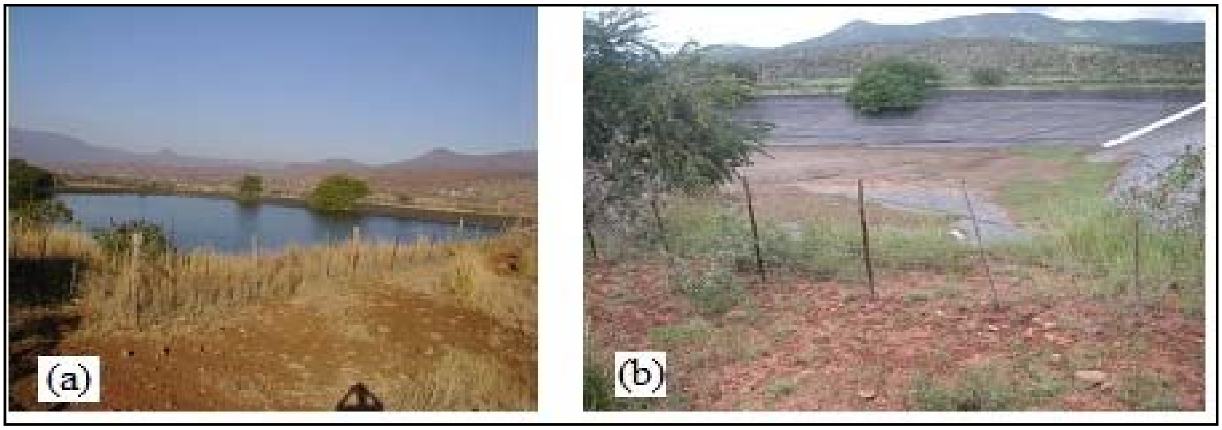

Figure 2.18 One of the balancing dams in Block 14, (a) the dam is full; (b) the dam had run dry

Considering that Molden *et al*., (1998) found a wide range of mean RIS values from 0.41 to 4.81 in 18 different irrigation schemes located in 11 countries, and Uysal and Atis (2010) in Turkey found RIS values of 1.2, 1.4 and 1.5 in the evaluation of Irrigation Management Transfer (IMT) as management intervention in the Aegean region, the results found in this study show that the performance is comparable to other countries around the globe.

2.5.4 Output per unit irrigation supply

The output per unit irrigation supply varied within and among the head, middle and tail-end blocks. The mean output of cabbage per unit water supplied was found to be 0.56, 0.56 and 0.81 kg/m^3 for head, middle and tail-end respectively. The results were compared in terms of mass since only one crop is considered as recommended by Molden *et al*., (1998); otherwise they would have been compared in terms of standardized market value. In each block the water productivity with respect to water supplied increased with an increase in distance from the main canal.

The farmers upstream and close to the main canal tend to use water carelessly since they have easy access compared to those who are further away. This may explain the variation in the output per unit water supplied. The farmers in the tail-end section of the scheme have limited water deliveries and they have adapted to producing with less water, hence higher water productivity with respect to irrigation.

Most of the studies that have been carried out around the world and in South Africa have expressed the value in economic terms, which makes it difficult to compare in terms of mass. However if compared to the study carried out by Yokwe (2009) at Zanyokwe irrigation scheme which found a value of R0.69 per m^3, the value found in this study of R0.63 per m^3 of irrigation water is within the same range.

There are various factors which were visible during the study period which could have contributed to lower water productivity with respect to irrigation such as lack of fencing which exposed crops to animals, and animals being herded in the scheme. There is evidence of tail-water not being used and flowing back to the river from the plots. There are signs of over-irrigation and poor farming practices such as lack of weeding that reduce crop production as can be seen in Figure 2.19.

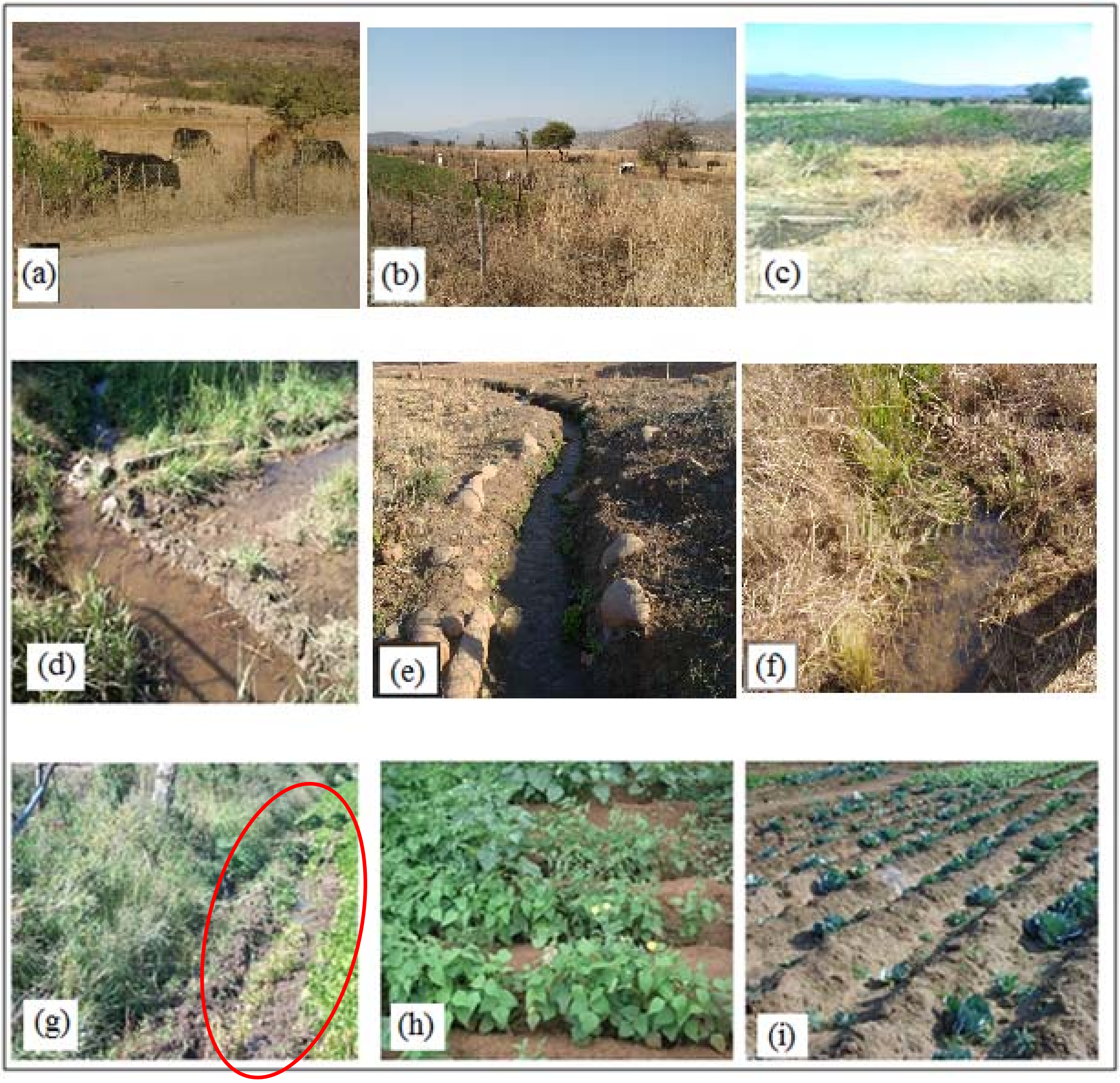

Figure 2.19 Factors affecting water productivity (irrigation) at MRIS
(a) & (b) animals are headed within the scheme; but (c) there is no fence to protect the crops; (d), (e) & (f)water diverted into a block for irrigation flows back to the river; (g) over-irrigating; (h) & (i) poor crop management practices

2.5.5 Output per unit water consumed by crop (ET)

The average values of water productivity with respect to crop evapotranspiration is (WP_{ET}) found for upper, middle and lower of the scheme were 5.4, 6.8 and 3.79 kg/m^3 respectively, ranging between 3.5 – 7.8 kg/m^3 throughout the season. The variation of WP_{ET} was not statistically significant within blocks and throughout the scheme.

The results are comparable to those found by Chafutsa *et al*., (2007) in Malawi which ranged between 5.1 – 8.4 kg/m^3, Domuta *et al.,* (2010) in Romania found range of 7.61 – 9.91 kg/m^{3}and 11.32 kg/m^3 found by Imtiyaz *et al* (2000) in Botswana but is far below that estimated by FAO (2002) of between 12 – 20 kg/m^3. The shortfall can be explained by the various factors. Lack of fencing contributed to reduced yields because the crops were exposed to animals and theft. The differences in the varieties of the cabbage grown by different farmers also contributed to the slightly lower output per unit water consumed. Some varieties produce more per water consumed. However, the most common variety was established to be *Conquestador*, distributed by the Department of Agriculture located within the scheme. The other problem which might have led to the disparity may be poor crop management as can be seen in Figure 2.19 (h) and (i) by the farmers due to lack of knowledge about the crops. Lack of or wrong application of fertilisers, pests and diseases may have also contributed to reduced yields. An investigation into these causes has been recommended below.

2.6 Conclusions and Recommendations

The main purpose of this study was to assess and understand the technical performance of the Mooi-River smallholder irrigation scheme, in relation to water supply and delivery and agricultural performance with performance indicators. The values of the indicators reveal that the scheme performance is comparable to results found in other parts of the world confirming that smallholder irrigation schemes perform below expectation.

Analysis of the conveyance efficiency shows the system delivers enough water to irrigate the whole scheme but lack of institutional framework hinders water distribution within and among the blocks. The recommendation here is to resuscitate management committees within the blocks to monitor the water distribution. It is also recommended to regularly carry out seasonal infrastructure inspection and repair damaged components. Replacement of the distributary canal with pipes may assist in improving delivery performance and monitoring water use.

Farmers located in the head section of the scheme have more and unlimited access to water at the expense of middle and tail-end farmers, which if regulated may improve the operational performance of the scheme. It is recommended that government assist in resuscitating scheme management committees to manage water allocation for blocks from the main canal. For this to be effective there must be a clear policy on irrigation hand-over to the farmers clearly defining the roles and responsibilities of the farmers and those of the government. There is also need to introduce water tariffs to curb carelessness in water use. Most of the farmers indicated willingness to pay for water as long as they will be guaranteed to get promised water in time.

Water productivity is generally low. It is recommended that financial and technical assistance be provided to farmers through qualified personnel. The scheme has only two qualified agricultural technicians who are also expected to cover dry-land agricultural advisory services and provide animal health services, among other responsibilities. There is need to engage irrigation specialists to advice farmers. Financial services can be in the form of fence for the scheme and training to the farmers on running irrigation as a business since it is their source of livelihood. It is also recommended that further long term studies be carried out in the scheme to cover social, economic and institutional performance and include the farming practices as well as crop management by SHI farmers.

Generally the scheme is still performing like others across the world but the trend of infrastructure destruction taking place could lead to further deterioration of performance. The best way to achieve this may be to deepen the participation of the farmers in the management of the scheme; carry out awareness campaigns as well as putting in place a regulating authority, which may involve traditional leadership. The traditional leadership is currently responsible for land allocation in the scheme. However, the involvement of traditional leadership may also be the problem since some people who are not interested in farming may be allocated plots to the exclusion of those interested who then extract water illegally.

2.7 References

Abdelhadi, WA, Hata, T, Tanakamaru H, Tada, A, and Tariq, MA. 1999. Estimation of Crop-Water requirements in arid region using Penman-Monteith equation with derived crop coefficients: a case study on Acala cotton in Sudan Gezira irrigated scheme. *Agricultural Water Management Journal 45 (2000) 203-214*

Akbari, M, Toomanian, N, Droogers, P, Bastiaanssen, W, and Gieske A. 2007. Monitoring irrigation performance in Esfahan, Iran, using NOAA satellite imagery. *Agricultural Water Management Journal 88 (99 – 109)*

Allen, RG, Pereira LS, Raes, D, and Smith M. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements - FAO Irrigation and Drainage Paper 56. FAO Publications. Rome, Italy.

Awulachew, SB, and Ayana M. 2011. Performance of irrigation: An assessment at different scales in Ethiopia. *Journal of Experimental Agriculture.47: 57-69*. Cambridge University Press. Cambridge, UK.

Bos, MG, Burton, MA, and Molden, DJ. 2005. Irrigation and Drainage Performance Assessment: Practical Guidelines. CABI Publishing, London, UK.

Bos, MG, and Nugteren J. 1974. On irrigation efficiencies. International Institute for Land Reclamation and Improvement (ILRI) Publication 19, Wageningen. The Netherlands

Bos, MG, Salatino, SE, and Billoud CG. 2001.The water delivery performance within the Chivilcoy tertiary unit, Mendoza, Argentina. *Irrigation and Drainage Systems 15: 311–325.*

Brouwer, C, Prins, K, and Heibloem, M. 1989. Irrigation water management: Irrigation scheduling. Training manual number 4. FAO Publications. Rome, Italy.

Burt, CM, and Styles, SW. 1998.Modern water control and management practice in irrigation: Impact on performance. Available on: www.fao.org/DOCREP/003/x6626E/x6626e09.htm. Accessed on May, 13 2011.

Chafutsa, W, Fandika, IR,. Kadyampakeni, D, Chiipanthenga M, Mapwesera, H, and Mafunga G. 2007. Comparative response of cabbage to Tea fertilizers, Compost manure and Inorganic fertilize under furrow irrigation. Kasinthula Agricultural Experiment Station Publications. Chikwawa, Malawi.

Chivate, BA. 2010. Irrigation performance benchmarking in Maharashtra. Center for River Basin Organizations and Management, Solo, Central Java, Indonesia.

Clarke, D, Smith, M, and El-Askari, K. 1998. CropWat for Windows: User Guide. FAO Publications. Rome, Italy.

Cousins, B. 2011. Personal communication. On-going research at Tugela Ferry. University of Western Cape, Cape Town, RSA, 03 Oct 2011.

Crosby, CT, and Crosby, CP. 1999. SAPWAT: A computer program for establishing irrigation requirements and scheduling strategies in South Africa. Water Research Commission, Pretoria, RSA.

Crosby, CT, and Crosby CP. 2010. SAPWAT 3: A computer program for establishing irrigation requirements and scheduling strategies in South Africa. Water Research Commission, Pretoria, RSA.

DAEA. 2001. Mooi-River Irrigation Scheme Topographic Survey, Southern region. Hilton, Pietermaritzburg, RSA.

Domuta, C, Sandor, M., Bara V, Ciobanu, Gh, Domuta, Cr, Bara L, Bara, C, Borza, I, Brejea, R, Gitea, M, Vuscan, A, and Moza, A. 2010. The irrigation influence on water use efficiency in autumn cabbage from Crisurilor Plain. *Journal of Horticulture, Forestry and Biotechnology Vol 14 (1) 69-72.*

Doorenbos, J and Pruitt, WO. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage paper No. 24. FAO Publications, Rome, pp. 15 – 29, 112 – 115.

Doorenbos, J. and Kassam, AH. 1979. Yield response to water. FAO Irrigation and Drainage paper No. 33. FAO Publications, Rome, pp. 19 – 36.

FAO.2002. Utilization efficiency for harvested yield (Ey) for cabbage heads. http://www.fao.org/landandwater/aglw/cropwater/cabbage.stm#supply. Accessed 06/06/2011.

FAO. 2009. Computer Software for calculation of crop water requirements. Rome, Italy.

FAO. 2010. International workshop on capacity development of farm management strategies to improve crop-water productivity using AquaCrop. Training manual 1 – 5 March. Bloemfontein. RSA.

Garces-Restrepo, C, Vermillion, D, and Muñoz, G. 2007. Irrigation Management Transfer: Worldwide efforts and results. FAO Water Report 32. FAO Publications, Rome, Italy

Global Water Instrumentation. 2009. FP111 – FP211 Global Water Flow probe User`s Manual.Global Water. California, USA.

Gorantiwar, SD, and Smout, IK. 2005. Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A frame work for evaluation. *Irrigation and Drainage Systems 19: 1 – 36.*

Gungor, Y, Ersozel, AZ, and Yildirim, O. (1996) “Sulama” “Ankara Univ., ziraat Fak.,”, Ankara, 1443, 424.

Imtiyaz, M, Mgadla, NP, Chepete, B, and Manase, SK. 2000. Response of six vegetable crops to irrigation schedules. *Agricultural Water Management Journal 45 (2000) 331-342.*

Korkmaz, N, Avci,M, Unal, HB, Asik, S, and Gunduz, M. 2009. An evaluation of the water delivery performance of the Menemen Left Bank irrigation system, Using variables measured in site. *Journal of Irrigation and Drainage Engineering*. Doi 10.1061/ (ASCE)IR. 1943-4774.0000053.

Latif, M and Tariq, JA. 2009. Performance assessment of Irrigation Management Transfer from Government-managed to Farmer-managed irrigation system: A Case Study. *Irrigation and Drainage Systems 58: 275 – 286.*

Malano, H, and Burton, M. 2001. Guidelines for Benchmarking Performance in the Irrigation and Drainage Sector. IPTRID and FAO, Rome, Italy.

Martin, EC. 2009. Measuring water flow and rate on the farm. *Arizona Water Series Number 24*. University of Arizona, USA.

Mateos, L, Lozano, D, Ould Baghil, AB, Diallo, OA, Go´mez-Macpherson, H, Comas J, and Connor, D. 2010. Irrigation performance before and after rehabilitation of a representative, small irrigation scheme besides the Senegal River, Mauritania. *Agricultural Water Management Journal 97: 901 – 909.*

Molden, DJ, Sakthivadivel, R, Christopher, J. Perry, C.J. and de Fraiture, C. 1998. Indicators for Comparing Performance of Irrigated Agricultural Systems Research Report 20. IWMI Publications, Colombo, Sri Lanka.

Ntsonto, NE. 2005. Economic performance of Smallholder Schemes: a case study of Zanyokwe, Eastern Cape, RSA. Unpublished MSc Thesis, University of Pretoria.

Perry, C. 2005. Irrigation reliability and the productivity of water: A proposed methodology using evapotranspiration mapping. *Irrigation and Drainage Systems 19: 211–221.*

Perry C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. *Irrigation and Drainage Systems 56: 367–378.*

Plusquellec, HL, Phail KM, and Polti C. 1990. Review of irrigation system performance with respect to initial objectives. *Irrigation and Drainage Systems 4: 313 – 327*.

Rao, PS. 1993. Review of selected literature on indicators of irrigation performance. International Irrigation Management Institute. IIMI Publications. Colombo, Sri Lanka.

Reid, PCM, Davidson, DCR, and Kotze, T.1986. A note on practical methods of improving conveyance efficiency on a government irrigation scheme. *Water SA Journal Volume 12 (2).*

Reinders, FB, van der Stoep, I, Lecler, NL, Greaves, KR, Vahrmeijer, JT, Benadé, N, du Plessis, FJ, van Heerden, PS, Steyn, JM, Grové, B, Jumman, A; Ascough, G. 2010. Standards and Guidelines for Improved Efficiency of Irrigation Water Use from Dam Wall Release to Root Zone Application. Report Number TT 465/10. WRC Publications. Pretoria, RSA.

Renault, D, and Vehmeyer, PW. 1999. On reliability in irrigation service preliminary concepts and application. *Irrigation and Drainage Systems 13: 75 – 103*

Sarkar, AA. 2008. Training Course on Irrigation and Technology: Design of Semi-Circular Canals. Bangladesh Institute of Nuclear Agriculture. Mymensingh, Bangladesh.

Shongwe, M. 2007. Water management practices in small-scale irrigation schemes in South Africa: A case of Tugela Ferry Irrigation scheme in KwaZulu-Natal, South Africa. Unpublished MSc Thesis, University of Pretoria. RSA.

Smajstrla, AG, and Zazueta, FS. (1995). Estimating Crop Irrigation Requirements for Irrigation System Design and Consumptive Use Permitting. University of Florida Publications, USA.

Svendsen, M, and Murray-Rust, DH. 2001. Creating and consolidating locally managed irrigation in Turkey: the national perspective. *Irrigation and Drainage Systems 15: 355–371.*

Ucar, Y, Senyigit, U, Kadayifci, A, and Tuylu, GI. 2010. Evaluation of water use efficiency at parcel and scheme levels: a case study of Sarkikaraagac irrigation scheme in Turkey. *Journal of Food, Agriculture and Environment 8 (2): 1046 – 1053.*

Uysal, OK, and Atıs E. 2010. Assessing the performance of participatory irrigation management over time: A case study from Turkey. *Agricultural Water Management Journal 97 1017–1025.*

Van der Stoep I. 2010. A water use efficiency framework for South Africa. Presentation at South African Institute of Agricultural Engineering CPD event Pretoria RSA. 29 September 2010.

Yoder, JL. 1999. Open channel flow: Methods, Applications, and New developments. Flow Research Inc. USA.

Yokwe S. 2009. Water productivity in smallholder irrigation schemes in South Africa. *Agricultural Water Management Journal 96 1223–1228.*

3. FARMERS` PERCEPTIONS OF THE PERFORMANCE OF SMALLHOLDER IRRIGATION SCHEMES

[a] T. Gomo; [b] M. Mudhara and [a] A. Senzanje
[a] School of Engineering, [b] Farmer Support Group,
University of KwaZulu-Natal, Pietermaritzburg, RSA

Abstract

Farmer satisfaction with using an irrigation service can be used as a measure of technical performance of the scheme. An investigation to determine factors that significantly influence the satisfaction status of farmers at Mooi-River Irrigation scheme (MRIS) was instituted. A multinomial Logit regression model was employed to analyse the response of the farmers. Results show that eight factors which indicate location of the farmer`s plot with respect to the water diversion point, location within a block from the main canal, age of the farmer, education level attained by the farmer, farming experience, the number of plots a farmer owns, fairness of water distribution across the blocks and the number of days a farmer accesses water, were found to be significant in influencing the satisfaction status of farmers with using the irrigation service. It was established that about 57% of the farmers are satisfied with using the irrigation service, 30% are not and 13% are neutral. The majority of farmers, accounting for 85%, either never went to school or went only up to primary level and these are mostly women, who own close to 80% of the plots in the scheme. It was concluded that there are many factors affect the satisfaction of farmers with using an irrigation services, among them access to irrigation water. This study recommends formulation of policies that support farmer initiatives to form scheme management and ensure maximum benefits are derived from the scheme by the farmers.

Keywords: Farmer satisfaction, technical performance, multinomial logit regression

3.1 Introduction

Irrigation performance has been the subject of research in the agricultural sector internationally for more than five decades. However, very little has been yielded from these efforts mainly as a result of the lack of collaborative implementation of recommendations on the part of stakeholders, which include farmers, policy-makers, environmentalists, donors, among others. Research work has been done from the point of view of the various stakeholder, but still the performance of irrigation schemes, especially in the communally-owned smallholder schemes, has remained low (Svendsen *et al*., 2009).

The performance of these schemes is affected by a complex set of factors. A comprehensive understanding of these variables will enhance smallholder irrigation performance, assist to improve the livelihoods of the rural poor and ensure sustainability of the schemes. The various performance issues in smallholder irrigation (SHI) schemes range from technical, economic, social to institutional. These can be explored from different stakeholders' perspectives. Several studies on smallholder irrigation performance have been carried out from the farmers` perspective (Naik and Kalro, 2000; Yercan, 2003; Ghosh *et al.*, 2005, Kuscu *et al.,* 2008; Kuscu *et al*., 2009) but, in South Africa, the focus has been on economic performance (Ntsonto, 2005; Yokwe, 2009) and social performance (Van Averbeke and Mohamed, 2006, Cousins, 2009).

Technical performance research studies related to water conveyance, delivery and use in the SHI schemes and implementation of the recommendations have usually been ignored by farmers (Plusquellec, 2002; Kuscu *et al*., 2009), probably due to the misplaced belief that they are unable to understand and contribute to technical issues (FAO, 2001). Contrary to this belief and in the wake of Participatory Irrigation Management (PIM) and Irrigation Management Transfer (IMT), farmers usually find themselves entrusted with the operation and maintenance of the schemes, and without technical information and proper management skills the schemes deteriorate quickly and frequently need rehabilitation only a few years after construction (FAO, 2001). However, several problems, such as subjective judgments and multicollinearity among factors considered, arise in analysing performance assessment data from the farmers` point of view (Magingxa *et al*., 2006).

The objective of this study was to investigate the social and technical factors that significantly affect farmer's assessments of the performance of smallholder irrigation schemes.

This study considers the solution for poor performance in SHI should be when involving farmers in performance assessments. Farmers` levels of satisfaction with both technical and managerial issues within a scheme can be used as a measure for assessing its performance. Data obtained from farmers can be analysed econometrically to assess the factors affecting the subjective judgements of the performance of schemes.

3.2 Model Specification

Various statistical analysis tools are available for partitioning the factors affecting farmers` perceptions on levels of satisfaction with the performance of their schemes. Probabilistic models such as the Logit Model (LM), Probit Model (PM) and the Linear Probability Model (LPM) can be used. A careful selection process must, however, be done to choose the best way to incorporate the farmers` views in the performance assessment studies.

Damisa *et al*. (2008) recommended the use of the Logit Model for the purpose of analysing the farmers` satisfaction status because it has the following advantages over the other models:

- The computation of the logistic distribution ensures the rate of the probabilities estimated always lie between 0 and 1.
- The probability does not increase linearly with a unit change in value of the explanatory variables, as it does in Linear Probability Model, and so the problem of heteroskedasticity is eliminated.
- It is easier to compute and interpret than the Probit Model.

- The dichotomous logit model has been used in other studies for analysing the farmers` satisfaction status (Damisa *et al*., 2008; Kuscu *et al*., 2009)

Logit regression analysis allows for estimating probability that an event occurs or not by predicting a binary or multinomial dependent outcome from a set of independent variables. For example, a farmer`s satisfaction status with using an irrigation service can take values such as 1, 2 or 3 denoting dissatisfied, neutral and satisfied, respectively. The status is dependent upon various independent factors. The Logit model can then be employed to estimate the satisfaction status of a randomly selected farmer from an irrigation scheme (Damisa *et al.,* 2008, Kuscu *et al*., 2009).

The logistic model to estimate the probabilities of farmer satisfaction status will have three categories and if probability of a farmer being satisfied by using the irrigation service, *Pr(Y=3),* is taken as the reference group, then Equations 3.1 and 3.2 are Logit functions relating to categories 'farmer is not satisfied' and 'farmer is neutral' to category 'farmer is satisfied'.

$$Z_1(X) = \ln\left(\frac{Pr(Y=1|x)}{Pr\,(Y=3|x)}\right) = \ln\left(\frac{P_1}{P_3}\right) = \beta_{10} + \beta_{11}X_1 + \beta_{12}X_2 + \cdots + \beta_{1k}X_k \quad (3.1)$$

And

$$Z_2(X) = \ln\left(\frac{Pr(Y=2|x)}{Pr\,(Y=3|x)}\right) = \ln\left(\frac{P_2}{P_3}\right) = \beta_{20} + \beta_{21}X_1 + \beta_{22}X_2 + \cdots + \beta_{2k}X_k \quad (3.2)$$

where $X_1, X_2 \ldots, X_k$ denote the set of explanatory factors assumed to have an effect on *Y*,

Y is the dependent variable ('satisfied', 'neutral' or 'not satisfied'),

β_{10} and β_{20} represent the intercepts

$\beta_{11}, \ldots \beta_{1k}$ and $\beta_{21}, \ldots, \beta_{2k}$ represent the slopes of the logit regression functions, $Z_1(X)$ and $Z_2(X)$ respectively (Uysal and Atis, 2010).

Following the dichotomous logit model (Damisa *et al*., 2008, Kuscu *et al.,* 2009, Uysal and Atis, 2010) where a farmer was considered to either be satisfied (Y=1) or not (Y=0), and considering the 3 category multinomial logit function as two dichotomous logistic functions, the probabilities of the 3 categories can be shown to be:

$$p_3 = Pr(Y = 3|x) = \frac{1}{1 + e^{z_1} + e^{z_2}} \tag{3.3}$$

$$p_2 = Pr(Y = 2|x) = \frac{e^{z_2}}{1 + e^{z_1} + e^{z_2}} \tag{3.4}$$

$$p_1 = Pr(Y = 1|x) = \frac{e^{z_1}}{1 + e^{z_1} + e^{z_2}} \tag{3.5}$$

with

$$p_3 + p_2 + p_1 = 1 \tag{3.6}$$

The model parameters are estimated using the Maximum Likelihood Method (Burnham and Anderson 2003). In irrigation studies, this model has several applications, which include selection of the best irrigation method suitable in an area (Karami, 2006). In this study, the Logit model was used to determine the significant factors that affect satisfaction of farmers in an irrigation scheme.

3.3 Materials and Methods

A structured questionnaire (Appendix I) was administered to 114 farmers from Mooi-River Irrigation scheme selected through stratified random sampling during the 2010/2011 irrigation season. Seven local enumerators, who spoke Zulu, the local language at the study site, were employed to administer the questionnaire. Information collected include age, gender, irrigation training, timeliness of water delivery, water distribution among the blocks, management, farming experience, farmer involvement in inspection of irrigation infrastructure and maintenance, among others. The logit model for this case was specified as follows:

$$Y = f\ (x_1, x_2, x_3, \dots \dots, x_k) \tag{3.7}$$

where Y is the dependent variable, in this case satisfaction with irrigation services,

$x_1, x_2, x_3, \dots \dots, x_k$ are the independent variables assumed to have an effect on Y

The factors investigated through the questionnaire were analysed through this model using SYSTAT software to determine those that have a significant bearing on farmers` satisfaction status (SYSTAT Manuals 2007).

3.3.1 Study site

The study was conducted in Mooi-River Irrigation Scheme (MRIS) located in the Msinga local Municipality along the floodplains of Mooi River in the Midlands region of KwaZulu-Natal province in South Africa. The scheme is over 600 ha in extent and is home to approximately 824 farmers (DAEA, 2010) and is within a 30 kilometre radius of a bigger SHI scheme, Tugela Ferry Irrigation Scheme (TFIS). KwaZulu-Natal ranks third in the number of smallholder irrigation schemes (11%) after Limpopo (57%) and Eastern Cape (23%) (Denison and Manona, 2007). For ease of management and water distribution, it is administratively divided, as shown in Figure 3.1, into 15 blocks of varying sizes with each block having its own local committee responsible for water allocation. The scheme has an overall management committee.

Water is distributed from the main canal through in-field canals to the edges of the plots. From the plot edge, it becomes the individual farmer`s responsibility to irrigate within a specified time of 30 minutes per plot. Each plot is approximately 0.1 hectares and the farmers grow mainly horticultural crops in winter for markets in surrounding towns and maize for subsistence during summer. More information about the scheme has been discussed in sub-section 2.3.1 of this dissertation.

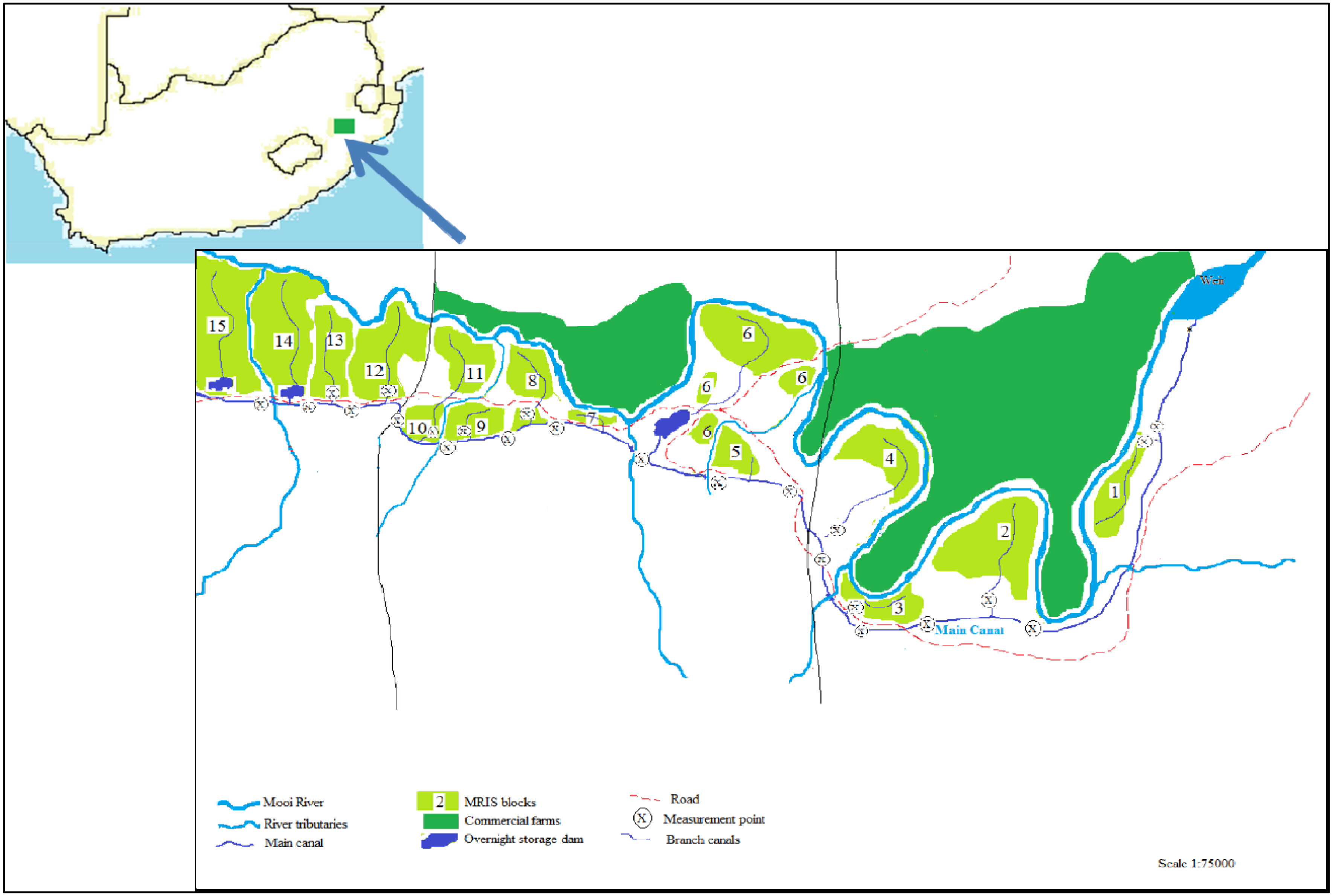

Figure 3.1 Location of MRIS and scheme layout (insert) showing sampling strata

3.3.2 Sampling procedure

The scheme was divided into three strata exhibiting similar characteristics in relation to water availability and irrigating days. The divisions are shown in Figure 3.1 and Table 3.1.

Table 3.1 Sampling strata

Stratum	Blocks
Head section blocks	1-4
Central section blocks	5-11
Tail end section blocks	12-15

Each stratum was further sub-divided into three zones: Upper, Middle, Lower for farmers who are located closer to the main canal, in the middle and further away respectively, from which the sample was taken. The sample was reduced to 114 from a possible of 269 using the Raosoft Inc. (2010) sample calculator at 95% level of confidence, see Equations 3.8 – 3.10.

$$x = Z(^{c}/_{100})^{2} r\,(100 - r) \tag{3.8}$$

$$n = {}^{Nx}/_{((N-1)E^{2} + x)} \tag{3.9}$$

$$E = \sqrt{\frac{(N-n)x}{n(N-1)}} \tag{3.10}$$

where N is the population size,

n is sample size,

E is margin of error,

r is the fraction of responses of interest to the researcher,

$Z(c/100)$ is the critical value at 95% confidence level

c is the confidence level, 95% in this study, and

x is the reduced sample size

A multinomial Logit Model was run on Student Version of SYSTAT 12, called MYSTAT (SYSTAT Manuals 2007), with the fifteen factors that were assumed to have an effect on the satisfaction status of the farmer. The factors were tested at 95% confidence interval. Each factor hypothesis is summarised in Table 3.2 and the coding for each category is shown in Table 3.3. The multicollinearity of the factors was taken into consideration when the data was input into the model by using the software to check from the data input into it. The model software allows a check of multicollinearity among the various factors

Table 3.2 Definition of variables in the satisfaction status of the farmer in using irrigation service

Variable	Description	Hypothesis
BLOCK	Location of the farmer with respect to the water diversion point	The farmers closer to the diversion point are satisfied since they have relatively unlimited access to water.
LOC	Location of the plot in relation to the main canal.	Farmers with plots close to the main canal will be satisfied.
GENDER	Shows the whether the plot is owned by a female or male.	Female farmer will be more satisfied.
AGE	Measures the actual age of the farmer.	Old farmers are more satisfied.
EDU	Measures the farmers` level of education.	Educated farmers are satisfied owing to ability to adopt improved innovations.
FARMEXP	Measures the irrigation farming experience of the farmer in the scheme.	Farmers with more farming experience in the scheme are satisfied.
RESOWN	Refers to resource ownership by the farmer.	Farmers with more resources are satisfied.
PLOTS	Measures the number of plots a farmer cultivates in the scheme.	The farmers with more plots in the scheme are expected are satisfied
TRAINING	Allows for the determination of farmers who have received water management training.	The farmers who have been trained in irrigation water management are more likely to be satisfied.
WATDEL	Measures the timeliness of water delivery.	Farmers receiving water in time are more inclined to be satisfied.
WATDIST	Measures the satisfaction of farmers with water distribution among the blocks	Farmers who are satisfied with the distribution will be satisfied with using the irrigation service.
WATSHORT	Measures the water quantity availed to plots.	Farmers who receive enough water will be satisfied
OPMAIN	Allows determination of farmers` involvement in operation and maintenance of the scheme.	Farmers involved in operation and maintenance are satisfied
INSPEC	Measures the involvement of farmers in seasonal inspection of the irrigation infrastructure.	It is expected that farmers involved in seasonal inspection are satisfied

Table 3.3 Coding of the factors assumed to affect farmer satisfaction status as used in MYSTAT

Variable	**Coding**
IRRISERV	Value 3 if farmer is satisfied with using irrigation service; 2 if neither satisfied nor dissatisfied; 1 if not satisfied
BLOCK	Value 1 if farmer is located upstream (Blocks 1-4), 2 in the middle (Blocks 5 -11) and 3 if farmers is located in the tail end (Blocks 12-15)
LOC	Value 1 if plot is located close to the head of distributary canal, 2 in the middle, 3 if close to the tail-end of the distributary canal
GENDER	Gender of the farmer: 1 = Male, 0 = Female
AGE	Actual age of farmer in years
EDU	Level of education of the farmer. Value 1 if farmer went for Secondary/Tertiary education, 0 otherwise
FARMEXP	Actual number of years the farmer has been irrigating in the scheme
RESOWN	Resource ownership by the farmer Value 2 if farmer owns tractor, 1 if farmer owns cattle/donkeys; 0 if farmer does not own tractor, cattle or donkeys
PLOTS	Actual number of plots the farmer uses within the scheme
TRAINING	Value 1 if farmer has received irrigation training, 0 otherwise
WATDEL	Actual number of days the farmer receives water per week
WATDIST	Value 2 if farmer is satisfied with water distribution among the blocks; 1 if neither satisfied nor dissatisfied; 0 if not satisfied with water distribution among the blocks
WATSHORT	Value 1 if water is sufficient, 0 otherwise
OPMAIN	Value 1 if farmer is involved in Operation and maintenance of the scheme, 0 otherwise
INSPEC	Value 1 if farmer is involved in annual/seasonal inspection of irrigation structures, 0 otherwise

3.4 Results

3.4.1 General statistics about the scheme

Results show that 57% of the farmers are satisfied with using irrigation service while 30% are not satisfied and 13% are neutral, that is, neither satisfied nor dissatisfied. Some 78% of the plots are owned or used by women. In addition, some 85% of the farmers only have upto primary school education while around 15% went up to secondary school and beyond. In terms of farming experience, about 46.5% of the farmers have more than 20 years in the scheme while those who have between 10 and 20 years of experience account for 36% of the sample and those who joined the scheme less than 10 years ago constitute the remaining 17.5%. It was also established that most of the farmers hire implements such as tractors and cattle or donkeys for farming activities since 65% have no draft power, 30% own cattle or donkeys for provision of draft power while 5% own tractors. In terms of land ownership, 7% own one plot in the scheme, while 83% have two to nine plots. 10% own ten or more plots. It was also established that 60% of the farmers have never received training in irrigation water management. Only 40% have been trained

Survey results also show that about 74% of the farmers do not access water at all for a whole week or have access to water for one day a week. Those in the central part of the scheme get water for more than a day but less than five days a week while those in the head of the main canal access water for six or seven days a week. Some 75% of the farmers complain of shortage of water while 25%, mostly in Block 4 and upstream, felt water was adequate. However, despite this water shortage 49% of the farmers are satisfied with the water distribution across the blocks, with 39.5 % not satisfied and the remainder being neither satisfied nor dissatisfied.

Survey data also showed that only 39.5% of the farmers are involved in seasonal inspection of the scheme infrastructure while the majority of the farmers do not take part. In terms of gender, 71% were women and 29% men. A summary of this statistical information is presented in Table 3.4.

Table 3.4 Summary of statistical information showing marginal percentages

Variable	Description	Marginal Percentage
IrriServ	Farmers not satisfied with using irrigation service	29.8%
	Farmers neither satisfied nor dissatisfied	13.2%
	Farmer is satisfied with using the irrigation service	57.0%
Block	Block 1-4	17.4%
	Block 5-11	52.8%
	Block 12-15	29.8%
Gender	Female	78.1%
	Male	21.9%
Age	20-30	4.4%
	31-50	24.6%
	Above 50	71.0%
Edu	Primary/Never went to school	85.1%
	Secondary/Tertiary	14.9%
FarmExp	<10years	17.5%
	10-20 years	36.0%
	>20	46.5%
Resown	Farmers neither own tractor, cattle nor donkeys	64.9%
	Farmer owns cattle/donkeys	30.1%
	Farmer owns tractor	5.0%
Plots	1	7.2%
	2-9	82.6%
	≥10	10.2%
Training	Farmer has not received any irrigation training	57.0%
	Farmer has received irrigation training	43.0%
Watdel	≤ 1	73.7%
	2-5	21.1%
	6-7	5.2%
Watshort	Water is short	75.4%
	Water is enough	24.6%
Watdist	Not satisfied with water distribution among the blocks	39.5%
	Neither satisfied nor dissatisfied	11.4%
	Satisfied	49.1%
Inspec	Farmer is not involved in annual/seasonal inspection of irrigation infrastructure	60.5%
	Farmer is involved	39.5%
OpMain	Farmer is not involved in operation and maintenance	34.2%
	Farmer is involved in operation and maintenance	65.8%

3.4.2 Multinomial Logit analysis

This section shows the results from the logit model run on MYSTAT 12, a student version of SYSTAT. The multinomial logit analysis had three levels of the response variable, IRRISERV.

It was established that 65 farmers were satisfied with using irrigation service, 34 were not satisfied while 15 were neutral. A frequency table (Table 3.5) from MYSTAT summarises the findings and shows the reference category choice. By default, 'farmer is satisfied with taking irrigation service' category was selected as the reference choice group. SYSTAT always chooses the highest level of the dependent variable as the reference group.

Table 3.5 Frequency table showing category choices and the reference category

Category Choices	**Level**	**Frequency (%)**
Farmer is not satisfied with using irrigation service	1	30
Farmer is neutral	2	13
Farmer is satisfied with using irrigation service (Reference)	3	57
Total		**100**

n = 114

MYSTAT used the Akaike Information Criterion (AIC) and the Schwarz`s Bayesian Information Criterion (BIC) for measuring the goodness of the model, which SYSTAT Manuals (2007) describe as more accurate than other methods.

The parameter estimation consists of two sets of estimates owing to the fact that the response variable IRRISERV has three levels. The first model consists of two IRRISERV categories 1 and 3, and the second has categories 2 and 3, as shown in Table 3.6.

Table 3.6 Results of multinomial Logit regression analysis of the factors affecting farmer satisfaction

Parameter	Estimate	Standard Error	Z	Odds ratio	p-value	95 % Confidence Interval	
						Lower	Upper
Reference category: Farmer is satisfied with using irrigation service							
Choice category: Farmer is not satisfied with using irrigation service							
1 CONSTANT	-1.561	2.056	-0.759		0.448	-5.590	2.468
2 BLOCK	0.939	0.458	2.050	2.558	0.040*	0.041	1.837
3 LOC	0.105	0.310	0.339	1.111	0.735*	-0.503	0.713
4 GENDER	-1.189	0.788	-1.509	0.305	0.131	-2.733	0.355
5 AGE	0.013	0.026	0.486	1.013	0.627*	-0.038	0.063
6 EDU	-0.142	0.437	-0.326	0.867	0.745*	-0.999	0.714
7 FARMEXP	0.008	0.021	0.379	1.008	0.705*	-0.034	0.050
8 RESOWN	-0.384	0.341	-1.123	0.681	0.261	-1.053	0.286
9 PLOTS	-0.124	0.118	-1.052	0.884	0.293*	-0.354	0.107
10 TRAINING	-0.254	0.495	-0.514	0.775	0.607	-1.224	0.715
11 WATDEL	-0.050	0.260	-0.192	0.951	0.847*	-0.559	0.459
12 WATSHORT	-0.707	0.779	-0.908	0.493	0.364	-2.232	0.819
13 WATDIST	-1.092	0.308	-3.546	0.336	0.000*	-1.696	-0.488
14 INSPEC	0.530	0.553	0.957	1.699	0.338	-0.555	1.615
15 OPMAIN	-0.268	0.511	-0.524	0.765	0.600	-1.271	0.734

Table 3.6 continued

Reference category: Farmer is satisfied with using farm irrigation service							
Choice category: Farmer is neither satisfied nor dissatisfied							
1 CONSTANT	3.908	2.441	1.601		0.109	-0.877	8.693
2 BLOCK	-0.600	0.561	-1.069	0.549	0.285	-1.700	0.500
3 LOC	-0.067	0.385	-0.174	0.935	0.862**	-0.822	0.688
4 GENDER	0.066	0.855	0.077	1.068	0.939	-1.610	1.742
5 AGE	0.001	0.028	0.027	1.001	0.979**	-0.054	0.055
6 EDU	0.000	0.274	0.000	1.000	1.000**	-0.536	0.536
7 FARMEXP	-0.051	0.032	-1.629	0.950	0.103**	-0.113	0.010
8 RESOWN	-0.339	0.370	-0.916	0.712	0.360	-1.065	0.387
9 PLOTS	-0.143	0.179	-0.802	0.866	0.422	-0.494	0.207
10 TRAINING	-0.521	0.542	-0.960	0.594	0.337	-1.583	0.542
11 WATDEL	-1.767	0.999	-1.768	0.171	0.077	-3.725	0.192
12 WATSHORT	-1.235	0.942	-1.311	0.291	0.190	-3.082	0.611
13 WATDIST	-0.106	0.413	-0.255	0.900	0.798*	-0.916	0.705
14 INSPEC	0.856	0.732	1.170	2.353	0.242	-0.578	2.290
15 OPMAIN	-0.460	0.679	-0.678	0.631	0.498	-1.791	0.870

** significant for both categories and * significant for one category at 95% confidence interval

Information Criteria	
AIC	220.587
Schwarz's BIC	302.673
McFadden's Rho-squared	0.257

McFadden`s rho-squared statistic was used in assessing the model as a whole (SYSTAT, 2007). In this model, it was calculated and found to be 0.257 which lies in the range 0.20 and 0.40, described by Hensher and Johnson (1981) as being very satisfactory.

The results also show that location with respect to the water diversion point, location within a block from the main canal, age of the farmer, education level attained by the farmer, farming experience, the number of plots a farmer owns, perceived fairness of water distribution across the blocks and the number of days a farmer accesses water are statistically significant in influencing the farmers` satisfaction. The same factors were also shown to influence the satisfaction status of the farmer with respect to being neutral, except location with respect to water diversion point and number of days a farmer accesses water. The statistical significance of each factor, however, differs depending on the category being considered. The estimate of each factor shows the magnitude of change in the log odds ratio for any change in the factor but does not explain the change in probability since the probability of satisfaction is a nonlinear function of the logit (SYSTAT Manuals, 2007). The estimate just reflects the relative importance of the factor.

The other factors do not have statistical significance in influencing the satisfaction status of the farmer.

3.5 Discussion

3.5.1 Location of a farmer`s plot in the scheme

Location of the farmer with respect to the water diversion point is indicated by the block in which a farmer is. The blocks are numbered along the canal from the diversion point. Farmers in the head section have access to water anytime of the day, while those in the tail-end wait for longer periods before getting water to their plots, as shown in Figure 2.10 (Chapter 2). A change from an upstream block to the next block downstream will increase the likelihood of a farmer being dissatisfied by a multiplicative factor of 2.558, as reflected by the odds ratio in Table 3.6. These results concur with the hypothesis in Table 3.2 that farmers in the head section were more satisfied. More than 70% of the farmers located in the head were satisfied with using the irrigation scheme, 59% of those located in the central section of the scheme were satisfied with using the irrigation service while 45% of those located in the tail-end section were satisfied. The infrastructure in the head section is still in good condition compared to the central and tail-end, which may help explain the importance of location with respect to water diversion point.

3.5.2 Location of plot within a block

Location with respect to the main canal within a block is shown to be statistically significant in making the farmer not satisfied or neutral. The likelihood of a farmer moving from being ‘satisfied’ to ‘not satisfied’ category increases by a multiplicative factor of 1.111 with an increase in the distance from the main canal. However, the likelihood of being ‘neutral’ decreases by multiplicative factor of 0.935 with an increase in the distance from the main canal. This can be explained in terms of easy access to irrigation water for their crops. Farmers close to the main canal can easily access water and are the first to access it on their day of irrigation, hence they are more satisfied than those located in the lower section. The decrease in the likelihood of a farmer being ‘neutral’ can be explained similarly. The farmers are more likely to be dissatisfied if they are far away from the water source than they are likely to be neutral.

3.5.3 Age of the farmer

The results on age of farmers suggest that younger farmers are more satisfied. As the farmers get older, the odds of being ‘not satisfied’ or ‘neutral’ increase by a multiplicative factor of 1.013. This can be attributed to the fact that older farmers might have memories of the time the scheme was performing better, hence contribute to their dissatisfaction.

3.5.4 Education level of the farmers

Farmers who have attained higher education levels are less likely to be satisfied with taking the irrigation service. The log odds in favour of 'satisfaction' with respect to 'not satisfied' decreases by a multiplicative factor of 0.867 as the farmers attain higher education levels. This probably because better educated farmers understand the potential of the scheme and better understand the operations. They also understand the irrigation business better and they try to aim better but are always prohibited by the prevailing conditions in the scheme such as vandalism to canals, as can be seen in Figure 2.17 (Chapter 2) resulting water shortage. Despite more educated farmers are more innovative in farming; their progress is hindered by difficulties in accessing water. The odds ratio of moving from 'satisfaction' to 'neutral' does not change with the level of education.

3.5.5 Farming experience

It was found that as the number of years a farmer has in the scheme increases, the log of odds in favour of 'satisfaction' increases by a multiplicative factor of 0.379 for each unit increase in number of years for farming experience, while it decreases in favour of being 'neutral' by a multiplicative factor of 0.950 as indicated by the negative sign of the estimate in Table 3.6. This implies that as the farmers gains more farming experience, they tend to be satisfied and the probability that a farmer will be neutral decreases. This could be attributed to skills gained in the years that a farmer spends farming, which would allow that farmer to adopt new technologies and innovations. It can also be that as the farmer gets older, the chances of formal employment diminish and, as such, that farmer is forced to be content with irrigation as the source of livelihood. The markets that a farmer could have penetrated during the long years of farming may mean a ready market for farm produce, thus contributing to satisfaction with using the irrigation service.

3.5.6 Number of plots

The negative signs on PLOTS in both categories in Table 3.6 indicate that as the number of plots a farmer owns increases, the log of odds in favour of 'satisfaction' with respect to 'not satisfied' decreases. This means that the probability of a farmer being satisfied decreases with an increase in the number of plots, contrary to what was expected. This can be attributed to the fact that farmers with more plots would like to take irrigation seriously to derive their livelihoods but are likely to be less satisfied due to the problems in the irrigation scheme, such as shortage of water, especially for farmers located in the tail-end section of the scheme. Lack of resources, as indicated in Section 3.4 with 65% of the farmers neither owning a tractor or cattle, for farming activities could be another factor contributing to dissatisfaction with larger pieces of land. It can be also due the lack of markets to sell the produce. The farmer might invest more on a larger piece of land and produce more but will not have the markets, thus contributing to dissatisfaction.

3.5.7 Fairness in water distribution

Perceived fairness in water distribution across the blocks shows the log odds in favour of satisfaction decreases considerably for both categories of the farmers being 'not satisfied' and 'neutral' as indicated in Table 3.6. The log odds decrease by a multiplicative factor of 0.336 in the category 'farmer is not satisfied with using irrigation service' and by a factor of 0.900 in the 'farmer neither satisfied nor dissatisfied' category. This might be because farmers are aware that some blocks receive more water than others. The farmers also indicated that the management committees are aware of water theft but they do not attend to it, hence other users get water illegally. This might be a factor contributing to the dissatisfaction. These findings complement the findings of Chapter 2 (Figure 2.10), where it was shown that some blocks have access to water every day.

3.5.8 Access to water

Access to water has been shown to have statistical significance in making the farmer 'not satisfied' from a 'satisfied' category. The log odds in favour of 'satisfied' with respect to 'farmer not satisfied' decreases by a multiplicative factor of 0.951 for a day's increase in the number of days farmers have access to water. The decrease is slight, most probably due to the fact that some farmers have realised that there is no need to access water every day, and access once a week will be enough to satisfy crop water demands. Farmers in the central and some in the tail-end blocks access water ones a week, as shown in Figure 2.10, and this is where most of the farmers are located.

The results found in this study are comparable to other studies carried out in Nigeria (Damisa *et al*., 2008) and Turkey (Kuscu *et al.,* 2009, Uysal and Atis, 2010). Damisa *et al*. (2008) concentrated on the economic factors which included availability of fertilisers, size of land owned and timeous delivery of inputs.

3.6 Conclusions and Recommendations

In this study, eight factors were found to have statistical significance in influencing farmers` satisfaction status at MRIS. The factors are location of a plot with respect to the water diversion point, location of a plot within a block from the main canal, age of the farmer, education level attained by the farmer, farming experience, the number of plots a farmer owns, fairness of water distribution across the blocks and the number of days a farmer accesses water.

Satisfaction status was mainly dependent on water availability for irrigation and on the benefits from the irrigation service, such as source of livelihood. It is recommended that policy makers pay special attention to the benefits that farmers are deriving from irrigation and formulate policies that support farmer initiatives. The government must also have a clear policy on irrigation elaborating the responsibilities of farmers. Farmers at MRIS were not aware of their responsibilities when it concerns water management.

It was concluded that farmers at MRIS are aware of the problems bedevilling their scheme but seemed to have no power to resolve them. As such, it is recommended that they play a greater role in decision making and management of their scheme. There is need to resuscitate block committees to steer management strategies and irrigation policies. The importance of incorporating farmers in performance evaluation should be understood by all stakeholders at scheme level, from the farmers to the scheme managers and government.

3.7 References

Burnham, KP, and Anderson, DR. 2003. Model selection and multi-model inference: A practical information-theoretic approach. Second Edition. Springer. New York, USA

Cousins, B. 2009. Personal communication. Ongoing research at Tugela Ferry. University of Western Cape, Cape Town, RSA, 10 Dec 2009.

DAEA. 2001. Mooi-River Irrigation Scheme Topographic Survey, Southern Region. Hilton, Pietermaritzburg, RSA.

DAEA. 2010. Mooi-River Irrigation Scheme records, Tugela Ferry Offices. Msinga, KwaZulu Natal, RSA.

Damisa, MA, Abdulsalam, Z, and Kehinde, A. 2008. Determinants of Farmers` Satisfaction with their Irrigation System in Nigeria. *Trends in Agriculture Economics Journal* 1 (1): 8-13.

Denison, J, and Manona, S. 2007. Principles, Approaches and Guidelines for the Participatory Revitalisation of Smallholder Irrigation Schemes Volumes 1 & 2. Water Research Commission Report No TT 309/07. Pretoria, RSA.

FAO. 2001. Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa. IPTRID Secretariat Food and Agriculture Organization of the United Nations Paper Number 3 – March2001. Rome, Italy.

Gosh, S, Singh, R., and Kundu, DK. 2005. Evaluation of Irrigation-Service Utility from the Perspective of Farmers. *Water Research Management Journal 19: 467 – 482.*

Hensher, D and Johnson, LW. 1981. Applied discrete choice modelling. Croom Helm London, UK.

Karami E. 2006. Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. *Agricultural Water Management Journal 87:101 – 119.*

Kuscu, H, Demir, AO, Korukcu, A, 2008. An assessment of the irrigation management transfer programme: case study in the Mustafakemalpasa irrigation scheme in Turkey. *Irrigation and Drainage Journal 57: 15 – 22.*

Kuscu, H, Boluktepe, FE, Demir, AO. 2009. Performance assessment for irrigation water Management: A case study in Karacabey Irrigation Scheme in Turkey. *African Journal of Agricultural Research 4(2): 124 – 132.*

Magingxa, LL, Alemu ZG, and van Schalkwyk, HD. 2006. Factors influencing the success potential in smallholder irrigation projects of South Africa: A Principal Component Regression. International Association of Agricultural Economists Conference. August 12 – 18, Gold Coast, Australia.

Naik, G, and Kalro, H. 2000. A methodology for assessing the impact of irrigation management transfer from farmer`s perspective. *Water Policy 2: 445 – 460.*

Ntsonto, NE. 2005. Economic performance of Smallholder Schemes: a case study of Zanyokwe, Eastern Cape, RSA. Unpublished MSc Thesis, University of Pretoria.

Plusquellec, H. 2002. How design, Management and Policy affect the performance of

Irrigation projects: emerging modernization procedures and design standards. FAO Publications. Bangkok, Thailand.

Raosoft Incorporation. 2010. Sample size calculator. Available on http://www.raosoft.com/samplesize.html. Accessed on February 10, 2011.

Svendsen, M, Ewing, M, and Msangi, S. 2009. Measuring Irrigation Performance in Africa.International Food Policy research Institute Discussion Paper 00894. Washington DC, USA.

SYSTAT. 2007. SYSTAT 12: Logistic regression manuals. Chicago, USA. Available from:http://www.systat.com. Accessed March 07, 2011.

Uysal, OK, and Atis, E. 2010. Assessing the performance of participatory irrigation management over time: A case study from Turkey. *Agricultural Water Management Journal 97: 1017 – 1025.*

Van Averbeke, W, and Mohamed, SS. 2006. Smallholder irrigation schemes in South Africa: Past, present and future. [Keynote address read at the 2nd Symposium of the South African National Committee on Irrigation and Drainage, 15-17 November 2006, Aventura Swadini, Mpumalanga]. Available from: http://www.sancid.org.za/files/keyNotesAdd.doc. Accessed January 21, 2010.

Yercan M. 2003. Management turning-over and participatory management of irrigation schemes: a case of the Gediz river basin in Turkey. *Agricultural Water Management Journal 62: 205 – 214.*

Yokwe S. 2009. Water productivity in smallholder irrigation schemes in South Africa. *Agricultural Water Management Journal 96: 1223–1228.*

4. DERIVING BEST MANAGEMENT PRACTICES FOR SMALLHOLDER IRRIGATION SCHEMES IN SOUTH AFRICA FROM THE FARMERS` PERSPECTIVE

T. Gomo; A. Senzanje and K. Dhavu
School of Engineering, University of KwaZulu-Natal, Pietermaritzburg, RSA

Abstract

Smallholder irrigation schemes are reportedly performing below expectations due to shortcomings in management of resources. To improve the performance of these schemes, management should be improved through adoption of best management practices (BMPs). Adoption of BMPs in smallholder irrigation (SHI) schemes, however present complex challenges to irrigation scheme managers, especially where irrigation water is shared among farmers. These challenges can be solved by involving farmers in deriving BMPs. There are several methods that can assist in making decisions in the presence of multiple criteria and alternatives, such as in the selection of BMPs for smallholder irrigation schemes. In this study, farmers were tasked with the selection and ranking of BMPs for their scheme. The BMPs were selected using the framework provided by Texas State Soil and Water Conservation Board (TSSWCB, 2005). The overall ranking of farmer-selected BMPs was done using Analytic Hierarchy Process (AHP). Pair-wise judgment of the BMPs was derived from questionnaires administered by the farmers and then ranked using SuperDecisions software. The results show that farmers have several BMPs they want adopted for the smooth running of their scheme. It was concluded that irrigation scheduling was the most preferred BMP, while volumetric water measurement was the least. It is recommended that farmers be involved in the selection of the irrigation BMPs for their scheme to ensure acceptability and responsibility in scheme water management.

Keywords: Best management practices, smallholder irrigation, water management

4.1 Introduction

Sustainability of smallholder irrigation (SHI) schemes, whether government-managed, farmer-managed or jointly-managed, has become a priority across the whole world. Improper irrigation management practices have detrimental effects not only to the environment but also exacerbate the effects of climate change on already depleted water resources and deprive other sectors of the economy of their fair share of the water resource (Harnandez and Uddameri, 2009).

To improve resource management in the smallholder irrigation subsector and ensure sustainability, practical and affordable approaches, called best management practices (BMPs) have been developed. An example of such BMPs in irrigation engineering is routine inspection of water conveyance infrastructure to identify leakages. These BMPs have been demonstrated to improve productivity in irrigation schemes, reduce pressure on water and other natural resources, and decrease negative impacts on the environment (Withers *et al.*, 2007; Hassanli *et al.*, 2009 in Hernandez and Uddameri, 2009). However, the effectiveness of BMPs depends on careful selection of those that apply to a particular geographic location considering demographic and climatic conditions as well as farming practices in that region (Hernandez and Uddameri, 2009).

The objectives of this study were to:

- derive farmer-recommended BMPs for Mooi River Irrigation scheme (MRIS) in South Africa, and to
- rank the derived BMPs according to farmer preference.

This study assumes that the performance of smallholder irrigation can be improved significantly by including farmers in the selection and ranking, according to preference, of best management practices for their scheme.

The selection of BMPs applicable to a particular irrigation sub-sector can be determined through multi-criteria decision making (MCDM) (Hernandez and Uddameri, 2009). MCDM involves several methods which assist in making decisions in the presence of multiple, usually conflicting, criteria. The various MCDM methods utilise a decision matrix to provide a systematic analytical approach for integrating risk levels, uncertainty, and valuation, which enables evaluation and ranking of many alternatives. Some of the MCDM methods which have been used in engineering management decisions include Analytic Hierarchy Process (AHP) (Saaty 1977, 1980, 1983, 1990, 1994), Multi-attribute utility theory (MAUT) and Multi-attribute value theory (MAVT) (Belton *et al.,* 2001). Selection of the appropriate MCDM method to be used depends on the objectives and the overall goal. Of these various MCDM methods available, AHP has been widely applied to aid decision making in irrigation and engineering fields (Triantaphyllou and Mann, 1995). Srdjevic and Srdjevic (2005) and Karami (2006) used AHP in the selection of the best irrigation methods in Yugoslavia and Iran, respectively. Young (2009) used the method in the selection of storm-water drainage BMPs and Okada *et al.* (2008a, 2008b) in evaluating whether an irrigation project improved crop yields.

Kasperczyk (2011) stated that the wide use of AHP has been because of its advantages over the other MCDM methods which are explained in Kasperczyk and Karlheinz (2006) as the following:

- The method allows a decision problem, such as selection of BMP, to be decomposed and builds hierarchies of criteria. The importance of each criterion becomes clear in this case (Macharis *et al.,* 2004).
- The method is flexible, intuitively appeals to decision makers and has the ability to check inconsistencies (Ramanathan 2001). Users also find pair-wise comparison of data input simple and convenient.
- AHP is capable of handling both subjective and objective evaluation measures common in irrigation where farmers are involved, at the same time providing consistency checks, thus reducing bias in decision making.

- AHP helps model situations of uncertainty and risk since it is capable of deriving scales where measures ordinarily do not exist (Millet and Wedley 2002).
- The method supports group decision−making through consensus by calculating the geometric mean of the individual pair-wise comparisons (Zahir 1999).

4.2 Application of AHP in the Selection of Irrigation BMPs

AHP involves an importance-ratio assessment procedure and uses a hierarchy to establish preferences and orderings (Dyer *et al.*, 1992). It assumes complete aggregation among criteria and develops a linear model which is used to rank alternatives. Selection of BMPs in irrigation is complex particularly in smallholder irrigation where individual irrigated plots are very small. AHP has been applied successfully on various complex resource management decisions (De Steiguer *et al.,* 2003; Ánagnostopoulos *et al.,* 2005; Srdjevic and Srdjevic, 2005; Karami, 2006; Man and Mustafa, 2006). The method is particularly useful where subjective, qualitative and quantitative data such as that obtained if farmers are involved (Karami, 2006).

In the ranking process of irrigation BMPs, criteria are developed to judge alternatives (Young *et al.,* 2009). The essence of the AHP is to decompose a problem into its constituent parts and allow the users to assess the relative weight of multiple alternatives against the developed criteria in an intuitive manner. The method ranks the alternatives by calculating eigenvectors. The method involves a few steps (De Steiguer *et al.,* 2003, Ánagnostopoulos *et al.,* 2005, Young *et al.,* 2009) which are briefly explained below.

Step 1: This step involves decomposing the problem of BMP ranking into its constituents and structuring the problem as a hierarchy which shows the complex relationships among the constituent parts. The hierarchy will have the objective at the top, the criteria in the intermediate level and the alternatives at the bottom as illustrated in Figure 4.1. This helps the decision maker to assess whether the elements in each level are of the same magnitude to allow for their comparison.

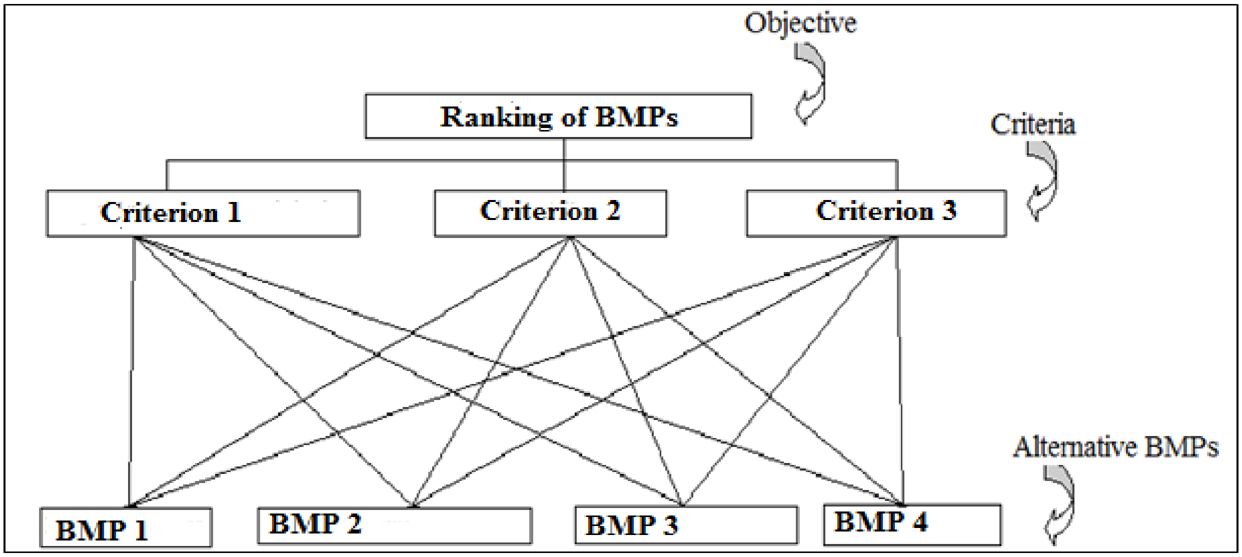

Figure 4.1 Hierarchy for ranking irrigation BMPs (after Srdjevic and Srdjevic, 2005)

At this stage, all participants associated with the problem are identified, such as extension officers, policy makers, donors and, most importantly, farmers in the case of irrigation BMPs (De Steiguer *et al.,* 2003).

Step 2: The second step involves setting relative importance between criteria by assigning weights, usually between 1 (equal importance) and 9 (extreme importance) (Ánagnostopoulos *et al.,* 2005) with the reciprocal of this value assigned to the other criterion in the pair forming comparison matrix. If we assume that criterion **A** is twice as important as **B**, **B** is 3 times as important as **C** and **A** is 4 times as important as **C**, then a comparison matrix showing the relative importance of each pair of criteria will look like that shown in Table 4.1. The inconsistency exhibited by the rough judgement will be corrected using the eigenvectors which are calculated and multiplied by the rough judgements.

Table 4.1 Comparison matrix

	A	B	C
A	1/1	1/2	3/1
B	2/1	1/1	4/1
C	1/3	1/4	1/1

The weights are normalized and averaged to get an average of each criterion.

Step 3: The third step involves the pairwise comparison of alternative options and scoring, with the better option awarded a score while the other option gets the reciprocal. The score is again in the scale of 1 (equally good) and 9 (absolutely better) (De Steiguer *et al.,* 2003). At this stage, consistency checks are done to ensure that each comparison matrix does not violate logical constraints. An example of a logical constraint can be defined in terms of three alternatives **A**, **B** and **C**. If **B** is 2 times as important **A** and **A** is 3 times as important as **C**, then it is logical to conclude that **B** is more important than **C**. A consistency check will ensure this logical constraint has not been violated (Young *et al.,* 2009).

Step 4: In the final step, the scores are combined with the criteria weights to produce a decision matrix which shows the overall ranking of the alternatives. The extent to which the alternatives satisfy the criteria is weighed according to the relative importance of the criteria. This process is done by simple weighted summation, as explained in Saaty (1980; 1983; 1990; 1994) and Srdjevic and Srdjevic (2005).

However, several computer programs have been developed which support such complex decision making processes and do all the mathematical calculations involved in AHP. SuperDecisions 2.0.8 software, developed by Adams and the Creative Decision Foundation (CDF) in 2009, can be used to run AHP model. SuperDecisions model was chosen in this study because it was easily available and it is user friendly.

4.3 Materials and Methods

Six extension officers and their assistants working in Mooi-River Irrigation Scheme (MRIS) and Tugela Ferry Irrigation Scheme (TFIS) assisted in selecting appropriate irrigation BMPs for the scheme. They were selected to assist because they understood the TSSWCB framework from which the BMPs for the scheme were based, unlike farmers, some of whom did not go to school. A set of seven BMPs, listed in Table 4.2, were developed by the irrigation experts working in the schemes. The BMPs were based on a questionnaire, Appendix II, administered to farmers in at MRIS and the framework provided by Texas State Soil and Water Conservation Board (TSSWCB 2005). TFIS is located within 30 kilometres from MRIS, and both schemes face similar water management problems. This necessitated the inclusion of extension officers from TFIS in the interpretation of the suitable set of BMPs suggested by the farmers in the local Zulu language for water management in SHI schemes, other than the fact there were too few extension officers from MRIS.

Table 4.2 Descriptions of selected BMPs (after Hernandez and Uddameri, 2009)

BMP	**Description**
Irrigation scheduling (IS)	Adhering to the water schedule in place at the scheme
Volumetric measurement (VM)	Assessment of water usage per each block through measurement and supplying the correct amount required
Lining of in-field canals (LC)	Re-lining of broken in-fields canals to avoid water loss
Replacement of in-field canals with pipes (RC)	Replacing the in-field canals with pipes to reduce water loss from damaged canals
Tail-water reuse (TWR)	Construction of water collection tanks and pump the water back into the scheme for use
Irrigation water fees (IrrigF)	Charging irrigation water fees to promote water use efficiency
Routine irrigation infrastructure inspection (INSP)	Carrying out seasonal infrastructure to check damaged canal walls and identify unofficial water withdrawal points

Each BMP was scrutinized through a set of five factors namely – (1) Applicability to communally-managed SHI scheme, (2) acceptance by the farmers in the schemes, (3) ease of implementation, (4) ability to meet water saving requirements, and (5) regulatory requirement oversight (Hernandez and Uddameri, 2009). The set of BMPs developed was presented in the form of a questionnaire, Appendix II, to twenty-five farmers in the MRIS for their contribution towards final ranking. The farmers were required to rank the selected BMPs in a scale of 1 – 9 relative to each other. The alternative with the greatest rank would be the most desirable while successively lower ranks indicate less desirable alternatives.

4.3.1 Sampling procedure

Twenty-five farmers were selected from those who had been previously interviewed, see Chapter 3. A questionnaire, Appendix II, containing BMPs derived from the previous questionnaire was administered to them for their input. Students from University of KwaZulu Natal were employed as enumerators. The sample was smaller owing to the number of farmers who could understand the technical language in the questionnaire and few farmers were irrigating at the time the interviews were conducted. The number of farmers from each stratum is shown in Table 4.3.

Table 4.3 Number of farmers section of the scheme.

Scheme section	Number of farmers interviewed
Head (Blocks 1-4)	6
Central (Blocks 5-11)	8
Tail-end (Blocks 12-15)	11

The data collected from the farmers were then averaged and input into the SuperDecisions program. SuperDecisions provide results in different forms ranging from graphical to numerical. The user has to select the best way to present results. In this study, the graphical presentation was used because it is easy to interpret.

4.4 Results

The BMP with the greatest rank was the most desirable while successively lower ranks indicate less desirable alternatives. The results show that the location of farmers had a bearing on their preferred BMP alternative. Farmers located in the head section of the scheme preferred routine inspection of irrigation infrastructure and repairing the damaged canal walls, while farmers located in the central blocks preferred adherence to set irrigation schedules. In the central blocks, the introduction and adherence to an irrigation schedule scored 0.30, while relining of in-field canals, being the least preferred, scored 0.09. In the tail-end section, emphasis was more on replacement of in-filed canals with pipe-lines, which scored 0.30. The least preferred BMP in the tail-end section was volumetric measurement of irrigation water with a very low score of 0.05. The BMP rankings from each section are shown in Figures 4.2 – 4.4. It must be noted however, that it is not be possible to implement the BMPs per section since water conveyance infrastructure is shared, but to the whole scheme, hence the need to have an overall ranking of the BMPs. The overall ranking for the whole MRIS prefer adherence to irrigation schedule in the scheme, scoring 0.2, as the best BMP before implementing any other, as can be seen in Figure 4.5.

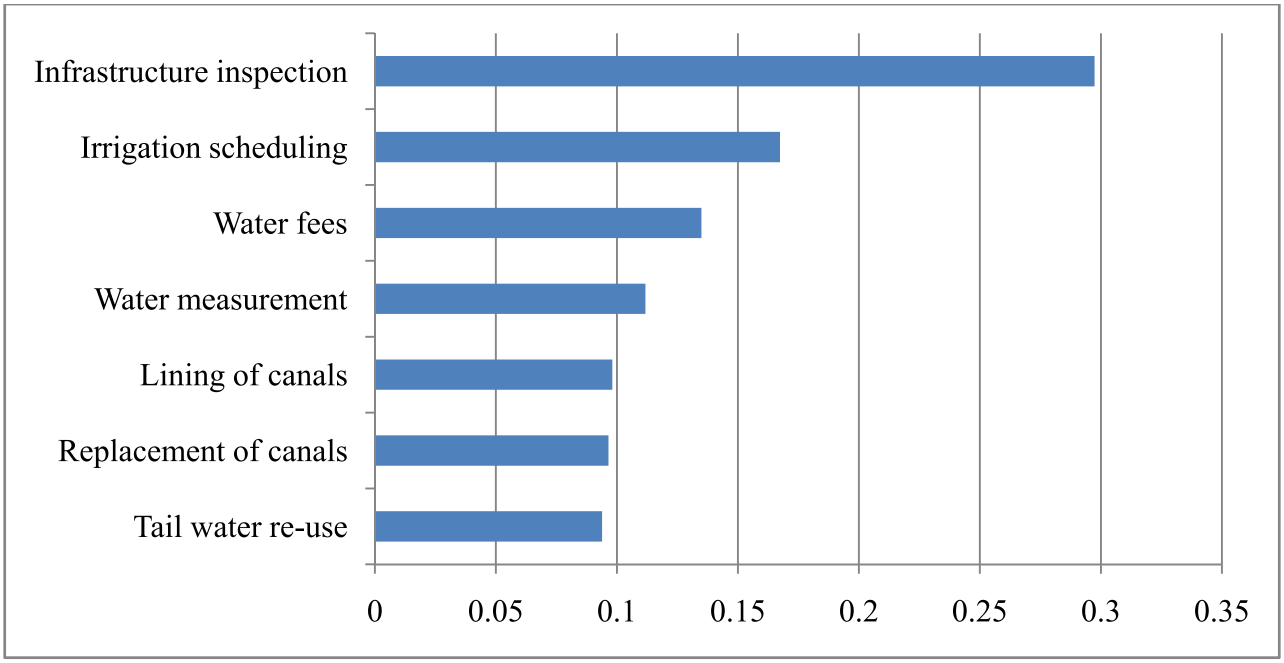

Figure 4.2 Ranking of BMPs by farmers located in the head section of the scheme

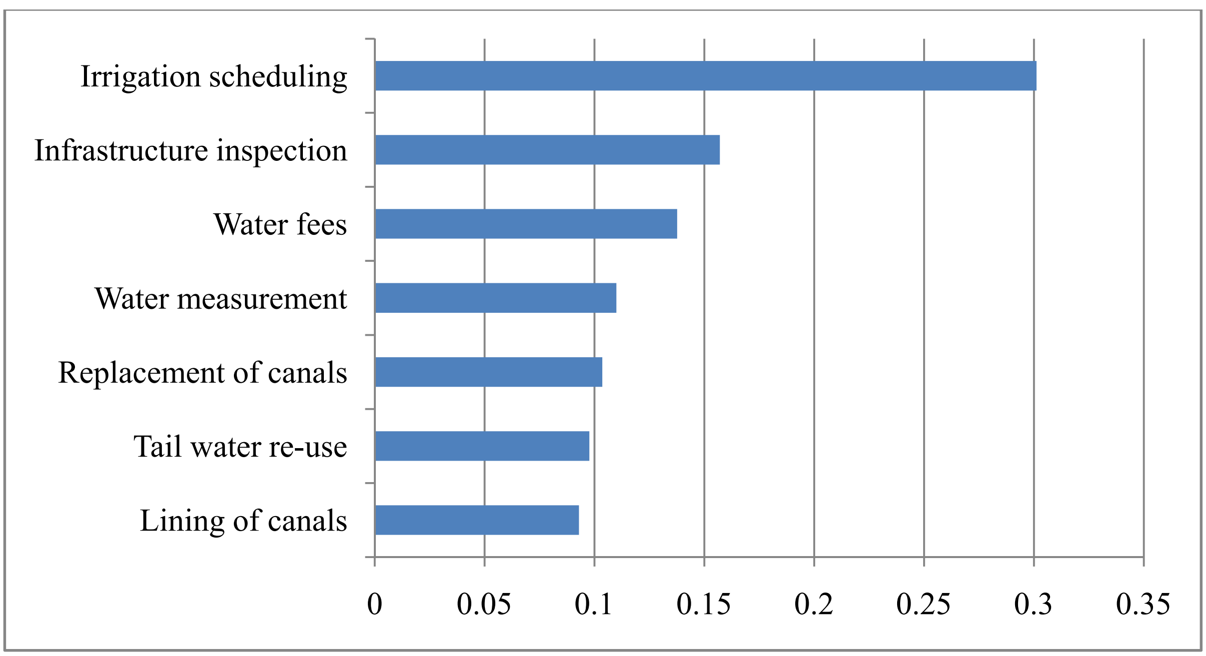

Figure 4.3 Ranking of BMPs by farmers located in the central section of the scheme

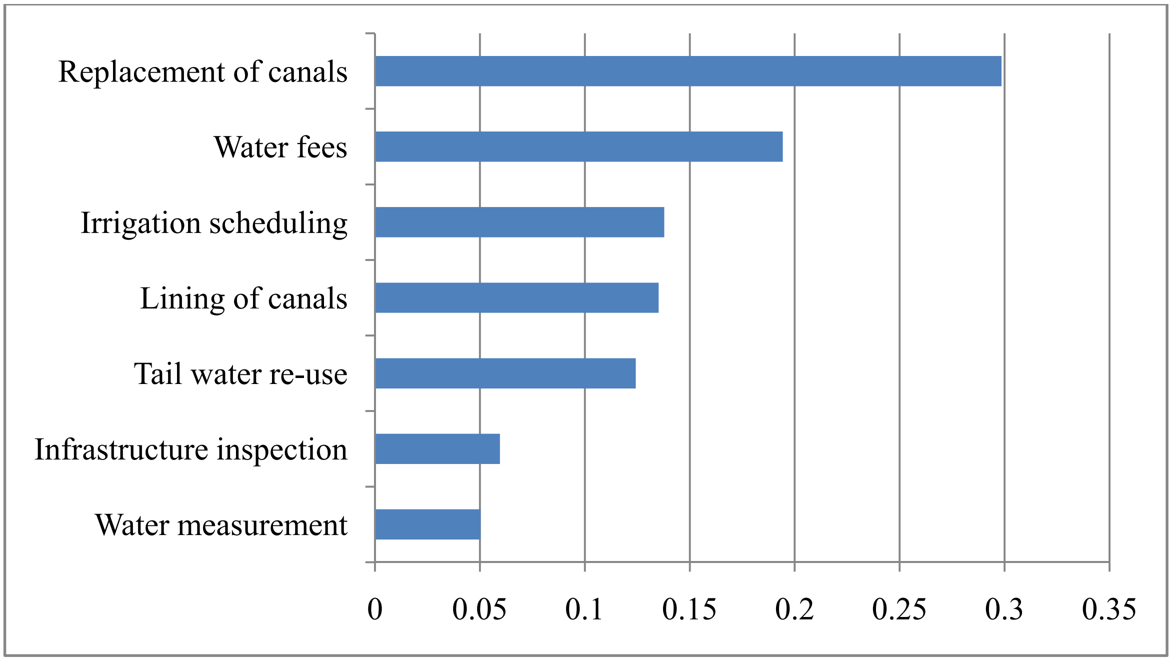

Figure 4.4 Ranking of BMPs by farmers located in the tail-end section of the scheme

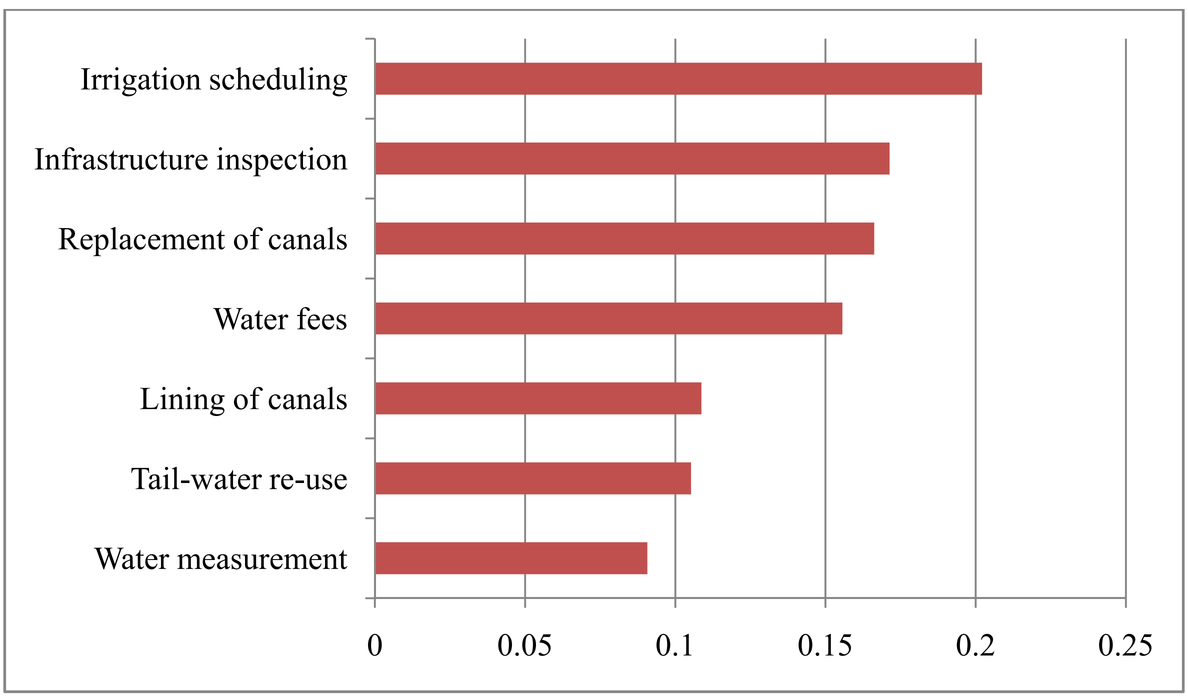

Figure 4.5 Overall ranking of BMPs by farmers at MRIS

4.5 Discussion

Farmers in the head section of the scheme prefer routine inspection of infrastructure probably because the farmers have access to water any time and the water loss they see is due to small leakages and 'theft'. The infrastructure is generally still in good condition indicating water availability which reduces vandalism. As such the farmers have given re-lining and replacement of in-field canals low rankings. However, they pointed out the need to stick to design irrigation schedules and charging of water fees after realising the reckless manner in which water is used in the upper blocks. Farmers in the lower end of upper blocks sometimes do not get water in time and as such highlighted the need to stick to 30 minute irrigation time per plot, as set in the schedule. This may help reduce water theft. Their high ranking of infrastructural inspection may be because they want to reduce water theft by farmers outside the demarcated boundaries of the scheme who siphon water from the canal. They also want to reduce withdrawal of water for other uses such as brick moulding which is evident, especially in Block 3.

The farmers in the central blocks emphasized irrigation scheduling because they get water on their allocated days, as can be seen in Figure 2.10. Sticking to the schedule would ensure they continue to receive water at the planned time. They also ranked infrastructure inspection high, probably due to reasons similar to those in the head section which entails stopping water theft by irrigators outside scheme boundaries and other uses of water. The introduction of water fees was ranked third, indicating a willingness by farmers to pay for the water. The condition for paying water fees was, however, categorically stated that they should be guaranteed to get water as promised. Their infrastructure is generally in good condition, hence the low ranking of re-lining and replacement of in-field canals with pipes, tail water re-use and volumetric measurement of irrigation water used in each block.

The tail-end farmers preferred replacement of in-field canals with pipes and introduction of water fees, as can be seen in Figure 4.4. This is due to comparison with part of Block 14 where in-field canals were replaced with pipes, thus reducing water shortage problems. The farmers also feel that if water fees are introduced in the scheme, the upstream farmers will use water more responsibly, hence they will be able to get the allocated water. Adherence to irrigation schedules was ranked third, indicating the farmers believe they can get water in time if farmers in the upper blocks stick to the schedule. Tail water re-use was also highly regarded as the farmers view it as an option to get water, even pumping water which would have flowed back to the river. Infrastructure inspection is lowly ranked since almost every farmer who is irrigating at the time of this study gets water through 'illegal' and unofficial withdrawal channels. The infrastructure is dilapidated due to farmers drilling and damaging the canal walls, thus competing for the little water that gets to their section of the main canal.

The overall ranking of BMPs in the scheme, however, shows that farmers prefer irrigation scheduling to all other BMPs in this study. This is be because farmers acknowledge that the water diverted is enough to irrigate the whole scheme if farmers across all the blocks adhere to the irrigation schedule set for them by the designers of the scheme. Routine infrastructure inspection is also highly preferred as it comes second in the overall ranking. This is because farmers realise that much of the water is lost due to illegal withdrawals and leaks, as can be seen in Figure 2.17. Regular inspection of the main canals and distribution facilities will help identify sections which need repair and maintenance. Reducing the water losses would improve the water availability for farmers.

Replacement of canals is ranked third in the overall scheme ranking of BMPs. This is because a larger number of farmers interviewed are from tail-end blocks, close to Block 14 where a section of the block had in-field canals replaced with pipes. The pipes seem to have eased water shortages for the farmers in that section; hence every farmer close to that block considers replacement of the damaged canals with pipes a solution. A further study may help determine if replacement of in-field canals with pipes is a sustainable option of water management and to determine the costs.

The introduction of water charges for irrigation was favoured by farmers. It appeared in the top three preferred BMPs in all the sections of the scheme, similar to irrigation scheduling, but on the overall scheme ranking, it is fourth. The farmers seem to agree that water pricing would encourage them to use water efficiently, and help in easing the water shortages. However, some were sceptical about this BMP as they feared it might increase water theft by some farmers to avoid payments.

The low ranking of re-lining of in-field canals and tail water re-use could probably be explained from experience. Farmers indicated these management options have been implemented before but have not resulted in any improvement. Re-lining of the in-field canals has been done in almost all the blocks, but the farmers highlighted that the management option has a failed as the canals are vandalised within a short space of time. Some farmers, especially in Block 15, had implemented tail water re-use and pumping water from the river but prohibitive costs of running pumps were involved.

Volumetric water measurement is ranked as the lowest BMP. Farmers highlighted that even if water used by each block is measured and that amount only supplied, all the water will be used up by farmers closer to the main canal. This indicated that the water shortage may be due to distribution within blocks. Therefore, volumetric measurement alone will not be enough to reduce the water shortage problems. They also indicated the tendency of farmers to withdraw water from the main canal through unofficial channels, and that water would not be accounted for.

The results found in this research complement those found by Mnkeni *et al.,* (2010) at Tugela Ferry and Zanyokwe irrigation schemes, which highlighted that the water shortages may be due to poor irrigation management and vandalism of in-field infrastructure. The results from this research are also comparable to those recommended by Waskom (1994) which include irrigation scheduling, change in technology used in irrigation and the appropriate use of chemicals in irrigation to reduce contamination of water in the state of Colorado in the United States of America. These recommendations were however for commercial irrigation.

4.6 Conclusions and Recommendations

The aim of this study was to derive and rank the best management practices that can be recommended for MRIS and possibly extended to other smallholder schemes in South Africa. From this study, it can be concluded that farmers can derive best management practices for their irrigation schemes. A set of seven BMPs were derived, based on a framework provided by TSSWCB (2005). It is concluded that the most preferred BMPs are the introduction and adherence to irrigation schedules, routine infrastructure inspection, replacement of in-field canals with pipes and introduction of water fees. It is also concluded that the farmers have solutions to the problems affecting their scheme, as seen in the BMPs they suggested, but they seem powerless to ensure adoption and enforcement of these BMPs.

It is recommended that all the BMPs suggested by the farmers be adopted in the order of preference for the whole scheme and that the farmers be guided by the irrigation specialists in the adoption process. It is also recommended that farmers be supported by the government in resuscitating institutional infrastructure, such as Block Committees and Scheme Committee, to ensure enforcement of the scheme by-laws.

4.7 References

Ánagnostopoulos, EP, Petalas, C, and Pisinaras, V. 2005. Water resources planning using the AHP and PROMETHEE multi-criteria methods: The case of Nestos River – Greece. Proceedings of the 7th Balkan Conference on Operational Research .BACOR 05. Constanta, May 2005, Romania.

Belton, V, Stewart, TJ, 2001: Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers: Dordrecht, The Netherlands.

De Steiguer, JE, Duberstein, J, and Lopes, V. 2003. The analytic hierarchy process as a means for integrated watershed management. Proceedings of the 1st Interagency Conference on Research on the Watersheds, Oct. 27-30, Agricultural Research Service, Benson, Arizona, pp: 736-740.

Hassanli, AM, Ebrahimizadeh, MA, and Beechan, S. 2009. The effects of irrigation methods with effluent and irrigation scheduling on water use efficiency and corn yields in an arid region. *Agricultural Water Management Journal 96(1):93 – 99.*

Hernandez, EA, and Uddameri, V. 2009. Selecting Agricultural Best Management Practices for Water Conservation and Water Quality Improvements Using Atanassov`s Intuitionistic Fuzzy Sets. *Water Resource Management Journal 24: 4589 – 4612.*

Karami E. 2006. Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. *Agricultural Water Management Journal 87:101 – 119.*

Kasperczyk N. 2011. Personal communication on 'The Analytic Hierarchy Process (AHP)' referencing (14 July 2011). Kasperczyk@ifls.de. German.

Kasperczyk, N, and Karlheinz, K. 2006. The Analytic Hierarchy Process (AHP). Available on http://www.ivm.vu.nl/en/Images/MCA3_tcm53-161529.pdf. Accessed on 16 July 2011.

Macharis, C, Springael, J, De Brucker, K, and Verbeke, A. 2004: Promethee and AHP: The design of operational synergies in multi-criteria analysis. Strengthening Promethee with ideas of AHP.*European Journal of Operational Research 153: 307 – 317*.

Man, NH, and Mustafa, A. 2006.Evaluating river management practices in Kedah Rivers by Analytic Hierarchy Process (AHP). Proceedings of the 2nd IMT-GT Regional Conference on Mathematics, Statistics and Applications. Universiti Sains Malaysia, Penang, June 13-15. Available on http://math.usm.my/research/OnlineProc/OR05.pdf. Accessed July 11, 2011.

Mnkeni, PNS. Chiduza C, Modi, AT, Stevens, JB, Monde, N, van der Stoep, I and Dladla, R. 2010. Best management practices for smallholder farming on two irrigation schemes in the Eastern Cape and Kwazulu-Natal through participatory adaptive research. WRC Report No. TT 478/10. Water research Commission Publications. Pretoria, RSA.

Millet, I, Wedley, WC. 2002: Modelling Risk and Uncertainty with the Analytic Hierarchy Process. *Journal of Multi-Criteria Decision Analysis 11: 97 – 107.*

Okada, H, Styles, SW, M.E. Grismer, ME. 2008a. Application of the Analytic Hierarchy Process to irrigation project improvement Part I. Impacts of irrigation project internal processes on crop yields. *Agricultural Water Management Journal 95: 199 – 204.*

Okada, H, Styles, SW, M.E. Grismer, ME. 2008b. Application of the Analytic Hierarchy

Process to irrigation project improvement Part II. How professionals evaluate an irrigation project for its improvement. *Agricultural Water Management Journal 95: 205 – 210.*

Ramanathan, R.. 2001: A note on the use of the analytic hierarchy process for environmental Impact assessment. *Journal of Environmental Management 63: 27 – 35.*

Saaty, TL. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology 15: 57-68.*

Saaty, TL. (1980). The Analytic Hierarchy Process. McGraw-Hill International. New York, U.S.A.

Saaty, TL. (1983). Axiomatic Foundations of the Analytic Hierarchy Process. *Journal of Management Science 32: 841-855.*

Saaty, TL. 1990. How to make a decision: The Analytic Hierarchy Process. *European Journal of Operational Research 48, 9-26.*

Saaty, TL. (1994). Fundamentals of Decision Making and Priority Theory with the AHP. RWS Publications, Pittsburgh, PA, U.S.A.

Srdjevic, Z, and Srdjevic, B. 2005. Valuation of irrigation methods by equal and weighted importance models and the analytic hierarchy process. Paperpresented at the 1st open International Conference on modelling andSimulation-OICMS 2005.

Triantaphyllou, E, and Mann, SH. 1995.Using the analytic hierarchy process for decision making in engineering applications: Some challenges. *International Journal of Industrial Engineering2(1):(35-44).*

TSSWCB (Texas State Soil and Water Conservation Board). 2005. Water Conservation Best Management Practices BMP Guide for Agriculture in Texas Report 362. Texas, USA.

Waskom RM. 1994. Best management practices for irrigation management. Bulletin XCM-173. Colorado State University. USA

Withers, PJA., Hodgikinson, RA, Bates, A, Withers, CL. 2007. Soil cultivation effects on sediment and phosphorus mobilization in surface runoff from three contrasting soil types in England. *Soil Tillage Res 93 (2): 438 – 451.*

Young, KD, Kibler, DF, Benham, BL, and Loganathan, GV. 2009. Application of the Analytical Hierarchical Process for Improved Selection of Storm-Water BMPs. *Journal of Water Resources Planning and Management DOI: 10.1061/ASCE 0733-9496(2009) 135:4(264).*

Zahir, S. 1999: Clusters in group: Decision making in the vector space formulation of the analytic hierarchy process. *European Journal of Operational Research 112: 620 – 634.*

5. FINAL DISCUSSION

5.1 Background

The performance of smallholder irrigation schemes across the world has been reported to be below expectations. The causes of low performance have varied among countries but have been relatively similar within countries. One of the drivers of low performance has been reported to be sub-optimal water management, especially in communally-managed smallholder schemes. In South Africa, the government invested significant amounts, ranging between R30, 000 and R60, 000 per hectare, in the revitalisation of smallholder schemes. The revitalisation programme is aimed at capacitating smallholder farmers, rehabilitation and modernisation of infrastructure in smallholder schemes and improving extension services. However, the question which had to be answered is "How are the schemes performing now?" Of particular concern to this study was the water management, farmer satisfaction as well as the derivation of best management practises that can be followed to improve the performance of smallholder schemes.

Water-related performance indicators were used in the study since water for irrigation is more constrained than land in South Africa. Farmers were interviewed to establish their satisfaction status with using the irrigation service from MRIS, the factors underlying their assessment and their suggestions to improve performance which resulted in best management practices.

5.2 Findings and Conclusions

The average conveyance efficiency in the MRIS was found to be 86.4%, slightly above 85% recommended for lined canals. However, the conveyance efficiency varied spatially in the scheme. It was concluded that conveyance efficiency was higher in the upstream blocks because the infrastructure is still intact and illegal water withdrawal is low since every farmer has easy access to water. However, it was lower in the tail-end blocks due to damaged canal walls, illegal water withdrawals from the canal and poor maintenance reducing canal capacity. The infrastructure is in need of repair to minimize water losses in the tail-end blocks.

In terms of dependability of irrigation interval between water applications, the scheme is performing below expectations. Upstream farmers access water daily, while tail-end farmers wait for periods of up to 17 days before getting water and this contributes to dissatisfaction with using an irrigation service from MRIS since access to water was established as a significant factor influencing the satisfaction status of farmers. In trying to curb the delays in water delivery, farmers in the tail-end of the scheme suggested replacement of infield canals with pipes, charging water fees and the establishment and adherence to an irrigation schedule. Replacement of infield canals would increase water access control as the gate valves can be closed. The introduction of water fees will deter over-irrigation and inefficient use by upstream farmers and save water for those downstream. The adherence to an irrigation schedule will ensure equitable water distribution among the farmers.

The relative irrigation supply varied among the blocks, with higher values found in the head blocks indicating over-irrigation. It was found that farmers lacked knowledge on appropriate irrigation water management techniques. For example, crops in the upstream plots were irrigated daily. Some farmers would irrigate as soon as the soil surface looks dry, unaware that there is still enough water for crops in the soil profile. It was concluded that farmers apply excess water and that this is due to lack of knowledge. The RIS values in tail-end blocks were found to be very low indicating that crop water requirements were not met. However, it was concluded that these farmers in the tail-end blocks are more efficient in water use, as can be seen in Figures 2.13 and 2.14, even though they do not have access to water readily. The farmers further away from the main canal, within a block and those in the tail-end of the scheme received less water but produced more per unit of water used.

The majority of the farmers, who are the most important stakeholder in the scheme, are satisfied by using the irrigation service at MRIS. The factors which were significant in influencing the satisfaction status of farmers with using an irrigation service were: location of farmers` plot with respect to the water diversion point, location within a block from the main canal, age of the farmer, education level attained by the farmer, farming experience, the number of plots a farmer owns, fairness of water distribution across the blocks and the number of days a farmer has access to water.

It was established that farmers were aware of the causes of ‘artificial’ water shortage in their scheme and the farmers suggested seven BMPs. Of the seven BMPs, the farmers generally preferred the introduction and adherence to an irrigation schedule, the introduction of water fees, the replacement of in-field canals with pipes and routine inspection of irrigation infrastructure. These four were ranked high for all the sections of the scheme while others such as re-lining of in-field canals, tail water re-use and volumetric measurement of irrigation water use by each block were ranked low in terms of preference.

Overally, it was concluded that the performance of MRIS was comparable to others around the world, in terms of the performance indicators assessed. The scheme performance meets the expectations of the stakeholders such as farmers in the scheme, the majority of whom are satisfied by taking the irrigation scheme.

5.3 Recommendations

It is recommended from this study that the BMPs suggested by the farmers be adopted and that irrigation and crop specialists be engaged to train extension officers and farmers in irrigation water management and agricultural production in general. The farmers indicated their willingness to learn more about irrigation to enhance their productivity. Routine farmer training on water management may improve, not only water productivity, but, also ensure equitable water distribution since the farmers will only withdraw water that is enough for their crops.

The need for a clear policy on irrigation is a fundamental recommendation from this study. The policy should define the roles of each stakeholder in the scheme, for example, the farmers would be advised that routine repair and maintenance of the canal is their responsibility. During the course of this study, there were conflicting of roles to be played by the government and farmers. With a clear role to play, farmers, through management committees, may assist in reducing illegal tampering with the infrastructure and water withdrawal. Farmers need to organize themselves to rehabilitate the damaged infrastructure in the scheme.

5.4 Future Research Needs

A further similar study in other communally-managed smallholder schemes may assist in deriving the best management practices which could be generalised and applied in South Africa and beyond. This study is not representative since it was only one scheme studied. Further studies are also recommended to establish the land ownership patterns and socio-economic dispensation of the scheme since some farmers have abandoned their plots, particularly in Blocks 1, 7 and 8.

APPENDIX I

QUESTIONNAIRE ON IRRIGATION PERFORMANCE

INTRODUCTION

My name is Taziva Gomo from University of KwaZulu-Natal, Pietermaritzburg. I am carrying out a study on the performance of Mooi-River Irrigation Scheme. I am kindly requesting you to assist by filling in this form. The questionnaire has 4 pages.

All the information obtained from this questionnaire is confidential and will only be used for this research.

GENERAL INFORMATION

Date: ....

Block Number: ....

PERSONAL INFORMATION

This questionnaire targets the head of the family irrigating.

(a) Sex: **[ ]** Female **[ ]** Male

(b) Age group **...**

(c) Education level **[ ]** Tertiary **[ ]** Secondary **[ ]** Primary **[ ]** Never went to school

(d) How long have you been irrigating in this scheme?..

(e) Do you own cattle or tractor? **[ ]** Tractor **[ ]** Cattle **[ ]** Donkeys **[ ]** None

(f) How many plots do you use in this scheme?...

(g) What do you use for ploughing in your plot(s)? **[ ]** Tractor **[ ]** Cattle **[ ]** Donkeys **[ ]** Hands

(h) If you use, a tractor or cattle, where do you get them from?..

(i) If you hire a tractor, donkeys or cattle,

(i) how much is it per plot?...

(ii) where do you get the money from?...

SCHEME MANAGEMENT

1. Have disputes occurred among farmers or between blocks due to water issues?

[ ] No **[ ]** Yes

(i) If Yes, what are/were the problems?

....

2. (i) If Yes in 1, have these problems been solved? **[ ]** No **[ ]** Yes

(ii) If yes in (i), how have these problems been solved? ....

(iii) If Yes in (ii), are you satisfied about the way the problems have been addressed?

[ ] No **[ ]** Yes

3. Compared to the situation three years ago, the number of problems is :

[ ] less **[ ]** same **[ ]** more **[ ]** There weren`t any problem

4. Do you (or your family member) attend meetings concerning block management?

[ ] No **[ ]** Yes

5. (i) Have you (or your family member) received training in irrigation water management?

[ ] No **[ ]** Yes

(ii) If yes, who was providing the training?

[ ] Irrigation staff/ Department of Agriculture **[ ]** Associate Farmer

[ ] Other, specify ....

6. Do you pay any water fees? **[ ]** No **[ ]** Yes, to who? ....

7. Are you satisfied with the way the committee operates? **[ ]** Yes **[ ]** No

Explain...

WATER DISTRIBUTION

8. How often do you get water into your plot?

[ ] everyday **[ ]** once a week **[ ]** once a month

[ ] Never **[ ]** other...

9. For how many minutes/hours do you let water into your plot on your irrigation day?

....

10. (i) Do you follow/respect the water distribution schedule? **[ ]** Yes **[ ]** No

(ii) Who makes the schedule?

[ ] Scheme management Committee **[ ]** Block management Committee

[ ] Department of Agriculture

11. Are you as farmers consulted in the making of water distribution schedule?

[ ] Yes **[ ]** No

12. Who is responsible for getting water from main canal into block?

[ ] Irrigation staff **[ ]** Farmer **[ ]** Other, specify......................

13. (i) Are you facing a shortage in irrigation water?

[ ] Yes **[ ]** No

(ii) Give reasons..

14. (i) Compared to the situation 3 years ago, amount of irrigation water you receive is :

[ ] less **[ ]** same **[ ]** more

(ii) If changed, what are the reasons for this change in water you receive?

....

15. (i) How do you feel about the water distribution in general?

[ ] satisfied **[ ]** not satisfied **[ ]** neutral

(ii) Explain..

OPERATION AND MAINTENANCE

16. As farmers are you involved in the cleaning of the main canals?

[ ] Yes [ ] No

Explain...

17. Are you involved in repair and maintenance of the main canal?

[ ] Yes [ ] No

Explain ....

18. Where do you report problems with the canal?

[ ] Irrigation staff/ Department of Agriculture [ ] Block committee

[ ] Other, specify ....

19. (i) Is there a seasonal/annual inspection of the irrigation canals/structures?

[ ] No [ ] Yes

(ii) If yes, who are participates in this inspection? (*Tick the appropriate box (es)*)

[ ] irrigation staff [ ] irrigation block management

[ ] block members [ ] Scheme irrigators/farmers

[ ] contractor [ ] other ....

20. (i) Are you satisfied with the operation and maintenance of the scheme?

[ ] No [ ] Yes

(ii)

Explain...

21. (i) Are you satisfied with the overall performance of the irrigation scheme

[ ] No [ ] Yes [ ] Neutral

(ii) Explain…………………...

Thank you for taking your time to complete this questionnaire

THE END

APPENDIX II

QUESTIONNAIRE ON RANKING OF BEST MANAGEMENT PRACTICES

INTRODUCTION

My name is Taziva Gomo from University of KwaZulu-Natal, Pietermaritzburg. I am continuing with the study on the performance of Mooi-River Irrigation Scheme. This questionnaire is a follow-up to the one previous administered in September 2010. I am kindly requesting you to assist by filling in this form.

All the information obtained from this questionnaire is confidential and will only be used for this research.

GENERAL INFORMATION

Date: ....

Block Number: ....

Sex: **[ ]** Female **[ ]** Male

Age group ....

RANKING OF BEST MANAGEMENT PRACTICES

In the tables below, please rank the BMPs in a scale of 1 – 9 according to your preference of the best management practices relative to the one on the left column of each table. 1 will be the least preferred while 9 will be the most preferred.

The enumerator will assist you as to where to put the scores.

Table 1

	Score		
Routine irrigation infrastructure			Establishment and adherence to irrigation scheduling
			Introduction of water fees
			Volumetric water measurement
			Re-lining of in-field canals
			Replacement of infield canals with pipes
			Tail-water re-use

Table 2

	Score		
Establishment and adherence to irrigation scheduling			Routine irrigation infrastructure
			Introduction of water fees
			Volumetric water measurement
			Re-lining of in-field canals
			Replacement of infield canals with pipes
			Tail-water re-use

Table 3

	Score		
Introduction of water fees			Establishment and adherence to irrigation scheduling
			Routine irrigation infrastructure
			Volumetric water measurement
			Re-lining of in-field canals
			Replacement of infield canals with pipes
			Tail-water re-use

Table 4

	Score		
Volumetric water measurement			Establishment and adherence to irrigation scheduling
			Introduction of water fees
			Routine irrigation infrastructure
			Re-lining of in-field canals
			Replacement of infield canals with pipes
			Tail-water re-use

Table 5

	Score		
Re-lining of in-field canals			Establishment and adherence to irrigation scheduling
			Introduction of water fees
			Volumetric water measurement
			Routine irrigation infrastructure
			Replacement of infield canals with pipes
			Tail-water re-use

Table 6

	Score		
Replacement of infield canals with pipes			Establishment and adherence to irrigation scheduling
			Introduction of water fees
			Volumetric water measurement
			Re-lining of in-field canals
			Routine irrigation infrastructure
			Tail-water re-use

Table 7

	Score		
Tail-water re-use			Establishment and adherence to irrigation scheduling
			Introduction of water fees
			Volumetric water measurement
			Re-lining of in-field canals
			Replacement of infield canals with pipes
			Routine irrigation infrastructure

Thank you for taking your time to complete this questionnaire

THE END