Adoption of irrigation scheduling methods in South Africa

by

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DECLARATION

I declare that the thesis, which I hereby submit for the degree Philosophy Doctor at the University of Pretoria is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE DATE

ABSTRACT

ADOPTION OF IRRIGATION SCHEDULING METHODS IN SOUTH AFRICA

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Irrigation scheduling is accepted as the process to decide when to irrigate crops and how much to apply and is assumed to play an important role in the general improvement of water efficiency on the farm. However, the idea that there is a single key to the adoption of irrigation scheduling on the farm is simplistic. It implies that science has all the answers, and "we need just to convince the farmers".

The objectives of this study were to investigate the adoption process in South Africa with the further purpose to identify the possible human and socio-economic factors that may influence it. In order to appreciate the spectrum of soil-plant-atmosphere irrigation scheduling models and techniques that are available to potential users, it was necessary to quantitatively describe and classify the scheduling methods. The adoption of irrigation scheduling methods among commercial and small-scale farmers was investigated on a scheme (macro) level as well as on-farm (micro) level through a quantitative assessment of scheduling methods on a national basis, semi-structured interviews with irrigation professionals, survey among a stratified sample of commercial farmers and case studies of small scale irrigation farmers.

It was hypothesized that the adoption behaviour of irrigation farmers is determine by socio-economic (independent) and intervening factors. It was also hypothesized that ground level support and effective dialogue between scientist and farmers are conducive for the implementation of irrigation scheduling.

The study indicates that only 18% of irrigation farmers in South Africa make use of objective irrigation scheduling method, while the rest make use of subjective scheduling methods based on intuition, observation, local knowledge and experience. Differential perceptions occur between farmers as well as between farmers and scientists with regard to the concept of "irrigation scheduling" commonly being used. These differences contributed to the communication gap between science and the practice of irrigation scheduling resulting in the unsuccessful communication between farmers and scientists and the ultimate low adoption rate.

The implementation of irrigation scheduling models are predominantly advisor-driven and not farmer-driven, as they are perceived by farmers to be complex and not easy to implement on the farm. Younger farmers are more willing to use irrigation models because of their higher computer literacy levels and positive attitude towards the use of computers in general. The technology level of a farm, size of farming operation and the value of the crop being produced determine the selection of irrigation scheduling methods. The general problems experienced by some farmers with regard to bulk water delivery hampers the implementation of more precise irrigation scheduling.

Farmers' awareness, flexibility and willingness to change, innovate and step outside of accustomed ways of implementing irrigation, are strongly influenced by their social, economic, cultural and institutional settings, and not merely by irrigation scheduling technology. Perceived indicators of efficient use of irrigation on the farm include increased production levels, decreasing electricity costs, improvement of crop quality and efficiency of fertiliser use. Farmers identified accuracy, reliability, ease of implementing and affordability as important technological characteristics of scheduling methods and devices.

The case studies of small-scale irrigation farming revealed that weak institutional arrangements and handling of farmers' affairs on the level of several small-scale irrigation schemes hampers sustainable agricultural development. Small-scale irrigators have reported that the lack of competent extension support prevents them from implementing irrigation scheduling. Also, the scientific framework used by scientists and advisors to convey information to irrigators often follows the linear transfer of technology approach instead of following the "learning based approach".

A significant relationship exists between the number of information sources used and the implementation of the type of scheduling methods The majority of irrigation farmers are more interested in the use of irrigation scheduling to identify "troubles or problems" experienced with irrigation, and inevitably farmers will differ in their selection of the most appropriate scheduling method and technique.

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In a study of this nature and magnitude a number of people make important contributions.

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  - Prof. Allan Bennie: University of Free State
  - Prof Gavin Fraser: University of Fort Hare
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LIST OF ACRONYMS

AC	Alternating Current
AE	Application Efficiency
AED	Atmospheric Evaporative Demand
Agri SA	Agriculture South Africa
ARC	Agricultural Research Council
ARC-ILI	Agricultural Research Council - Instituut vir Landbou Ingenieurswese
ARDRI	Agricultural and Rural Development Research Institute of the University of Fort Hare
BBP 3	Beste Besproeiings Praktyke No 3
BBP 17	Beste Besproeiings Praktyke No 17
BEWAB	Besproeiingswater Bestuursprogram
BMP	Best Management Practices
CANEGRO	Cane growth model
CANESIM	Cane simulation model
CASP	Comprehensive Agricultural Support Programme
CMA	Catchment Management Agency
CROPWAT	Crop Water Requirements Program
CU	Christiansen uniformity coefficient
DBSA	Development Bank of South Africa
DoA	Department of Agriculture
DOA Northwest	Northwest Provincial Department of Agriculture
DSSA	Decision Support System for Agro Technology Transfer
Du_{lg}	Distribution uniformity
DWAF	Department of Water Affairs and Forestry
E	Soil water evaporation
Em	Maximum total evaporation from specific crop surface in given growth stage
Eo	Pan Evaporation
ECDA	Eastern Cape Department of Agriculture
ECATU	Eastern Cape Appropriate Technology Unit
ET	Evapotranspiration

ETref	Reference evaporation (Penman-Monteith Method)
ET0	Evapotranspiration as calculated from evaporation pan
FAM	Freely available moisture
FAO	Food and Agriculture Organisation of the United Nations
FDR	Frequency Domain Reflectometry
FSDA	Free State Provincial Department of Agriculture
FFS	Farmer Field School
FSU	Farmer Support Unit
GIS	Geographical Information System
GWK	Griekwalandwes Cooperative
IT	Information Technology
KDA	KwaZulu Provincial Department of Agriculture
KSA	Key Strategic Areas
LAI	Leaf Area Index
LANOK	Landbou Ontwikkelings Korporasie
LL	Lower limit of water storage
LPDA	Limpopo Provincial Department of Agriculture
LWP	Leaf Water Potential
ML	Mega Litre
MPDA	Mpumalanga Provincial Department of Agriculture
MSSA	Marketing Surveys and Statistical Analysis
NAFU	National African Farmers Union
NCDA	Northern Cape Provincial Department of Agriculture
NDA	National Department of Agriculture
NEPAD	New Partnership for Africa's Development
NEWSB	New Soil Water Balance
NIEP	Nkomazi Irrigation Expansion Programme
NWA	National Water Act (Act No. 36 of 1998)
NWRS	National Water Resource Strategy
O&M	Operation and maintenance
OHS	Open Hydroponics System
ORWUA	Orange Riet Water User Association
PCA	Plant Canopy Analyser
PAWC	Plant Availability Water Capacity

PRWIN	Probe for Windows
PUTU	PUTU crop growth model
RAW	Readily Available Water
RDP	Rural Development Program
RESIS	Revitalising Program of Small-scale Irrigation Schemes
RF	Refill point
SAM	South African Malsters
SAPWAT	South African Procedure for estimating Irrigation Water Requirements
SASA	South African Sugar Association
SASRI	South African Sugar Research Institute
SIS	Scientific Irrigation Systems
SMS	Short Message Service
SPSS	Statistical Package for Social Science
SSI	Small-scale Irrigation
SST	Small-scale Irrigation Technology
SWB	Soil Water Balance
T	Transpiration
TAM	Total Available Moisture
TDR	Time Domain Reflectometry
TRA	Theory of Reasoned Action
TOT	Transfer of Technology
TSB	Transvaal Suiker Beperk
UDL	Upper Drained Limit
USAID	United States of America Department of International Aid
VINET	Vineyard Evaporation for Irrigation System Design and Scheduling
WC/DM	Water conservation/Demand Management
WFD	Wetting Front Detector
WMP	Water Management Plan
WRC	Water Research Commission
WUA	Water User Association
WUE	Water Use Efficiency
WUI	Water Use Index

PART ONE

BACKGROUND AND SCOPE OF THE RESEARCH

CHAPTER 1

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 ROLE OF IRRIGATION IN SEMI-ARID SOUTHERN AFRICA

Irrigation is essential for food production to overcome deficiencies in rainfall and to stabilize agricultural production especially in the semi-arid and arid areas. Worldwide irrigation is practised on about 263 million ha (1996) with about 49% of the world's irrigation in China, India and the United States. In 2000, the total water requirements of South Africa were 13280 million m^3 per annum, with irrigation and urban usage accounting for 54% and 25% respectively (Shand & Basson, 2003). Rainwater runoff and deep percolation become available as surface – and groundwater of which approximately 62% is used for irrigation (DWAF, 2004), which is equivalent of 2.5% of the rainfall.

Agriculture in southern Africa with its semi-arid climate is a very important activity in terms of economic development and a key to poverty reduction in rural areas, but is also identified as one of the major water users in the region. In South Africa at least 35% of the economically active population of approximately 14 million people is directly or indirectly dependent on agriculture (Dept. Agric, 2001). The total area in South Africa under irrigation for commercial and smallholder agriculture is 1290 132 ha with a potential expansion of 283 350ha, given the available water resources. Irrigated agriculture in southern Africa plays a disproportionately important role because it is generally two or three times more productive than rain-fed agriculture, and because irrigation also uses roughly 70% of the region's water demand as indicated in Table 1.1.

Table 1. 1: Irrigated land and water demand for SADC countries (2004)

Country	[2]Size of country (km^2)	[2]Area arable land (km^2)	[2]Area irrigated land as % of arable land	[1]Water use (million m^3/annum) (1995)	[3] % of total water demand
Angola	*1 246 700*	*24 934*	*3*	*750*	*27*
Botswana	*585 370*	*5 853*	*0.3*	*47*	*31*
Lesotho	*30 355*	*3 339*	*0.9*	*160*	*59*
Malawi	*94 080*	*31 987*	*0.9*	*1 820*	*70*
Mauritius	*1 850*	*906*	*18*	*460*	*Not available*
Mozambique	*784 090*	*31 363*	*3.8*	*3 000*	*93*
Namibia	*825 418*	*8 254*	*0.7*	*248*	*66*
South Africa	*1 219 912*	*121 991*	*10.4*	*12 764*	*54*
Swaziland	*17 203*	*1 892*	*35.4*	*331*	*65*
Tanzania	*886 037*	*26 581*	*5.6*	*10 450*	*85*
Zambia	*740 724*	*51 850*	*0.9*	*1 580*	*72*
Zimbabwe	*386 670*	*32 480*	*3.6*	*4 980*	*80*
Average		*28 452*	*7.0*	*3 049*	*70*

[1] *Heyns, 1995. DWAF, Namibia.*
[2] www.worldatlas.com, 2002
[3] *Rothert, 2000*

1.1.1 Water use efficiency and the implementation of irrigation scheduling

This section aims to put the reason for improving water use efficiency through irrigation scheduling into perspective from the different stakeholders' perspective. The stakeholders include the community as a whole (represented by government), the irrigation farmers, the water management institutions (represented by CMAs and WUA) and the environment.

The efficiency of water use in agriculture is subject to a number of negative perceptions held by stakeholders from other water sectors in terms of water use efficiency. Therefore, the requirement is that water resources must be utilized productively and greater efforts must be made to increase productivity growth and thereby the competitiveness of agriculture (Backeberg, 1996). Frühling (1996) indicated that only 45% of water abstracted from surface and groundwater sources is believed to reach the crop root zone. Approximately 35% of irrigation system losses return to the river systems by overland flow and seepage but this return water is normally nutrient enriched and polluted with herbicides, pesticides and other pollutants that affect water quality of rivers and streams. Irrigation methods, irrigation scheduling, soil preparation, crop selection and evaporation all have a significant impact on the efficient usage of irrigation water (ARC, 1999). As the largest water user, irrigated agriculture will need to ensure that the greatest benefit is being obtained from the use of water resources, while ensuring efficiency and sustainability.

The requirement of proving beneficial use has led many countries to implement benchmarking exercises (Molden *et al.*, 1998; Malano, 2000; Malano & Burton, 2001, Fairweather, Austin & Hope, 2003) like the use of irrigation performance measures and indicators. Benchmarking is the process of identifying and implementing organization-specific practices with the goal of improving competitiveness, performance and efficiency (Malano & Burton, 2001). Thus, benchmarking requires the determination of current levels of performance and the identification of practices that can be implemented to improve the current situation.

The definition of water use efficiency was found to cover a vast range of terms and often led to some confusion. Water Use Efficiency (WUE) is a generic label to describe a “toolbox” of performance indices that can be used to evaluate water use in irrigation. In general, the term index was used to represent a relationship between water (input) and agricultural product (output) and efficiency to relate an output (e.g. water arriving at destination) to an input (e.g. water diverted from the source). In this way, Fairweather *et al.* (2003) and Purcell & Currey (2003) make a distinction between the agronomic performance of the crop and the engineering aspects of the design and management of the system. For example, farm Water Use Index (WUI, kg/ML) is defined as the crop production (kg or trays of fruit or quality of fruit) divided by water delivered to the farm gate (ML) and Farm Efficiency (%) is defined as the water retained in the soil (directly available to the crop) (ML) divided by the water delivered to the farm gate (ML). It is clear from the above-mentioned examples that temporal and spatial boundaries need to be defined with performance term used (Purcell & Currey, 2003). Water use indices are usually calculated over a season, whereas some efficiency terms can be calculated over an event, season or year.

The main pathways for enhancing WUE in irrigated agriculture is to increase the output per unit water, reduce losses of water to unusable sinks and reduce water degradation (environmental aspects). Possible ways of more efficient use of available water supply for irrigation include a coordinated approach at different levels of the water system or irrigation management sub-systems as indicated in Figure1.1. This is the scheme level sub-component, which includes the segment from the water source to the farm boundary, the farm and field sub-systems, which extends from the farm edge to the bottom of the root zone. At the scheme level sub-system, conveyance efficiency is the responsibility of the Catchment Management Associations (CMAs), Water User Associations (WUAs) and Department of Water Affairs (DWAF). Farm efficiency (or the volume of water delivered to the field edge divided by the volume delivered to the farm) and field efficiency (defined as the volume of irrigation water that replenishes the rooting zone as a function of the water supplied to the field) are the responsibility of the farmer.

From the different sub-systems shown in Figure 1.1, six efficiency terms can be defined: conveyance effiency, on-farm distribution efficiency, in-field system effiency, soil storage efficiency, irrigation efficiency and application efficiency. Any definition of water use efficiency on the farm will depend to a large degree on the perception of the person (the social, economic, political and strategic considerations taken into account producing the definition) and will be defined for each of these sub-systems identified. Those managing the

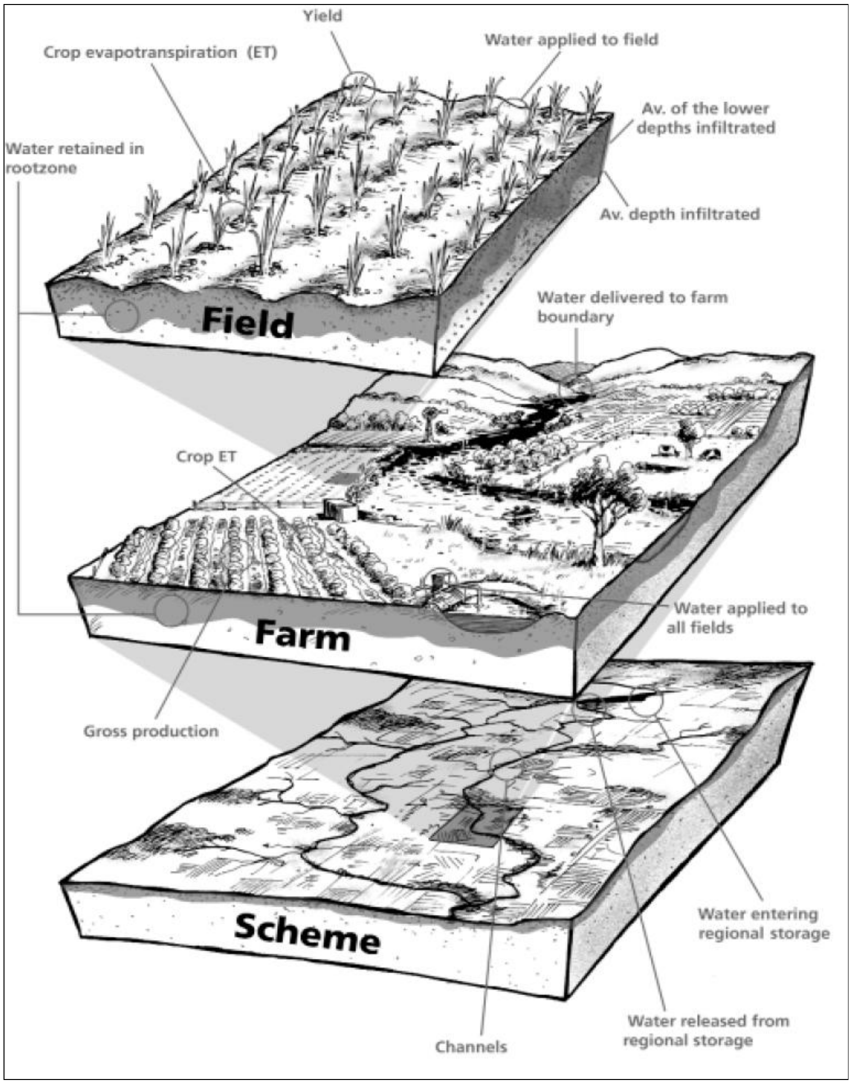

Figure 1. 1: Water use efficiency parameters applicable for the different sub- systems of water management

supply of bulk water tend to see efficiency simply in terms of losses in the delivery system, or the gross amount of water consumed by each of the customers as compared to some average or ideal figure. Irrigation farmers are more interested in how much product or quality of product, or perhaps how much profit, they can produce with a given amount of water. For this reason, the water use efficiency terms for each of these sub-components of the system as indicated in Table 1.2 will have to be used in conjunction with other sources of information when assessing the use of irrigation water.

Table 1.2: Potential water saving options to improve water use efficiencies (CSIRO, 2005)

Efficiency ratio	Water saving options
Irrigation efficiency: Conveyance efficiency	Identify and remediate seepage losses in supply channels
Irrigation efficiency: Farm efficiency	Identify and remediate on-farm seepage losses On-farm storage and recycling of drainage water Covering storage dams
Irrigation efficiency: Field efficiency	Laser leveling Flow monitoring Matching crop and groundwater depth Conversion to pressurized irrigation systems
Irrigation efficiency: Water use efficiency	Irrigation scheduling and soil water monitoring
Irrigation efficiency: Water productivity	Optimizing crop water requirements

Water management on a farm, of which irrigation scheduling is one aspect, expects the farmer to understand the total system that he is involved in. Making improvements to one part of the system or water management sub-component will have implications for the other (e.g. demand base irrigation scheduling requires flexible delivery of water or on-farm water storage facility). Therefore, increases in water use efficiency at the field level will require simultaneous improvements in each of the different sub-components.

Howell (2001) presents four options for the improvement of irrigation efficiency at a field level based on the findings of Walace and Batchelor (1997):

- *Agronomic:* The application of crop management to enhance the capturing of rainfall and reduce water evaporation (e.g. conservation tillage, improved varieties, or advanced cropping strategies to maximize cropped area during period of lower water demands or periods when rainfall may have a greater possibility of occurrence.

- *Engineering:* The selection and use of irrigation systems that reduce application losses improve distribution uniformity; apply cropping systems that enhance rainfall capture.

- *Institutional:* Collaborate and participate in an irrigation district or scheme with regard to water use, water pricing and water conservation.

- *Management*: The application of demand–based irrigation scheduling techniques; deficit irrigation to promote deeper soil water extraction, avoiding over irrigation. Management is an important aspect and as well as being listed explicitly, it is also inherent to the other three options.

There is an increasing interest shown in improving the water use efficiency in South Africa, mainly due to phasing out of subsidies on agricultural inputs, changing policies on the ownership of land and water resources as well as increased public awareness of soil and water ecological issues. Implementation of irrigation scheduling technologies could play an important role in improving water use efficiency on a farm level and reducing the production cost (Annandale *et al.*, 2002).

As this thesis has at its core the objective to determine and analyse the human factors that influence adoption of irrigation scheduling methods by irrigation farmers in an effort to improve the on-farm water use efficiency, the rest of the discussion will primarily focus on the use and implementation of irrigation scheduling methods as possible water saving options. It is however necessary to provide a brief overview of the various definitions, purposes and descriptions of irrigation scheduling contained in the literature.

Irrigation scheduling has been defined as a planning and decision making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season for each crop that is grown (Jensen, 1981). The conceptual framework underpinning the filling and emptying of the root zone is well accepted. The soil has a full point determined by the upper drain limit (UDL), which describes the maximum amount of water, the soil can hold. The UDL has a conventional definition namely, the water content after 48 hours free drainage from covered soil after saturation, which is not only an intrinsic soil property but in reality depends on the complex interplay between the antecedent water content, evapotranspiration rate and soil variability (Stirzaker, 2005). The lower limit (LL) of water storage is defined as the soil water content at which the plant wilts even when the transpiration rate is negligible. The refill point occurs somewhere between the UDL and LL and is often considered the half waypoint or 50% depletion. Total available water and readily available water to plants are calculated by multiplying (UDL-LL) and (UDL-RF) with the rooting depth for each growing stage of a crop (Stirzaker, 2005).

With this conceptual framework in mind, the general aim of irrigation scheduling is to apply water before the crop experiences an unacceptable stress and to replenish, but not overflow the root zone (Hill, 1991). The method used can be based on soil, plant and atmospheric measurements and is commonly known as scientific irrigation scheduling (SIS) (Lieb *et al.*, 2002). Although the acceptance of SIS has grown world wide (Fereres, 1996), the main aim of SIS was found to be solving of specific problems, while the successful dissemination and adoption of irrigation scheduling depends on producers' needs and perceptions on the farm (Howell, 1996).

Irrigation scheduling requires a good workable knowledge of the crop's water requirements and of the different soils' water holding characteristics that determine when to irrigate, while the adequacy of the irrigation system determines the accuracy of how much water to apply. The skill and experience of the farmer will determine the effectiveness of the application of the irrigation scheduling at field level.

1.2 PROBLEM BACKGROUND AND STATEMENT

Water scarcity has become an increasing social and economic concern for policy makers and competitive water users in South Africa and around the world. On a regional level the Comprehensive Africa Agriculture Development Programme of New Partnership for Africa's Development (NEPAD, 2003) identified land and water management as one of the three pillars for priority investment in raising the productivity of agriculture to ensure predictable outputs. In recent years there has been a major shove for the use of modern irrigation technologies to improve on-farm efficiency of water to address the problem of water scarcity and environmental degradation in South Africa (de Lange & Maritz, 1998; Versfeld, 2000; Badenhorst, de Lange, Mokwena & Rutherford, 2002; Seetal, 2002; Karar, 2003).

At the end of 2001, the National Department of Agriculture, Agri SA and National African Farmers Union (NAFU) released the Strategic Plan for South African Agriculture (Department of Agriculture, 2001). One of the core strategies in the sector plan for agriculture is sustainable resource management, which also impacts on efficient water use. With this in mind, the Water Research Commission (WRC) of South Africa has since 2002/2003 embarked on Key Strategic Areas (KSA) of Water Utilization in Agriculture identified for research with the overall objective to utilize scarce water resources efficiently, beneficially and sustainably to increase household food security and farming profitability (Backeberg & Sanewe, 2005).

Embedded in this overall objective of the WRC as identified for this Key Strategic Areas this study was planned and designed to investigate the factors that influence the adoption of irrigation scheduling methods and models amongst irrigation farmers. The science of irrigation scheduling has a long, illustrious pedigree and a large number of soil-atmosphere-plant irrigation scheduling methods and models (Chapter Two) have been developed to determine when crops require water, and how much irrigation needs to be applied. Irrigation scheduling was introduced to farmers thirty years ago (Shearer & Vomocil, 1981; Fereres, 1996). Despite the apparent importance of irrigation scheduling and the large amount of research resources devoted to it, the worldwide adoption of objective irrigation scheduling methods by irrigation farmers has been well below expectations (Cox, 1996; Lynch, Gregor & Midmore, 2000; Leib *et al.,* 2001). A national census in Australia during 1999 revealed that less than 15% of the farmers used scientific–based tools, whereas over 90% relied heavily on local knowledge (Stirzaker, 2003).

Three different approaches of system thinking were found in the literature to address the potential adoption of irrigation scheduling methods. The interplay between these different systems approaches are not only important as a background for the literature, it also provides the framework for the developing and answering of the research questions for the thesis.

First, a hard system approach from the natural science (ecology and physiology) is followed to understand and describe the impact of irrigation scheduling on crop production and the natural resource base. The use of system thinking in this tradition is first to ask, "Why is it so?" Major tools for managing climate variability, are the use of simulation modelling and sophisticated measuring devices and techniques which are grounded in the daily impact of climate on crop and soil processes. With these efforts scientists tried to conserve water/energy (Shearer *et al.,* 1981; Dockter, 1996; Alam, Duke & Orendoff, 1996), improve crop yield and quality (Silva & Marouielli, 1996; Tacker *et al.,* 1996), and reduce non-point pollution (Boesch, Humphrey & Young, 1981; Klock, Schneedloth & Watts, 1996 and Nguyen, Nieber & Misra, 1996).

Secondly, a hard system approach that comes from the applied science of engineering and management science is used. As applied science, the first question is not why it is so - but rather what can we do about it? The engineering and management science treatment of systems has become the dominant approach in applied agricultural science. Therefore, various studies in the literature were found to analyse on-farm adoption of irrigation technologies using the engineering notion of irrigation water efficiency as defined by Whinlesey, McNeal & Obersinner (1986); Barret, Purcell & Associates (1999) (i.e. ratio of water stored in the crop root zone to the total water diverted for irrigation). Other studies evaluate the economic and technical attributes of irrigation technologies, and found that some combination of water saving and yield increase was necessary in order for farmers to induce the adoption of water conserving technologies (e.g. Coupal & Wilson, 1990; Santos, 1996; Droogers, Kite & Murray-Rust, 2000, Arabiyat, Segarra & Johnson, 2001) and that risk has been considered as a major factor reducing the rate of adoption (Jensen, 1982). Squires (1991) argued for the need to classify farming systems so that they could be compared, analysed and evaluated. This approach is using the engineering analogy, while agricultural and management sciences are essentially the exercising of natural science within a social environment.

The pioneering work of Griliches (1957) on the adoption of hybrid corn in the USA, and the analysis of farmer decisions to adopt technology innovation (Linder, 1987; Fischelson & Rymon, 1989; Dinar & Zilberman, 1991; Dinar, Campbell & Zilberman, 1992; Dinar & Yaron, 1992, Federer & Umali, 1993; Ruttan, 1996; Vanclay, 1997, Barr & Cary, 2000; Cary, & Webb, 2001, Cary *et al.,* 2002; Vanclay, 2003), followed a different approach. They have made use of a soft systems approach, in their attempt to explore the influence of socio-economic, demographic and structural factors on adoption behaviour. Ison (1991) maintains that the hard system tradition focuses on how to solve the problem, whereas the soft system approach opens up questions of what is the problem, why does it exist and for whom does the problem exist?

Shearer and Vomocil (1981) indicated that behavioural patterns and attitudes of farmers, as well as the need for continuous technical support of the farmers are some of the major constraints that prevent farmers from implementing irrigation scheduling. Several authors have empirically investigated technology adoption and diffusion taking into account farmers' perception about the degree of risk concerning future yield (Federer & Umali, 1993; Saha, Love & Schwart, 1994, Pannel, 1999; Batz, Peters & Jansen, 1999).

According to Howell (1996) there has been little change in the theory and methodology of irrigation over the last 25 years, however the changes in information technology need to update irrigation scheduling methods, which changed drastically over the last few years. Jensen (1981) indicated that the challenges are to develop complete and reliable irrigation technologies to be adapted to farmers' requirements as well as training of extension personnel. Shearer *et al.* (1981) reported that most of the successful scientific irrigation scheduling programs in Oregon are disbanded once programs are no longer offered free of charge, while Itier, Maraux, Ruelle & Deumier (1996) contend that scheduling methods and techniques must be simplified to match time constraints, training level, and income potential of producers.

Non-adoption of farming practices developed from research findings by individuals occurs for many reasons, but it is typically the result of a logical thought process rather than an uninformed or unruly attitude (Vanclay & Lawrence, 2001, Linehan & Johnson, 2002). Shannon *et al.,* (1996) carried out a participatory learning program amongst cane growers in the Burdekin (Australia). In this study growers were encouraged to collect crop growth and water use data, which helped them in the understanding of the processes and problems and improved the credibility of the result.

In South Africa a limited number of studies (Annandale, vd Westhuizen & Olivier, 1996; Botha, Steyn & Stevens, 2000) referred to possible reasons for the low adoption of irrigation scheduling practices by farmers. Very often, the complexity of computerized systems is an obstacle to the implementation of irrigation scheduling. De Jager & Kennedy (1996) indicated that three levels of technology (high, intermediate and minimum) could be adopted for dissemination of irrigation scheduling advice. Koegelenberg & Lategan (1996) recommended the support of professional trained irrigation advisors in monitoring the soil water balance in the field. While these studies address some of the reasons for the slow adoption of irrigation scheduling, they however did not address the critical behavioural determinants, which according to Tolman (1967) and Düvel (1991) are immediate precursors of behaviour. This study endeavours to analyse and identify the possible socio-economic and human factors that influence the adoption of on-farm irrigation scheduling which will help us to identify what type of irrigation management information and technology in what format should be offered for optimum use by irrigation farmers.

1.3 THEORETICAL OVERVIEW

This literature overview provides a short discussion of the concepts innovation and an overview of the most important models of behaviour change.

1.3.1 Technical and social dimensions of innovations

In order to understand the innovation process, it is important that the reader has clarity of what exactly constitutes an "innovation" and what kind of process is needed to arrive at it. The traditional view of an innovation regards it as an idea, practice or technical product perceived as new by an individual and that is created in a research facility (Rogers, 1983). However, it is well known that many new ideas, products and processes developed within the research facility never reach the stage of being applied in everyday life (Little *et al.*, 2002).

Leeuwis (2004) proposes a more pragmatic conception of an innovation. According to him, an innovation is not only composed of novel technology or procedures, but also of new adapted human practices, including the conditions for such practices to happen. In other words, it may be "a new way of doing things" or even "doing new things", but it can only be considered as an innovation if it actually works in everyday life. Given that innovations consists of a package of social and technical arrangements, the design requires a multi-faceted process taking place at different point in time and space, and involvement of different set of actors (Leeuwis, 2004).

1.3.2 Models of behavioural change

According to Tolman (1967), human behaviour is intentional and governed by experience about the environment. In its simplest form it can be conceived as a type of movement brought about by forces from a system in disequilibrium (Düvel, 1990). This intentional nature makes human behaviour situation specific but also complex, which is inevitable as the same person at different situations make different decisions (Düvel, 1987).

Despite the dynamic nature of human behaviour, social scientists have managed to formulate conceptual constructs of behaviour change models, where important behaviour determinants have been identified that impact on effecting and maintaining behaviour change. Some describe it as various steps in learning while others simply describe it as stages in the problem-solving process. The following is an overview of different models and approaches for the purpose of assessing them with regard to their usefulness as models of behaviour analysis and intervention.

a) Traditional approaches

Albrecht (1964) quoted by (Düvel, 1991) recognized five distinguishable approaches namely, the teaching, socio-cultural, atomistic communication, socio-structural communication and the situation-functional in a critical analysis of adoption research development. Düvel (1991) emphasised the contribution of the situational-functional approach, which in contrast to the other approaches, regards behaviour change not as the cause of a single factor but rather as interplay of a number of dynamic inter-dependent factors.

b) Classical 5-stage adoption process (NSRC, 1955)

Adoption studies indicated that adoption of innovations is not something that happens overnight, but rather it is a final step in a sequence of stages. However the most widely used characterisation of stages in connection with the adoption of innovations derives from the North Central Rural Sociology Committee (1955). This model built heavily on the normative theories about rational decision-making and consisted of the following stages:

1. Awareness: where the individual become aware of an innovation or the problematic situation, and adequate information is required.

2. Interest: the individual becomes more interested in the new idea and seeks additional information.

3. Evaluation: the individual reflects on its advantages/disadvantages and mentally applies innovation to his present and anticipated future situation.
4. Trialling: where the individual test the innovation within his or her current situation.
5. Adoption or Rejection: individual seeks for reinforcement for the decisions made – apply innovation or behaviour changes.

This model assumes that the process starts with awareness of an innovation where people require and search for different kinds of information during each stage. The information requirements evolved from:

- Information clarifying the existence of tensions and problems addressed by the innovation;
- Information about availability of promising solutions;
- Information about relative advantages and disadvantages of alternative solutions;
- Feedback information from one's own or other peoples' practical experiences;
- Information reinforcing the adoption made.

This model illustrated several shortcomings with regard to the adoption process:

- Awareness of an innovation could either be problem-oriented or innovation oriented.
- As been mentioned, the normative models about rational decision-making, heavily influenced the original conception of the adoption process and its stages.

c) Campbell model (1966)

Campbell (1966) argues that many adoption stages are problem-oriented, whereby the individual becomes aware of a problem, then seeks solutions and consequently becoming aware. The decision to adopt or reject can be the result of either rational or non-rational decision-making process. According to Campbell (1966) the decision-maker may take up any of the four proposed paths for adoption (Figure 1.2)

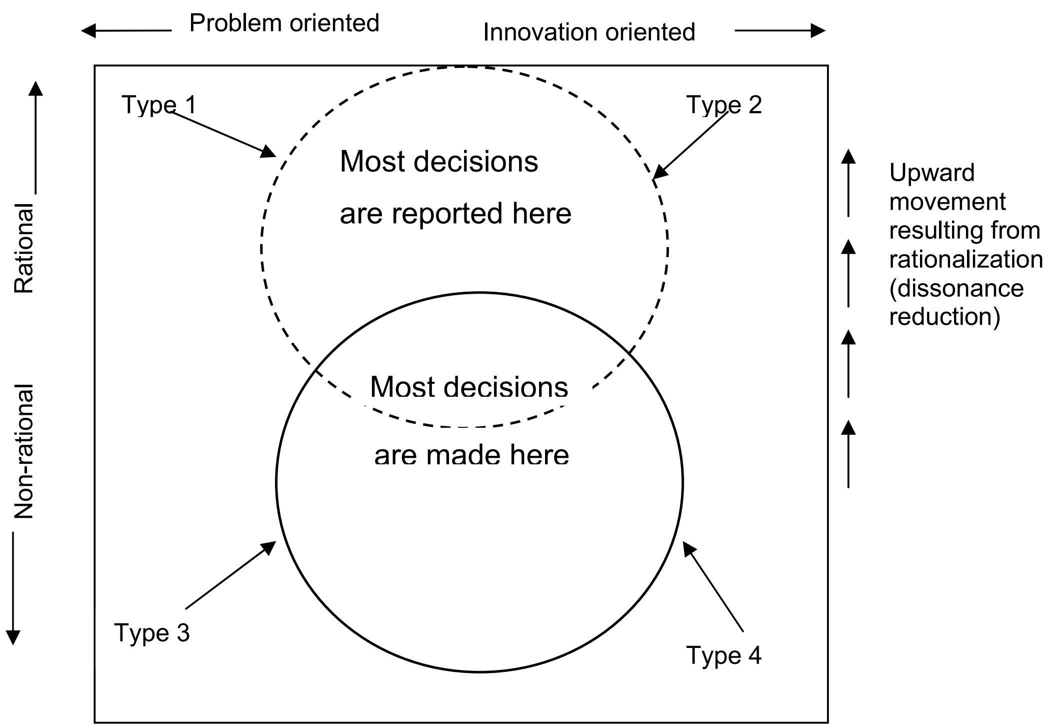

Figure 1. 2: A paradigm of individual decision-making and adoption (Campbell, 1966)

- *Rational-Problem Oriented*: Following stages:-problem ► awareness ►-evaluation ► rejection or trial ►adoption or rejection.

- *Rational–innovation Oriented:* Following stages:-awareness ►interest► evaluation ► rejection or trial ►adoption or rejection.

- *Non-Rational-Problem Oriented*: Following stages:- problem ►awareness► adoption or rejection ►resolution (including information seeking).

- *Non-Rational–innovation Oriented:* Following stages: -awareness►-adoption or rejection ►resolution (including information seeking).

Campbell (1966) is of the opinion that the majority of decisions fall between two extremes namely, "rational" and "non-rational" decision-making, since they have elements of both of them. "Rational" is defined as a process in which the possible alternatives and consequences of the decision are considered before any action is taken, whereas "non-rational" is any process that occurs without consideration of possible alternatives or consequences including impulsive decisions (Campbell, 1966). This model assumes that decision-making starts with a problem or a need, and the relative more rational offering of decision–making, also links to the cognitive dissonance theory of Festinger (1957).

d) Innovation Decision-Making Process (Rogers & Shoemaker, 1971; Rogers, 1995)

Rogers & Shoemaker (1971) and Rogers (1995) describe the innovation-decision process as a process through which an individual passes from first knowledge of innovation, to forming an attitude towards the innovation, to decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision. This model was developed taking into consideration principles of learning, theories of attitude change and decision-making and consist of the following stages:

- Knowledge: about the existence of a new innovation;
- Persuasion: shaping attitudes under the influence of others;
- Decision: adoption or rejection of the innovation;
- Implementation: adapting the innovation and putting it into use;

- Confirmation: seeking reinforcement from others for decisions made, leading to continuation or discontinuation.

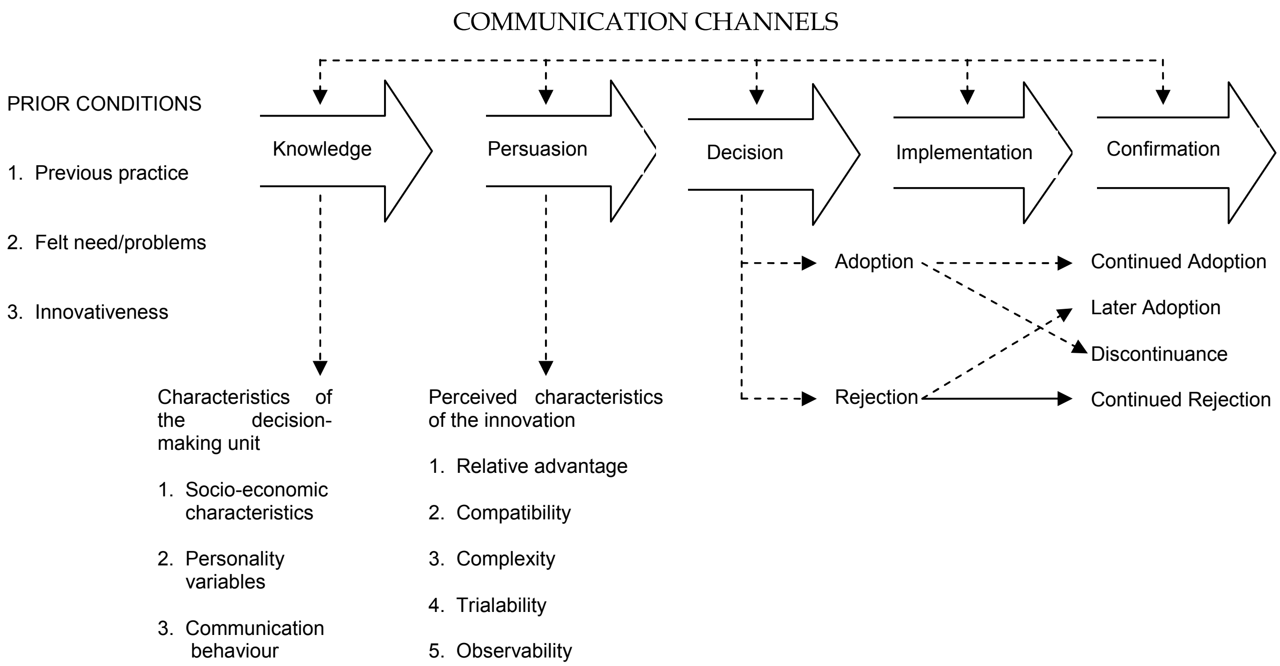

Figure 1. 3: The innovation-decision process (Rogers, 1983)

Düvel (1991) asserts that this model has successfully overcome the weakness of previous models except its shortcoming to offer guidelines in terms of how change can be directed or implemented. Since rational decision-making is often a practical impossibility, this model includes stages, which are less inspired by normative decision-making theory. De Klerk (1979) and Botha (1985) noted that although this model does not accommodate the decisive role of needs or problems in behaviour analysis, it is more flexible than the Classical 5 stage adoption model and therefore useful for behaviour analysis.

Rational decision-making still figures as an important step in the separation between the different stages of adoption in this model. Leeuwis (2004) is of the opinion that this approach of decision-making as described by Rogers (1983) is logically connected with the idea that adoption of innovations is largely an individual affair. Leeuwis (2004) is of opinion to rather start with the assumption that an innovation is a collective process, where other key processes like social learning become important when thinking about adoption.

e) The Psychological Field Theory of Lewin (1951)

According to Düvel (1974), de Klerk (1979) and du Plooy (1980) the model of Lewin (1951) is a most appropriate model and conceptual framework for the behaviour analysis especially from an extension point of view.

The central element of this model is a life space or psychological field in which a person exists. One of the basic principles of the psychological field theory is the principle of contemporary, which states that any behaviour or any change in the psychological field depends on the forces that operate in the psychological field at that time (Lewin, 1951). Anything in a situation that is perceived by the person as a goal, or as a path or barrier to a goal, is understood as a force operating on the person's behaviour. Behaviour (B) is a function of the person (P) in the perceived environment (E).

$$\mathbf{B=f\ (P,\ E)}$$

The factors of both the environment (E) and the personality (P) can become behavioural determinants, which are interdependent according to Lewin (1951). Thus the same facts and objects of the environment or personality may cause different actions.

This model assumes that the basic motivation for every organism is to maintain equilibrium. A disturbed equilibrium is experienced as need tension, i.e. felt need to reduce the tension. In this state the person tends to mobilize forces or energy to reduce the tension and re-establish equilibrium under the given conditions. The effects of the felt tension on perception, cognition and action are therefore such as to change the field in order to restore the tension-reduced situation.

Behaviour change or the lack thereof is in principle explainable by the “force field’ that causes action. Change can be brought about and directed by changing the force field i.e. by adding or strengthening “driving forces” (positive forces) and by weakening or eliminating “restraining forces” (negative forces). According to this field theory, a person who finds himself in a relatively stable situation may assume a new behaviour if and only if this seemingly stable situation (equilibrium) is disturbed and need tension (dissonance situation) is created. In an attempt to eliminate or reduce need tension and re-establish a new equilibrium, the person starts from phase 1 where the pressure of positive forces (driving forces) outweigh the opposite pressure from restraining forces (barriers or negative forces). The movement continues to a level or until a new equilibrium is reached (Figure 1.4).

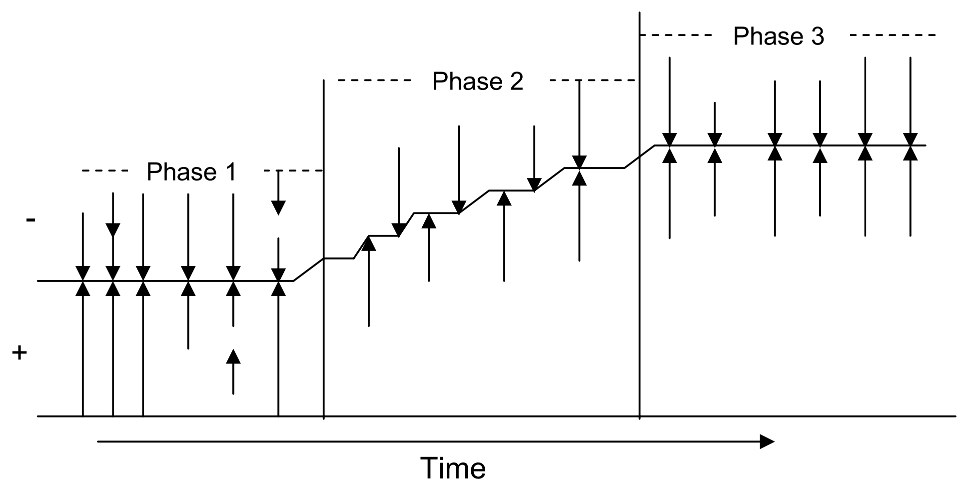

Figure 1. 4: Behaviour change model of Lewin (1951) (Düvel (1974)

According to Düvel (1991) the practical advantages of the model are as follow:

i. It provides a conceptual framework in terms of which the complexity of any real life situation, in respect of behavioural relevant factors, can be analysed.

ii. The theory is not limited to change but also explains non-change. It provides guidelines for situation analysis as well as for the planning of change and for evaluation.

iii. It can also be used for the analysis of greater social units like groups of clients and organisations.

iv. The model is relatively easy and simple to understand with the exception of the mathematical descriptions and quantifications because of familiar concepts and principles used in the model.

This field theory of Lewin (1951) makes provision as to how behaviour change can be brought about, by restricting the causes of behaviour to the psychological field. This model sufficiently overcomes the weakness of the process-centred behaviour models, and was used by Düvel (1974) to analyse behaviour change. He reached the conclusion that perception is an immediate precursor of behaviour change.

f) Tolman model (1967)

The theory of Tolman (1967) is a mixture of behaviourism and combination of aspects of cognition and intension. According to Düvel (1991) this theory makes a valuable contribution to behaviour analysis, since Tolman (1967) is the person who introduced the concept of intervening variables.

The immediate precursor to action is the "behaviour space" which Tolman (1967) defines as "a particularised complex of perceptions as to objects and relations and the behaving self", evoked by the given environmental stimulus situation and by a controlling and activated belief–value matrix which implies a mental trial-and error behaviour. Tolman (1967) differentiates according to his model, three sets of variables, namely independent, dependent and intervening variables (Figure 1.5)

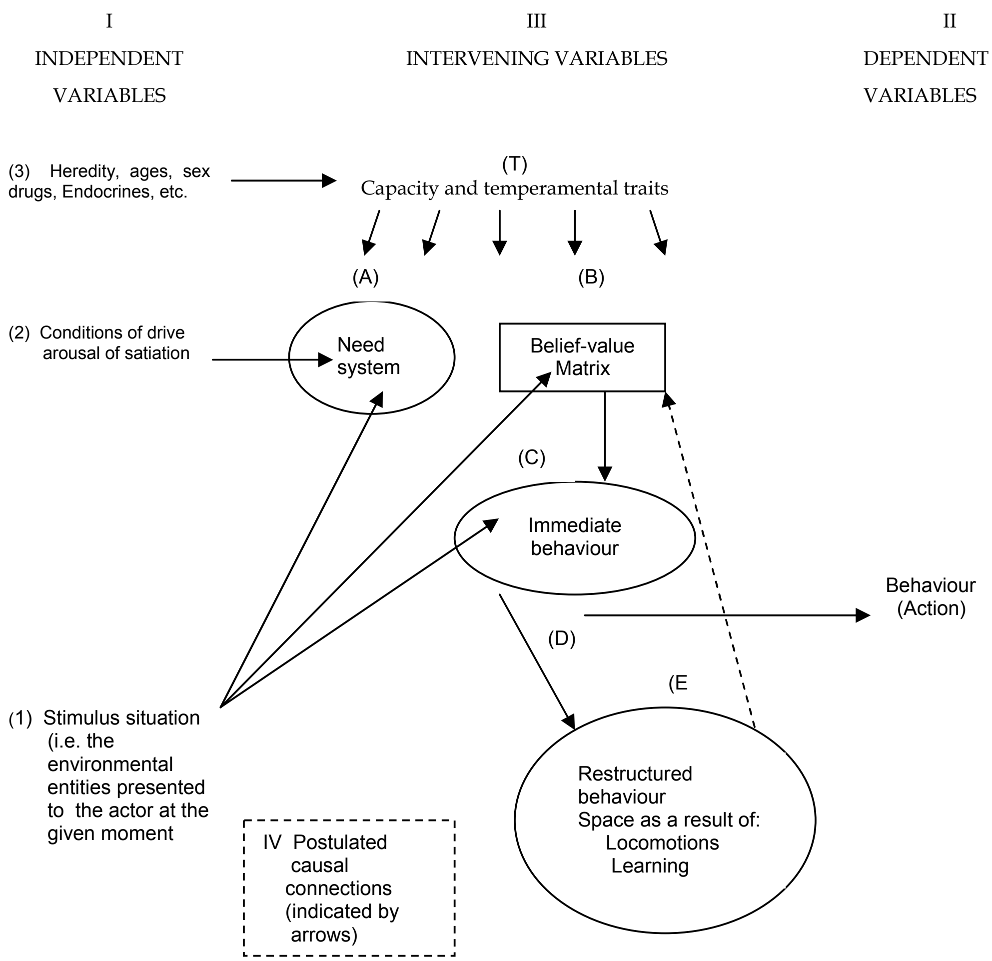

Figure 1. 5: The Tolman model (1967)

Tolman (1967) regarded both independent and dependent variables as observable, as opposed to intervening variables, which he identified as the motives of behaviour and which are not observable. The intervening variables are postulated explanatory entities conceived to be connected by one set of causal functions to independent variables, on the one side, and by another set of functions to the dependent variable of behaviour, on the other side, as illustrated in Figure 1.5.

According to Düvel (1991), Tolman's theory seems a successful combination of the majority of modern theories. Amongst others, it accommodates Lewin's field theory (1951), as well as the similarities between Tolman's "behaviour space" and Lewin's "psychological space". Düvel (1991) indicated that the intervening variables as part of the behaviour space as defined by Tolman (1967), provide the potential to distinguish between direct and indirect causes of behaviour.

g) Fishbein and Ajzen's attitudinal determinants of behaviour

The model that Fishbein and Ajzen (1975) use to describe the determinants of behaviour is called Theory of Reasoned Action (TRA). This model has been developed to determine how attitudes and beliefs are related to individual intention to change their behaviour. According to TRA, as presented in Figure 1.6, attitude towards behaviour is determined by behavioural beliefs about the consequences of behaviour (based on the information available or presented to the individual) and the affective evaluation of those consequences on the part of the individual. Most people hold both positive and negative beliefs about an object, and attitude is viewed as corresponding to the total affect associated with their beliefs. Beliefs are defined as the individuals estimated probability that performing a given behaviour will result in a given consequence. The totality of a person's beliefs serves as the informational base that ultimately determines his attitudes, intentions and behaviours. They elaborated that the performance or non-performance of a specific behaviour with respect to some object usually cannot be predicted from the knowledge of the person's attitude toward the object. Instead, a specific behaviour is viewed as determined by the person's intention to perform that behaviour.

According to Fishbein & Ajzen (1975), a person's intention is the function of beliefs concerned with the behaviour and not about the object. Some of these beliefs may influence a person's attitude toward his behaviour. Affective evaluation is an "implicit evaluation response" to the consequence (Fishbein & Ajzen, 1975). This represents an information processing view of attitude formation and change which states that external stimuli influence attitudes only through changes in the person's belief structure (Ajzen & Fishbein, 1980)

Thus, the Theory of Reasoned Action provides a rationale for the flow of causality from the external stimuli (such as the design of an irrigation scheduling device or practice) through user perception to attitudes about the technology, and finally the actual behaviour (Fihbein & Ajzen, 1975). This theory is based on the assumption that human beings are usually quite rational (reasoned action) and they consider the implication of their action before deciding to engage or not to engage in a given behaviour (Ajzen& Fishbein, 1980). A person's intention is assumed to capture the motivational factors that have an impact on behaviour. According to the TRA, a person's intention is a function of two basic determinants, the one personal in nature (the individual's positive or negative evaluation of performing the behaviour), which is referred to as "attitude towards behaviour" and the other reflecting the social influence, called subjective norms.

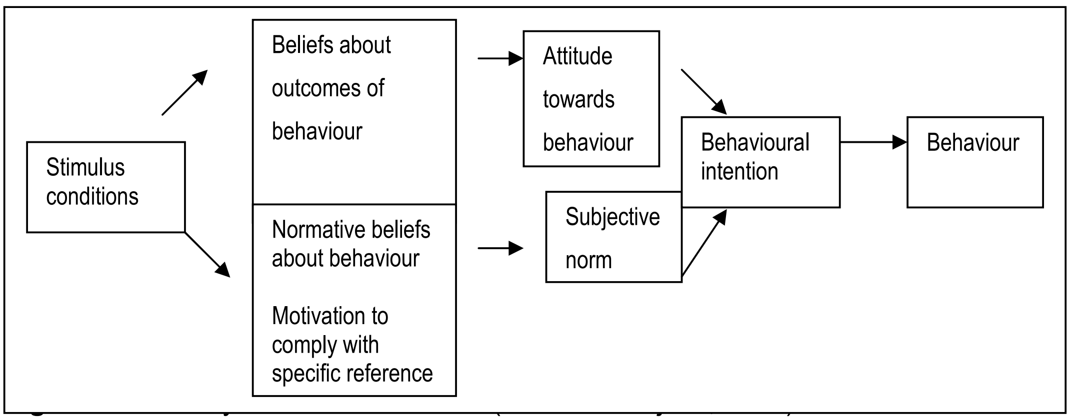

Figure 1. 6: Theory of Reasoned Action (Fishbein & Ajzen, 1975)

The analysis of behaviour by Fishbein & Ajzen (1975) however does not make reference to the role of intervening and independent variables suggested explaining behaviour as was done by other behaviour analysts. They however recognise that factors like personality characteristics and personal variables belong to the "external variables" whose influence is indirect (Ajzen & Fishbein, 1980). They are of the opinion that these variables have an effect on behaviour only to the extent that it influences the determinants of that behaviour and not directly the behaviour itself. This association of independent variables to an only indirect influence on behaviour is very similar to the view of Tolman (1967).

h) The Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) as described by Davis (1989) is derived from the TRA model and predicts user acceptance based on the influence of two factors: perceived usefulness and perceived ease of use of technology. TAM hypothesizes that user perceptions of the usefulness and ease of use determine attitude towards the use of an innovation or technology. Consistent with TRA, behavioural intentions to use an innovation is determined by the attitudes towards the specific innovation. According to the model, the behavioural intentions to use in turn determine actual use of the innovation. This model proposed that a direct relationship between perceived usefulness and behavioural intentions to use technology exists (Figure 1.7).

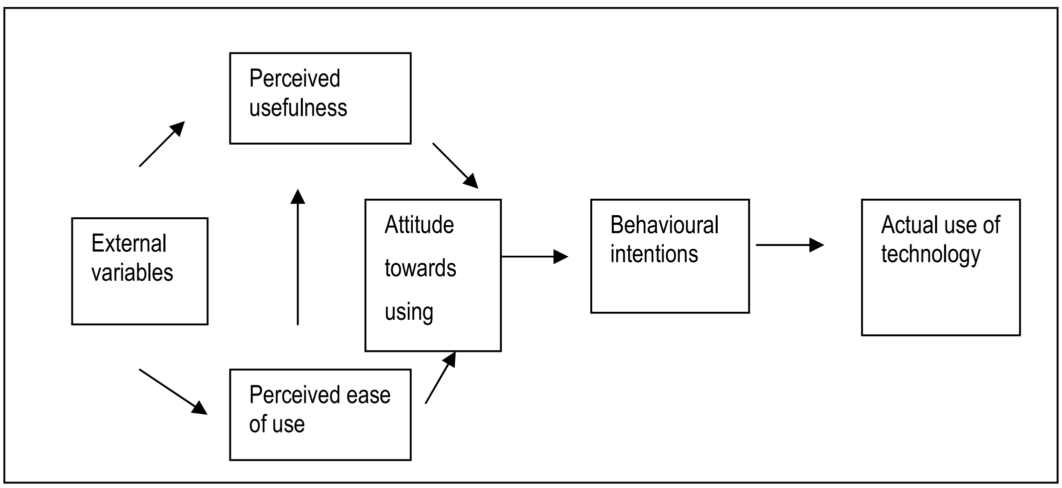

Figure 1. 7: Technology acceptance Model (Davis *et al.,* 1989)

Within TAM, perceived usefulness is defined as the degree to which a user believes that using the technology or innovation will enhance his performance. Perceived ease of use is defined as the degree to which the user believes that using the system will be free from effort. Both perceived usefulness and perceived ease of use are modelled as having a significant impact on the user's attitude towards the innovation. Behavioural intentions to use are modelled as a function of perceived usefulness and perceived ease of use, and therefore determine the actual use of the innovation. Research by Davis *et al.,* 1989; Taylor & Todd, 1995) has consistently shown that behaviour intention is the strongest predictor of the adoption of an innovation.

According to Davis (1989), there exists a direct effect of perceived ease of use on perceived usefulness. In other words, between two technologies that are offering identically functionality, a user should find the one that is easier to implement more useful. Davis (1993), with reference to the use of computer systems states “making a system easier to use, all else held constant, should make the system more useful. The converse does not hold, however”.

As this model is based on the principles of TRA, the shortcomings of this model with reference to the role of intervening variables in behaviour analysis are also applicable. These authors like Fishbein & Ajzen (1975) classified the personal variables as external variables in their model. The goal of the development of TAM is to predict information system acceptance and diagnose design problems before users have any significant experience with a computer system (Davis, 1989). TAM has been found to be extremely robust and has been replicated using different tasks and tools (Adams. *et al.,* 1991). In comparison with other models, Mathieson (1991) found that TAM predicted intention to use for instance a spreadsheet package, better than alternative models. The value of TAM lies in its parsimony - the model is strongly grounded in existing psychological theories, yet it is relative easy to apply (Mathieson, 1991)

i) Düvel’s Behaviour Analysis Model

Based on the findings of Tolman (1967) and Lewin (1951), the concepts of intervening variables as part of the behaviour space and the role of field psychological forces helped Düvel (1975) to establish a conceptual framework for identifying the most significant causal factors that determine human behaviour. The aim with this model is to provide a checklist that is surveyable and still sufficiently comprehensive to make provision (directly or indirectly) for all causes of behaviour. He states that “although the classification of behaviour determinants on the basis of potentially direct and indirect influence on behaviour is reasonably clear, there is no clear cut boundary”.

Louw & Düvel (1993) indicated that the model (Figure 1.8) drastically reduced the field forces in accordance with Tolman’s view (1967) of the concept of intervening variables, to certain behaviour determinants that are more intervening and mediating in nature and thus represent the more direct precursors or causes of adoption behaviour, while the influence of independent variables are manifested through these intervening variables. The intervening variables perception, needs and knowledge have been identified to be immediate and direct precursors of human behaviour or decision-making. Perception and needs are identified to be more immediate determinants of behaviour. The use of intervening variables as predictor of human behaviour has been tested extensively (Düvel, 1975; Louw & Düvel, 1978; de Klerk & Düvel, 1982; Düvel & Scholtz, 1986; Botha, 1985; Düvel & Botha, 1990).

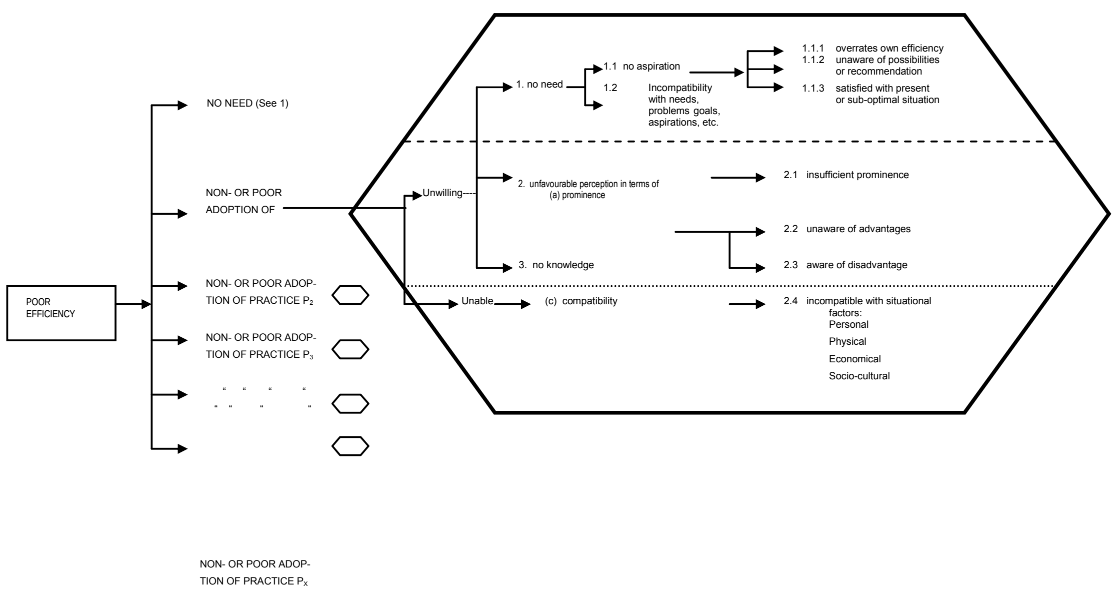

Figure 1. 8: Düvel’s behavioural analysis model (1975)

According to Düvel (1989) the major advantages of using intervening variables for behaviour analysis and intervention are the following:

- They are direct determinants of behaviour, the logical focus of intervention, and consequently also the logical criteria of evaluation.

- These determinants will, if properly monitored, reveal why or why not change has occurred. Also progress with regard to the adoption of proposed practices could be monitored, and adaptations could be made where needed.

The literature review showed that researchers have used both hard and soft system approaches in an attempt to explore the influence of engineering, technical, socio-economic and demographic factors as important for behaviour changes. Although these approaches partially addressed reasons for the adoption or rejection of irrigation scheduling methods, it did not address the role of critical decisive intervening factors like needs, knowledge and perception in behaviour determination. The main objectives of this study are to determine the implementation status of on-farm irrigation scheduling and possible reasons responsible for implementation or discontinuing of irrigation scheduling by irrigation farmers. Düvel's behavioural analysis model (1975) and the Technology Acceptance Model (TAM) as described by Davis (1989) were selected to meet these objectives of this study i.e. it provides a frame of reference and directives for the collection and analysis of data to answer the research questions raised in this study.

1.4 TOWARDS THE FORMULATION OF HYPOTHESES

Against the conceptual framework of this study as discussed in this chapter, the following research hypotheses emerge:

Hypothesis 1:

The implementation of on-farm irrigation scheduling practices is determined by independent and intervening variables.

Hypothesis 1.1:

There is a significant relationship between independent personal and environmental factors and the implementation of irrigation scheduling.

Hypothesis 1.2:

There is a significant relationship between intervening variables (perception, knowledge and needs) and the implementation of irrigation scheduling.

Hypothesis 2:

More precise irrigation scheduling offered by scientists is perceived to improve production efficiency.

Hypothesis 3:

The technology level of farmers and the specific farm business characteristics determine irrigation farmers' approach to problem solving and learning.

Hypothesis 4:

Competent ground level support by research and extension professionals is conducive for the implementation of irrigation scheduling.

Hypothesis 5:

Effective research-extension-farmer dialogue is necessary for the improvement of implementation status of irrigation scheduling practices on-farm.

1.5 OBJECTIVES

The research questions that steered this study consist first of all of the identification and classification of the spectrum of soil-atmosphere-plant irrigation scheduling methods and techniques that are available for the use by irrigators, researchers and extensionists in irrigation management in South Africa.

The second research question to be answered was to determine the current adoption or implementation of irrigation scheduling methods and techniques by both small-scale and commercial irrigation farmers on the various irrigation schemes and to determine the human and socio-economic factors that influence the implementation of irrigation scheduling methods and techniques. Part of the second research question was to identify whether the information offered through the implementation of objective scheduling methods was perceived by the farmer to add value to the management decisions made by irrigation farmers.

The identification of networking and information sources that irrigation farmer's use in their effort to learn more about irrigation management formed the third research question. The study is not aiming at questioning the validity of science, but rather the usefulness that science has for practical irrigation management of irrigation farms. Important questions at this level are appropriate levels of precision in technology and management, and the value of more accurate soil water status information for irrigation management purposes.

The specific objectives of the research aimed at answering the above research questions are therefore as follows:

1. To review concepts of behaviour change and models with a view to assess their potential use as conceptual models appropriate for behaviour analysis and intervention.

2. Identify and quantitavilely describe and classify the spectrum of soil-atmosphere-plant irrigation scheduling methods and techniques used in South Africa.

3. Investigate, analyse and describe the levels of implementation of irrigation scheduling models and methods by a cross section of smallholder and commercial farmers.

4. Investigate, analyse and describe the possible reasons from a cross section of smallholder and commercial farmers for using the different irrigation scheduling methods and models.

5. Investigate, analyse and describe why irrigators discontinue with the implementation of irrigation scheduling.

1.6 AN OVERVIEW OF THE THESIS STRUCTURE

The thesis has been structured in such a way as to ensure adherence to the fact that the concepts presented within the document must flow logically from one part to the next in order to maximise reader comprehension of the various topics presented. In order to ensure that, the individual chapters of this thesis have been grouped together in seven separate parts namely:

- Part 1: Consist of the scope of the research and an overview of the role of irrigation scheduling in the general improvement of on-farm irrigation management and specifically for increasing water use efficiency. It provides a quantitative description and classification of the atmosphere-plant spectrum of soil-irrigation methods and techniques used by irrigation farmers, researchers and extensionists in South Africa.

- Part 2: A quantitative assessment on a national basis among irrigation schemes (macro level) which provides an overview of the current state of irrigation scheduling and factors that influence the implementation of irrigation scheduling methods and models among commercial and small-scale farmers.

- Part 3: Identification and analysis of the possible human and socio-economic factors amongst commercial farmers that influence the adoption of irrigation scheduling practices on the farm (micro) level.

- Part 4: Identification of possible human and socio-economic factors that influence the implementation of irrigation scheduling practices by small-scale irrigation farming through semi-structured interviews with irrigation professionals and case studies of small-scale irrigation farming.

- Part 5: Consists of a detailed analysis of knowledge information systems used by commercial and small-scale irrigation farmers to learn about irrigation scheduling and investigate the supportive role that irrigation consultants and advisors play in the implementation of irrigation scheduling.

- Part 6: Recommendations are provided for the propagation and institutionalising of irrigation scheduling methods and areas for further research are identified.

CHAPTER 2

DESCRIPTION AND CLASSIFICATION OF IRRIGATION SCHEDULING METHODS AND TECHNIQUES

2.1 INTRODUCTION

Every irrigator practises some form of irrigation scheduling. The basis for irrigation scheduling and the level of sophistication vary enormously. It ranges from irrigation based on the experience of the farmers (intuition) and application of simple rules, to the practice of techniques based on computer models and sophisticated instruments that can assess soil, water and atmospheric parameters.

Various strategies for scheduling may be adopted depending on the crop response to water stress, the water holding properties of the soil, the availability of irrigation water, and the limitations of the irrigation application system. Basic scheduling methods normally involve either soil-water budgeting or the monitoring of a single component of the soil-plant-atmosphere continuum. Most irrigation scheduling methods imply that the soil water balance needs to be quantified. To be able to do that, the soil-plant-atmosphere continuum needs to be taken into account as quantitatively as possible. The following section alludes to various irrigation scheduling approaches that attempt to integrate a quantitative description and the classification of the spectrum of soil-atmosphere-plant irrigation scheduling methods and techniques most commonly used by irrigators, researchers and extensionists in South Africa.

2.2 RESEARCH METHODOLOGY

This chapter outlines the methodology adopted to identify and classify the various irrigation scheduling approaches from which irrigation farmers, researchers and extensionists in South Africa can select to assist them with more informed irrigation scheduling decisions. Orientation and planning of this part of the study commenced in 2000 and the purpose for this part of the study was to obtain a clear picture of the technology level available, time required for the collection and interpretation of irrigation data, approximate cost of the irrigation scheduling equipment and potential users of the various methods and computer scheduling models and programs available. This information was not only imperative for the research team to be able to describe, contextualise and understand the choices available for the different managerial needs of irrigation farmers, but was also used for the categorising of the irrigation scheduling aids in an attempt to help farmers, extensionists and researchers in their selection and decision making in this regard. Since the development of a category of irrigation scheduling approaches had not been done for South Africa, various opinion leaders in irrigation management were consulted before this part of the study was started.

A comprehensive literature review was done to identify basic scheduling methods normally involved with either soil-water budgeting or the monitoring of a single component of the soil-plant-atmosphere continuum. This literature review made use of various information sources namely books, conference proceedings, journal articles, newspaper and magazine reports, industry information brochures and internet resources to mention a few. The literature review was much more than the collection of texts, but involved a review of the existing “scholarship or available knowledge” (Mouton, 2001) on the various scheduling approaches. Data on some of the older and more subjective irrigation scheduling methods like Scheeperspan, use of intuition, observation of plant stress, pegboard method, etc was not readily available in the literature and could only be retrieved with the help of key informants through face-to-face interviewing. The classification and qualitative description of irrigation scheduling methods helped the research team to be well informed about the range of research products that are available for potential users in South Africa.

This was followed by wide consultation of key informants in South Africa and abroad (i.e. Australia). The first step was to identify key informants from the irrigation industry (which included retailers and experts from the irrigation industry, irrigation engineers, irrigation scientists from universities and technicons in South Africa involved with irrigation scheduling, researchers from the ARC, developers and designers of irrigation scheduling models, equipment like weather stations and soil water content monitoring devices. A qualitative approach was followed where key informants were interviewed using the face-to-face research method. Data was collected through semi-structured conversations held with them on the specific methods or models in use or which they are familiar with, in an effort to collect as much information and insights possible. The information collected through the literature review served as a discussion document during these interviews together with relevant open-ended questions. Several of the irrigation consultants, extensionists and designers that were selected for the semi-structured interviews as referred to in Part Five (Chapter 19), also participated in this part of this study.

The face-to-face interviews with various key informants was followed by focus group discussions as part of the meeting arranged for steering committee members during annual progress report meetings conducted by the WRC. Since this study was funded by the WRC, regular annual meetings of the steering committee in Pretoria at the WRC headquarters and telephone and Internet (e-mail) discussions took place. The members who were strategically selected to represent different interests of the industry and served on the steering committee of the WRC for this project from 2000 till 2005 appear in Table 2.1.

This focus group helped to steer the research and categorising of scheduling approaches through their critical evaluation and discussions. In addition to the members listed in Table 2.1, Prof. Richard Stirzaker (CSIRO, Australia) was visited and contacted on a regular basis. Their valuable and appreciated vision and insight helped tremendously in the final categorising of the approaches. The main advantage of the focus groups was the opportunity to observe a large amount of interaction on irrigation scheduling approaches over a wide spectrum of users in a limited period of time.

Table 2. 1: List of persons serving on the steering committee as selected by the WRC (2000-2005)

Name of steering committee members	Institution
Dr G Backeberg	Water Research Commission, South Africa
Prof GH Düvel	University of Pretoria
Prof GJ Steyn	University of Pretoria
Prof JG Annandale	University of Pretoria
Prof GCG Fraser	University of Fort Hare
Mr JLH Williams	University of Fort Hare
Prof ATP Bennie	University of Free State
Mr FPJ van der Merwe	Department of Water Affairs and Forestry
Dr NZ Jovanovic	University of the Western Cape
Mr FJ du Plessis	Murray, Biesenbach & Badenhorts Consulting Engineers
Mr NMP Opperman	Agri South Africa
Dr SS Mkhize	Water Research Commission, South Africa
Mr AT van Coller	National Department of Agriculture

The final draft of the categorisation of irrigation scheduling approaches was distributed amongst steering committee members, some of the more progressive irrigation farmers, irrigation extensionists and consultants before finally adopted as a possible classification of irrigation scheduling methods and models available for use by South African irrigation farmers.

2.3 CLASSIFICATION OF IRRIGATION SCHEDULING MODELS AND METHODS

The following chapter refers to the classification of the various irrigation scheduling methods and tools that are commonly used and quantitatively described in Section 2.4. There is a spectrum of soil-atmosphere-plant irrigation scheduling methods and techniques available that users can select from to help them to assist with the decisions to be taken to ensure that peak crop growing conditions prevail by holding soil water content at the optimum level. To assist making a decision on choosing the correct method, the potential users should ask the following questions?

- How much time can I spend on using the specific method or device and what time is needed for interpretation?

- What level of technology am I comfortable with?

- How much money am I willing to spend?

- What level of technical and maintenance support is available?

- The soil variation on the property will also influence the number of units required if soil water content is to be measured?

Taking into account the above-mentioned questions generally asked by potential users, the following principles were used for the classification of the various irrigation scheduling methods as indicated in Figure 2.1:

- First principle was to identify and distinguish between the various soil, plant and atmospheric based irrigation scheduling methods available to try and quantify the soil-plant-atmosphere environment. The spectrum of potential soil-plant-atmosphere scheduling methods and devices identified vary from very simple methods up to scheduling methods where a computer is needed to analyse and view data.

- The second principle was to identify and distinguish between the various integrated soil-water balance methods available for users. These methods available included both pre-programmed irrigation scheduling methods as well as real time irrigation scheduling methods, where daily accounting of the soil water balance is done with the use of sophisticated measuring equipment and the use of computer programs and /or in combination with the use of scheduling simulation models.

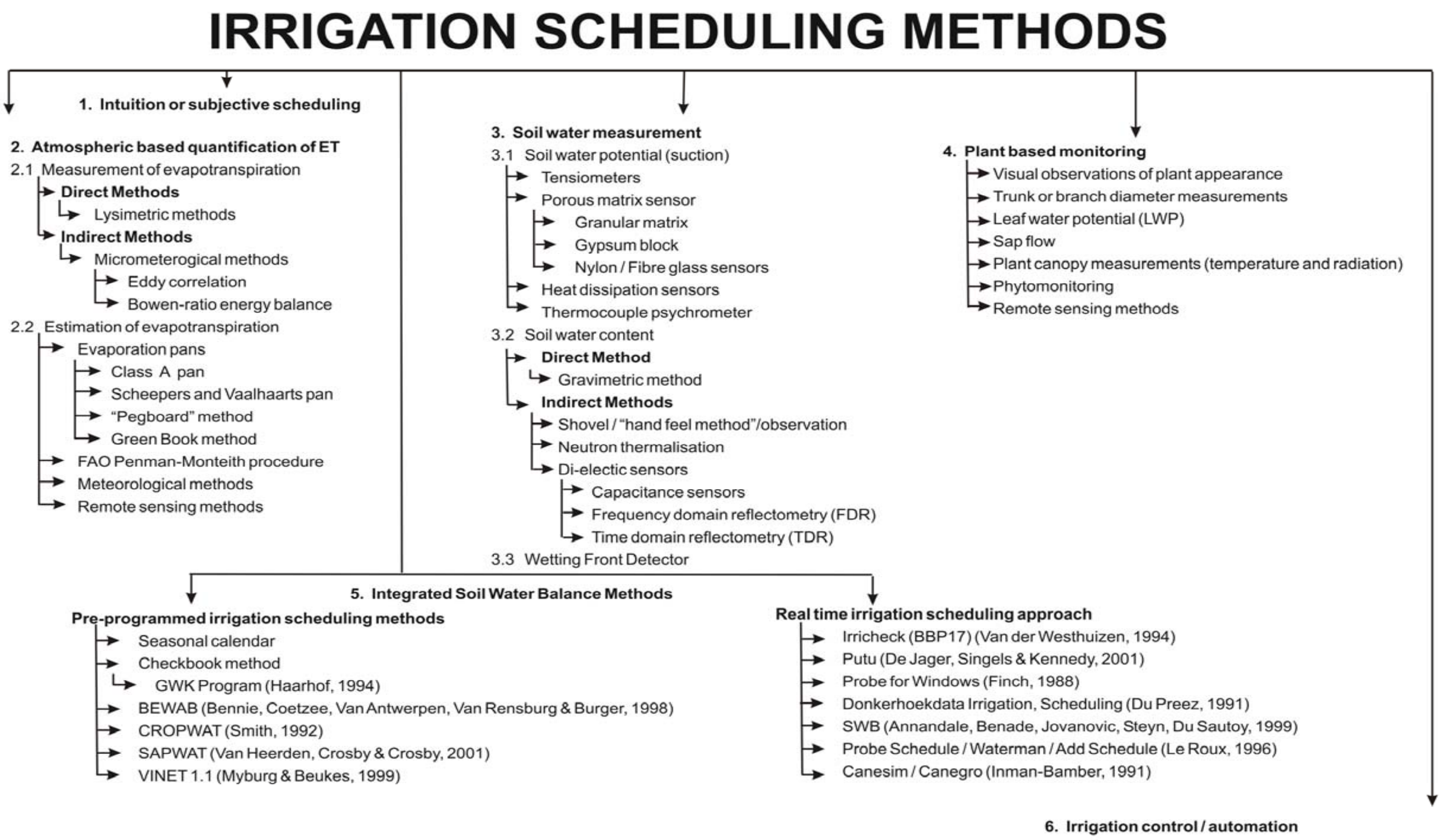

Figure 2. 1: Classification of irrigation scheduling models and methods used in South Africa

It is realised that any attempt to classify the spectrum of soil-plant-atmosphere irrigation scheduling methods and approaches will to a certain degree display the sentiments and objectives that are important to the designer of such a classification, and therefore also this attempt is realised to reflect just that.

2.4 DESCRIPTION OF IRRIGATION SCHEDULING METHODS AND MODELS USED BY IRRIGATORS

The following irrigation scheduling approaches (Figure 2.1) are often used by irrigators of, which some will be transferable to farmers while others will be considered as research tools.

2.4.1 Intuition or subjective scheduling methods
2.4.2 Atmospheric based quantification of evapotranspiration (ET)
2.4.2.1 Measurement of ET
2.4.2.2 Estimation of ET
2.4.3 Soil water measurement:
2.4.3.1 Soil water potential
2.4.3.2 Soil water content
2.4.3.3 Wetting Front Detector
2.4.4 Plant based monitoring
2.4.4.1 Visual observation of plant appearance
2.4.4.2 Trunk and branch diameter measurement
2.4.4.3 Leaf water potential (LWP)
2.4.4.4 Sap flow
2.4.4.5 Canopy measurements (temperature and radiation)
2.4.4.6 Phytomonitoring
2.4.4.7 Remote sensing methods
2.4.5 Integrated soil water balance methods:
2.4.5.1 Pre programmed irrigation scheduling methods
2.4.5.2 Real-time irrigation scheduling methods
2.4.6 Irrigation control or automation

2.4.1 Intuition or subjective irrigation scheduling

Description It varies from where a crop is watered whenever the farmer or his "irrigation manager" fancies it, to irrigation scheduling managed by "the seat of the pants". Intuition is developed over years of experience plus a basic knowledge level and regular close observation of plant, soil and climate characteristics. The producer has enough experience with a specific crop to determine what the irrigation need is, how much and when to irrigate. There are two types of intuition that farmers apply: the one decision-making criteria is developed by irrigation farmers as a result of years of past experience and intimate contact with the crop, soil, and climate and is mostly applicable to one set of farming circumstances (therefore based on knowledge gained through experience) while the other type of intuition is based on traditional practices used by their father or other role players on the farm (more of a recipe).	
Mode of operation	Intuitive
Advantages: This type of irrigation scheduling management is thought to be remarkably accurate, but no evidence was found or documented about testing for accuracy.	
Shortcomings: Inexperienced farmers lack the necessary skills and knowledge to observe and interpret findings into a "workable" recipe for a specific farm.	
Users: Farmers (small-scale and commercial).	

2.4.2 Atmospheric based quantification of evapotranspiration (ET)

Irrigation scheduling based on estimating evapotranspiration is used worldwide and microcomputer capability has vastly improved this technology. This approach follows a meteorologically imposed evapotranspirational demand as it varies over time, and the irrigation requirements are determined accordingly. This technique requires the use of both an empirical or physically based relationship between ET and any number of meteorological variables. Irrigation scheduling using these techniques requires both the estimation of the evapotranspiration and the incorporation of this information in some form of soil-water balance model to predict the interval of watering (Burman *et al.*, 1983). When running a water balance, one obtains ET either through measurements or from estimates. The ability to quantify evaporation from the bare soil and to partition evapotranspiration from soil covered with vegetation into its two components – evaporation (from soil) and transpiration (from plants), is critical to irrigation scheduling.

The drawbacks of this scheduling technique include the development of appropriate crop coefficients suited for different areas and crop types, and the unavailability of computing facilities to small-scale farmers.

2.4.2.1 Measurements of evapotranspiration

A. Direct method

2.4.2.1.1 Lysimetric methods

B. Indirect methods

2.4.2.1.2 Micrometeorological methods:

- Eddy correlation
- Bowen-ratio

A. Direct method

2.4.2.1.1 Lysimetric methods

Description
Direct measurement of ET for time periods when no rain or irrigation occurs is only possible with a weighing lysimeter. A weighing lysimeter measures the mass of the soil water (along with the soil and plant mass), hence any temporal changes in mass are attributed to water uptake and transpiration by plants or evaporation from the soil (or plant) surface. Most weighing lysimeters range from 0.5 to 2.0 m deep and the surface area they cover is in the order of 0.1 to 10 m^2. Because of their large mass they are generally weighed *in situ*. Two methods for measuring evaporation of water from small bare areas of soil are: the evaporimeter tray and the microlysimeter.

<table>
<tr><td colspan="2">Validity of any lysimetric method of determining evaporation hinges on whether the evaporation from the isolated body of soil is essentially the same as from a comparable non-isolated body. A number of factors can cause conditions in a lysimeter to deviate from reality:
❑ Imposition of a water table at the bottom of the lysimeter
❑ Cuttings of roots by the lysimeter walls
❑ Disturbance of the soil inside the lysimeter during construction, and conduction of heat by the lateral walls.</td></tr>
<tr><td>Mode of operation</td><td>Weighing lysimetric method</td></tr>
<tr><td colspan="2">Advantages:
❑ The microlysimeters are very accurate to within 0.5 mm cumulative evaporation for at least one to two days, depending on the initial soil wetness. Microlysimeters can be used at a large number of locations where the cost of the larger lysimeter is sometimes prohibitive.
❑ The two methods mentioned, namely the evaporimeter tray or atmometer tray and the microlysimeter have the advantage that they could be used for measurement in situations for which the spatial resolution of traditional lysimeters is too large.</td></tr>
<tr><td colspan="2">Shortcomings:
❑ It is an expensive method.
❑ Time consuming.</td></tr>
<tr><td colspan="2">Users:
Mainly used by researchers to determine real time ET, and for irrigation scheduling purposes.</td></tr>
</table>

B. *Indirect methods*

2.4.2.1.2 Micrometeorological methods:

- **Eddy correlation**

<table>
<tr><td colspan="2">Description
❑ The Eddy correlation and the Bowen-ratio are some of the micrometeorological measurements used for ET measurements near the land surface (i.e. a few meters above the plant canopy) to determine the fluxes of energy, momentum or trace gases. The techniques allow total evaporation to be measured by placing most of the sensors in the atmosphere and are more “portable” than buried sensors (viz. lysimeters).
❑ The Eddy correlation method has gained predominance among micrometeorological methods recently because of its minimal theoretical assumptions and improved instrumentation (Shuttleworth, 1993).
❑ Eddy correlation measurements are based on the correlation between turbulent motions of the air, and the abundance of constituents being transported by turbulent motions (e.g. heat or water vapour) (Campbell & Norman, 1998). The average vertical wind speed above a flat land surface is considered to be zero, because the ground surface is neither a source nor sink for air; therefore, for heat to move from the surface into the atmosphere, the upward motions of turbulence must be warmer than the downward motions. Similarly, for water vapour to undergo turbulent transport from the land surface up into the atmosphere, upward air motions must be more humid than the downward motions.
❑ The correlation between fluctuations in vertical wind speed and humidity is positive during evaporation, and during frost or dew the correlation is negative. The Eddy correlation method uses high frequency (~ 10 Hz) measurements of vertical wind speed, temperature, and humidity to compute the correlation between vertical air motions and the constituent of interest. The flux is then computed directly from this correlation (Shuttleworth, 1993).</td></tr>
<tr><td>Mode of operation</td><td>Measurement of eddies</td></tr>
<tr><td colspan="2">Advantages:
❑ The most direct measurement of sensible and latent heat fluxes is possible with micrometeorological methods (Shuttleworth, 1993).</td></tr>
</table>

- The Eddy correlation methods agreed better with lysimeter measurements than Bowen ratio measurements do, since the low evaporation rates from the play surface result in such low humidity gradients, that the Bowen-ratio was found to be unreliable (Tyler *et al.,* 1997) - No assumptions are required about the land surface properties such as aerodynamic roughness or zero-plane displacement, and no corrections for atmospheric stability are necessary. This is especially advantageous in sparse heterogeneous vegetation canopies and the widely varying stability conditions that exist in semi-arid environments. - Off-shelf Eddy correlation systems are freely available (Campbell Scientific, Optical Scientific, Hukseflux Thermal sensors, Ekopower)
Shortcomings: - Instrumentation is relatively expensive and fragile.
Users: Mainly used by researchers to determine real time ET, and for calculations of a water budget.

b) Bowen-ratio energy-balance

Description The heat load on a leaf exposed to full sunlight is very high. This enormous heat load dissolute by the emission of long wave radiation, sensible (or perceptible) heat loss and by evaporative (or latent) heat loss. Evaporative heat loss occurs because the evaporation of water requires energy. Thus, as water evaporates from a leaf, it also withdraws heat from the leaf and cools it. Sensible heat loss and evaporative heat loss are the most important processes in the regulation of leaf temperature, and the ratio of the two is called Bowen-ratio (Campbell & Norman, 1998). ***Bowen ratio = sensible heat loss/evaporative heat loss*** When the evaporation rate is low, because water supply is limited, the Bowen-ratio tends to be high. The Bowen-ratio is about 10 for deserts, 2-6 for semi-arid regions, 0,4-0.8 for temperate grasslands and forests, 0.2 for tropical forests and 0.1 for tropical oceans (Gay, 1992).

Plants with very high Bowen-ratios conserve water but have to endure very high leaf temperatures in order to maintain a sufficient temperature gradient between the leaf and the air. Slow growth is usually correlated with these adaptations. One can calculate the evapotranspiration rate for an entire canopy using measurements of Bowen-ratio, net incident radiation, the heat loss from the soil, and gradients in temperature and water vapour concentration above the canopy. The Bowen-ratio technique requires measurements of air temperature and water vapour pressure at two vertical points (separated by a distance of about 1 m) above the canopy (typically at 0.5 and 1.5 m above canopy) as well as net irradiance and soil heat flux density measurements. More recently, Campbell scientific has been marketing a Bowen-ratio-CO_2 system for total evaporation, sensible heat and carbon dioxide measurement.	
Mode of operation	Measurement of fluxes
Advantages: ❑ The Bowen-ratio can run unattended for a week or more whereas the Eddy correlation requires almost daily attention (Savage *et al.*, 1996)	
Shortcomings: ❑ Instrumentation is relatively expensive and fragile. ❑ Instrumentation needs to be extremely accurate and well maintained in order to accurately estimate fluxes.	
Users: Researchers to determine real time ET mainly use this method.	

2.4.2.2 Estimation of evapotranspiration

2.4.2.2.1 Meteorogical methods

2.4.2.2.2 Evaporation pans

a) Class A pan

b) Scheepers and Vaalharts pan

2.4.2.2.2.1 Pegboard method

2.4.2.2.2.2 Green Book method

2.4.2.2.3 FAO Penman-Monteith procedure

2.4.2.2.4 Remote sensing methods

2.4.2.2.1 Meteorological methods (Adcon, MCS, Campbell Scientific and Davis automatic weather stations)

Description The use of meteorological data for irrigation management purposes implies that climate variables like incoming or net radiation, air temperature, relative humidity and wind speed are taken above a bare soil surface or above or within a crop and are interpreted to give estimates of evaporation. The concept of atmospheric evaporation could be used as indirect indicator of when and how much to irrigate. Meteorological data are commonly used in soil water balance computer programs and models like SWB, PRWIN, Irricheck, Donkerhoekdata, Canesim, etc.	
Mode of operation	Meteorological measurements
Advantages: ❑ Automated weather stations could be installed on the farm, and data collected and ET calculated for a specific site in a relatively short time. ❑ Weather station networks provide weather statistics that can be used by media outlets like the radio, cell phone Short Message Service (SMS), and fax format (visually), which can reach a broad network of users of weather data for irrigation scheduling. Information from the automatic weather station is processed into a user-friendly format that is useable by irrigators. Previous week's weather data and disease indexes could be retrieved through the use of the phone or a fax by providing the digital code of the nearest automatic weather station. These data are then used to calculate the gross irrigation demand for a specific crop.	
Shortcomings: ❑ Weather data are normally obtained from a weather station situated far from the specific site, and topography is an important factor that determines the applicability of information. Representative meteorological stations are needed and are critical for high quality information. ❑ Weather instruments need to be maintained properly because erroneous data are difficult to detect, even with good data screening. ❑ Crop factors are often gained from crops planted in other areas and from other varieties.	
Users: ❑ Researchers, extensionists, consultants and farmers. ❑ The service is available to crop producers in the Free State, Northern Cape and	

Western Cape (Paarl, Worcester, and Robertson). Institutions like the University of the Free State, Agricultural Cooperatives, Department of Agriculture of the Free State and the SA Sugar research Institute are rendering these services to commercial farmers in their respective areas.

2.4.2.2.2 Evaporation pans

Crop ET is estimated using evaporation pans and crop coefficients, which relate crop ET to the evaporation measured in the pan (Doorenbos & Pruitt, 1977). While the standard Class A-evaporation pan is most widely used in South Africa, other pan configurations like the Scheepers and Vaalharts pan, have been successfully used for irrigation management in the past (Myburgh, 2002). Only a few farmers in the Northern Cape still use the Vaalharts pan for the measurement of evaporation.

Evaporation pans are commonly constructed of galvanised steel, but there are also stainless steel and monel (plated steel) models available, but these materials are more expensive.

a) Class A pan

Description

This is one of the most widely tried and tested empirical methods used for the last 60-70 years in South Africa. This method assumes that over a given period, evapotranspiration (ET) is directly proportional to pan evaporation (Eo).

The following formula is used to determine the daily water depletion of the crop:

$$ET = Eo \times f$$

ET = daily water depletion in mm of evapotranspiration of the crop

Eo = daily A pan evaporation

f = constant of proportionality known as the crop factor

A cumulative record is kept of the daily water consumption and when the estimated water depletion equals the readily available water (RAW) in the root zone of the crop, the water depleted since the last irrigation must be replaced. A range of environmental factors like wind, soil heat flux, vegetative cover around the pan,

painting and maintenance conditions and use of screens influence the daily evaporation of water from the pan. Therefore, proper exposure and calibration are needed in these respects. The importance of exposure has been shown by Pruitt and Angus (1961) who found that readings from two evaporation pans, one sited in a large grass field and the other in an ungrassed area, differed by 30% (Doorenbos & Pruitt, 1977).	
Mode of operation	Pan evaporation measurement
Advantages: ❑ Best method for people that don't irrigate frequently- in other words they will irrigate once a week/every ten days (low frequency) and then calculate how much they need. ❑ Simple method, however, the pan is not the same as the plant- so there will always be an error within certain bounds. Hence, pan coefficients are better suited to longer periods.	
Shortcomings: ❑ The relevant crop factor for a specific crop is also determined by spacing, age, irrigation frequency and method, and other factors. The RAW (Readily Available Water) in the root zone of the specific crop can therefore differ considerably depending on external factors. ❑ This measure relates to a specific microclimatic condition and may differ considerably for other locations. One should be careful when extrapolating data, for instance to terrain forms or microclimates that might differ substantially from the site of the evaporation pan. ❑ The crop factor may not be sufficiently accurate for critical crop stages (e.g. flowering). ❑ Requires daily attention by the user and some maintenance. ❑ Requires calibration according to local conditions and is excessively sensitive to very high values of evaporative demand.	
Users: Farmers, researchers, extensionists, irrigation consultants. Very popular amongst commercial farmers and consultants in the Breede River water management area.	

<table>
<tr><td colspan="2">b) Scheepers and Vaalharts pan</td></tr>
<tr><td colspan="2">Description
Traditionally been used as on-farm evaporation pan for the measuring of evaporation. This evaporation pan is manufactured by farmers themselves using a standard 200 l oil barrel, and is not made from stainless steel or special low carbon steel as in the case of the commercially available evaporation pans. The pan is usually 250 mm deep and 570 mm in diameter with the measuring scale prepared from Perspex.</td></tr>
<tr><td>Mode of operation</td><td>Pan evaporation measurement</td></tr>
<tr><td colspan="2">Advantages:
❑ The measuring rule could be adapted for different crop factors, thus excluding the calculations needed when using the Class A pan.
❑ Less expensive than the commercial evaporation pans (Class A pan).</td></tr>
<tr><td colspan="2">Shortcomings:
❑ The lowest crop factor that could be taken into account is 0.5, as the pan is too shallow to accommodate lower crop factors.</td></tr>
<tr><td colspan="2">Users:
Commercial farmers and advisors.</td></tr>
</table>

2.4.2.2.2.1 Pegboard method

<table>
<tr><td>Description
This type of scheduling monitors the accumulation of evaporation until predetermined levels are reached, which indicates the need for irrigation application. The operation of the pegboard entails using coloured pegs.
The information on the pegboard relates to:
❑ Canopy: the degree of canopy ground cover during the interval in between irrigations (0-full).
❑ Days: calendar date. At month end calendar peg returns to the beginning of the month.
❑ TAM: Total available water (mm).
❑ FAM: Freely available water (no yield reduction due to water stress) where the soil water is equal to TAM x 60%.
❑ Standing time of sprinkler.
❑ Net mm per standing time.</td></tr>
</table>

- Total accumulated irrigation per crop (George, 1988).

The amount of freely available soil water expressed in terms of evapotranspiration, is known as *the evaporation deficit* as represented by the peg in the column of holes under each field. A second peg represents the accumulating daily evaporation amount. This peg will reach the deficit or indicator peg in the number of days it will take to deplete the available moisture and gives a clear indication of when to irrigate. As this method use evapotranspiration, the amount of irrigation and rainfall will have to be divided by the relevant crop factor and the resultant figure will dictate the downward movement of the peg.

Mode of operation	Accumulation of evaporation

Advantages:

- Ease of operation and obvious clarity.
- Minimum record to be kept on paper or with any other aid (computer).
- This method of scheduling suits any irrigation system.
- Can easily be reflected on a spreadsheet.

Shortcomings:

- No permanent record is kept.

Users:

Sugarcane farmers (small-scale and commercial farmers) in KwaZulu Natal and Mpumalanga.

2.4.2.2.2.2 Green Book method

Description

For many years the Green Book (Green, 1985 a&b) was accepted as the South African standard for the estimation of irrigation requirements of crops for planning and design purposes. The pan evaporation method is used in this method of estimating crop water requirements.

The method comprises of the following stages:

- An optimum value must be decided upon for the maximum amount of water loss (depletion), which may be permitted from a root zone before irrigation becomes necessary. This establishes how much to irrigate on a particular soil with a particular irrigation system.
- The daily rate of water loss (evapotranspiration) is calculated from actual weather records, taking into account the crop type and stage of development.
- Starting from field capacity, the daily level of soil water depletion is calculated

by accumulating daily evapotranspiration losses. Recorded daily rainfall is used throughout to adjust the soil water depletion level. When this depletion reaches the permissible maximum value, application of appropriate irrigation amount becomes necessary. ❑ Calculations are carried out continuously through the entire growing season of a crop and repeated for a couple of years. This statistical summary of the irrigation history of the crop is then used as basis for estimation of future irrigation requirements. This method implies that, over a given period, evapotranspiration (ET) is in direct relation with pan evaporation (Eo). **ET = kc x Eo** *Where kc = crop factor. Reviewed kc values empirically related to pan evaporation and growth periods for crops grown in South Africa were developed.*	
Mode of operation	Evaporation and crop factors
Advantages: ❑ Relatively easy to use and low cost. ❑ The evaporation data was obtained from three different sources namely: the Weather Bureau, Department of Water Affairs and Forestry and the National Department of Agriculture. The exposure of pans was therefore mostly in accordance with standards laid down for weather station networks and therefore fairly free of effects of local obstructions.	
Shortcomings: ❑ The lack of knowledge during the stage of development of these manuals did not permit crop factors used in the manuals to be adjusted for the different climatic zones and growing seasons. Once decided upon, the crop factors were used unchanged in all production areas over all the growing seasons.	
Users: Used by some farmers involved in pasture production and advisors in the field.	

2.4.2.2.3 FAO Penman-Monteith procedure

Description A large number of more or less empirical methods have been developed over the last 50 years worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved not to be globally valid. Testing the accuracy of methods under each new set of conditions is

laborious, time-consuming and costly, and yet evapotranspiration data is frequently needed at a short notice for irrigation scheduling. To meet this need, guidelines for predicting crop water requirements were published in the FAO Irrigation and Drainage Paper No 56 (Doorenbos & Pruitt, 1977). Since the 1980's, the preferred terminology used is reference ET, rather than potential ET (Burman *et al.* 1983). This standard ETo method eliminates some of the shortcomings identified with the other methods like the Green Book and the Class A pan. It is recommended the use of hypothetical short grass reference evaporation in association with the four-stage approach for the development of crop factors (viz. initial stage, crop development stage, mid season stage and late season stage).

The FAO method of reference evapotranspiration (ETref) is linked to any given crop by way of a standard crop factor (kc) for any given period during the growing season as described by Harrington & Heerman (1981).

ET = kc x ETref

ET = daily water depletion in mm of evapotranspiration of the crop

ETref = reference evapotranspiration (mm)

kc = crop factor

kc =(kcb x ks) + ke

kcb = the basal crop coefficient, i.e. corresponding to a crop grown under no water shortage

ks = a soil water availability factor (0-1, also called stress coefficient)

ke = the soil water evaporation coefficient.

The modified Penman-Monteith method is considered to offer satisfactory results with the minimum error in relation to the living grass reference crop. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climate conditions confirmed the recommendation by the FAO for the acceptance of this method as the sole standard method. It is a method with a strong likelihood of correctly predicting ETo in a wide range of locations and climates, and has made provision for application in limited data situations (Doorenbos & Pruit, 1977).

Mode of operation	Estimation of evapotranspiration

Advantages:

- The crop factors cater for regional variations and varieties, management practices and irrigation methods. In contrast to the crop factors used with the

A pan, reference evapotranspiration and kc can be adjusted consistently and
with confidence to accommodate differences in climate zone and farming practice ❑ It is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in limited data situations. The reference (ETref) figures used changed from the A pan crop factors to a modified range based on the universally accepted FAO procedure. For real time irrigation scheduling systems, ETref for the forthcoming days can be directly estimated from meteorological service forecasts.
Shortcomings: ❑ In situations where large saturation deficits and high temperatures exist, this method did not work satisfactorily and should be used together with field observations. ❑ ET models are typically one-dimensional and do not take the two-dimensional nature of irrigation and rainfall spatial variability into account.
Users: Researchers, extensionists, consultants and farmers with the support of professionals.

2.4.2.2.4 Remote sensing methods

Description In remote sensing methods, evaporation is evaluated (usually in conjunction with meteorological methods) by determining certain radiative properties of the soil and crop as viewed from a great distance. This is a relatively new tool for irrigation scheduling, but unfortunately this tool is not well known to water resource managers and irrigation engineers (Bastiaansen & Bos, 1999). Two aspects could be covered with this method: ❑ Description of irrigation performance at a multitude of scales ❑ Estimation of the parameters of the soil-vegetation-atmosphere continuum, such as soil water, crop evapotranspiration and crop biomass production (D'Urso & Menlenti, 1995). This method provides an opportunity to study the crop growing at scales ranging from individual fields to scheme level. The multi-spectral satellite images can be used for the appraisal of irrigation management information. Information such as land use

surface patterns, crop mapping, identification of irrigated areas and other crop related parameters might be surveyed and monitored extensively in space and time by means of satellite image. This evades the need to use standardised *kc* values such as provided by Doorenbos & Pruitt (1977).	
Mode of operation	Processing of remote imagery
Advantages: ❑ Remote sensing provides opportunities to retrieve new performance indicators such as: depleted fraction of soil water, crop water deficit, relative evapotranspiration, relative soil wetness and biomass yield on a scheme level. ❑ This is a major benefit for large irrigation schemes and river basins in circumstances where the hydro-informatics infrastructure and database management is absent. ❑ This method provides a combination of indicators that enhances the diagnostic opportunities, especially when the entire flow path from the reservoir up to the root zone can be quantified. It provides a more comprehensive description of the total system as compared to classical indicators describing water delivery and service levels (Malano & van Hofwegen, 1999). ❑ It is mainly used to support decision-making in irrigation water management of large districts. This information, together with historical data, constitute the input set for the simulation of soil water flow, from which the actual crop water requirements can be determined.	
Shortcomings: ❑ Remotely sensed information does not explain the causes, it only measures net effects of land surface processes. ❑ High-resolution images are delivered more than a month after acquisition and at a relatively high cost per scene. Low-resolution images can be obtained daily, but the resolution is 1.1 km^2. This is however too coarse for direct interpretations at plot scale for a single crop. Conversion equations are needed to overcome this problem, but it comes at the cost of accuracy (Bastiaansen *et al.*, 1998). ❑ The practical implementation requires a large effort and the whole procedure is heavily reliant on computer skills. The acquisition of a large volume of data input is rather complex and requires the support of professionals.	
Users: Irrigation engineers, scheme managers (e.g. WUA Oranje Riet) and irrigation consultants.	

2.4.3 Soil water measurement

Soil water measurements provide an indication of water extraction and availability within the crop root zone and can be used to directly schedule irrigation events. This is also an accurate way of obtaining information on both how much irrigation water to apply and when to apply it.

Soil water status can be measured directly or estimated indirectly using various parameters. There are three ways of measuring availability of soil water for plant growth:

- Measuring how strong the water is retained through measurement of soil water potential.
- Measuring the soil water content.
- Measuring the depth of the wetting front after irrigation.

Soil water potential, in simple words, is the energy required to remove a finite increment of water from the soil. Soil water content does not tell one how 'happy' the plant is, but suction (soil water potential) indicates the water availability to the plant. Some devices are set into the soil permanently while others are portable and could be moved around from point to point to take readings of soil water potential.

Soil water availability is usually expressed as a fraction of available water. This fraction is given by the ratio of available water content over available water capacity, which is defined as the difference between field capacity and wilting point. The available water to the plant is a fraction of the soil water content. Whatever the method used to determine this measurement, one has always to deal with the problem of spatial variability. Generally speaking the more accurate devices are also more expensive and usually portable. Accuracy of measurement of soil water content can be expressed in absolute and relative terms.

- Absolute accuracy refers to the ability of the device to produce readings of the actual moisture content of the soil.

- Relative accuracy is the ability to reflect changes in soil water content accurately.

Wetting front detection: As infiltration from irrigation and rainfall occurs, a wetting front develops. This wetting front is the transition zone between the dry and wet soil. The wetting front detector (Full Stop) is a device that indicates the advance of the wetting front.

The four main methods of soil water measurement which currently dominate irrigation management are:

- Measurement of soil water potential (with tensiometers)
- Electrical resistance/capacitance
- Gravimetric sampling
- Neutron scattering (Hardie, 1985).

2.4.3.1 Soil water potential (suction)

Soil water potential is measured through the use of:

- Tensiometers
- Porous matrix sensors
- Heat dissipation sensors
- Thermocouple psychrometry

2.4.3.1.1 Tensiometers (Irrometer/Jetfill/ Adcon's electro-tensiometer / Delta T)

Description
Tensiometers operate by allowing the soil solution to come into equilibrium with a reference pressure indicator through a permeable ceramic cup placed in contact with the soil. Retention of water by soil and its relationship to the soil water free energy level has become know as "the potential concept of soil-water."

The standard tensiometer is used to measure real time soil matric potential down to –80 kPa. Standard tensiometers are available in standard lengths of 15cm, 30 cm, 45 cm, 60 cm and 90 cm. The new model “LT” irrometer introduced in 1995 is ultimate in sensitivity at the very wet end of the soil water range (below 20 kPa). It was designed to operate in very low water holding capacity soils like coarse sand and planting mixtures used in the container nursery industry, where soil water needs to be maintained in the 5-15 kPa range (Hillel, 1982). Jetfill tensiometer has basically the same components as a standard tensiometer, but is equipped with a reservoir and a refill mechanism. At a push of the button the Jetfill mechanism instantly injects water from the reservoir into the body of the tensiometer and removes accumulated air. Electronic tensiometers are portable pressure sensors for measurement of the soil water tension, measured through a tensiometer tube placed in the soil. The measuring device can be moved from tensiometer tube to tensiometer tube allowing an unlimited number of measurements over a short period of time. The measuring range is from 0-1000hPa with a very high accuracy. This device is becoming popular amongst irrigators because they are relatively cheap and data can be logged. However, they need correction for temperature and exhibit some problems under water logging conditions (Lorentz, 2003).	
Mode of operation	Tension measurement
Advantages: ❑ The same site is used all season and readings can be compared. ❑ Not affected by osmotic potential of soil solution (the amount of salts dissolved in the soil water), as salts can move into and out of the ceramic cup unhindered. ❑ Very simple instrument to use but attention should be paid to proper preparation before installation, proper installation, proper servicing of tensiometers and storage if removed from the soil after use. ❑ Relatively affordable and easily obtainable.	
Shortcomings: ❑ It provides point measurements and therefore representative sites or stations are prerequisites before installation in the field. Since the information is localised and site specific, many observations are needed for accurate characterisation of a field. ❑ High labour requirement if it is not automatically logged.	

- High degree of maintenance and management required. Regular service needed after installation – each tensiometer should be inspected for air accumulation often. - Range of operation: between saturation and approximately –70kPa. Therefore not regularly used for measurements at the dry end of the spectrum. - To prevent regular refill of tensiometers that have sucked air, most farmers are tempted to keep tensiometer readings at low suctions (below 50 kPa), often resulting in over irrigation. - The relatively long response time (particularly at suctions above 30kPa) makes tensiometers less suitable as a portable measurement device. - Temperature-sensitive. - Needs a retention curve to convert measured data into volumetric water content.
Users: Farmers, consultants, researchers and extensionists.

2.4.3.1.2 Porous matrix sensors

The principle of operation is that electrical resistance (electrodes embedded in porous matrix) is proportional to its water content. For each type of soil there is a relationship between suction and the soil water content. Electric resistance of a soil volume depends not only upon its water content, but also upon its composition, texture and soluble-salt concentration. Electrical resistance sensors do not directly measure soil matric potential, and therefore empirical calibration is required (Shock *et al.*, 1996).

A variety of porous materials have been used to construct electrical resistance sensors: gypsum (1958), fibreglass (1949), nylon (1949) and granular matrix.

(a) Gypsum block
Description Gypsum blocks slowly dissolve providing a saturated solution of Ca and SO_4 ions in the porous matrix. They are less sensitive to salts than nylon and fibreglass as the saturated solution buffers the effect of changes in the soil salinity on measured electrical resistance. This type of sensor is suited to various irrigation applications where only “full” and “refill” points are required.

For more exact work, gypsum blocks tend not to have the range, sensitivity or reaction time required. Upon drying, tight contact between the block and surrounding soil may be lost.	
Mode of operation	Electrical resistance measurement
Advantages: ❑ They are easier to implement than standard tensiometers and very convenient to use. ❑ Inexpensive, which allows many replicates in the field. ❑ Relatively accurate and can be left in the field for automatically monitor continuously. ❑ Multiple depths are possible with many sensors.	
Shortcomings: ❑ High labour if not logged. The sensors need to be read quite often to get good data. ❑ Disintegration appears over time due to the dissolution of gypsum blocks, changing the pore geometry and altering the calibration. This makes the measurement of matric potential unreliable. Disintegration depends on the pH of the soil water, and gypsum blocks need replacement after 2-3 seasons. ❑ It needs correction in relation to soil temperature as temperature affects the electrical resistance reading. ❑ Soil profile is disturbed during installation. ❑ Because of the pore size of the material used in most electrical resistance blocks, particularly those made of gypsum, the water content and thus electrical resistance of the blocks does not change dramatically at suctions less than 50 kPa. Resistance blocks are therefore not reliable for use in sandy soils. ❑ All such types of blocks are subjected to hysteresis (less resistance in wetting up than drying out at set water tension). The range is usually only up as far as 100 kPa tension. The sensitivity in the dry range is usually very flat (a large change in dryness reflects small changes in measured resistance).	
Users: Farmers, researchers, extensionists	

(b) Nylon and fibre glass sensors
Description The *fibreglass and nylon sensors* are longer lasting, but the electrical resistance output includes both matric and osmotic effects.

Mode of operation	Electrical resistance measurement
Advantages: ❑ Longer lasting than gypsum blocks.	
Shortcomings: ❑ Individual osmotic effects and field calibration of fibreglass units are recommended due to the high variability in calibration of individual sensors.	
Users: Farmers, researchers and extensionists.	

(c) Granular matrix sensors (Watermark / Aquaprobe)	
Description This sensor is made of fine sand material held in place by a synthetic porous membrane. The membrane prevents penetration of fine soil material, which could change the physical properties of the block. The sensor provides a desorption estimate of soil water potential in the range between 0 and 200 kPa (Jovanovic & Annandale, 1997) This is an electrical resistance - type sensor: It is read by a hand–held meter, which converts the electric resistance reading to a calibrated reading of kPa of soil water suction. It operates under the same electrical resistance principle as gypsum blocks and contains a wafer of gypsum imbedded in the granular matrix. The gypsum wafer slowly dissolves, to buffer the effect of salinity of the soil solution on electrical resistance between electrodes. The particle size of the granular filling material and its density determine the pore size distribution in granular matrix sensors and their response characteristics.	
Mode of operation	Electrical resistance measurement
Advantages: ❑ It is very similar to gypsum blocks, cheap and it can monitor multiple depths. ❑ Little maintenance is required. ❑ It is very popular due to the simplicity of management-simple to use and suitable for logging. ❑ It is relatively cheap compared to other soil water sensors. ❑ Problems inherent to gypsum blocks are overcome because most of the granular matrix sensors are supported in a metal or plastic screen. ❑ Manual measurement of matric potential with a hand held meter would certainly be a cheaper option than the installation of a data logging system (Thomson & Armstrong, 1987).	

Shortcomings:
❑ It is hard to establish water use patterns unless daily readings are taken. ❑ It is temperature sensitive: block temperature should be measured in order to compensate for the effect that the soil temperature has on the electrical resistance reading to obtain a reliable estimate of soil water potential. Differences in temperature cause large variations in the soil matric potential values. ❑ It provides point measurements at specific sites – therefore many representative observations are needed to properly characterize a field. ❑ It is susceptible to inaccuracies caused by soil disturbance during installation. ❑ It needs individual calibration (calibration dependent), which is time consuming. Regular calibration and manual reading are often required, although readings could also be logged with a computer. ❑ Retrieval of these instruments is difficult in clay soils.
Users: Farmers, researchers, and extensionists.

2.4.3.1.3 Heat dissipation sensors (Campbell Scientific 229 & BCP Electronics)

Description	
The temperature in a porous block is measured before and after a small heat pulse is applied to it. The amount of heat flow from the pulse-heated point is mostly proportional to the amount of water contained within a porous material. This means a wet material will heat up slower than a dry one. The rise in temperature is measured with an accurate thermocouple in the sensor tip and calibrated against the soil water potential.	
Mode of operation	Thermal conductivity
Advantages: ❑ Accurate and continuous monitoring of both soil water and temperature of the probe site. ❑ With heat dissipation sensors, thermal conductivity is measured rather than electrical conductivity as with gypsum blocks, and hence the salinity of the water has no major effect. ❑ It estimates matric potential over a wide soil water range. The optimal range of measurement is from 0 to 100 kPa.	

Shortcomings:
❑ Fairly extensive power requirements if measurements are required frequently. Computer logger and extensive cabling is required. ❑ The sensitivity of the heat pulse sensor in sandy and sandy loam soils are considered to be fairly good, while sensitivity problems are experienced in heavier clay soils. ❑ Tedious calibration is needed to ensure accuracy.
Users:
Researchers.

2.4.3.1.4 Thermocouple psychrometer

Description	
It infers the water potential of the liquid phase of a soil sample from measurements within the vapour phase in equilibrium with it. The major difficulty with measuring stems from the fact that the relative humidity in the soil gas phase changes only slightly. Practically all measurements lie in the narrow relative humidity range between 0.99 –1.0. The first development of an instrument to measure relative humidity in equilibrium with a plant or soil sample was that of Spanner (1951) and since then major developments took place concerning improvement of accuracy and reliability of measurement. Modern psychrometers consist of a miniature thermocouple junction, placed within a sample chamber that can be cooled to condense water on it (Peltier effect). The junction is connected to a voltmeter to estimate its temperature depression as the water evaporates. Neuman & Thurtell (1972) introduced an improved technique that measures the dew point rather than the wet–bulb temperature depression to estimate relative humidity, which has certain advantages.	
Mode of operation	Measurements of humidity
Advantages:	
❑ It measures the total water potential rather than water content. ❑ Calibration of sensors and sensor readings are independent of soil type and soil particle size. It is calibrated empirically, with solutions of known water potential connected to the psychrometer chamber.	

Shortcomings:
❑ It is temperature sensitive because it measures relative humidity of the air in equilibrium with the sample. Any difference in temperature between the sample and the chamber air will introduce a systematic error, unless the difference is measured and corrected. ❑ It does not provide good differentiation at the wet end of the soil water potential scale, where critical irrigation decisions must be made for many crops and it is not as easy to log remotely. ❑ Relative expensive equipment needed.
Users: Mainly researchers.

2.4.3.2 Soil water content

Accurate assessment of soil water deficits and irrigation efficiencies are possible using volumetric soil water measurements. Soil water measurements are useful for verifying ET models and for the starting or stopping of irrigation, but are not very useful in forecasting the need of irrigation. Soil water measurements are necessary for feedback information on the irrigation scheduling practice based on ET.

There are direct and indirect methods to measure soil water content, as yet no universally recognised standard method of measurement exist.

- Direct method: water is removed from a sample by evaporation. This includes gravimetry with oven drying.
- Indirect methods: certain physical properties of the soil vary with water content and indirect methods are those that measure the property of the soil that is affected by soil water content. These methods include hand feel method by the use of soil auger and spade, nuclear techniques (the use of the neutron probe) and di-electric conductivity measurement (capacitance sensors, frequency domain reflectometry and time domain reflectometry techniques).

A. *Direct methods of soil water measurement*

2.4.3.2.1 Gravimetric method

Description	
Soil samples are collected at different depths within the root zone with a soil auger and volumetric soil water content (dry and wet mass) is calculated in the laboratory: $$W = \frac{\text{Wet mass} - \text{Dry mass}}{\text{Dry mass}}$$ (W= gravimetric wetness) Through this formula the ratio of the mass of water to the mass of the dry soil is obtained.	
Mode of operation	Measurement of mass
Advantages: ❑ One of the most accurate methods to determine soil water because it is the only direct method of measuring soil water content. It serves to calibrate other soil water measurement techniques.	
Shortcomings: ❑ More than one sample (replication) is needed for accuracy. ❑ The sampling method is destructive. ❑ It is laborious and time consuming, since a period of 24 hours is usually considered necessary for complete oven drying at 105°C. ❑ Water content values for stony and gravely soils, both on a mass and volume basis, can be grossly misleading because of the coarse fraction.	
Users: Researchers, mostly to calibrate equipment used for indirect measurements.	

B. Indirect methods of soil water measurement

2.4.3.2.2 Measurement of soil water through observation and "feel method" by use of soil auger / shovel or spade

Description As the name implies, the "hand-feel method" involves estimating soil water by feeling the soil. Soil samples are collected at different depths with the help of a soil auger or spade and then the water content is estimated by observation and hand-feel. Soil is squeezed between the thumb and index finger and the operators' experience will indicate the relative amount of water in the soil. To help inexperienced irrigators in this regard, guidelines for determining soil water by feel are available.	
Mode of operation	Feeling soil wetness
Advantages: ❑ Inexpensive. ❑ An easy and simple method but experience is needed for accuracy. ❑ Soil classes are identified through observation, and the soil water content is determined with the help of standard tables.	
Shortcomings: ❑ The major drawback with this method is that estimation of soil water content is subjective and is not the exact amount of soil water. ❑ Cannot compare sites to previous results or other sites. ❑ The reliability of this method depends on the experience of the operator. With repetition and experience it is possible to be accurate within 10-15% ❑ It does not give any lead-time for irrigation. ❑ Not able to supply continuous results. It is hard to establish water use patterns unless daily samples are taken.	
Users: It is the most widely adopted technique by commercial and small-scale irrigators, researchers and extensionists.	

2.4.3.2.3 Neutron thermalisation

(Neutron probe (CPN 503, Waterman, Troxler))

Description	
The neutron probe was first developed in the 1950's and is still regarded as the most accurate instrument for measuring soil water. The volumetric water content is determined through the use of scattering and slowing down of neutrons by the hydrogen nuclei of water molecules. The detector counts the number of slow neutrons. A calibration curve is needed to establish the relationship between the volumetric water content and the counts of slow neutrons. Data is collected at regular intervals and downloaded into specialist software that enables both graphical and tabular analysis.	
Mode of operation	Neutron scattering and measurement of slow neutrons
Advantages: ❑ It is relatively easy to use, reliable and accurate. Soil water measurements can be made at different depths in the soil profile. ❑ It is non-destructive and measurements can be performed with minimum disturbance of the soil. ❑ This allows one to follow the water content changes with time through taking measurements at the same locations and depths. ❑ Unlike the capacitance and TDR probes, the neutron probe has a larger and therefore more representative sphere of measurement. ❑ It is practically independent of temperature and pressure. ❑ It is portable and it is used to measure soil water at many sites.	
Shortcomings: ❑ Initial costs are relatively high, although it can be used at several locations in one field and for several fields. ❑ The main limitations relate to safety rules, which have to be followed for safe operation, transport and storage of the radioactive probe. It requires an operating licence because it contains radioactive material (Stone & Nofziger, 1988). ❑ Calibration is delicate, time and labour consuming. Using the neutron probe with a single calibration equation for all soils provides only limited accuracy (Kennedy *et al.*, 2000). ❑ Background hydrogen molecules, bulk density, and other chemical components may influence the measuring results. ❑ A low degree of spatial resolution is found. Information is localised and site	

specific. It needs many observations for accurate characterisation of a field.
Users: More suited for use by a group of farmers because of the cost of the instrument, estates, irrigation consultants, researchers and extensionists.

2.4.3.2.4 Di-electric sensors:

- Capacitance sensors *(Enviroscan, Diviner 2000, C-probe, Silora, Troxler Sentry, Gopher, Aquaterr)*
- FDR (Frequency Domain Reflectometry)
- TDR (Time Domain Reflectometry) *(Spectrum's TDR 300, Aquaflex)*

Di-electric sensors (Capacitance, FDR and TDR sensors)
Description All of the sensors within this group use an oscillator to generate an AC (alternating current) field, which is applied to the soil in order to detect changes in soil dielectric properties linked to variations in soil water content. The characteristics of this propagation depend on the soil water content through the dielectric properties of the soil. **Capacitance sensors** consist essentially of a pair of electrodes (either an array of parallel spikes or circular metal rings), which form a capacitor with the soil acting as the dielectric medium. The capacitor works with the oscillator to form a tuned circuit, and changes in soil water content are detected by changes in the operating frequency. The capacitance technique determines the dielectric permittivity of a medium by measuring the charge time of a capacitor, which uses this medium as a dielectric medium. These sensors (for example the Sentek) operate from within access tubes and are not in contact with the soil. This allows multiple sensors to be lowered into an access tube and take measurements at all depths. **Frequency Domain** sensors use a swept frequency. The resonant frequency (at which the amplitude is greatest) is a measurement of the soil water content, and the amplitude is a measure of soil electrical conductivity. Like capacitance sensors, their measurement is a single frequency, but the exact frequency depends on the soil water content.

<table>
<tr><td colspan="2">TDR probes also use an oscillator to generate an AC signal but the soil water content is measured from the amplitude of the standing wave, which is formed when the reflected AC signal interacts with the generated AC signal. They operate at a single fixed frequency. TDR depends on discontinuities in the medium of transmission. Combined with knowledge of the propagation velocities of waves in the medium being use, these discontinuities can be located by observing the change in energy levels at fixed points in the medium. Energy that does not become dissipated returns to its source. The probe tips of a TDR appliance present a discontinuity in the wave propagation path of the energy initiated at the signal source.</td></tr>
<tr><td>Mode of operation</td><td>Di-electric measurement</td></tr>
<tr><td colspan="2">Advantages:
❑ The ability to capture real time variation in soil dynamics and most sensors can be connected to conventional data loggers. Continuous monitoring and automation of irrigation systems are possible when installed semi-permanently.
❑ Non-radioactive.
❑ No specific knowledge of analysing waveforms is required. Most of these sensors operate at lower frequencies (100 MHz or less) and can therefore detect “bound” water in fine particle soil.</td></tr>
<tr><td colspan="2">Shortcomings:
❑ Only applicable to the site being measured with heterogeneous soil it becomes very difficult to extrapolate from one site to sites not measured. Regular calibration is needed.
❑ Expensive equipment is required and complex electronics, which is most of the time beyond the range of equipment affordable by farmers.
❑ Adequate software is included, but skilled operator in set-up and interpretation is needed.
❑ Readings are heavily influenced by soil water content and air gaps in the soil volume nearest the electrodes. With the access tube models, it is extremely critical to have good sensor tube-soil contact for reliable estimation of soil water content. It is difficult to use in cracking clay soils.</td></tr>
<tr><td colspan="2">Users:
❑ More suited for use by a group of farmers because of the cost of the instrument, researchers, extensionists and consultants.</td></tr>
</table>

2.4.3.3 Wetting Front Detector (WFD)

Description	
The detector works on the principle of flow line convergence. Irrigation or rainwater moving downwards through the soil is concentrated when the water molecules enter the wide end of the funnel. The soil in the funnel becomes wetter as the funnel narrows and the funnel shape has been designed so that the soil at its base reaches saturation when the wetting front outside is at a similar depth. Once saturation has occurred, free water flows through a filter into a small reservoir and activates a float (Stirzaker *et al.* 2000, Stirzaker 2003). The wetting front detector was developed and patented by CSIRO Land and Water, Australia, in 1997. The wetting front detector can be used to schedule irrigation, because the time it takes for water to reach a certain depth depends on the initial water content of the particular soil (Philip, 1969). If the soil is dry before irrigation, the wetting front moves slowly because the water must fill the soil pores on its way down. Therefore, a lot of water is needed before the detector will respond. If the soil is quite wet before irrigation, then the wetting front will move quickly through the soil. This is because the soil pores are already mostly filled with water so there is little space for additional water to be stored. Thus a short irrigation will cause the detector to respond. The float in the detector is activated when free water is produced at the base of the funnel. Water is withdrawn from the funnel by capillary action after the wetting front dissipates. Depending on the version used, capillary action can be used to "reset" the detector automatically, or water can be removed via a syringe. The water sample can be used for routine salt and fertilizer monitoring.	
Mode of operation	Measurement of wetting front
Advantages: ❑ It is robust, accurate and visible even when the farmer is absent and the information is stored until the farmer chooses to reset the device. ❑ A small sample of soil water can be retained for nutrient monitoring. ❑ It is simple, easy to understand and to apply by the farmer. The information that farmers get from the detectors is easy to understand - either the wetting front has or has not reached the desired depth. ❑ The WFD concept acknowledges the existing knowledge of irrigators and each irrigation becomes an experiment from which the farmer can learn. The mechanical version is adapted for the circumstances and needs of the small-	

scale farmer. ❑ Excellent learning tool for farmers and users to become acquainted with irrigation scheduling principles. ❑ WFD can also be used to evaluate the immediate past irrigation events. ❑ This device offers a robust method to combine the WFD with estimates of transpiration from reference crop evaporation and crop factors.
Shortcomings: ❑ It is labour intensive to install. ❑ Sensitivity problems occur with irrigation systems like centre pivot and furrow irrigation. ❑ Installation depth is crucial.
Users: Farmers (commercial and small-scale), researchers, extensionists and consultants.

2.4.4 Plant based monitoring

Instead of measuring the soil water content, a number of plant indicators can be used to determine whether irrigation is needed. These indices include the observation of the general plant appearance, changes in diameter or trunks or branches, leaf water potential, sap flow, canopy temperature and radiation.

Plant water status has remained one of the most difficult parameters to measure (Howell, 1996). Direct measures of plant water status are useful as a measure of plant water stress and can be used to schedule irrigation events. However, the use of this scheduling method is more appropriate for researchers and environmental physiologists rather than for the practical application of irrigation scheduling by farmers, although a few high valued fruit growers in the Western and south-western Cape are using these methods with the necessary support.

While a range of techniques has been used in research applications, plant stress sensors are not widely adopted by commercial farmers in South Africa. One reason may be that measurements of plant water status often do not provide sufficient lead time to schedule irrigation while avoiding crop water deficits affecting yield and often they don't respond fast enough to provide adequate information on when to terminate irrigation applications. The other possible reason is that the available methods of plant monitoring require sophisticated devices and the support of professional people and therefore their practical application for irrigation scheduling has been limited.

The following plant monitoring methods will be discussed:

2.4.4.1 Visual observation of plant appearance
2.4.4.2 Trunk or branch diameter measurements
2.4.4.3 Leaf water potential (LWP)
2.4.4.4 Sap flow
2.4.4.5 Canopy measurements
2.4.4.6 Phytomonitoring
2.4.4.7 Remote sensing methods

2.4.4.1 Visual observation of plant appearance

Description The visual observation of general plant appearance includes observation of possible retardation in foliar growth or fruit development that usually depends on a visual expression of soil water stress. It is likely that, when external symptoms of soil water stress are evident, the crop may already be permanently set back. Knowing what plants look like at the initial stages of soil water stress can be used to indicate irrigation need.	
Mode of operation	Visual observation
Advantages: ❑ Regular monitoring and visual observation, together with weather information and understanding of soil water holding capacity, can make irrigation scheduling successful.	
Shortcomings: ❑ If experience is lacking, the symptoms of plants under stress will be discovered too late and possible economic losses will occur. ❑ Irrigation scheduling by plant stress observation can result in less water application than required. ❑ Farmers with a large area of multiple irrigation systems find simple visual observations of plant symptoms insufficient and time consuming, and must	

usually rely on more complex and sophisticated methods.
Users: The visual observation of plant stress symptoms and leaf extension (*viz.* sugarcane) is a common technique used by experienced farmers, extensionists and researchers.

2.4.4.2 Trunk or branch diameter measurements

Description The dendrometer is a sensitive dial gauge attached to the trunk or branch of a tree for measuring small changes in diameter as water status of the plant changes during the day. This sensor helps to determine the need for and the amount of irrigation from the change in diameter, which occurs over a certain time period. Pre dawn and midday leaf water potential have been the most popular plant water status parameters proposed for irrigation scheduling of orchards. Research has indicated that midday stem water potential is a significant reliable plant water status indicator for irrigation scheduling of fruit trees (Noar, 1999; Schakel *et al*., 2000; Chone *et al*., 2001, Noar, 2001). An indirectly relationship exists with LWP (Klepper, 1971).	
Mode of operation	Measurement of diameter
Advantages: ❑ It is fairly easy to install and must be connected to a logging system (Schackel *et al.*, 2000)	
Shortcomings: ❑ The main problem encountered seems to be that the same responses are sometimes obtained with both excess and shortage of water. Small diurnal changes are observed in the case of high water stress conditions (as a result of stomatal closure). For mild water stress conditions, diurnal changes depend on species and varieties. ❑ This procedure does not detect water stress as rapidly as the leaf water potential method, but provides a more integrated measurement of conditions being experienced by the entire tree.	
Users: Mainly used by researchers, but also by a few progressive commercial fruit growers and horticulturalists in the Western and south-western Cape.	

2.4.4.3 Leaf water potential (LWP)

Description	
Irrigation timing techniques that ensure attainment of the upper boundary values of water-yield relationships are important and leaf water potential measurement is one of these methods. LWP is a criterion for irrigation timing. A miniature sensor attached to the leaf is used to measure the reduction in leaf thickness, and thus turgor pressure, as water stress of the plant increases. The main interest in this method lies in the possibility to link values of pre-dawn leaf water potential to relative evapotranspiration. To operate effectively, the method requires careful selection of a fully exposed leaf, which accurately represents the average response for the entire plant throughout the day.	
Mode of operation	Measurement of plant reductions in leaf thickness and turgor pressure.
Advantages: ❑ It is claimed that such a system is capable of reacting, almost immediately, to the onset of plant water stress, thereby preventing stomatal closure.	
Shortcomings: ❑ Limitations, such as the sampling needs, are presented by this technique. These are relatively difficult for farmers to apply. ❑ Measurements must be taken before dawn to avoid meteorological effects. ❑ Measurements on many representative fields are required.	
Users: Researchers and a few commercial fruit and wine producers in the Western Cape with the help of consultants.	

2.4.4.4 Sap flow

Description
It measures how rapidly a pulse of heat is transported by the sap flow up the trunk. Relative ET values are obtained by measuring sap flow along the trunk and comparing trees under water shortage to well irrigated trees using both steady heat flux or heat pulse technology. Two techniques are available: ❑ Sap flux density technique: limited by the need to determine the cross-sectional area of the water conducting tissue. ❑ Mass flux technique.

Mode of operation	Sap flow measurements
Advantages: ❑ Direct measurements of plant water status can be used in conjunction with ET models to provide feedback data on crop water deficits.	
Shortcomings: ❑ Problems such as sampling range of instruments needed for a complete crop season (differing stem sizes) or sensor movement from plant to plant, besides the physical problems of instrumentation, make sap flow gauges mainly useful for research. ❑ Both sap flux and mass flux techniques require tree sampling and lead to necrosis of the trunk. This is why it is necessary to change sampling site frequently.	
Users: Researchers, progressive commercial fruit growers and wine producers in the Western Cape with the help of consultants.	

2.4.4.5 Canopy measurements (Temperature and radiation)

Description
Since the 1980's, a new technology was developed to remotely sense crop or plant temperature (Jackson *et al.,* 1981). Surface temperature measurements are performed by infrared radiometers, and infrared gun, and used to determine the degree of water stress. Measurements are based on the principle that objects emit radiation in proportion to their surface temperature. When the surface of the leaf is warmer than the air, evaporation is reduced. Change in leaf temperature is closely related to the availability of water, which indicates critical soil-water content when stress becomes detrimental to crop growth. Remote sensing of a plant canopy includes both reflected and emitted radiation. Remote sensing methods evaluate evaporation (in conjunction with meteorological methods) by determining certain reflective properties of the soil or crop, as viewed from a great distance. The spread of modelling techniques has encouraged use of input data from remote sensing with the support of GIS for manipulating large data sets. Spectral radiation as seen by reflected wavebands does follow the leaf area of the crop and under full cover, the changes in crop canopies caused by leaf rolling

can be depicted with the vegetative index. Information is used to support decision-making in water management of large districts that involves correct schematisation of the areas of interest and of water transport processes in each part of the system. By means of appropriate interpretation, digital images can be used to produce multi-temporal maps of crop requirements over large areas.	
Mode of operation	Measurement of plant and canopy temperature.
Advantages: ❑ Rapid assessment of large areas is possible. ❑ A portable device that is relatively easy to use and could easily be moved from one site to another. ❑ It is stable in a wide range of ambient temperatures.	
Shortcomings: ❑ Problems are experienced regarding the index threshold values, which need to be adjusted for each crop. ❑ Although the measurement of temperature is accurate, the translation of this measurement into plant water status requires additional information such as the net solar radiation, air temperature, humidity, etc. To be able to do this, calibration for a specific crop and site is required unless a theoretical model is used. ❑ It can only be used if weather conditions are not rapidly changing (wind and radiation) and only for fully developed crops (in order to avoid soil surface temperature influence on measurements). ❑ Accurate measurement of crop temperature is not useful on its own without supplementary environmental data rendering the technique difficult to apply using satellites (Howell, 1996). ❑ Relative expensive.	
Users: Limited to advisors and researchers.	

2.4.4.6 Phytomonitoring

Description
This technique was developed in Israel as a tool for direct monitoring of actual growth of plants and the environment. It is aimed at improvement of the controllable crop factors, as part of the worldwide change to precision agriculture. Plant-sensing

techniques, sampling rules, measurements protocols, data interpretation and crop-specific application techniques are incorporated. This serves as an interpreter between the plant and grower. It is a specialized real time information system for horticulture and crop production. The purpose is to derive new crop–related information for supporting decision-making and irrigation control. The phytomonitoring system combines:

- A data acquisition system based on a number of specifically designed sensors (up to 64 different sensors that can be allocated around a central unit). Remote sensors that can be selected with their own data loggers are:
  - *A. Plant sensor*: stem diameter, trunk diameter, leaf temperature, sap flow rate, and a variety of dendrometers and fruit growth sensors for different plant types.
  - *B. Environmental sensors*: solar radiation, air temperature and humidity.
- Data processing software is used to display measured data in terms of plant physiology (Kopmyt *et al.*, 2001).

Phytomonitoring involves more than just irrigation scheduling. It is by definition a management information system for crop production. This information system helps to monitor soil characteristics, weather patterns (air temperature, humidity) and provides measurement of leaf temperature, sap flow relative rate, stem micro-variations and fruit growth. It can identify plant physiological disorders at early stages of their development as well as disclose the crop physiological response to any environmental changes in a short time (Ton & Nilov, 1996). It helps the grower to monitor climate, irrigation and fertigation regimes and treatments in a trial-and-error approach. Three functions of phytomonitoring as a management information system are:

- Standard reporting: the system can generate a customized set of measured values and their derivatives, used in daily control practice.
- Exception reporting (watch-dog): the system enables clear detection of unexpected disorders in plants, and this function is based on a variety of phytomonitoring indicators of plant physiological disorder.
- Decision-support system: it enables the monitoring of climate and irrigation regimes though a trial-and error approach (Ton *et al.*, 2001).

Mode of operation	Management information system making use of plant sensing techniques.

Advantages:

- The system is tailored to specific growers and is simple to operate and maintain.

It can be installed by using simple building blocks: remote sensors; data connector and communication channels. Three options of communication channels are available direct cable or GSM cellular modem or web server. ❑ It can be configured for each grower's demands by making use of the trial-and-error regime. Graphic software presents the information in clear and easy to use way to the user. ❑ It helps to disclose hardly detectable, accumulated physiological disorders. Only a few examples are necessary for effective monitoring of plants. ❑ It is a convenient tool for comparative examination of different treatments and materials. ❑ It allows continuous monitoring of physiological parameters of the plants. ❑ Extremely high sensitivity and short response time of phytomonitoring channels eliminate the risk of crop damage.
Shortcomings: ❑ It is rather expensive. ❑ It needs extensive technical support with the start up of the system.
Users: Greenhouses, vineyards, and progressive fruit growers in the Western and south-western Cape.

2.4.4.7 Remote sensing methods

Remote sensing can also be used for plant based monitoring to estimate crop biomass and study crop growing on scales ranging from individual field to scheme level (See 2.4.2.2.4 Remote sensing).

2.4.5 Integrated soil water balance methods

Irrigation scheduling by the integrated soil water balance approach is based upon using either soil water balance models and/or crop growth models to calculate evapotranspiration. The soil water balance approach is analogous with the use of the checkbook method where daily withdrawals are subtracted from the checkbook balance and deposits are added. This method requires tedious calculations if done by hand. Irrigation scheduling approaches based on soil water balance calculations imply that irrigation should start when a threshold value of water content in the soil is reached. To facilitate its use, several computer programs and models are available that could assist the irrigation consultant and farmer with decision-making. Many of the computer programs and models allow the user to choose the method of ET calculation. The data required are weather, crop and soil and management information. The crop growth models often calculate soil water evaporation (E) and crop transpiration (T) separately (Ritchie, 1972) for daily periods using leaf area index (LAI) to partition ET into the T and E components.

Two approaches of integrated soil water balance irrigation scheduling, namely *pre-programmed irrigation scheduling* and *real time irrigation scheduling*. With a pre-programmed irrigation scheduling approach, the decision on how much to irrigate and when to irrigate is determined in advance and a few corrections usually dependent on rainfall are made during the season. A real time irrigation scheduling approach is where the decisions on when and how much to irrigate is based on actual daily conditions, usually the soil water content or atmospheric demand. In real time irrigation scheduling, the ETref for the forthcoming days is sometimes directly estimated from meteorological services or forecasts.

Models can either be physically based or empirical mathematical equations and can be used either for strategic planning or tactical purposes. The use of computer programs to help with irrigation scheduling was introduced in the 1970's, however only recently with the introduction of fast, personal computers have they begun to gain wider acceptance. Strategically one may wish to indicate what area to irrigate, which crops to plant, and how to distribute the available water supply during the season (water delivery), for evaluation of irrigation strategies, and support to regional agro-meteorological information. Irrigation scheduling models can also be used for tactical decisions regarding when and how much irrigation to apply.

2.4.5.1 Pre-programmed irrigation scheduling methods

The following irrigation scheduling methods and models are applied by irrigators for pre-programmed irrigation scheduling:

- Seasonal calendar for irrigation (fixed or flexible).
- Checkbook scheduling with the help of computer programs like the GWK program.
- Models like BEWAB, CROPWAT, SAPWAT, SWB and VINET 1.1. These models are suited for estimating crop water requirements and for planning irrigation strategies. A calendar of expected irrigation dates can be provided through the use of these models.

2.4.5.1.1 Seasonal calendar

Description
Irrigation strategies make use of long-term historical data for full season irrigation scheduling programmes. The intention with calendars is to promote easy and ready adoption of improved water management practices by farmers by presenting simple, non-technical scheduling guidelines. It is the intention to prepare a schedule of anticipated weekly crop water requirements. Calendars are developed using daily soil water balance crop yield models to express most appropriate dates of irrigation. Therefore, following a soil water budget based on weather data and/or pan evaporation does this. The selected value for the fixed net application depth depends on the soil type, crop type, irrigation method and local irrigation practices at farmers' fields (Hillel & Allen, 1995). Once developed, the calendars require little updating and input by technical personnel, but the farmer needs to keep record of the water applied (must ensure water applications are on schedule). Rain is usually treated as if it was an irrigation event. Within this pre-programmed irrigation scheduling approach, irrigators often use two strategies: Fixed irrigation schedule: where farmers use the pre-programmed irrigation schedule without any seasonal adjustments for pertinent reasons like the lack of flexibility in terms of irrigation systems or delivery of bulk water.

Semi-fixed or flexible irrigation schedule: where irrigators use a pre-programmed irrigation schedule with in-season adjustments made as needed.	
Mode of operation	Compilation of schedule using historic weather data.
Advantages: ❑ Calendars are usually developed for several planting dates, crop varieties, soil types and initial water contents. ❑ This is a simple approach of assisting farmers in their decision-making process. ❑ It is ideal for small-scale farmers and commercial farmers without high value crops, and is also applicable to relatively low rainfall areas. ❑ Usually, this scheduling package is developed for flood or sprinkler irrigation where the irrigation cycle varies from one to two weekly applications. ❑ The availability of estimates of irrigation water usage during the season on a weekly basis enables the farmer to edit the original programme. These estimates are usually based on automatic weather data and crop coefficients.	
Shortcomings: ❑ The biggest problem is to account for rainfall in calendars based on long-term data. This makes calculations very uncertain. To solve this problem, one can either assume average rainfall or no rainfall, or utilize probable rainfall during the crop-growing season.	
Users: Farmers, extensionists and consultants.	

2.4.5.1.2 Checkbook method

Description
Checkbook irrigation scheduling enables irrigation farmers to estimate a field's daily soil water balance (in terms of soil water deficit), which can be used to plan the next irrigation. The checkbook method is a record-keeping model, which accounts for all water inputs and outputs. This method requires the irrigator to monitor: ❑ The growth stage of the crop. ❑ Maximum daily temperature. ❑ Relative humidity. ❑ Rainfall or irrigation applied to the field. ❑ Select the daily ET estimation from the crop water use table. ❑ Calculate the new soil water deficit.

Usually, estimates of water use have been developed for average climatic conditions for a particular area based on expected crop growth stage and environmental conditions. Soil water can be measured or estimated in a variety of ways including the low cost "feel" method to more accurate, expensive neutron probe units. This helps to provide an accurate starting point as well as makes provision for corrections or adjustments to the soil water deficit throughout the season. A computer spreadsheet version or hand keeping of records can be followed. This water balance worksheet is operated like a "checkbook" - the irrigation manager maintains a rainfall and irrigation record and mathematically determines a net water balance. To decide when to start irrigating, farm managers should compare the latest soil water deficit in relationship to selected irrigation water management strategies for a crop, the crop's projected water needs, and the weather forecast. The irrigation management strategy will depend either on factors like crop development (critical growth period) or the irrigation system's normal net application amount (Shock, 2000).	
Mode of operation	Calculation of soil water balance.
Advantages: ❑ It is relatively easy to operate. If, for any reason, the soil water balance sheet is interrupted and a period elapses, the balance sheet can be restarted anytime whenever the irrigator has installed soil water instruments or irrigation is anticipated (Trimmer & Hansen, 1994). ❑ Several fields can be scheduled in a very short period of time depending on the number of crops and field locations. ❑ If properly maintained and occasionally verified by soil water measurements the checkbook can be highly successful. ❑ It is handy for daily record keeping of crop water use, soil water deficits along with dates, crop stage, rainfall and irrigation.	
Shortcomings: ❑ Effectiveness of checkbook depends on the accuracy and regularity of the in-field observations and measurements by the irrigator. ❑ Since the crop water use is influenced by more climatic factors than considered in this method, regular field visits and observations are necessary to determine the existing soil water deficit in the field and comparisons to the soil water balance sheet prediction. ❑ To set-up and operate an effective soil water accounting system like this, several field characteristics and soil-water-plant factors need to be understood and quantified by the irrigator.	
Users: Cooperative extensionists (*viz*. GWK program), consultants and farmers.	

Models	Developed	Principles of the model	Application
2.4.5.1.2.1 GWK program	1994, Dup Haarhof, GWK Ltd (Griekwaland Wes Cooperative)	❑ The GWK computer program is a typical checkbook scheduling method where the farmer receives information once week on the current level of the soil water content of the profile, and then based on checks and balances, decides whether he should step up or reduce the irrigation applications during the subsequent week. ❑ Applies checkbook-scheduling principles through the use of a simple, user-friendly spreadsheet computer program based on ETref and crop factors. This software programme that was developed in 1994 uses data from soil water sensors (mainly from neutron probes) and calculates the crop water use. ❑ This software creates a spreadsheet-like working file for each field that reflects the different soil types and depth, available water holding capacity, crop type and emergence date. It is expected of farmers to monitor rainfall and irrigation amounts on a daily basis, while the relative humidity, maximum and minimum daily temperatures, and ETref is collected from representative automatic weather stations. Farmers can use this meteorological data either from automatic weather stations situated on their farms or from weather stations in the specific area. ❑ The software generates a water depletion graph (depth and time graph) for each field for any date, which is printed to take to the field or is filed with other seasonal information on performance and input records. ❑ The program is designed to run in Lotus but is also available in Microsoft Excel. Farmers can either receive information e-mailed to them or just receive the printed information prepared by GWK irrigation expert's hand delivered or fax to them. ❑ *Advantages:* ➢ Quick method of observation by the farmer on the current rate of depletion. The programme incorporates farmer observation, meteorological data of the site and soil water content monitoring to decide on the amount of water to be applied. ➢ The farmer takes ownership of irrigation scheduling decisions based on the information (depth-time graph) provided. ❑ *Shortcoming:* ➢ It needs a sophisticated soil water instrument like neutron probe, Diviner or Enviroscan to monitor the of soil water content status. ➢ An irrigation consultant or expert needs to interpret the data.	❑ Crops: Potatoes, wheat, maize, onions, cotton. ❑ Areas: Northern Cape (Vaalharts, Douglas, Prieska, Barkley-Wes, Rietrivier, Taung). ❑ Commercial and small-scale farmers, consultants.

Models	Developed	Principles of the model	Application
2.4. 5.1.3 *BEWAB* **(***Besproeiingswater Bestuursprogram***)**	ATP Bennie, MJ Coetzee, R van Antwerpen, LD v Rensburg & R du T Burger (UOVS) 1988	❑ Pre-programmed scheduling model for a specific range of crops in the relatively dry areas of RSA (<600mm/annum). ❑ Scheduling is done by applying predetermined amounts at prescribed times or intervals. ❑ The pre-scheduling irrigation water management program is based on soil water budgeting principles and used under low rainfall conditions (< 600 mm/annum), deep soils with plant available water capacity (PAWC) higher than 800 mm. ❑ Maintenance of relatively full profile from early season to provide for the peak demand periods of ET during mid season is an important principle. ❑ BEWAB provides options for profile water status at planting – either 100%, 50% and 0% of PAWC. The upper limit of PAWC is estimated from the silt plus clay content and the lower limit is estimated through simulation of the root water uptake. ❑ Written in Turbo Pascal and GW Basic. Water balance model used for calculation of water use. ❑ Inputs needed to run programme: type of crop, length of growing season, target yield, depth of soil, silt plus clay content for 200 mm depth intervals, rain storage capacity. ❑ Estimating crop water requirements: an output is produced in terms of the number of days after planting and pre-scheduled water application programme for the different options. ❑ *Advantages:* ➢ User-friendly program and logical to implement. ➢ A calendar of expected irrigation dates is provided. ❑ *Shortcomings:* ➢ Initial support with the introduction and set up of the program is needed.	❑ On farm irrigation scheduling and irrigation planning at farm level. ❑ Planners, developers, consultants, irrigation board for calculations of water need and planning of irrigation strategies. ❑ Applicable for mechanised (sprinkler) and flood irrigation. ❑ The program can also be used to design water application requirements of irrigation systems. ❑ This program makes provision for wheat, maize, cotton, peanuts, soybeans, peas and potatoes. ❑ Users in semi-arid regions like Sandvet, Vaalharts, Ramah, Kalkfontein, vd Kloof, Scholtzburg, Petrusburg, Modderrivier, Northwest areas like Brits, Koedoeskop.

Models	Developed	Principles of the model	Application
2.4. 5.1.4 CROPWAT (Crop Water Requirements)	Smith , 1992	❑ FAO computer program for irrigation planning and management (FAO 46) that is accepted as international standard. ❑ Calculations of crop water requirements and irrigation requirements are carried out with inputs of climatic and crop data. Standard crop data are included in the program and the climatic data for 144 countries can be obtained through the CLIMWAT database. ❑ Furthermore, the development of irrigation schedules and evaluation of rain fed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided. ❑ Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No 24 “Crop water requirements” and No 33 “Yield response to water” ❑ The new version of CROPWAT, CROPWAT version 7, contains a completely new version in Pascal, and can be run in the MS-Windows environments. ❑ CROPWAT includes a revised method for estimating reference crop evapotranspiration, adopting the approach of Penman-Monteith as recommended by the FAO Expert Consultation held in May 1990 in Rome. Further details on the methodology are provided in the Irrigation and Drainage Paper No 56: “Crop Evapotranspiration". ❑ Main functions: ➢ To calculate: o Reference evapotranspiration. o Crop water requirements. ➢ To develop: o Irrigation schedules under various management conditions. o Scheme water supply. ➢ To evaluate: o Rain fed production and drought effects. o Efficiency of irrigation practices.	❑ Used for estimation of irrigation requirements by irrigation planners, designers and agronomists. ❑ CROPWAT is meant as a practical tool to help agro-meteorologists, agronomists and irrigation engineers to: ➢ Carry out standard calculations for evapotranspiration and crop water use studies. ➢ Design and manage irrigation schemes. ❑ It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (Smith, 1992).

Models	Developed	Principles of the model	Application
2.4. 5.1.5 SAPWAT **(South African Procedure For Estimating Irrigation Water Requirements)**	Crosby & Crosby, 1999 Van Heerden, Crosby & Crosby, 2001	❑ A computer program that enables the planner, water manager and designer to develop realistic estimates that reflect the complex factors that determine crop water requirements. This planning and management aid is supported by an extensive South African climate and crop database. ❑ The methodology employed is based on atmospheric demand utilising the Penman-Monteith calculated evapotranspiration. The advantage of the FAO procedure is that crop factors can be developed to cater for regional variations, different varieties, management practices and irrigation methods. ❑ The purpose of SAPWAT is to satisfy the needs for a user-friendly aid to help with the planning and scheme management, and is therefore seen as a component of the decision support system. ❑ More suited for estimating crop water requirements and for planning irrigation strategies than for actual irrigation scheduling although some irrigators are using it for actual irrigation scheduling. ❑ SAPWAT takes the user through a process from the selection of up to six weather stations out of 350, which are shown on a map, comparative evaporation graphs, crop factors for a selected crop and a screen that shows the water requirements for that specific crop, effective rainfall and irrigation requirement. Several options are provided, enabling the user to replicate a specific situation. These include choice of growing periods, planting dates, geographic regions, basic irrigation management options, and changeable irrigation efficiency levels. ❑ SAPWAT conforms to the principles embodied in FAO 24. ❑ *Advantages:* ➢ Users, as they gain experience, can contribute to improving and up-dating the databases and develop new techniques for approaching local and specialised situations. ➢ A website has recently been created to promote a two-way communication between the SAPWAT authors and the diverse users of the program, as well as between the users themselves and the irrigation scientists, in order to develop specific applicable instruction sheets, which could also be updated periodically (Crosby, 2004). ➢ A calendar of expected irrigation dates is provided. ❑ *Shortcomings:* ➢ Initial professional support with the introduction and set up of the program is needed.	Users: ❑ DWAF encourage designers, planners, farmers and scheme managers of WUAs and irrigation schemes to use it as a planning aid. SAPWAT is used by irrigation scheme managers to make certain inputs for the development of a water management plan by the WUA. ❑ Some commercial farmers also use it for irrigation scheduling.

<table>
<tr><th>Models</th><th>Developed</th><th>Principles of the model</th><th>Application</th></tr>
<tr>
<td>2.4.5.1.6
Vinet 1.1
(Estimating Vineyard Evaporation for Irrigation System Design and Scheduling)</td>
<td>PA Myburgh and C Beukes (ARC Infruitec Nietvoorbij)
1999</td>
<td>❑ This is a water consumption prediction model that takes into account the unique qualities and variation between different vineyards.
❑ This computer program makes use of an empirical model to simulate the water use of plants (ET).
❑ Traditional irrigation scheduling practices of farmers in vineyards usually only take one or two crop factors together with the ETo into account, and ignore the variation between vineyards in terms of leaf layer, trellis systems, cultivar characteristics, plant density, and climatic factors. The program takes into consideration conditions that have an influence on transpiration and evaporation.
❑ The heat pulse velocity technique was calibrated for measuring sap flow over short periods of time in grapevine trunks. A calibration curve of sap flux against time was developed.
❑ A Li Cor LAI 2000 Plant Canopy Analyser (PCA) was calibrated to measure leaf area index (LAI) in selected vineyards. Leaf area development was measured in eight vineyards varying in cultivars, vine spacing, and trellising system in five grape growing regions of Limpopo, Western Cape and Northern Cape. Seasonal leaf area development could be predicted by means of a third order polynomial equation-using day of season as the independent variable. Based on these predictions, potential growth curves were developed for the respective summer and winter rainfall regions.
❑ Transpiration and surface evaporation models are combined with this model to serve as basis for the prediction of evapotranspiration. The Boesten & Stroosnijder evaporation model was evaluated and adaptations were necessary to account for canopy shading effects viz. horizontal canopies vs. vertical canopies.
❑ Parameters like vine spacing, soil type, trellising system, leaf area, ETo and a constant factor that represents evaporation losses from different soil types were used as input parameters in this model.
❑ Advantages:
➢ This model takes into consideration different vineyard sites and conditions.
➢ The program is user-friendly and logical to implement.
❑ Shortcomings:
➢ Initial support by irrigation specialists with the introduction and set up of the program is needed.</td>
<td>❑ Commercial wine and table grape growers, consultants, engineers and small-scale table grape farmers.
❑ Areas:
➢ Summer rainfall region:
o Northern Cape
o Limpopo
o Mpumalanga
o Northwest Province
o Gauteng
o Northern Cape: Eksteenskuil
➢ Winter rainfall region:
o Western Cape</td>
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2.4.5.2 Real time irrigation scheduling approach

In the context of this discussion, real time irrigation scheduling comprises of three main elements:

i) Soil water content as determined through regular measurement of the soil water status

ii) The use and availability of weather data and

iii) A decision support system which relies on field soil water content, weather forecast and crop cultural practises to select the most appropriate course of action in the scheduling of crops.

Models	Developed	Principles of the model	Application
2.4. 5.2.1 Irricheck (BBP17)	AJ vd Westhuizen & T Daldorf ,1994.	❑ Management program with the aim of real- time irrigation scheduling. ❑ This is the final product of a program initially called: BBP17 (Beste Besproeiings Praktyke). This program started as BBP 3 and was upgraded through feedback from farmers and field experience. ❑ It uses weather, soil, crop and management data to simulate daily water balance and daily real time irrigation scheduling. ❑ Crop factors are used to simulate growth and development of crops ❑ Crop coefficient together with grass reference daily evapotranspiration is used to calculate the water requirements of a plant. The crop coefficient can change according to local conditions. ❑ Evapotranspiration is calculated by taking into account the crop coefficient and weather data. ❑ Soil water balance is used to simulate the available soil water. ❑ Soil water balance can be crosschecked with the use of soil water measurement devices (neutron probe and gravimetric measurement of soil water). ❑ Both the original BBP17 and Irricheck are used in the field. ❑ *Shortcomings:* ➢ Support with the introduction and set up of the program is needed. ❑ *Advantages:* ➢ This program is used by commercial farmers and is relatively user friendly. ➢ This program is very much a bottom-up initiative, where farmers and their experiences in the field were included in the development of the program.	❑ Applicable to different regions in RSA – commercial farmers, consultants. ❑ Areas used: Limpopo, Mpumalanga Northwest, Gauteng, Vanderkloof, Petrusburg and KwaZulu Natal. ❑ Irrigation consultants in the Limpopo, Mpumalanga and Northwest Provinces use the BBP 17 version. ❑ This program makes provision for: ➢ Agronomic crops: maize, popcorn, sugarcane, sweet corn, wheat, tobacco, cotton, potatoes, groundnuts, soybeans, dry beans. ➢ Pastures: lucerne, rye grass ➢ Vegetables like: tomatoes, onions, green pepper, garlic, cabbage, pumpkins, sweet melons, carrots, beetroot, peas, ➢ Citrus and table grapes., ➢ Subtropical crops: bananas, avocado, mangoes, tea and coffee.

Models	Developed	Principles of the model	Application
2.4.5.2.2 PUTU	De Jager, Van Zyl, Kelbe & Singels,1987 De Jager, Singels & Kennedy, 2001	❑ PUTU is a crop growth model that attempts to arrive at a specific yield using water use predictions for specific conditions. ❑ The PUTU model was created for maize in 1973, with the initial development described by de Jager and King (1974) and de Jager (1979). A version for wheat (PUTU 6) followed in 1981 as described by de Jager, Botha and van Vuuren (1981). ❑ PUTU 6 was modified for irrigation scheduling and re-named PUTU 9 (1984/85). While PUTU 9 utilizes most of the functions of PUTU 6 it computes hourly time steps. It became subsequently apparent that daily time steps are more adequate and necessary for irrigation scheduling. So, the daily irrigation version PUTU 9.86 was developed in 1987 and further developed to PUTIRRI as a generalised application model. ❑ This is a simulation model for scheduling irrigation of wheat and maize on individual farms using weather data received from an automatic weather station. It calculates the daily values of Em (maximum total evaporation from a specific crop surface in a given growth stage) and ETref (reference evaporation) from the hourly data obtained from an automatic weather station (de Jager, 1992). ❑ Hourly values of crop total evaporation (Em) are calculated from the weather data, while daily values of Em are found by integrating these over the daylight period. ❑ This model provides accurate simulations of water use and the onset of crop water stress. ❑ Farmers receive the following information: ➢ Indication of the danger of the onset of water stress ➢ The daily water use over the past seven days ➢ The percolation of water out of the root zone ➢ The expected timing of the next irrigation ➢ The current plant available water in the root zone and assessment of the managers performance ❑ *Shortcomings:* ➢ The program is not that user-friendly, and therefore only a few farmers can use the program without support rendered by irrigation professionals. ❑ *Advantages*: ➢ Graphical presentations offer a simple way of communicating information to managers. ➢ It is expected that operators of the weather service should regularly visit the clients, and apart from meeting the needs of the manager, this acts as a valuable source of information to the weather service operator.	❑ Commercial farmers all over the country and in certain African countries like Tanzania, Swaziland and Lesotho. ❑ This service comprised of advisors in Bloemfontein and Pietermaritzburg who telephonically and /or with computers link to various clients in South Africa and some countries in Africa. ❑ Adapted for the following crops: pastures, maize, soybeans, wheat, peas, dry beans, potatoes, runner beans, sugarcane, barley, cotton and vegetables.

Models	Developed	Principles of the model	Application
2.4.5.2.3 Probe for Windows (PRWIN)	Trevor Finch, Research Services, New England, Australia, 1998	❑ Computer program that uses data from soil water sensors and schedules irrigation and the management of crops. The data on soil water content are derived from measurements by neutron probes and other instruments like the Diviner 2000 and Enviroscan at different depths down the soil profile. The program uses direct soil water measurements instead of atmospheric climate data or crop parameters to simulate plant growth. ❑ The prediction of irrigation requirement is based on the soil water measurement of a specific locality and the rate of soil water depletion and historic data on the depletion of soil water. Schedules are calculated using three different values of crop water use: ➢ Calculated from the soil water status. ➢ Calculated from ETo. ➢ Calculated from crop factors or models or historical data. ❑ This program outputs various reports that constitute the basis for a water audit: ➢ Gains report: printed at the end of the season, it shows the total amount of water delivered to each site by rain/irrigation, together with effective amount retained in the soil profile. ➢ Site history report: it shows each irrigation and rainfall in the season. ➢ Season summary report: time graph showing the root zone water content, the actual crop water use, and a "standard" crop water use curve as a comparison, total delivered and efficient irrigation and rainfall together with yield efficiency per mm of water. ➢ Scheduling report: it lays out the scheduled irrigation for each site together with total farm water requirements on a day-by-day basis for the next two weeks. ➢ Irrigation request report: simplified output designed to help valve operators or for export as a comma delimited text to automatic control systems (Motorola). ➢ Calculate water use report: it shows the amount of water used by the plant during the season – calculated by adding the daily water use each day. ❑ *Advantages:* ➢ This program does not simulate crop growth and therefore doesn't distinguish between crops - applicable to all types of crops. ➢ It provides information for planning of irrigation scheduling. ❑ *Shortcomings:* ➢ It needs intensive soil water measurements because of spatial variability. ➢ Initial support by irrigation specialists with the introduction and set up of the program is needed.	❑ It is used for irrigation scheduling purposes, based on intensive soil measurements. The soil water measurements are used for real time irrigation scheduling. ❑ It is widely applied throughout the country: irrigation consultants, commercial farmers and researchers

Models	Developed	Principles of the model	Application
2.4.5.2.4 Donkerhoek Data Irrigation Scheduling Program	Donkerhoek data Pty Ltd , Tienie du Preez & D Mercker (DFM Software Solutions) (1991)	❑ It uses real time weather data in the prediction of daily irrigation requirements. ❑ The program offers information on scheduling irrigation, automated control, fertiliser management and logging of fruit or plant growth. (Koch, 1996). ❑ The irrigation scheduling program offered is driven by: ➢ Crop factors together with Class A pan evaporation figures used to simulate the crop water need (and the prospects are very good that Penman-Monteith figures could be used in future). ➢ The user needs to enter on a daily basis figures on evapotranspiration, rainfall and irrigation for the previous 24 hours. With this information, the program calculates the soil water status of each locality and makes the necessary irrigation scheduling recommendation. ❑ Through soil measurement, the actual soil water contents are compared to estimates. If the calculated figures differ from the actual readings, the model can be corrected. ❑ *Advantages:* ➢ The program offers the option of full irrigation automation if required, where the figures are then automatically transferred to the control software that will control the pumps and blocks. ➢ The program does have the function to calculate the irrigation recommendations for a complete season or only a part of it, based on historical data. ➢ Apart from effective irrigation scheduling, an efficient communication program between the program operator and the irrigators is offered with this program. ➢ It is user friendly – although daily record keeping of E_0 is needed. ➢ It provides automatic control of irrigation systems, taking system capacity into account. ➢ It is adaptable to the use of Penman-Monteith evaporation figures if data from a meteorological weather station are available. ➢ The recommendations on irrigation scheduling are automatically transferred to the control software that controls the blocks and pumps. The inputs of the farmer are therefore minimal. ❑ *Shortcomings:* ➢ Initial support by irrigation specialists with the introduction and set up of the program is needed.	❑ Commercial farmers, consultants in the Western Cape and Orange River. ❑ Crops: Wine and table grapes, deciduous fruit (like: pears, apples, plums); citrus; sugarcane.

Models	Developed	Principles of the model	Application
2.4.5.2.5 SWB (Soil Water Balance)	Annandale, Benadé, Jovanovic, Steyn & Du Sautoy 1999	❑ It is a mechanistic daily time step, generic crop real time, and irrigation scheduling model. ❑ It is based on the improved crop version of the New Soil Water Balance (NEWSWB) model of Campbell & Diaz, 1988. ❑ SWB gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data. ❑ SWB is a generic crop growth model, where parameters specific for each crop have to be determined using weather, soil and crop growth data analysis. Each field to be irrigated is set up in the model and all users need to do is to enter the weather data. ❑ The SWB model calculates the FAO Penman-Monteith grass reference evapotranspiration. ❑ This model has a very well designed water uptake procedure that estimates crop water as a process that can be limited by water supply or atmospheric demand. ❑ SWB simulates crop growth in two ways: ➢ Crop growth model ➢ FAO model: The FAO model is commonly used where specific crop growth parameters are not available ❑ Although SWB model is written in Delphi 4,a Windows version of the SWB model is available. ❑ Extensive use is made of database graphics, with the soil water balance presented at the end of a simulation. ❑ *Advantages:* ➢ It can be used for crop growth and water consumption under saline conditions. ➢ Long-term water and salt balance simulations with generated weather data can be run (suitable for planning purposes). ➢ Site-specific irrigation calendars can be generated for users unable to schedule irrigations real-time. ➢ The mechanistic approach to estimating crop water has advantages over the use of more empirical methods. ➢ It is possible to update the layer water content and/or canopy cover at any stage during the season, should the simulation be out of line. ➢ Several fields can be simulated simultaneously. ❑ *Shortcomings* ➢ Professionals are needed to initially set up the program and to assist in the interpretation of the results.	❑ Irrigation consultants, commercial farmers and researchers in the RSA. ❑ Deficit irrigation strategies can be accurately described. where water supply is limited

Models	Developed	Principles of the model	Application
2.4.5.2.6 Probe schedule (Neutron probe) **Add schedule** (Diviner) **Waterman** (Neutron probe) (du Plessis, 2000)	J le Roux, Bokkeveld Besproeiing BK, 1996	❑ These are software programs used to calculate the theoretical soil water balance and the schedule for the next irrigations in a printable report taking prevailing weather, rainfall and irrigation into account. ❑ This integrates the principles of climate-driven water balance simulation accounting actual soil water measurements by the neutron probe (program can handle any soil water sensor) and direct soil water probing through the Probe Scheduling Program. ❑ The soil water information is used to correct the soil water balance of the simulation and to refine the simulation model. ❑ For each field or locality, a specific database is set up for the specific crop and weather data set. This is cross-validated by direct measurement of soil water. ❑ The necessary management and soil parameters are also entered in the program to run the simulation. ❑ Readings of actual soil water content by a neutron probe (or any other soil water sensor) provide soil water information measured every week or fortnight to correct the soil water balance of the simulation and to refine the simulation of the crop model. ❑ The ETo is calculated with data from the automatic weather station and the Penman-Monteith formula. ❑ The relevant information is displayed in full colour graphics, to give a farmer an instant overview of the irrigation status of his fields. ❑ *Advantages*: ➢ The synthesis of calculation and measurement enables farmers to determine the actual soil water absorption of the plants and the efficacy of rain and irrigation. ➢ It is a time effective and quick way of monitoring of soil water content and adjustment of irrigation scheduling is possible. ➢ Data could be collected by farmer or irrigation manager and sent *via* Internet to the irrigation expert for interpretation. ❑ *Shortcomings* ➢ The help and support of irrigation experts is needed especially during the initial stages to help with the interpretation of data and any adjustments to the model.	❑ Any generic crop of which crop factors are available can be entered. ❑ It is user friendly and easy to use by irrigators. (vd Merwe, 2000) ❑ Commercial farmers, consultants are needed for the initial stages. ❑ Western Cape commercial fruit growers.

Models	Developed	Principles of the model	Application
2.4.5.2.7 CANESIM & CANEGRO (South Africa) APSIM (International)	Inman–Bamber (1990) SA Sugar Association & University Natal (1990) DSSAT format (1997) (Univ Wageningen, Kiker & Inman-Bamber)	❑ The CANEGRO model was developed in response to questions put to scientists by growers and millers of the SA Sugar Industry. This model simulates on a daily basis the mass of the leaves, stalks, roots, leaf area, and root density and tiller population of sugarcane. It simulates processes like soil water movement, crop water use, radiation interception, photosynthesis and dry matter portioning. It requires daily weather data and management input factors. ❑ SQR-CANESIM is a computer program to support general agronomic management. This program was developed from IRRICANE (French program) and a Windows version is available. Precursor to CANEGRO, SQR-CANESIM was developed around the CERES-Maize water balance, which utilised a simple radiation based evaporation model (Inman-Bamber, 1990). ❑ The CANEGRO simulation model helps to predict optimum harvest age for sugarcane. At the same time, this model offers the development of a field record system, which provides growers with summaries of their field records of averages of yields, and sucrose content across soil types, varieties and harvest age, among other factors. ❑ The largest effort in CANEGRO was to develop the capability to simulate water stress. Up to 1991 the soil water balance and root water use based on algorithms of the CERES-Maize model was used. Subsequently, the Penman-Monteith evaporation method is used. ❑ The SQR-CANESIM model is a PC software program that fits in within the DDSAT system. ❑ *Advantages:* ➢ This is a simple computer program that utilises weather data to calculate crop water use and generates irrigation advice and yield information for sugarcane crops. The model used is a robust evaporation model capable of coping with a relatively wide range of conditions. ➢ This model predicts the stalk and sucrose yields of the sugarcane crop. ❑ *Shortcomings:* ➢ Over prediction of the stalk biomass yield (over estimation of yields). ➢ Not applicable to all the cultivars since more parameters are needed. The biggest need is to determine CANEGRO parameters for local cultivars. ➢ It is not a user-friendly program and it is perceived to be high technology, which will need the support of irrigation specialists with the initial set up and interpretation of results. Currently officials from SASRI are working on possibilities to address this concern of farmers.	❑ Since 1997, with the adaptation for the Decision Support System for Agrotechnology Transfer (DSSAT), this model is also used for many other sugar growing regions world- wide: ➢ South Africa ➢ Thailand ➢ Australia ➢ Swaziland ➢ Mauritius **Users:** ➢ *CANEGRO*: researchers from SASRI, which forms an integral part of the agronomic research programme with sugarcane production. ➢ *SQR-CANESIM:* Commercial and small-scale sugarcane growers with the help of the sugar industry's extension personnel. Recently an irrigation scheduling service was initiated for small-scale growers where CANESIM is used to provide the grower with real-time information via a SMS on when to start, stop or continue to irrigate.

2.4.6 Irrigation control or automation

<table>
<tr><td colspan="2">Description
Automated control of irrigation requires the use of soil, plant or atmospheric sensors to determine the need for irrigation (Younger et al. 1981; Phene et al., 1990; Singh et al., 1995) and then either a logic-type controller or a computer to control the irrigation sequence. The automated controller may need to use various control modules to properly manage the irrigation system. These control modules measure pressure and/or flow or other parameters at selected points and control pumps, filters, chemical injectors, etc. It is important for the controllers to have a safety shut down mode. Either pre-programmed or real-time irrigation schedules could be used for the determination of the irrigation schedules programmed in the controller.</td></tr>
<tr><td>Mode of operation</td><td>Automation through soil-plant-atmosphere measurements</td></tr>
<tr><td colspan="2">Advantages:
❑ Most control systems are designed for unattended operation with periodic operator intervention.
❑ Irrigation management automation can reduce peak electric loads. Since in many areas power costs are the main costs for irrigation, it represents one way to impact costs directly.</td></tr>
<tr><td colspan="2">Shortcomings:
❑ Irrigation control systems that use either soil or plant water sensors, in general, are affected by sensor location and field placement.</td></tr>
<tr><td colspan="2">Users:
Farmers and irrigation consultants.</td></tr>
</table>

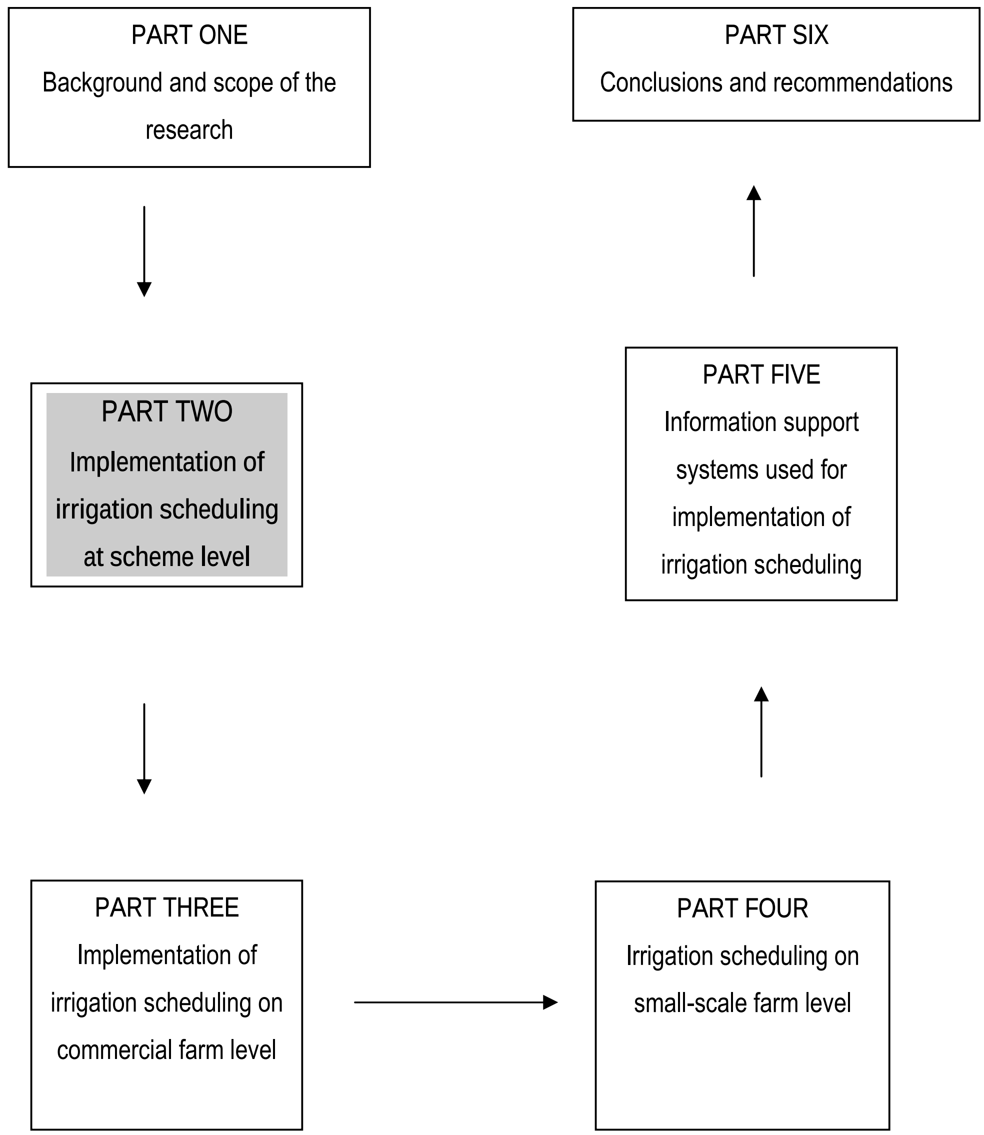
2.5 SUMMARY

The timing and application depth criteria for irrigation scheduling can be established using several approaches based on soil water measurements, use of integrated soil water balance estimates and plant stress indicators in combination with simple rules, observations or very sophisticated models. Some of these methods as indicated in this report were found to be "transferable " to farmers while others will only be considered as research tools, or "sophisticated gadgets". These methods can range from very subjective as in intuition, to very objective measurements, where technical assistance is usually required.

Some farmers are not prepared to deal with real time scheduling and therefore use simple irrigation scheduling methods like an irrigation calendar or a "pegboard" to help them with decision-making. Others, however, will opt for more sophisticated and high technology methods, as they are willing to perform field measurements.

PART TWO

IMPLEMENTATION OF IRRIGATION SCHEDULING AT SCHEME LEVEL



CHAPTER 3
INTRODUCTION AND RESEARCH METHODOLOGY

3.1 INTRODUCTION

Part Two of this report presents the results of a quantitative assessment of the implementation status and distribution of irrigation scheduling methods and models in the nine provinces amongst irrigation farmers. This provides an overview of the implementation and distribution of different methods and techniques of irrigation scheduling by commercial and small-scale farmers on a scheme level (macro level). It also reflects the internal and external factors that influence the implementation of irrigation scheduling on a scheme level.

3.2 RESEARCH METHODOLOGY

3.2.1 Profile of respondents, data collection and analysis

The findings in Part Two are derived from a national survey that was conducted in the nine provinces involves approximately 332 operational irrigation boards and government schemes. Surveys and structured interviews were the main tools for gathering information and assessing the implementation of irrigation scheduling by irrigation farmers.

The respondents involved in this part of the survey were irrigation scheme representatives or spokesmen providing information regarding the respective irrigation schemes. The number of respondents, therefore, corresponds with the number of the irrigation schemes (irrigation board and government schemes). Thirty eight percent of the respondents had access to records and responded by providing actual figures on the situation within the irrigation schemes, which will be referred to as “recorded figures or data”. The rest (72%) of the respondents gave estimates based on consensus figures after consultation with other executive members or the leading irrigation farmers from the specific irrigation scheme or the opinion irrigation farmers in the area ("reported figures"). This is therefore a fairly accurate reflection of the conditions on the different schemes. For the irrigation scheme boards with relatively small numbers of participants, the task of collecting the actual figures was comparatively easy.

The total population of registered irrigation board schemes, government schemes and Water User Associations were considered, to ensure accuracy and representation of the current irrigation situation. An address list obtained from the Department of Water Affairs and Forestry (DWAF) was initially used to identify the 332 existing irrigation board and government irrigation schemes. However, the address list was found to be outdated and alternative ways were subsequently selected. Methods used for collecting data included telephonic interviews, face-to-face interviews and questionnaires (with instruction letters) faxed or e-mailed to clients *(Appendix 1*). While telephonic interviews proved to be very effective, responses to the latter two (faxed or e-mailed questionnaires) were initially disappointing, presumably because of the effort involved and the reluctance among respondents to release information.

The main objective guiding this part of the investigation was to obtain a broad picture of the implementation and distribution of irrigation and irrigation scheduling methods in the nine provinces by commercial and small-scale farmers. A structured questionnaire was compiled which consisted of four parts:

- The first part dealt with information on the number of irrigation farmers and area under irrigation in the scheme, the irrigation methods applied, the implementation of irrigation scheduling by farmers, irrigation allocation (m^3/ha/annum), and irrigation tariff applicable.

- The second part was concerned with the major crops grown in the irrigation area (an estimation of the proportions of each crop) and the type of farming business enterprises, viz. a one-man or owner-managed enterprise or a corporate (or estate farming) enterprise found in the specific scheme.

- The third part of the questionnaire was aimed at an appraisal of the irrigation scheduling methods generally used in the specific irrigation scheme as well as the support systems or information sources that farmers in general use to make decisions specifically in terms of water management and irrigation scheduling.

- The fourth part referred to the perceptions and attitudes of irrigation consultants regarding irrigation scheduling, with specific reference to important attributes regarding competency, training and experience.

Eventually a relatively high response (74%) was obtained in the survey due to special follow-up efforts made by the project team to contact respondents again where necessary. DWAF officials, irrigation board officials, extensionists, and irrigation advisors also assisted in the collection of information especially in the provinces of Kwa-Zulu Natal, Western Cape, Mpumalanga, Northwest and Limpopo. Two hundred and forty six usable surveys were returned from the commercial farming sector with the distribution frequency as indicated in Table 3.1.

Table 3. 1: The response rate from irrigation schemes in the different provinces (N=332)

	Limp	NW	GP	MP	KZN	EC	WC	NC	FS	Total
No of irrigation scheme boards	25	36	7	43	33	32	109	32	15	332
Returned Questionnaires	20	33	6	34	25	14	67	32	15	246
% Response	80	91	86	79	76	44	62	100	100	74

Limp=Limpopo; NW= Northwest; GP= Gauteng; MP= Mpumalanga; KZN= KwaZulu Natal; EC=Eastern Cape; WC=Western Cape; NC= Northern Cape; FS= Free State provinces

Fifty one small-scale irrigation schemes, encompassing 40 irrigation scheme boards and 11 community food gardens were also included in the survey. The data regarding small-scale farmers was collected by personal structured interviews with farmers, as well as from discussions held with local extension officers and advisors involved with the support of these farmers.

The analysis of the data involved the use of statistical package for social science (SPSS version 10). Before analysis, data was captured into a computer readable format, which involved coding, editing, data cleansing. Where necessary modifications were made regarding the collapse or creation of new variables.

3.2.2 Irrigation area and number of irrigation farmers

The 297 surveys returned (246 surveys from commercial irrigation schemes and 51 from small-scale irrigation schemes), represent 759 019 ha (59%) of the present 1 290 132 ha currently irrigated in South Africa, and they relate to perceived representative opinions of 15 789 (60%) of the commercial irrigation farmers and 18 639 of the small-scale farmers as recorded by MMSA (1999).

Table 3. 2: Total area reported for the survey under irrigation and the number of irrigation farmers per province (N=297)

Province	Area under irrigation (ha)	Number of irrigation farmers accounted per province (n)
Gauteng	1 586	100
Free State	44 925	1 710
KwaZulu Natal	74 431	886
Mpumalanga	70 196	1 081
Northern Cape	155 193	2 894
Eastern Cape	44 049	929
Western Cape	116 271	3 833
Limpopo	49 779	1 107
North West	93 241	3 349
Small-scale	109 347	18 639
Total	**759 019**	**34 528**

CHAPTER 4
IMPLEMENTATION OF IRRIGATION SCHEDULING ON IRRIGATION SCHEMES

4.1 CURRENT STATE OF ON-FARM IRRIGATION SCHEDULING

The implementation of irrigation scheduling does not appear to be complicated. There is field capacity point, a refill point and many monitoring tools or computer models are available that can assist the irrigator with decision-making when to irrigate and how much to irrigate.

Respondents were requested to indicate the implementation of irrigation scheduling practices on irrigation schemes. The question invited farmers to indicate more than one method of scheduling, as farmers usually make use of a combination of scheduling methods. According to the survey results the mean percentage farmers implementing irrigation scheduling is 33 on the different irrigation schemes while the median is 18 percent. This indicates a huge variation in irrigation scheduling figures as reported by respondents for the different provinces (Figure 4.1).

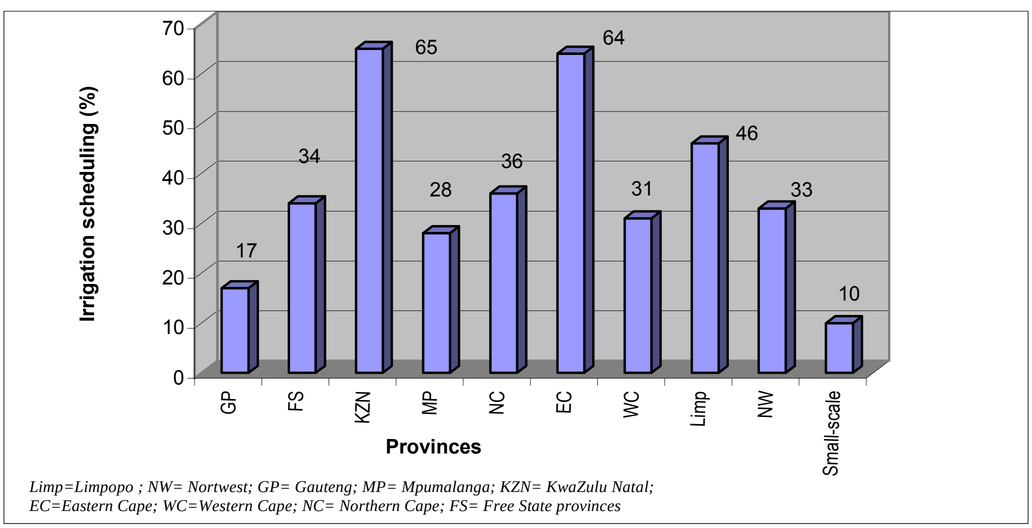


Figure 4. 1: The perceived percentage implementation of irrigation scheduling as indicated per province (N=297)

Figure 4.1 shows that there are significant differences in the perceptions between farmers regarding the commonly used terminology of "irrigation scheduling" (F=2.16; p=0.000). The highest implementation of irrigation scheduling methods was reported for KwaZulu Natal (65%) and the Eastern Cape (64%). This however, is not a true reflection of the implementation of objective irrigation scheduling methods for these provinces as 68 percent of the respondents of KwaZulu Natal and 71 percent the respondents in the Eastern Cape, perceive subjective irrigation scheduling methods like the use of intuition and local experience to fit their definition of "irrigation scheduling". Subjective irrigation scheduling methods were not perceived as belonging to the definition of "irrigation scheduling " to the same extent in the other provinces, where continuous monitoring instruments for soil water content, or the use of computer models for calculating long-term ET figures and real–time ET were perceived as fitting the terminology "irrigation scheduling".

The figure reported for the implementation of irrigation scheduling by small-scale irrigation farmers (10%) represents mainly the perception of extension officers and irrigation scheme officials responsible for serving these farmers in agricultural development, which fits more the definition as used by scientist namely, objective irrigation scheduling.

4.2 DIFFERENTIAL PERCEPTION REGARDING THE IMPLEMENTATION OF IRRIGATION SCHEDULING

Perception, according to Atkinson *et al.*, (1985), is the process by which human beings organize, integrate and recognize patterns of stimuli. Perception is not merely a passive reception and automatic interpretation of stimuli, but rather an active process in which incoming data are selectively filtered to the existing cognitive structure and therefore a key dimension in the process of behaviour change. "Perception refers to the world of immediate experience - the world as seen, heard, felt, smelled and tasted" (Morgan & King, 1966). This finding illustrates that different perceptions exist between farmers but also between irrigators and scientists regarding the commonly used terminology of "irrigation scheduling", which influence the adoption of scientific or objective irrigation scheduling techniques.

According to Düvel (1975), all causes of negative decision making as well as all the forces or potential forces of change, can be directly traced back to the psychological field. Several studies (Düvel, 1975; Koch, 1985; Botha, 1986; Koch, 1986; Louw & Düvel, 1993; Botha & Stevens, 1999) provide evidence of this, and this has led to Hypothesis 1.2, stating that the implementation of irrigation scheduling practices is determined by an intervening variable namely the perception of the user of irrigation scheduling methods.

Based on the response by respondents on the state of on-farm implementation of irrigation scheduling and because of the large variation in the perceptions of irrigation scheduling that exist, respondents were divided into five groups of reported irrigation scheduling implementation as indicated in Figure 4.2.

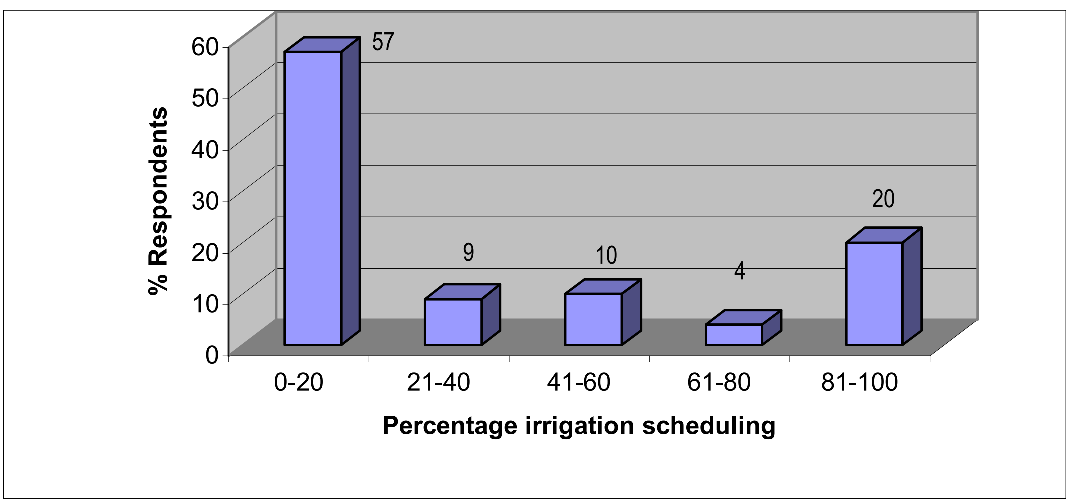


Figure 4. 2: Percentage distribution of irrigation groups (schemes) according to the reported percentage implementation of irrigation scheduling (N=297)

The majority of respondents (57%) reported the implementation of irrigation scheduling to be between 0-20 percent. Twenty percent of the respondents perceived the implementation of irrigation scheduling on the irrigation scheme level between 80-100 percent. The reasons for this huge variation in opinion regarding the implementation of irrigation scheduling on an irrigation scheme level is because of the differential perception amongst many respondents regarding the terminology of “irrigation scheduling” and lend evidence in support of Hypothesis 1.2.

The degree to which intuition fits the definition of irrigation scheduling as perceived by irrigation farmers was further investigated. Figure 4.3 reveals the percentage of respondents who use intuition and those who use objective scheduling methods within each category of reported percentage scheduling.

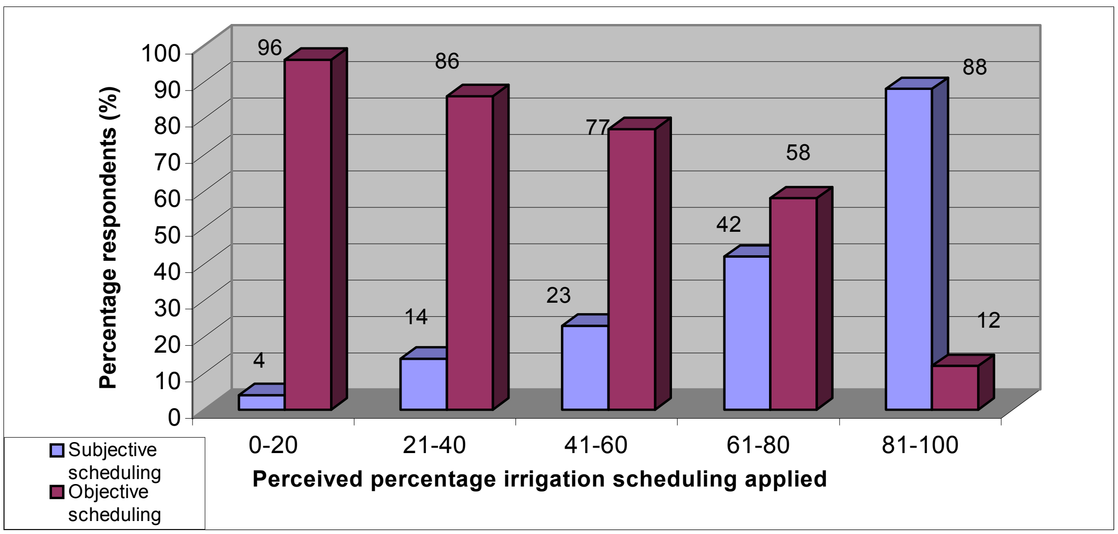


Figure 4. 3: Percentage distribution of respondents according to the perceived percentage irrigation scheduling applied and the percentage ratio between subjective and objective irrigation scheduling (N=297).

The fact that the percentage of respondents who regard the use of subjective scheduling methods (intuition) as part of irrigation scheduling increases dramatically (4% to 88%) with the increased percentage of reported irrigation scheduling, clearly shows that variation in reported irrigation scheduling figures can be largely attributed to the variation in the irrigation farmers’ understanding of the terminology "irrigation scheduling". A highly significant negative relationship exists between the reported percentage of irrigation scheduling and the use of subjective irrigation scheduling methods (r=-0.605; p=0.000). This implies that the higher the reported percentage of irrigation scheduling is the more farmers make use of intuition, observation and local experience as a form of irrigation scheduling. This finding supports Hypothesis 1.2, namely that intervening variables like perception, knowledge and needs influence the adoption behaviour of irrigation farmers with regard to the practicing of irrigation scheduling.

These findings are important, especially for irrigation consultants and the extensionists with regard to the planning and implementation of appropriate communication strategies to promote awareness and adoption of objective irrigation scheduling among farmers. Farmers from the group associated with the use of subjective irrigation scheduling are likely to have different needs for their irrigation management decisions, than farmers from the group using objective irrigation scheduling in their decision making. The needs and aspirations of the five different irrigation scheduling groups are compelled to clear differences, which must be taken into account by irrigation advisors and extensionists in their future support strategies.

The reported figures of irrigation scheduling reflected in Figure 4.3 reveal three distinguishable groups of respondents' perception regarding the implementation of irrigation scheduling:

- For some of the respondent's irrigation scheduling is perceived as the use of intuition and experience which fits the model of subjective understanding of irrigation scheduling and was correspondingly included in the figures reported on the implementation of irrigation scheduling. This group therefore recorded relative high figures of irrigation scheduling application on the different schemes (up to 100%).

- Some respondents considered continuous monitoring of soil water content, or the use of computer models for calculating long-tem ET figures and real time ET to be objective or scientific scheduling methods. This group of respondents therefore recorded implementation figures of irrigation scheduling that reflect solely the use of objective irrigation scheduling methods on a scheme level. These recorded figures are therefore relatively lower because of the differential perception that exists. The median figure of 18% reported for the implementation of irrigation scheduling is therefore accepted as a more accurate reflection of the application of objective scheduling by farmers.

- The third group of respondents uses a combination of both scientific (or objective) and subjective irrigation scheduling methods. Although this group acknowledges the role of intuition in irrigation management decisions, they perceive intuition-based decisions alone as not adequate to ensure efficient irrigation management and therefore also make use of objective irrigation scheduling methods to help them with decision-making.

4.3 STATE OF IRRIGATION SCHEDULING ON DIFFERENT TYPES OF IRRIGATION SCHEMES

South Africa has four general types of irrigation schemes that are linked to the different economic development phases experienced in the country (FAO, 2000):

- Private irrigation schemes (approximately 450 000 ha). Private schemes exist where the water source can be privately owned and owners extract water directly from weirs, boreholes, and farm dams. The farmer carries all costs and the registering of these water sources are currently in process.

- Irrigation board schemes (approximately 400 000 ha). They statute under the earlier water legislation established irrigation boards. They are autonomous, democratically run institutions elected by participating irrigation farmers from within their own ranks. They are empowered to provide their own infrastructure and levy fees to cover full costs. Historically they had access to subsidy in respect of capital works and also state loans. This facility is no longer available (Pretorius, 2003). Under the National Water Act (No. 36 of 1998), all irrigation boards will be converted to WUAs.

- Government (state) schemes: 350 000 ha where the infrastructure was provided by the state. Management and maintenance of the distribution system is a state function and farmer involvement is limited to the participation on advisory committees. Water charges are levied for operation and are charged to farmers. Membership of these schemes will also be transferred to WUAs in due course.

- Small-scale schemes: 100 000 ha distributed among small-scale farmers and include:

  - Bureaucratically managed schemes fully administered by the state or an agency of the state.

  - Jointly managed schemes, where the irrigation development agency and project participants jointly are responsible for the functions on the irrigation scheme.

  - Community schemes, usually small in size, operated by water users themselves.

  - State or corporation financed schemes, such as in sugar cane production, where farmers are selected and infrastructure is provided to field edge.

  - Large estate schemes state or privately financed, managed by agents producing high value cash crops.

Following budgetary reprioritization and maintenance that was withdrawn, many small-scale schemes collapsed or are in a poor physical state (Maritz, 2004). The operating costs are charged to farmers at a subsidized rate.

In the survey three types of irrigation schemes were included namely government irrigation schemes, irrigation board schemes and the newly established WUAs as summarized in Table 4.1.

Table 4. 1: Frequency distribution according to the types of irrigation schemes included in the survey (2003) (N=297)

Type of scheme	n	Percentage (%)
Irrigation board schemes	214	72
Government scheme	48	16
WUA	35	12
Total	**297**	**100**

The new National Water Act (NWA) (Act 36, 1998) promotes integrated and decentralized water resource management and is to be implemented through the National Water Resources Strategy (NWRS). Social development, economic growth, ecological integrity and equal access to water are key objectives of the new water legislation. The NWRS makes provision for, amongst others, the establishment of Catchment Management Agencies (CMAs) and Water User Associations (WUAs) in each of the 19 water management areas in the country, as declared in Government Notice 1160, October 1999 (DWAF, 2000). These institutions are in the process of being established at the regional and local level, pursuing a more participatory approach to water resource management.

The CMAs are statuary bodies, established by Government Notice, with jurisdiction in a defined water management area. The functions and responsibilities of the CMAs include the development of catchment strategies, management of water resources and coordination of water related activities.

WUAs are cooperative associations of individual water users who wish to undertake water related activities at a local level for their mutual benefit. The WUAs usually operate in terms of a formal constitution and are expected to be financially self-supporting from water use charges paid by the members (Knoetze, 2003). A WUA falls under the authority of the CMA in whose area it operates, if the agency has received powers from the Minister to operate the WUA's activities. According to Schedule 5 of the NWA, one of the functions of the WUA can be "to regulate and supervise the distribution and use of water from the water resource according to the relevant water use entitlements, by erecting and maintaining devices for measuring and dividing, or controlling the diversion of the flow of the water". Through the constitution and business plan of the WUA, it must be shown how "the WUA makes progress towards measuring the quality and quantity of inflows and outflows, losses and water supplied to its customers, and towards the use of acceptable devices and techniques. The strategy and business plans are currently being tested through three pilot studies on the development of water management plans for the Gamtoos, Oranje-Riet and Orange-Vaal WUAs (Knoetze, 2003).

Some of the irrigation board schemes and government schemes have already been transformed into WUAs. The transformation of the irrigation boards into Water User Associations (WUA) has progressed very slowly, and during 2003, when this part of the study was completed only 23 WUAs had been established (Karar, 2003). The relatively high number of WUAs reflected in the survey is misleading because of duplication in the nomination, and therefore the reflection of 35 instead of 23 WUAs indicated by Karar (2003). As in the case of the Oranje Riet Water Users Association, the irrigation schemes of Scholtzburg, Modderrivier, Rietriver, and Oranje Riet River are regarded as four different WUAs for statistical reasons while they are incorporated into one WUA.

Respondents belonging to the three types of irrigation schemes have different perceptions with regard to the definition of "irrigation scheduling" as indicated in Figure 4.4.

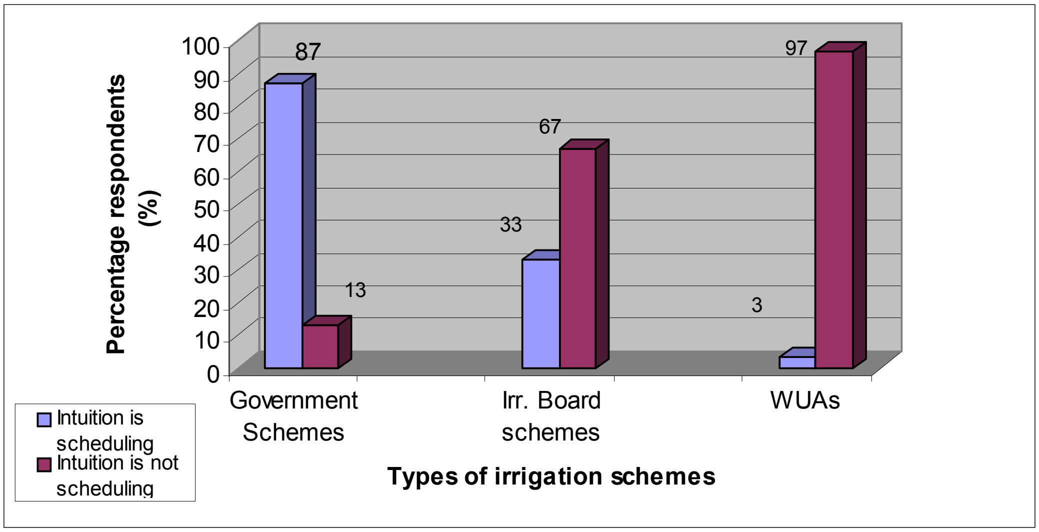


Figure 4. 4: Percentage distribution of respondents according to the percentage ratio between subjective and objective irrigation scheduling implemented on the different types of irrigation schemes (N=297)

Figure 4.4 illustrates that farmers irrigating on the three different types of irrigation schemes differ in their perception with regard to the understanding of the terminology "irrigation scheduling" (F=3.46; p=0.044). The majority (87%) of respondents farming on government irrigation schemes are of the opinion that subjective scheduling fits the general definition on irrigation scheduling, while only three percent of respondents from WUAs and 33% of irrigation board schemes respectively share the same opinion. This finding indicates that farmers irrigating on irrigation schemes that were transformed into WUAs, are in general more aware of the scientific definition of irrigation scheduling. This relationship is supported by the highly positive correlation coefficient (X^2=28.26; df=8; p=0.001), which is in accordance with the expectations (Hypothesis 1.2), namely that environmental factors in the form of proper structured and functioning irrigation management institutions (WUA) influence the implementation of irrigation scheduling.

4.4 ADOPTION OF ON-FARM IRRIGATION SCHEDULING METHODS

Field water use efficiency is defined as the amount of irrigation water that replenishes the rooting zone as a function of the amount of water supplied to the field. The challenge to the irrigator is to fill the root zone depleted by evapotranspiration. Central to this task is the ability to predict or measure the depletion of water in the root zone so that irrigation water can be applied according to the crop requirement.

In Chapter Two various irrigation scheduling approaches used by irrigators have been quantitatively described and classified. The spectrum of soil-plant-atmosphere irrigation scheduling methods commonly used by irrigation farmers as captured by the survey are clustered into seven groups:

- Use of long term evaporation figures like the use of evaporation pans (Class A pan), pegboard and the Green Book.

- The use of real time ET calculations as collected by automatic weather stations and distributed by fax modem or Short Message System (SMS).

- Plant based monitoring like sap flow, leaf water potential, and phytomonitoring.

- Measurement of soil water content and potential with soil water sensors: tensiometers, neutron probes, capacitance sensors (Diviner, Enviroscan, etc), and dielectric sensors (gypsum blocks).

- The use of irrigation scheduling models is used within the integrated soil water balance approach where irrigation scheduling is based upon either using soil water balance models and/or crop growth models to calculate evapotranspiration.

- Feel and appearance method: where a tile probe, soil auger or spade is used to determine the status of the soil water content.

- The use of intuition based on local experience, knowledge, observation and feeling as part of the farmers' repertoire or mental model for decision-making.

Figure 4.5 summarizes the percentage implementation of different irrigation scheduling methods as reflected by (a) recorded figures (38 percent of the irrigation schemes) and (b) as reported by representative respondents but supported by consensus opinion of a smaller reference group. These figures indicate that the reported and recorded figures regarding the implementation of the different irrigation scheduling methods do not differ substantially.

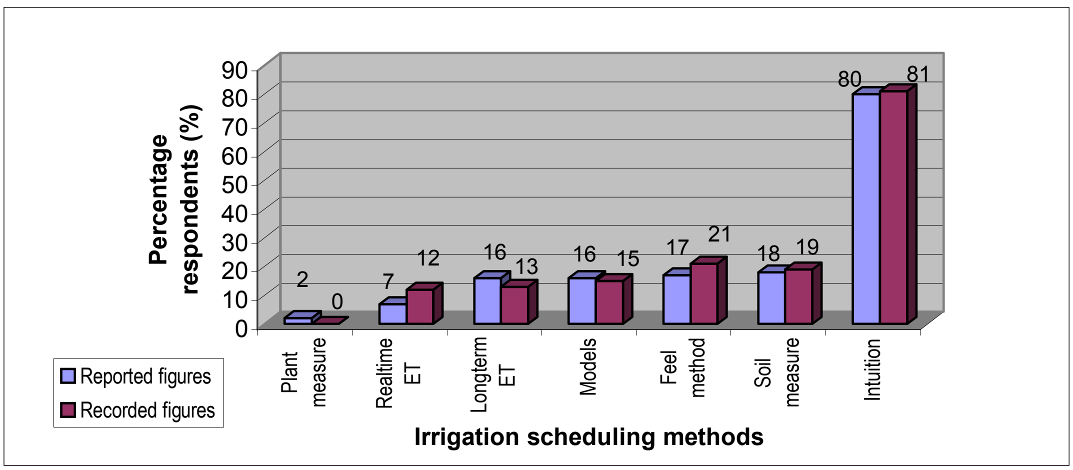


Figure 4. 5: Implementation of different irrigation scheduling methods by irrigation farmers according to figures recorded and figures reported by representative respondents from the different irrigation schemes (N=297).

The majority of respondents (81%) make use of subjective irrigation scheduling methods (intuition), while the reported implementation figures of objective scheduling methods vary between 2% and 18%, as indicated in Figure 4.5, with the median 14%. The recorded percentages vary slightly more. Only a few commercial fruit and wine grape growers in the Western

Cape reported the use of plant based monitoring (2%) for example the measurement of leaf water potential, sap flow and phytomonitoring.

The use of subjective irrigation scheduling methods by irrigation farmers entails the incorporation of fixed or semi-fixed irrigation calendars based on intuition, local experience, knowledge, observation and feeling. Intuition forms part of the farmers' repertoire or mental model, which brings "reflection" into the centre of understanding of what irrigation farmers do and is also sometimes described as "thinking on the feet". According to the Webster New International Dictionary of the English Language, intuition is a looking upon, a seeing either with the physical eye or with the "eye of the mind". This knowledge used for decision making is usually obtained without recourse to interference of reasoning, and is often referred to as innate or instinctive knowledge, insight, familiarity, a quick or ready insight or apprehension (Rowan, 1986).

4.4.1 Interrelationship between irrigation scheduling method selected and the implementation of irrigation scheduling

Figure 4.6 shows the relationship between the different irrigation scheduling methods selected by farmers with the implementation of on-farm irrigation scheduling.

As depicted in Figure 4.6 there are significant differences between the different irrigation scheduling groups ($F=165.1$; $p=0.000$). It is illustrated that farmers that fall within the bracket of 0-40% irrigation scheduling applied (scheduling groups 1-2), are more prepared to rely on the use of objective irrigation scheduling methods viz. monitoring of soil water content and the use of computer models or programs to schedule irrigation on the farm than the use of intuition. The use of intuition was restricted to less than 10% amongst these irrigation farmers. Figure 4.6 also indicated that as the respondents reported relatively higher figures of implementation of irrigation scheduling, the contribution of intuition (subjective scheduling methods) also clearly increased (scheduling groups 3-5). These findings provide evidence in support of Hypothesis 1.2, namely that higher reported percentage of irrigation scheduling is correlated with the use of intuition as a form of irrigation scheduling.

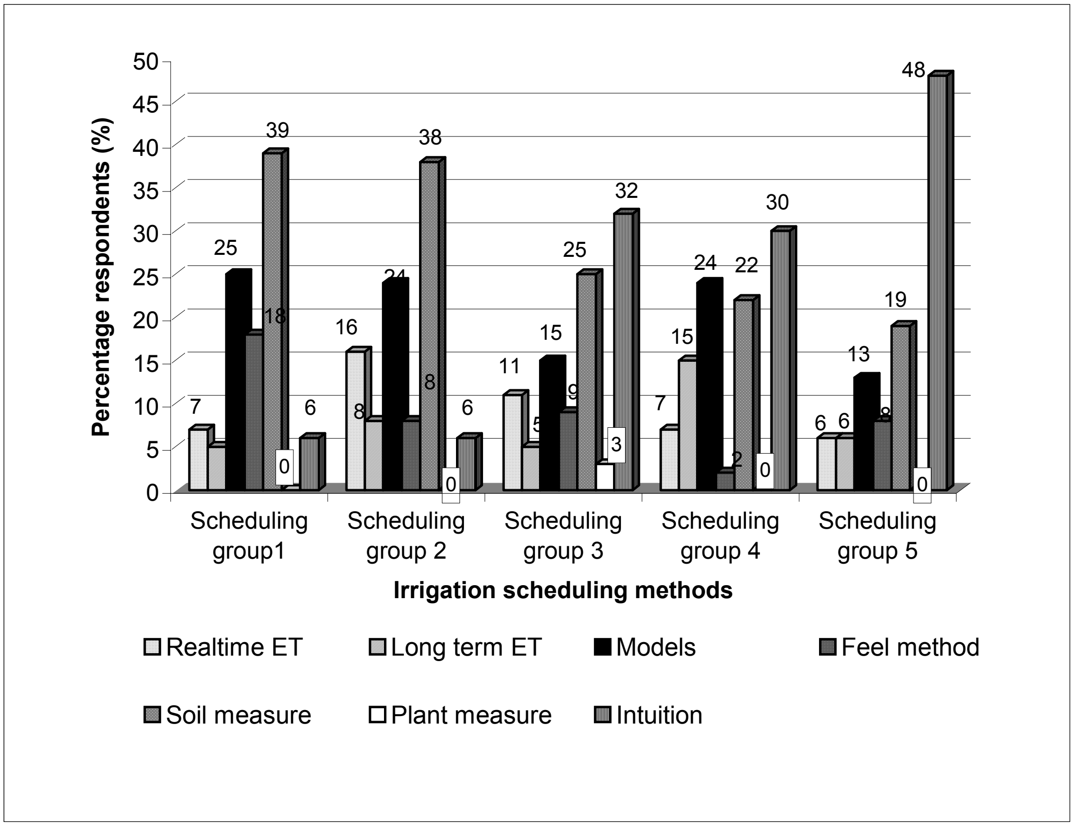


Figure 4. 6: Implementation of different irrigation scheduling methods by scheduling groups 1- 5 (N=165)

4.4.2 Computer irrigation scheduling models and the interrelationship with on-farm irrigation scheduling

Computer usage for farm management decisions becomes more popular, as there is a growing need amongst farmers for intensive physical and financial planning of farming operations where information is used for everyday management decisions. However the use of irrigation scheduling models among irrigation farmers is still limited and the majority of irrigation farmers (72%) who reported engagement in irrigation computer software also referred to the necessary help and support required from irrigation consultants and extensionists in this regard.

The majority of irrigation scheduling programs and models are used to generate advice, and are referred to in management literature as decision support systems (DSS). The complexity of farming systems is commonly used as the justification for modeling and decision support systems "Never before have we been able to analyze so much data relating to a specific situation, and arrive at a solution to a complex problem " (Hamilton *et al.*, 1991) or "to deal with complexity we need more sophisticated decision aids" (Hochman, 1995). Some of the irrigation scheduling models are relative simple and contain trivial calculation models, while others are much more complex and make analytical predictions with the help of simulation models. Figure 4.5 indicate that 16 percent of the irrigation schemes referred to the use of computer irrigation scheduling models by farmers.

As discussed in Chapter Two, numerous irrigation scheduling models and computer software programs have been developed and are available to farmers, consultants and researchers. These models are based on integrated soil water balance principles, with various degrees of sophistication, including mechanistic approaches to crop growth. A model like SAPWAT was developed with the main aim to help with strategic decisions on a scheme level while models like SWB, Irricheck, PRWIN, etc are real time irrigation scheduling models. These irrigation scheduling models were developed to help the farmer towards better-informed decisions in on-farm water management. The real time irrigation scheduling models and programs are based on actual daily conditions, usually soil water content and atmospheric demand, and therefore need regular measurements and monitoring of the soil-water-atmosphere conditions prevailing. Figure 4.7 illustrates the implementation of the different irrigation scheduling models as reported by the respondents.

PRWIN was found to be most popular among the irrigation farmers, as 18% of the respondents either referred to the use of this programme by an irrigator within the irrigation scheme or were using it themselves. The reported figure on the use of Probe Sched (8%), also includes the implementation of computer programs *Add Sched* that consultants and farmers generally use together with soil measurement devices like the Diviner and *Waterman Sched* generally used together with neutron probes supplied by Geoquip.

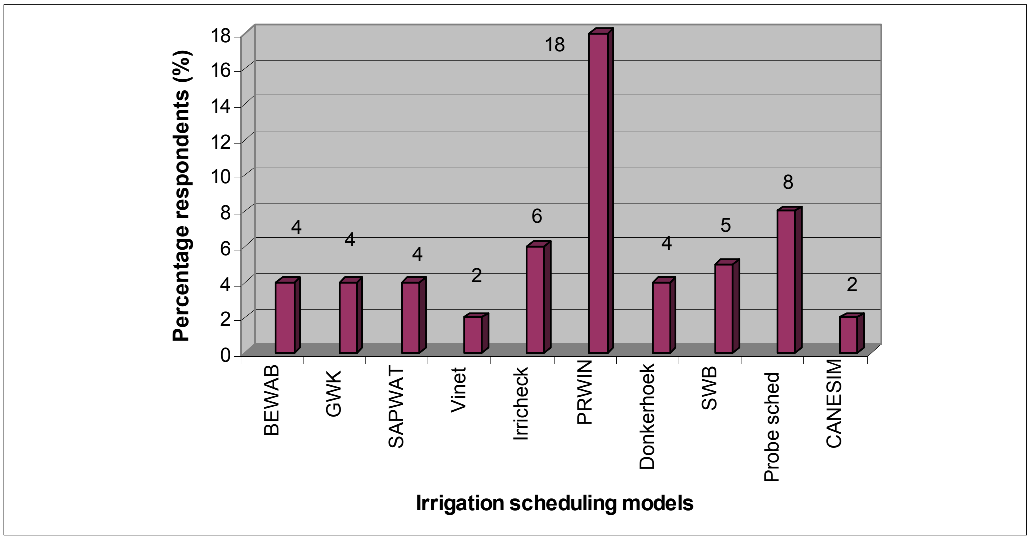


Figure 4. 7: The implementation of irrigation scheduling models by farmers (N=297)

From the responses received from respondents and field experience it appears that farmers need appropriate technical support of extensionists and irrigation consultants with the implementation of soil water balance models and programs, as it is often perceived to be complex and therefore difficult to apply on the farm. Literature reveals a positive association between extension and the adoption behaviour of farmers (Koch, 1985; Frank & Chamala, 1992; Chamala, 1996; Botha *et al.*, 2000; Leeuwis, 2004) and this led to the hypothesis that competent ground level support by research and extension is imperative for the adoption of irrigation scheduling on the farm (Hypothesis 4).

As depicted in Table 4.2 a highly significant negative relationship exists between the implementation of computer models or programs on-farm and support rendered by fellow farmers (Cramer's V value=0.940; p=0.000) or farmers themselves (Cramer's V value=0.610; p=0.020). These findings illustrate that the implementation of computer irrigation scheduling models and programs are predominately advisor-driven and not farmer-driven, which provides evidence in support of Hypothesis 4, namely that competent ground level support by irrigation advisors and extensionists is conducive for the implementation of objective scheduling practices on-farm.

Table 4. 2: Relationship between the adoption of computer irrigation scheduling models and programs and ground level support as reflected in a test of association (N=297)

Ground level support offered	Cramer's V	
	Value	**p**
Cooperative extension and industry support	0.238	0.050
Private irrigation consultant	0.592	0.080
Fellow farmers	0.940	0.000
Farmers themselves	0.610	0.020

Advisors and service providers who are in regular contact with farmers have considerable influence on farmers' decision making (Daniels & Chamala, 1989). Irrigation consultants and advisors usually select and use irrigation scheduling models and software packages, which fit their specific business needs and style of service delivery. The differences between the provinces regarding the rank order of irrigation scheduling models and programs implemented by farmers are significant (F=3.5; p=0.046). The difference lies in the fact that it appears that the adoption of irrigation scheduling models and programs appears to be advisor specific, and therefore the implementation of specific scheduling programs and models by farmers are also geographically bounded as indicated in Table 4.3. This clear relationship finds expression in the significant Cramer's V value (Cramer's V=0.576; p=0.004).

Table 4. 3 Distribution of irrigation scheduling models and programs in the nine provinces according to their adoption as indicated by respondents (N=297)

Computer models and programs	Distribution of implementation of computer models in various provinces per ranking order*				
	1	2	3	4	5
BEWAB	Free State	Northern Cape	Northwest		
Irricheck	Limpopo	Free State	Northern Cape	KwaZulu Natal/ Mpumalanga	Northwest
SAPWAT	Northern Cape	Free State/ Eastern Cape	Mpumalanga	KwaZulu Natal	Northwest
SWB	Limpopo	Mpumalanga	KwaZulu Natal	Eastern Cape	
PRWIN	Western Cape	Mpumalanga	Northern Cape	KwaZulu Natal Eastern Cape/ Limpopo	Free State/Northwest
CANESIM	KwaZulu Natal	Mpumalanga			
Probesched	Western Cape/ Northern Cape	Mpumalanga	Eastern Cape		
Donkerhoek	Western Cape	Eastern Cape			
GWK	Northern Cape	Northwest			
Vinet	Western Cape	Northern Cape			

*) *1= Highest implementation, 5= Lowest implementation*

4.5 SUMMARY

Although a large number of irrigation scheduling tools and methods have been developed for South African irrigation farmers, the implementation of objective irrigation scheduling methods are below expectation. Only 18% of the respondents confirm the use of objective irrigation scheduling methods and thereby adhere to the strict definition of scheduling. The majority of farmers do not monitor the status of soil water content, but rather use subjective irrigation scheduling methods.

Different perceptions exist between irrigators regarding the definition of "irrigation scheduling" and its implementation on the farm. This differential perception was clearly illustrated in the reported figures regarding the implementation of irrigation scheduling on an irrigation scheme level. A strong negative relationship exist between the use of subjective scheduling methods like intuition and the irrigation scheduling figures reported by respondent. This implies that the higher the reported percentage of irrigation scheduling the more the farmers make use of intuition and observation as subjective scheduling methods.

Although the computer models used for irrigation management decisions incorporate and link formalised knowledge from different disciplines, and allow for the making of complex calculations that would otherwise never be realistically carried out, the implementation of irrigation scheduling models, especially real time models, has proved to be restricted due to their complexity. The use of real time irrigation models amongst farmers is mainly restricted to regions where private consultants or advisors support their implementation. User-friendly and understandable models like BEWAB, which can be used for the development of irrigation calendars, seem to be more easily adopted by farmers especially where limited support by extensionists and private irrigation consultants is available.

CHAPTER 5
THE INFLUENCE OF INTERNAL FACTORS ON IMPLEMENTATION OF ON-FARM IRRIGATION SCHEDULING

5.1 TYPE OF FARMING BUSINESS ENTERPRISES

Two major types of farming business enterprises are often found on irrigation schemes, namely:

- One-man enterprises (owner-managed): These are farming units where the individual farmer, usually the owner, is responsible for all the management activities on the farm.

- Corporate enterprises: These are usually of a much bigger scale with the irrigation management usually assigned to a specific person(s) or consultant (s) who do form part of the owner's day-to-day management decisions.

This distinction between the two types of farming operations was important for the research team because it was assumed that the more precise and objective irrigation scheduling methods are the more likely it to be used by the big corporate or estate enterprises, while the owner-managed enterprises tend to use the more subjective irrigation methods. Table 5.1 provides an overview of the distribution of respondents representing irrigation schemes according to the occurrence of corporate enterprises.

The percentage of corporate farming enterprises is relatively small and in 64 percent of the cases, respondents reported none at all. The survey indicates that the majority of farmers are still involved in owner-managed or family enterprises. It can be argued that although farming is increasingly seen as a business, the importance of the farm family's social fabric is too often neglected when trying to introduce change. Vanclay (2003) argues that farming is a social activity and made the following statement: "Farmers do not

Table 5. 1: Distribution of respondents according to occurrence of corporate enterprises (N=297)

% Corporate enterprise	Number of respondents (n)	% respondents
0%	190	64
0.5-10%	70	24
11-20%	6	2
21-40%	10	3
41-60%	6	2
61-100%	9	3
Missing	6	2
Total	**297**	**100**

make conscious decisions about most issues – they do what is consistent with their social situation". This is an important finding to be taken into consideration by research and extension or advisory services before farmers are introduced to new innovations and expected to change practices.

Table 5.2 illustrates the distribution of the respondents according to the types of farming operations and the implementation of irrigation scheduling methods. The findings illustrate that corporate or estate enterprises tend to make use of objective scheduling methods but this is not statistically significant. A significant negative correlation (r=-0.499; p=0.000) exists between the use of intuition as an irrigation scheduling method and the type of enterprise, meaning that corporate enterprises are in general more prepared to make use of objective irrigation scheduling with the necessary support of the irrigation extensionists and consultants. This relationship between the use of irrigation scheduling practices and the business enterprise of a specific farm provides evidence in support of Hypothesis 3, namely that the approach to problem solving and learning is determined by the obtained technology level of the farmers as well the business characteristics of a specific farm.

Table 5. 2: Distribution of respondents according to the types of farming operations and the implementation of irrigation scheduling methods (N=291)

Irrigation scheduling methods	Corporate enterprise (n=101)		One-man enterprise (n=190)		Total
	(n)	%	(n)	%	(N)
Plant measurement	3	100	0	0	3
Real ET	24	57	18	43	42
Long term ET	16	50	16	50	32
Computer models	59	60	39	40	98
Feel method	29	53	26	47	55
Soil water measurement	74	51	72	49	146
Intuition	101	35	188	65	289

This relationship is also evident from the figures reflected in Table 5.2, where only 35% of farmers involved in corporate business enterprises, rely on subjective scheduling decisions based on intuition and experience as opposed to 65% of the one-man enterprises.

5.2 INFLUENCE OF CROP SELECTION

The assumption is that objective irrigation scheduling practices become more important for commodities where water intensive and high-value crops (e.g. horticultural crops) are produced. These crops are usually very sensitive to periods of subnormal irrigation, which will directly impact on the production quality and yield. With crops like irrigated pastures the expectation is that farmers are more inclined to use fixed or semi-fixed irrigation scheduling programs. The following figures (Figure 5.1 – 5.1) provide an overview of the crops grown under irrigation as reported by respondents on the different irrigation schemes.

5.2.1 Cash crops

The most important irrigated cash crop types currently grown under irrigation based on the percentage irrigation schemes planted to each crop type are reflected in Figure 5.1

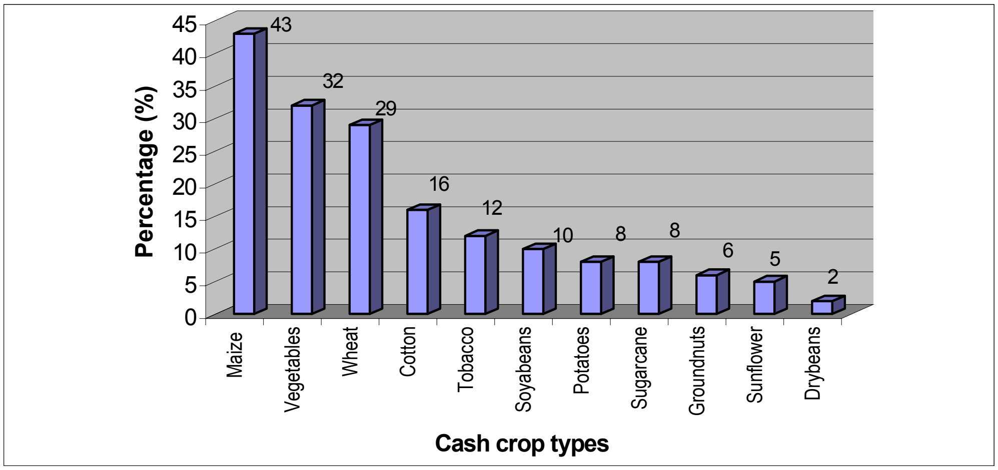


Figure 5. 1: Percentage irrigation schemes on which various cash crops are produced (N=297)

Cereals (e.g. maize, wheat),vegetables and cotton are most commonly cash crops grown under irrigation. Crops like paprika, sugar beans; barley, peas and rice are grown by less than 2% of the respondents.

5.2.2 Intensive horticultural crops

The main horticultural crops grown under irrigation based on the percentage irrigation schemes planted are indicated in Figure 5.2.

Grapes (wine and table grapes) and citrus are popular intensive horticultural crops planted under irrigation, followed by deciduous and subtropical fruit. Other intensive crop types like strawberries, almonds, olives, tea and coffee were also mentioned, but are found on less than one percent of the irrigation scheme.

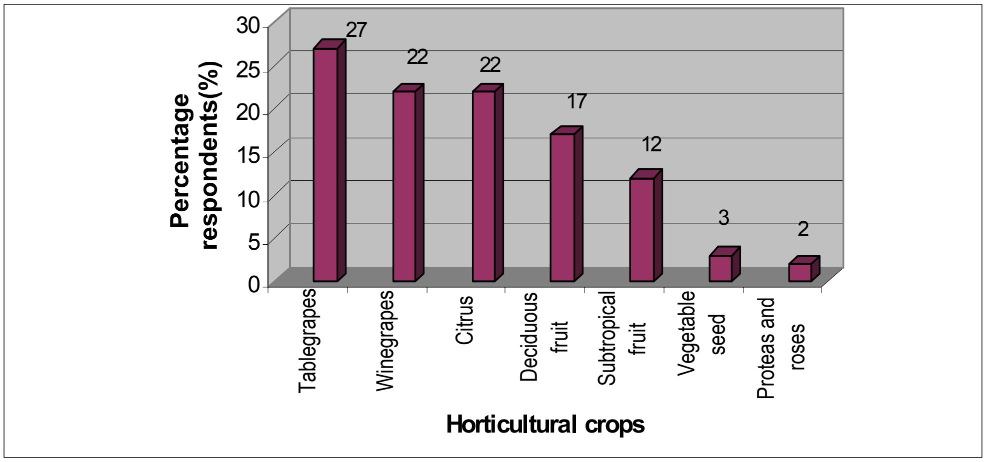


Figure 5. 2: Percentage irrigation schemes on which the different intensive horticulture crops are grown (N=297)

5.2.3 Pastures

Forty-five percent of the respondents indicate that irrigated pastures are grown on their schemes, with lucerne constituting the most important irrigated pasture (grown by 32% of the respondents). Other types of pastures produced under irrigation like ryegrass, kikuyu, and festival were also mentioned.

Table 5.3 indicates the frequency distribution of irrigation schemes according to the different crops and combination of crop types grown as well as the ratio between subjective and objective irrigation scheduling methods. Cash crops like cereals alone or in combination with intensive, high vale horticulture crop types and pastures are planted on the majority of irrigation schemes.

The differences between the various types of crops and the implementation of irrigation scheduling practices are significant (X^2=96; df=2; p=0.000), suggesting that farmers involved in the growing of relatively intensive horticultural crops are more inclined to schedule irrigation precisely with the support of objective irrigation scheduling methods. This relationship is supported by a significant positive correlation coefficient (r=0.271; p=0.001) to exist between the crop types selected by the farmer and the percentage

Table 5. 3: Frequency of irrigation schemes under different crops and combination of crops (N=297)

Crop types	Irrigation scheduling method		N	%
	Subjective scheduling methods	Objective scheduling methods		
Intensive crops[1)]	11	36	47	15
Cash crops[2)]	69	17	86	29
Pastures[3)]	5	3	8	3
Intensive + Cash crops	16	70	86	29
Intensive crops + pastures	3	18	21	7
Pastures + cash crops	21	17	38	13
Intensive + cash crops+ pastures	2	9	11	4
Total	**127**	**170**	**297**	**100**

[1)] Intensive crops = high value crop types like horticulture, [2)] Cash crop types like maize, wheat, cotton, sugar cane, etc.; [3)] Pasture = lucerne, kikuyu, ryegrass, etc.

objective irrigation scheduling that farmers apply. These findings provide evidence in support of Hypothesis 2, namely that more precise irrigation scheduling is perceived necessary to improve production efficiency (yield and quality) by industries like horticulture production and the growing of high-value crops. This significant relationship provides further evidence in support of Hypothesis 3, namely that the technology level of the farmer and the business characteristic of the farm (intensive,high-value *versus* cash crop commodities) determine farmers' approach to learning and problem solving through the adoption of specific irrigation scheduling methods.

Table 5.4 indicates the implementation of the different irrigation scheduling methods as reported for the different crop types and combination of crop types grown.

Table 5. 4: Percentage distribution of irrigation schemes according to the types of crops and irrigation scheduling methods used (N=297)

Irrigation scheduling method	Intensive or high value crops		Cash crops		Pastures	
	(n)	%	(n)	%	(n)	%
Plant measurement	3	2	0	0	0	0
Real ET	15	9	3	2	2	4
Long term ET	6	3	8	6	2	4
Scheduling models	33	19	13	9	3	6
Feel method	14	8	6	4	5	10
Soil water measurement	45	26	27	19	10	21
Intuition	59	33	83	60	26	55
Total	**175**	**100**	**140**	**100**	**48**	**100**

Significant positive correlations exist between the implementation of subjective irrigation scheduling and the production of cash crops like cereals, cotton, vegetables, tobacco and sugarcane (r=0.531; p=0.000) and pastures (r=0.238; p=0.032) which provide evidence in support of Hypothesis 3, namely that the business character (high value crops *versus* cash crops) influence the farmers' approach to irrigation scheduling. This finding can be attributed to the possibility that a relatively high percentage of cash crop types and the majority of pastures reported by respondents are grown under conditions where the amount of irrigation applied and the irrigation interval are determined by the irrigation method (sprinkler irrigation), and the time it takes to get around the whole farm.

With regard to the growing of vegetables and sugar cane respondents relate the low adoption of objective scheduling to the fact that these industries typically have large number of fields all at different growth stages. The number of sites that would be needed for representative monitoring and the time taken to analyse and interpret data of each field are perceived by respondents to be prohibitive, especially as irrigation is usually at a frequent interval.

The relative low adoption of precise or objective irrigation scheduling methods by cash crop farmers may also relate to the general perception of 80% of these farmers that they have a very good workable knowledge of the crop water requirements of most of the cash crops grown on the farm, and therefore operating somewhere around the optimum point of irrigation.

5.3 INFLUENCE OF ON-FARM IRRIGATION METHOD

The on-farm irrigation method is critical as it determines the amount of irrigation that can be applied to the crop and at what interval. Irrigation scheduling defines "when" to irrigate and "how much", but does not take into account the actual performance of the irrigation systems selected by the farmer for his specific conditions.

The selection of appropriate irrigation methods and assessment of economic benefits are important aspects of on-farm irrigation management. The method selected should be capable of applying water efficiently and uniformly. The choice of on-farm irrigation methods usually depends on many factors including capital and the operation costs, water use efficiency, labour requirements, ease of management, local soil potential (irrigability) and field topography.

5.3.1 Implementation of on-farm irrigation methods

Sprinkler irrigation is often considered to be comparatively efficient for surface irrigation because it enables better control of water application. However, this control is dependent upon the quality level in irrigation system design and on the selection of equipment, but also requires that farmers develop appropriate skills and knowledge to manage their irrigation system (Stimie, 2003). Figure 5.3 indicates that the majority of irrigation farmers (53%) are using quick coupling or hand shift sprinkler irrigation systems.

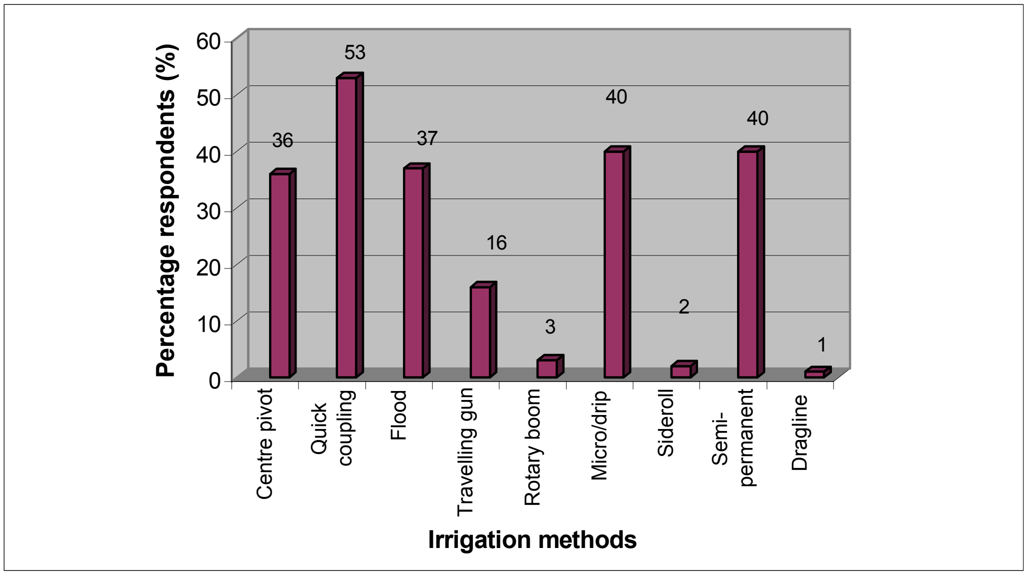


Figure 5. 3: Percentage distribution of respondents according to the implementation of different irrigation methods (N=297)

The classification of irrigation systems used in Figure 5.3 is based on a categorization developed by the ARC (1997). This figure illustrates that centre pivots, quick coupling sprinkler and micro/drip irrigation systems currently enjoy relative high acceptance by farmers and that little change took place since the Agrimarket survey (MSMA, 1999). There is however a tendency those farmers generally are prepared to use more micro/drip and mechanized irrigation systems on the farm, and are scaling down on the use of flood and sprinkler irrigation.

a) Flood or surface irrigation

Surface irrigation (predominantly border, short- and long- furrow and basin irrigation) is still a dominant method of water application to pastures and a wide range of field crops. Especially the short and long furrow irrigation methods are very popular among small- scale irrigation farmers but also often used in the Lower Orange irrigation scheme for growing of grapes (wine and table) and lucerne. The majority of farmers make use of traditional systems where the water control is carried out manually, according to the judgement of the irrigator. Many farmers (commercial and small-scale) indicated the difficulty to control "how much" water to apply.

Photo 5. 1: Short furrow irrigation implemented by the majority of small-scale irrigation farmers

b) *Mechanized irrigation systems*

- *Stationery irrigation systems* include both permanent or semi permanent systems like floppy irrigation systems. Set systems irrigate in fixed position (semi-permanent) and because there are no limitations to the duration of the set time, they can be utilized to apply small volumes of water at frequent intervals, which is usually not possible with the moveable systems because of operational constraints.

Photo 5. 2: Floppy irrigation systems (semi-permanent systems) are often used in sugarcane fields within the Inkomati water management area

- *Continuous move or mobile irrigation systems* include centre pivots, linear move, and traveling gun.

Photo 5. 3: A linear irrigation system in operation on the Riet River Irrigation Scheme (2003)

- *Portable irrigation systems* include dragline; semi-dragline, hand shift or quick coupling, rotary boom and side roll systems. These systems in general are not suitable for applying very small volumes of water because of limitations in the system's capacity.

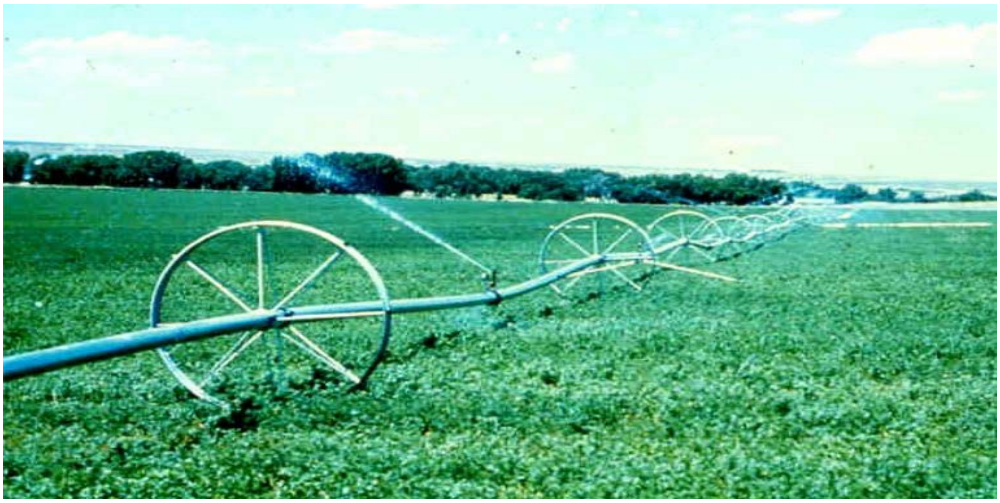


Photo 5. 4: Lucerne production under a side roll irrigation system in the Sand/Vet Irrigation Scheme

Photo 5. 5: Sprinkler, quick coupling irrigation system used for wheat production in the Riet River Irrigation Scheme

- *Micro-irrigation systems* typically apply to several systems operating at low pressure including drip, trickle, miniature distributors, bubblers and tapes. They are characterized by the localized application of irrigation water using low flow and high frequency applications, either to the surface of the ground or underground (subsurface).

Photo 5. 6: Table grape production under drip irrigation in Mpumalanga

5.3.2 Influence of on-farm irrigation methods on irrigation scheduling

There are significant differences between the on-farm irrigation scheduling methods used and the implementation of irrigation scheduling practices ($F=5.81$; $p=0.018$) as indicated in Figure 5.4.

Regarding the adoption of objective irrigation scheduling methods and the selection of on-farm irrigation methods, a clear tendency exists that farmers who use micro, drip and mobile systems on the farm are more inclined to use precise irrigation scheduling, while farmers that use portable, flood and permanent stationary systems are more inclined to use subjective irrigation scheduling practices.

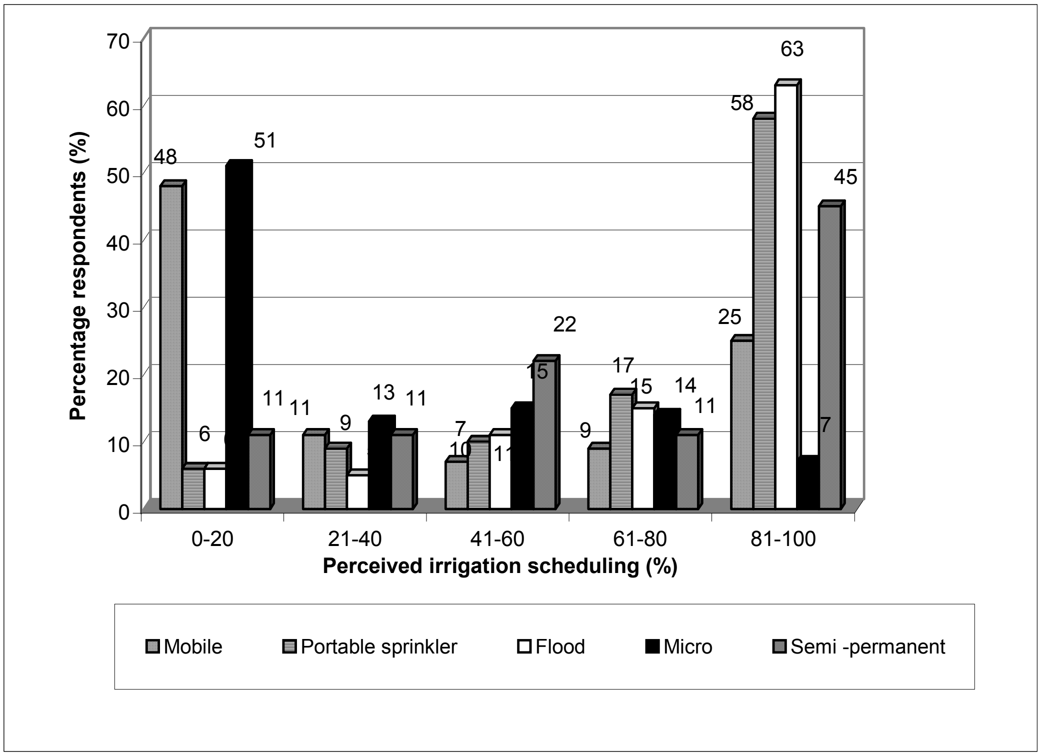


Figure 5. 4: Frequency distribution of irrigation schemes according to the use of different irrigation methods and percentage irrigation scheduling (N=297)

Table 5.5 indicates the significance of relationship between the variables as expressed by Cramer's V values and correlations (Pearson or Spearman). A significant positive relationship exists between the use of micro/drip irrigation systems and the implementation of objective scheduling as expressed in the highly signficant Cramer's V value (Cramer's V=0.540; p=0.000). Although the relationship between the use of mobile irrigation systems and the implementation of objective scheduling is significantly positive as illustrated by the Spearman correlation (r=0.290; p=0.002), the strength of association as illustrated by Cramer's V value is not statistically significant (Cramer's V =0.558, p=0.059).

Significant negative correlations exist between the use of stationery irrigation systems (Cramer's V=0.758; p=0.000), flood system (Cramer's V=0.549; p=0.000), portable irrigation systems like hand shifting (Cramer's V=0.486;

p=0.000) and the implementation of objective scheduling. This suggest that these farmers are not in a position to implement precise scheduling due to the choice of irrigation systems. These significant relationships provide evidence to support Hypothesis 1.1, namely that the implementation of irrigation scheduling practices is determined by personal and environmental factors like the choice of an irrigation system.

Table 5. 5: Relationships between on-farm irrigation methods and the implementation of objective irrigation scheduling (N=297)

Irrigation method	Cramer's V			
	Value	p	r	p
Mobile systems (centre pivot, travelling gun)	0.558	0.059	0.290	0.018
Portable system (dragline, semi-dragline, side roll, hand shift)	0.486	0.000	-0.246	0.002
Flood system (short furrow, flood basin)	0.549	0.027	-0.271	0.025
Micro system (micro, drip)	0.540	0.000	0.294	0.032
Stationery system (semi permanent, floppy)	0.758	0.000	-0.825	0.023

5.4 SUMMARY

The technology level of the farm, size of the farming operation and the type of crops produced on the farm determine the selection of scheduling methods. The use of a centre pivot and drip/micro are positively associated with the use of objective irrigation scheduling. Corporate farming enterprises and farms with high value irrigated crops are more likely to adopt and invest in precise scheduling methods.

CHAPTER 6
INFLUENCE OF EXTERNAL FACTORS ON THE IMPLEMENTATION OF ON-FARM IRRIGATION SCHEDULING

6.1 BULK WATER DELIVERY ON IRRIGATION SCHEME

Irrigation scheduling at farm level implies real time decision as to when and how long to irrigate, expressed in absolute values. This however, depends on the regular and effective supply of bulk water. Four approaches to the management of irrigation water conveyance systems are generally found:

- *"Continuous flow or on demand approach*

  In this system the scheme manager aims to maintain the supply of the system so that any user can abstract water at any time. In canal and river systems, this usually means that the scheme manager has to monitor the flow depth at strategic points, and adjust the in-flow to the system accordingly. In pipeline systems, the pressure (and sometimes the flow rate) in the conduit has to be monitored and controlled.

  According to Knoetze (2003), the scheme manager needs to be experienced and know the system and relevant farming practices on the scheme well in order to operate a scheme in this way. Especially in the case of river schemes, he needs a few seasons to understand the flow of the river, since water releases can take up to a few days to reach the point in the system where there is a shortage. This system lend itself well to the use of telemetric monitoring of critical points, since it eliminates driving to the point itself to observe the flow.

- *The "request" approach*

  The objective of this type of management system is to supply the amount of water that is requested by the users in advance. Farmers request the water they will need, specifying the flow rate at which they will abstract the water, the period of time they will be abstracting it for, and the time during the week they will be abstracting. The scheme manager then uses this information for planning the water releases into a system and how it will be adjusted to meet the constraints of the system (van Strijp, 2002).

- *Irrigation turn approach*

  This system is usually followed where a conveyance system has insufficient capacity for an “on demand” approach to be followed. In this approach, each user is allowed to abstract water at certain times within an applicable schedule (e.g. every 7 days or fortnight). The flexibility of irrigation farmers’ decision making regarding the application rate and intervals of irrigation within this system is very limited. For these farmers the advantages of on-farm storage facilities could be enormous in providing additional flexibility in terms of irrigation management, since a farmers irrigation time may come at a time when he does not need to irrigate or he may need water during a hot spell but his turn is still a few days away (Eksteen, 2002).

  Many of the small-scale irrigation schemes were designed to operate using irrigation turns. Therefore these scheme were divided into blocks along the main canal, and farmers in each block receive an irrigation turn on a specific day.

- *Water quality management approach*

  The objective with this approach is to maintain an acceptable water quality in the distribution system by monitoring the water quality and releasing additional water from the source if necessary. The quality of water is the limiting factor rather than the quantity that needs to be abstracted by the users in the distribution system.

Twenty five percent of the farmers were of the opinion that they could hardly implement precise crop-based scheduling methods due to fixed proportional bulk water delivery system, or due to problems they experience with the advance ordering of irrigation water due to the lack of canal capacity, especially during peak irrigation requirements periods in the production season. Delivering irrigation water with a high degree of flexibility and reliability depends not only on the technical means but also requires:

- o decentralization of decisions and responsibilities of the delivering system (e.g. main canal level and secondary canal levels), and

- o the institution of seasonal or yearly water allocations (Burt, 1996, Knoetze, 2003).

Irrigation scheduling based on soil water balance requires that farmers take an appropriate amount of water from the irrigation water supply system at the proper time. However where fixed turns of bulk water delivery are experienced, this approach usually results in excessive water being applied by irrigation farmers when the water is available. Water stress periods can occur during the gaps between successive water applications when these gaps are too large as in the case reported by some of the small-scale farmers. The rigidity of the “irrigation turn approach” that many of the small-scale farmers and some commercial farmers in areas of the Western Cape and Northern Cape experience, caused them not to use the system as intended, but as “on demand system”.

The inappropriate design of canals where water takes a considerable time to travel the length of the canal and where insufficient canal capacity often causes shortages especially during peak periods of irrigation requirements during the growing season, were raised as some of the constraints that prevent farmers from the practising of objective irrigation scheduling methods.

Reliability, as recalled by Burt (1996) is a prerequisite for the implementation of precise irrigation scheduling. Whatever the delivering schedule applicable, either dictated by a water institution or as an agreement between neighbours, either rigid or flexible, it is imperative that water is supplied in conformity with the expectations of the user. Reliability of water was found to be sufficient in the majority of cases where interviews were held, but some farmers complained about not receiving what was due to them, especially farmers at the end of a canal delivery system. Reliability of bulk water delivery was also found to be an essential condition for the establishment of trust and confidence between water management institutions and irrigation farmers.

Figure 6.1 indicates the percentage distribution of irrigation schemes according to the percentage irrigation scheduling applied and the perception of farmers with regard to the flexibility of bulk water delivery on the irrigation scheme. Significant differences exist between the different irrigation scheduling groups with regard to the perceived flexibility of bulk water delivery on the irrigation scheme (F=6.14; p=0.014). The difference lies in the fact that with increasing reported irrigation scheduling figures there is a tendency that farmers also perceive bulk water delivery to be less flexible.

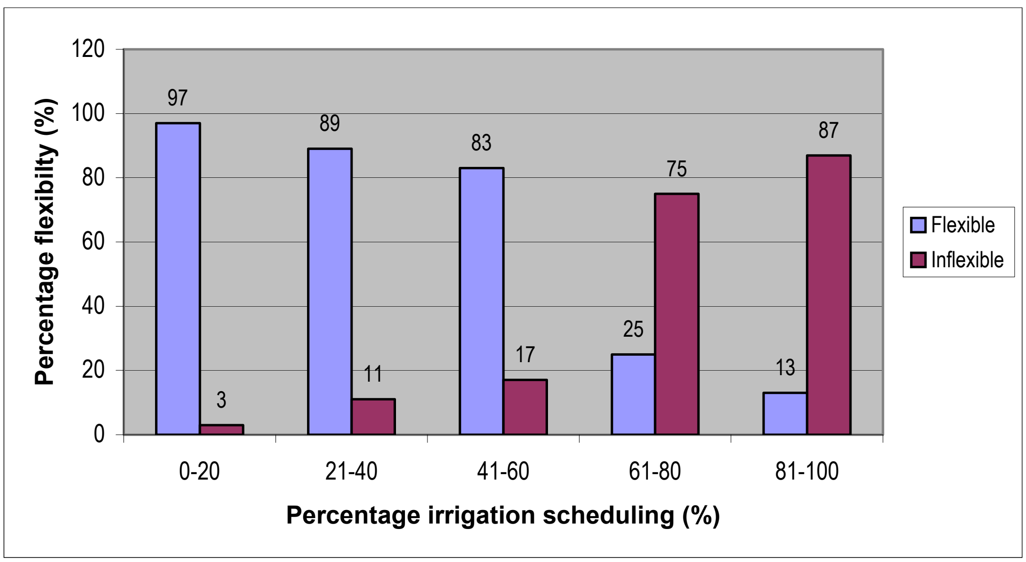


Figure 6. 1: Percentage distribution of irrigation schemes according to the percentage irrigation scheduling applied and the percentage ratio between perceived flexibility of water delivery (N=297)

The relationship between flexibility of bulk water delivery to the farm and the implementation of objective irrigation scheduling is significantly negative (r=-0.316; p=0.006) implying that increased flexibility in bulk water delivery is associated with higher reported implementation of objective irrigation scheduling. Respondents in the Northern Cape (Lower Orange and Upper Orange water management areas) indicated the lowest flexibility (25%) in terms of freedom to irrigate. The majority of respondents (62%) in this province use surface irrigation and indicated that precise irrigation scheduling is very difficult to associate with a higher reported implementation of objective irrigation scheduling. This also means that higher levels of fixed turn bulk water delivery are associated with higher levels of reported implementation of subjective irrigation scheduling. This significant relationship provides evidence in support of Hypothesis 1.1, namely that an independent environmental factor, like bulk water delivery, determines the ability of farmers to implement on-farm objective irrigation scheduling methods.

Respondents in the Northern Cape (Lower Orange and Upper Orange water management areas) indicated the lowest flexibility (25%) in terms of freedom to irrigate. The majority of respondents (62%) in this province use surface irrigation and indicated that precise irrigation scheduling is very difficult to implement due to fixed water delivery and the practicing of surface irrigation methods. The performance of these specific irrigation methods are still considered to be low, and irrigation efficiency must be evaluated in terms of uniformity of water application and the ease of scheduling and timing of irrigations (Eksteen, 2002). According to Terblanche (2003), the adoption of laser levelling shows the way to a significant improvement in accuracy of distribution uniformity. This practise also contributes to improvement of water use efficiency and production yields.

6.2 ALLOCATION OF IRRIGATION WATER

On many of the schemes, individual abstractions are not measured, even though the rate of abstraction may be specified. In most river systems, no quantitative data on the abstractions are available.

There are generally two approaches involved with paying for the use of irrigation water followed by farmers:

- Pay the full allocation of irrigation water, regardless of the actual amount of water used. Water is usually requested on a weekly basis, which is then monitored and compared with the allocation.
- Pay only for the volume of water (m^3) they are likely to use based on the areas planted under a specific crop. The allocation is then based on the specific water crop requirements in that area (See Box 6.1: Oranje Riet WUA area).

Box 6.1: Oranje Riet Water Users Association

"The Oranje Riet WUA has conducted a survey to determine the total area under irrigation as well the major crops grown within the WUA district. The area under production for each crop was determined with the use of satellite technology. This information was included in the database of the Oranje Riet WUA. The net monthly and annual irrigation requirements for the WUA were subsequently calculated. Farmers in this WUA are receiving a predetermined allocation based on the average crop water requirements as calculated on the combination of possible crops typically grown as based on "crop grow norms" for the area. This allocation however includes additional water to safeguard farmers against very hot spells or other extreme climatic conditions.

Farmers are paying a minimum flat tariff for 85% of the predetermined allocation as based on crop requirements and historical data. The rest (15%) of the allocation can either be used for additional irrigated area (double cropping) at a differentiated tariff or sold to other farmers within the scheme who may need more water than they have been allocated. This differentiated tariff structure serves as a motivation and incentive for farmers to use water more efficiently on the farm and also provide some flexibility in terms of their water management"

According to Pretorius (2003), the differentiated tariff system applied by the Department of Water Affairs and Forestry (DWAF) until 1998 encouraged farmers to use water efficiently. This system included a minimum fixed tariff for 75% of the allocation, while the rest of the allocation was based on volumetric supply against a differentiated tariff. He is of the opinion that this tariff system provides farmers with financial incentives to use water more efficiently. However, he also agrees that this did not prevent farmers at the beginning of the conveyance systems to take more than was allocated unless effective measurements were introduced for individual abstractions.

Photo 6. 1 Main irrigation canal system used for water distribution at Riet River Irrigation Scheme

Ninety four percent of the respondents indicate the licensing of specific allocation of irrigation water while the rest, mainly private irrigation farmers, make use of boreholes and weirs. The mean irrigation allocation applicable for the nine provinces is 8 336 m^3/ha/annum, with the Lower Orange River scheme receiving the highest allocation of 15 000 m^3/ha/annum because of relative higher evaporation figures. The majority of irrigation farmers (57%) received an allocation for irrigation between 6 201-11 000 m^3/ha/annum (Figure 6.2).

The general expectation that farmers with bigger allocations are more reluctant to implement precise irrigation scheduling is partially supported. Sixty one percent of the farmers with bigger allocations (>11000 m^3) perceive irrigation scheduling to imply the use of subjective irrigation scheduling methods, while 72 percent of the farmers that belong to the smaller allocations (<6201 m^3) perceive irrigation scheduling to entail objective scheduling methods.

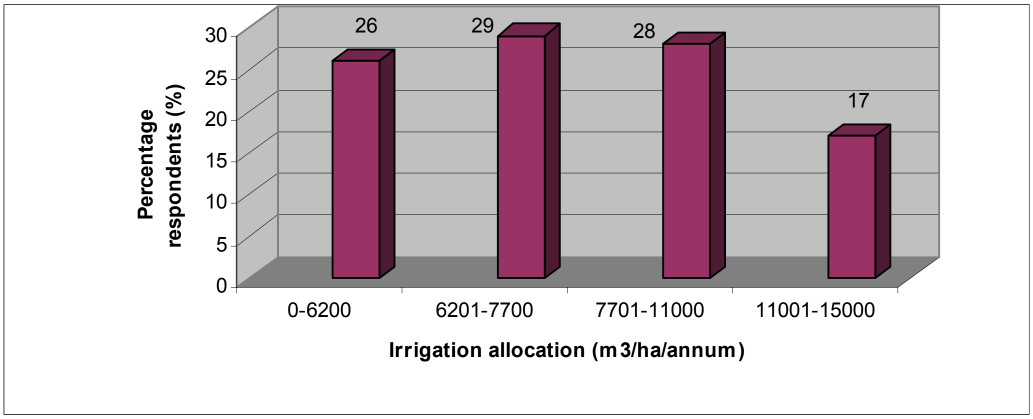


Figure 6. 2: Distribution of respondents regarding irrigation water allocation in South Africa (N=297)

Table 6.1 reveals a significant positive correlation between volume of irrigation water allocations and the use of intuition (r=0.242; p=0.004) as well as the feel method (r=0.447; p=0.045). This provides partial evidence in support for Hypothesis 1.1, namely that environmental factors like irrigation water allocation influence the implementation of irrigation scheduling methods. However, it needs to be emphasized that many of the respondents with bigger irrigation water allocations also make use of surface irrigation or receive water on fixed turns (e.g. farmers from the Lower Orange) and are therefore not in a position to apply precise irrigation scheduling methods.

Table 6. 1: Relationships between implementation of irrigation scheduling methods and irrigation water allocations as reflected in a test of association (N=297)

Irrigation scheduling methods	r	p
Real time ET	- 0.515	0.097
Long term ET	-0.144	0.448
Computer irrigation scheduling models	-0.188	0.068
Soil water content measurement	-0.168	0.066
Feel method	0. 477	0.045
Intuition	0.242	0.004

Although the majority of farmers that belong to smaller irrigation allocations perceived irrigation scheduling to entail the use of objective irrigation scheduling methods, Table 6.1 indicates that no significant correlations exist between the implementation of objective irrigation scheduling methods and the allocation of relative smaller volumes of irrigation water.

6.3 IRRIGATION TARIFFS

The National Water Act (1998, No 36) determines that any person who is registered in terms of a regulation or is holding a license to use water, must pay all imposed charges. Since 1996/97 new water tariffs are imposed on commercial irrigation farmers and on government schemes. The implementation of the new water tariff structure applies within a three-tiered structure:

- The first tier is determined by the pricing of bulk raw water supply, and relates to water supplied by DWAF.
- The second tier relates to water supplied by water boards and irrigation boards.
- The third tier deals with water supplied and managed by local authorities.

Farmers on the irrigation schemes are responsible for two different charges that are included in the current water tariff:

- *Water resource management charge*

  The water resource management charge relates to the expenditure of activities that are required to regulate, manage and maintain the water resources or catchments in a specific water management area. Initially the water resource management will continue to be the task of DWAF, however within the new act the intention is to delegate or assign significant water resource management functions to the Catchment Management

Agencies (CMAs) that are established or in the process of being established. The water resource management charge relates to all water utilized within the water management area, and is therefore charged to all water users.

- *Water resource development and use of waterworks (O&M) charge*
  This cost includes the related costs of investigation, planning, design and construction of water schemes, which constitutes the capital cost of irrigation projects. In order to recover fully the water resource development costs, the capital component of the unit cost of water is determined by a depreciation charge and a return on assets charge. This charge is only levied on the users of specific government schemes or systems, and is based on the costs associated with that particular scheme (Van der Merwe, 2004).

The water tariffs, as indicated in Table 6.2, reflect the water resource management charges levied for users of irrigation board schemes and WUAs as per province, while the tariff applicable to irrigation farmers on government irrigation schemes include the water resource development as well as the operation and maintenance (O&M) charge. According to Table 6.2, it appears that the irrigation tariffs (R/ha/annum) significantly differ (X^2=67.33; df=27; p=0.001). On an irrigation scheme like Pongola, for instance, the tariff that irrigation farmers are paying also recovers a portion of the capital investment of the newly built Bivane or Parisdam and amounts to approximately 16c/m^3 for irrigation water or R1 285 per (registered) irrigated hectare per annum. The dam was funded through a three-way partnership between Pongola sugarcane growers, Illovo Sugar Limited and DWAF.

The mean tariff that irrigation farmers pay for irrigation water is R397.97 per hectare per annum, with the highest tariff R3 900 per hectare per annum reported in the Western Cape. Fifty nine percent of irrigation farmers that pay the higher irrigation tariff (R1044 - 3900/ha/annum) are farming in the Western Cape. Irrigation water tariffs are a flat rate based on the sum of the individual volumetric allocations field edge, adapted for assurance of supply to represent long-term average annual use, plus average annual distribution losses on communal infrastructure (Van der Merwe, 2001). According to Table 6.2, irrigation farmers from Gauteng Province pay the lowest mean irrigation tariff, namely R109/ha/annum, while farmers from the Western Cape recorded the highest mean irrigation tariff (R622/ha/annum).

Table 6. 2: The distribution of respondents according to the irrigation tariffs reported as per province (N=297)

Province	Irrigation tariffs (R/ha/annum)								Mean tariff (R/ha/ annum)	Total number respondents	
	0-250		251-520		521-1043		1044-3900				
	(n)	**%**	**(n)**	**%**	**(n)**	**%**	**(n)**	**%**		**(N)**	**%**
Gauteng	5	3	0	0	0	0	0	0	109	5	2
Free State	6	4	2	3	7	13	0	0	414	15	5
KwaZulu Natal	19	13	3	4	1	2	2	12	253	25	8
Mpumalanga	19	13	12	16	3	6	0	0	241	34	12
Northern Cape	8	5	12	16	10	19	2	12	504	32	10
Eastern Cape	6	4	4	5	1	2	2	12	487	13	4
Western Cape	35	24	12	16	9	17	10	59	622	66	22
Limpopo	11	8	7	9	2	4	0	0	232	20	7
Northwest	18	12	5	7	10	19	0	0	305	33	11
Small-scale	19	13	17	23	9	17	1	6	337	46	15
No figure reported										8	3
Total	**146**	**100**	**74**	**100**	**52**	**100**	**17**	**100**		**297**	**100**

Seventy eight percent of the small-scale farmers pay less than R520/ha/annum, since they are supported through the inclusion into a concessionary period during which the full cost of water is not levied. In this survey the majority of small-scale farmers on government schemes indicated that they are only responsible for the maintenance and operation costs (electricity costs) of irrigation on the scheme.

Figure 6.3 compares the different types of irrigation schemes regarding the irrigation tariffs reported for the respective irrigation schemes. There are significant differences between type of irrigation schemes with regard to the irrigation tariffs that farmers pay (X^2=16.46, df=6; p=0.011), i.e. farmers on irrigation board schemes and WUAs are paying more than those on government irrigation schemes. Forty eight percent of irrigation farmers on government schemes and 51 perecent irrigation farmers respectively on irrigation board schemes are paying water tariffs of R250 per hectare per annum or less for their irrigation water allocation.

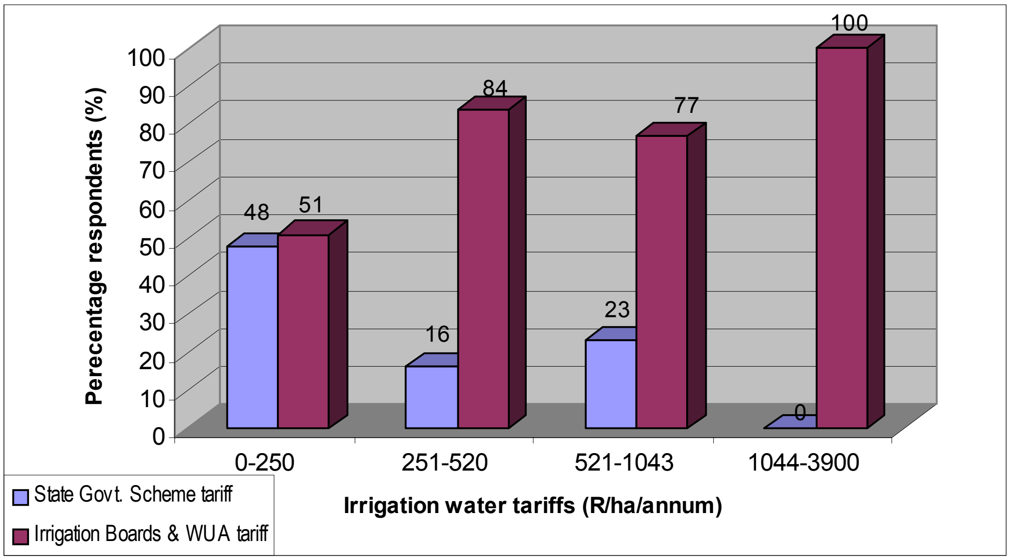


Figure 6. 3: Percentage distribution of the irrigation schemes according to the irrigation tariffs applicable (N= 297)

Caswell & Zilberman (1985 and 1990) argue that higher water tariffs would induce the adoption of water saving technologies like objective irrigation scheduling. Table 6.3 shows the correlations that were found between the implementation of irrigation scheduling methods and the applicable water tariffs for irrigation schemes.

Significant negative correlations exist between perceived implementation of intuition (r=-0.177; p=0.001) as well as the feel method (r=-0.227; p=0.002) and the applicable irrigation water tariff for irrigation farmers. Except for significant correlations that exist between objective irrigation scheduling methods like the application of real time ET methods (r=0.331; p=0.009) and the use of plant monitoring (r=1.0; p=0.014), no statistically significant correlation between the adoption of the other mentioned objective irrigation scheduling methods like soil water measurement, use of computer models or the use of long term ET figures and water tariffs exist.

Table 6. 3: Relationship between the implementation of irrigation scheduling methods and irrigation tariffs (N=297)

Irrigation scheduling methods	r	p
Plant measurement	1.0	0.014
Real time ET	0.331	0.009
Long term ET	0.203	0.141
Computer irrigation scheduling models	0.085	0.242
Soil moisture measurement	0.063	0.408
Feel method	-0.227	0.002
Intuition	-0.177	0.001

These findings provide partial evidence in support of Hypothesis1.1, namely that independent environmental factors like irrigation water tariffs influence the adoption behaviour of irrigation farmers regarding the implementation of irrigation scheduling methods. However, from this study it is clear that other factors are outweighing the water tariff factor. Some of these factors are crop diversification potential in a specific area of cultivation and the risk and flexibility involved in water delivery (i.e. the irrigation farmers guarantee of receiving his entitled water allotment). These factors have to be taken into account as well when analyzing the potential effects that a given pricing policy may have on the adoption of water saving or on incentives to engage in water use management strategies like irrigation scheduling.

Technical endowments in the different schemes have a decisive influence on the capacity that different pricing schemes have to induce in the reduction of water consumption. The relatively older irrigation schemes have a substantial margin for improving their technical conditions and therefore for attaining large water saving levels. The more modern irrigation schemes have already been endowed with more effective irrigation systems and for this reason their response to price signals by more efficient water use strategies is perhaps smaller.

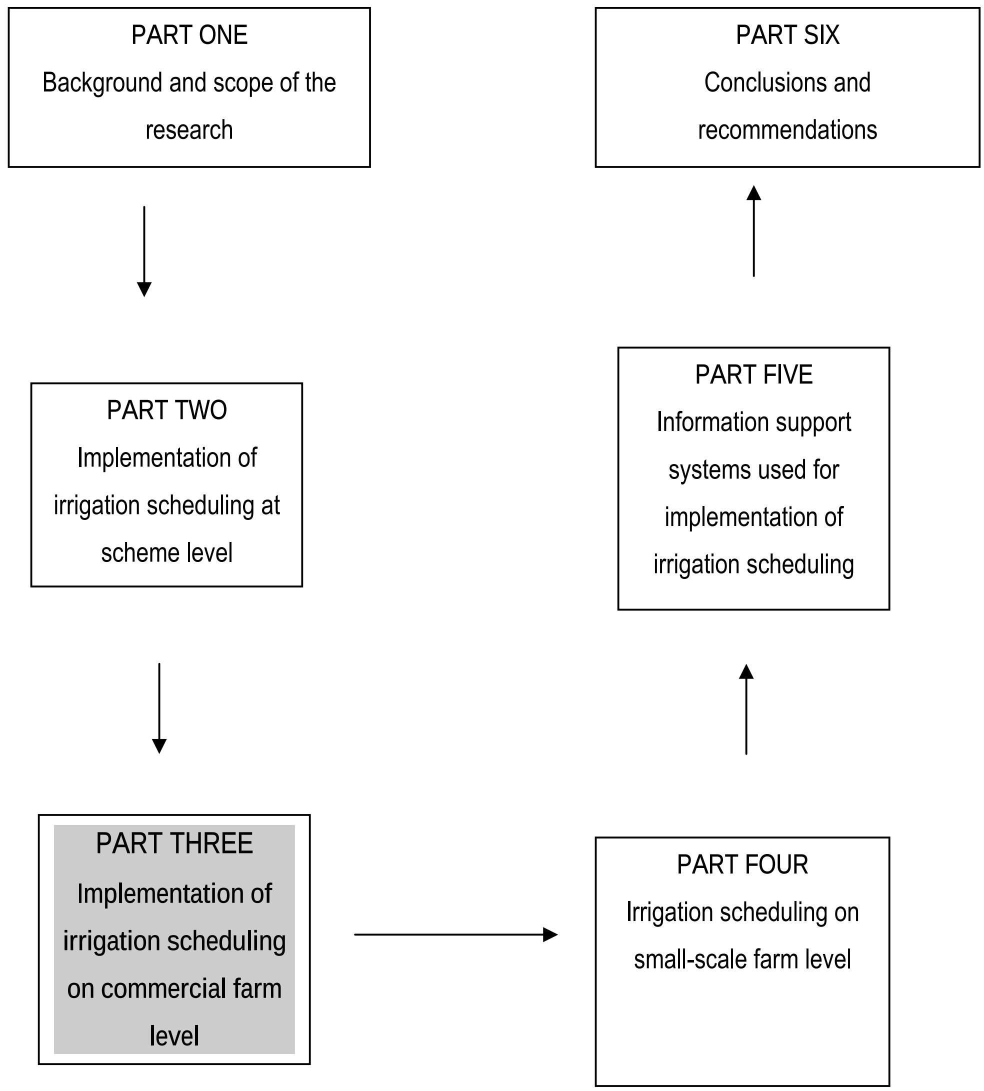
6.4 SUMMARY

A negative interrelationship between bulk water delivery and the application of objective irrigation scheduling exist. The general problems experienced by some irrigation farmers confined to the relative poor state of canals due the age of many of the irrigation schemes and also the lack of canal capacity during peak production periods, hamper implementation of more precise scheduling methods.

Evidence indicates that farmers with relatively bigger irrigation water allocations and lower water tariffs tend to make more use of intuition and are more reluctant to implement precise irrigation scheduling. However, from the study it is clear that other factors are outweighing the water tariff factor like flexibility with regard to bulk water delivery on scheme level.

PART THREE

IMPLEMENTATION OF IRRIGATION SCHEDULING ON COMMERCIAL FARM LEVEL



CHAPTER 7
INTRODUCTION AND RESEARCH METHODOLOGY

7.1 INTRODUCTION

Irrigation farming encompasses a group of interrelated activities occurring in an economic, cultural and social context and hence farming activities are influenced by values and social norms as well as by economic, financial and technical imperatives. Adoption of new irrigation scheduling practices is a dynamic process that is potentially determined by various factors, including farmers' perceptions of the relative advantages and disadvantages of new technologies vis-à-vis that of existing technologies and the efforts made by extension and change agents to disseminate these technologies. Other factors, which influence adoption, are resource endowments, socio-economic status, demographic characteristics, and access to institutional services (extension, input supply, markets, etc).

Commercial farmers showed reasonable awareness of irrigation technologies that could help them irrigate more accurately, but were less sure how these technologies would translate into profitability on their farms (Feather & Amacher 1994). From a farmer's perspective, the implementation of an innovation involves (1) some form of immediate investment with long term expected returns, (2) trade offs between current yield and future yields, (3) trade offs between yield and its production costs, (4) trade offs between yield and its related risk. All decisions to adopt or reject an innovation and the subsequent behaviour or practice change, rest with the individual or the farmer. Continuous learning and complex responses to stimuli that rarely produce observable constancy, characterize human behaviour.

In general, review of the literature indicates that the research tradition in the area of behavioural sciences is largely dominated by an investigation of the relationships between socio-economic and personal (independent) variables and behaviour. Rogers (1983) generalizations based on the findings of more than 200 adoption studies, indicated that factors responsible for behaviour change of farmers are mainly confined to the role of these independent variables, without taking account of the direct influence of intervening variables (need, perception and knowledge), which according to Tolman (1951) and Düvel (1975) are immediate precursors of behaviour.

Since Part Three deals with the human factors and constraints that impact on adoption of irrigation scheduling practices, the objective of this part of the study was to identify the socio-economic and personal characteristics of respondent farmers such as age, education and farming experience, which are assumed to differentiate irrigation farmers into those that implement objective irrigation scheduling methods and those that are implementing subjective scheduling methods. It is however also intended to evaluate the influence of the intervening variables perceptions and knowledge of farmers on the selection and use of irrigation scheduling tools and to gain insight into the practice adoption behaviour of commercial farmers in the study areas of the following provinces: Northwest, Free State, Northern Cape, Eastern Cape, KwaZulu Natal, Western Cape, Limpopo and Mpumalanga.

7.2 RESEARCH METHODOLOGY

The following outlines the methodology used to investigate and describe the reasons from a cross section of commercial farmers for using the different irrigation scheduling methods and models and to investigate and describe why irrigators discontinue the implementation of irrigation scheduling.

7.2.1 Research area

Instead of selecting only one specific research area for the detailed micro level on-farm survey, preference was given to the inclusion of various irrigation areas from the eight provinces as indicated in the outcome of the national survey. This was done to ensure the inclusion of sufficient variation regarding irrigation scheduling methods as well as the perceptions of respondents in different stages of the innovation-decision process. Irrigation systems form an integral part of the different farming systems and therefore effective irrigation scheduling is, in addition to the technical capacity of the system and agricultural requirements of the crop, determined by a set of cultural, social and institutional conditions. To try and accommodate these differences in institutional and social cultures, irrigation schemes from eight different water management areas and provinces were included. Respondents were selected on the basis of:

- Availability: respondents who resided in the area or who could be reached for interviews.

- Experience in irrigation farming: new irrigation farmers as well as farmers with many years of experience were included to capture the differences in perceptions that prevail.

- Irrigation scheduling: farmers were included that were either still involved in irrigation scheduling or have discontinued scheduling practices.

- Ownership: interviews were conducted with farm owners or irrigation managers who are responsible for decision-making concerning irrigation management.

The following areas within the water management areas of South Africa were identified and selected after discussions with Steering Committee members and opinion leaders in irrigation:

- ***Sundays River and the Gamtoos Valley irrigation schemes***

These irrigation schemes form part of the Fish to Tsitsikama water management area, which is situated in the south-eastern part of South Africa, within the Eastern Cape Province (Figure 7.1). This area is characterized by poor quality of natural water, which drains from the inland areas. The Fish and Sunday Rivers are of natural high salinity, and large quantities of good quality water are transferred from the Orange River (Upper Orange water management area) to blend with local resources (DWAF, 2004).

Figure 7. 1: Base map of the Fish to Tsitsikama water management area (DWAF, 2004)

The Sundays River and Gamtoos Valley are well known for their choice of citrus, and vegetables. After consultation with the chief executive officer from the local citrus cooperative, twenty-three farmers in the Kirkwood, Hankey, Patensie and Boskop area were randomly selected from a list of cooperative members as respondents for this survey and face-to-face interviewed *(Appendix 3).*

- ***Northern Cape: Rietriver / vd Kloof /Rust /Lower Orange River Irrigation Schemes (Boegoeberg, Keimoes, Malanshoek).***

These irrigation schemes belong to the Upper and Lower Orange water management areas. The Upper Orange water management area lies to the centre of South Africa and extends over the southern Free State and parts of the Eastern and Northern Cape provinces while the Lower Orange water management area largely corresponds with that of the Northern Cape Province. The latter is situated in the western extremity of South Africa and borders on Botswana, Namibia and the Atlantic Ocean (Figure 7.2).

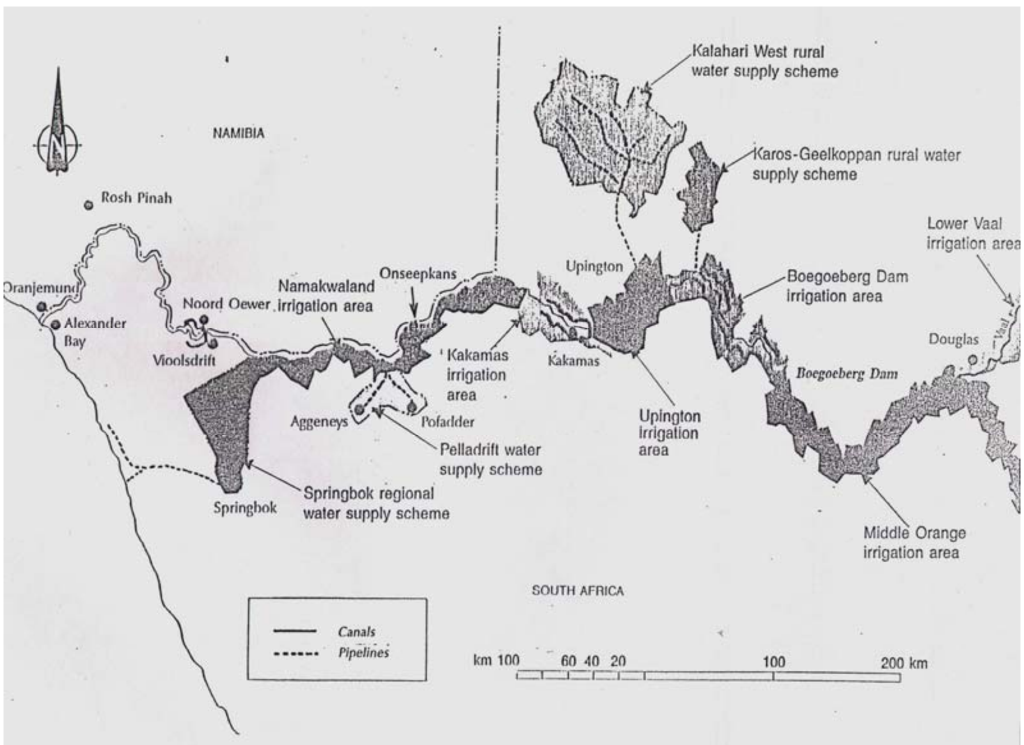


Figure 7. 2 Location map of the Upper Orange water management area (DWAF, 2004)

The Riet River Irrigation Scheme (Figure 7.3) was selected after discussions with members of Griekwaland Wes Agricultural Cooperative and various opinion leaders in the Free State and Northern Cape. General consensus exists that this area represents one of the largest areas of land under irrigation scheduling. It was also an excellent opportunity to monitor the changes that took place since the previous survey done by Botha, Steyn & Stevens (1999/2000) in this area where factors that influence the acceptance of irrigation scheduling models were researched. Thirty-seven farmers from Riet River, Van der Kloof and Lower Orange River irrigation schemes were selected for participation in the survey.

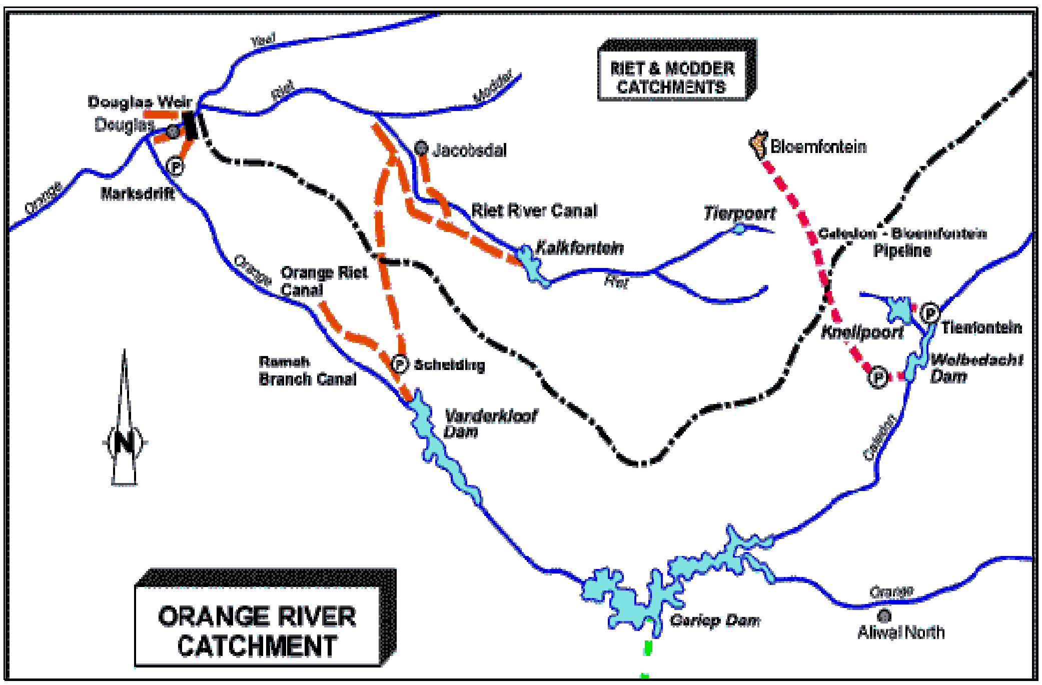


Figure 7. 3 Location map of the Orange Riet River catchment area (DWAF, 2003)

After consultation with the CEO at Orange Riet Water User Association (ORWUA) a random sample of 17 respondents of this irrigation area was selected in terms of availability, experience, and application of irrigation scheduling and relevancy of the typical irrigation farming systems at the irrigation scheme. In the van der Kloof irrigation scheme, after the consultation of a private irrigation consultant, 10 farmers were randomly selected from a list provided. In the Lower Orange River irrigation area, 10 farmers were randomly selected with the help of the local extension officer and officials from the Department of Water Affairs at Upington.

o ***Mpumalanga: Nelspruit/Malelane and Onderberg***

The study area is situated in the Inkomati water management area (Figure 7.4), which borders on Mozambique and Swaziland and all rivers flow through Mozambique to the Indian Ocean. The Komati, Lomati and Crocodile rivers service this water management area. In this area most important economic activities centres on irrigation with related industries and commerce.

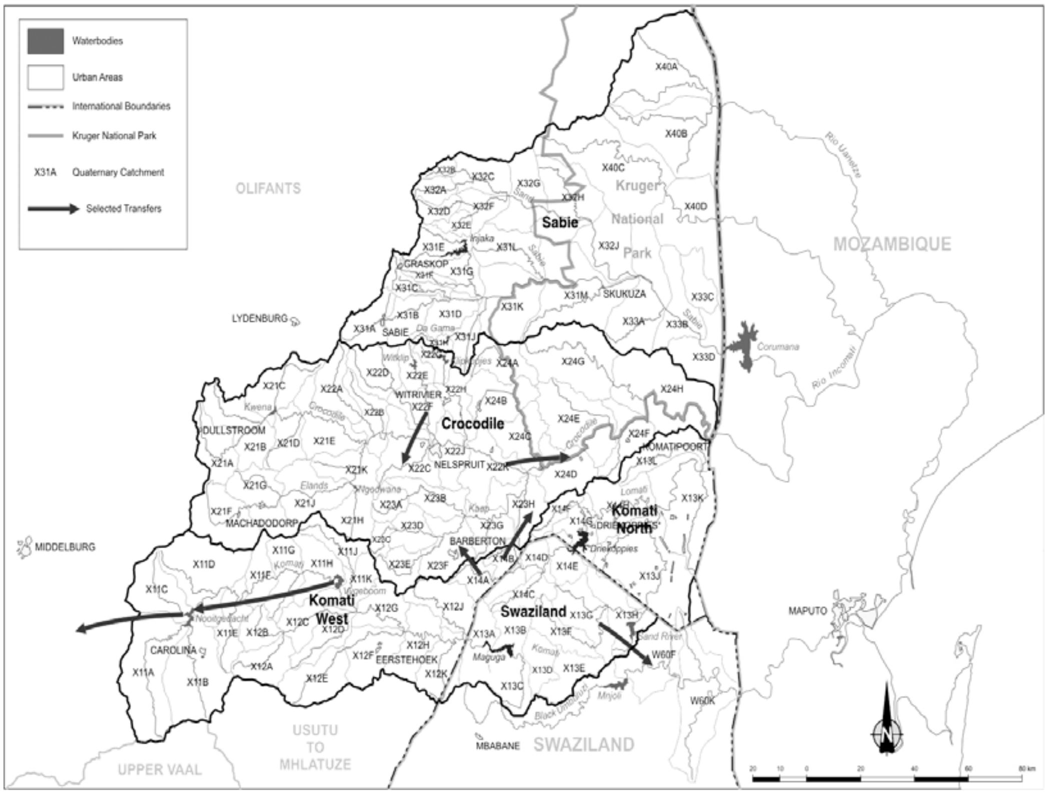


Figure 7. 4 Base map of the Inkomati water management area (DWAF, 2004)

Onderberg area is well known for the production of citrus, subtropical fruit and sugar cane. This forms an integral part of the Komati/Lomati River and Crocodile River catchments areas. Seventeen farmers of this area were interviewed during December 2002 and January 2003. Farming operations in this area are generally operated on a relatively high skill-level and irrigation scheduling support services are mainly rendered by the sugar industry, and citrus, mango, avocado and banana producer societies and private irrigation consultants. Active study groups in the banana, mango, avocado and citrus industry play a very important role in informing farmers of the important aspects of irrigation scheduling in the production of quality fruit. In general farmers are very much aware of objective irrigation scheduling devices and possible models that are available. The consultants in this area do enjoy a high credibility for the kind of service that they render. The seventeen respondents included from this area were randomly selected with the help of officials from SASRI, citrus cooperatives, Mpumalanga Department of Agriculture and Department of Water Affairs and Forestry.

- ***Mzimvubu to Keiskamma water management area (Kokstad/Underberg)***

The Mzimvubu to Keiskamma water management area lies predominantly within the Eastern Cape Province, and borders on Lesotho to the north. The Mzimvubu River, which also reflects in the name of this water management area, is the largest undeveloped river in South Africa (DWAF, 2004). The Mvoti to Umzimkulu water management area borders on the Mzimvubu to Keiskamma water management area in the south and lies predominantly within the KwaZulu Natal, with a small portion in the southern part which falls in the Eastern Cape. The main rivers found in this water management area being the Mvoti, Mgeni, Mkomazi, Umzimkulu and Mtamvuna Rivers, with several small coastal rivers in between. The general location of these two water management areas is illustrated in Figure 7.5.

Seventeen respondents from these two water management areas (Underberg and Kokstad), mainly involved in crop and pasture production, were interviewed by an experienced member of the research team. The random selection of the respondents was done with the help of officials from the local cooperative of Underberg.

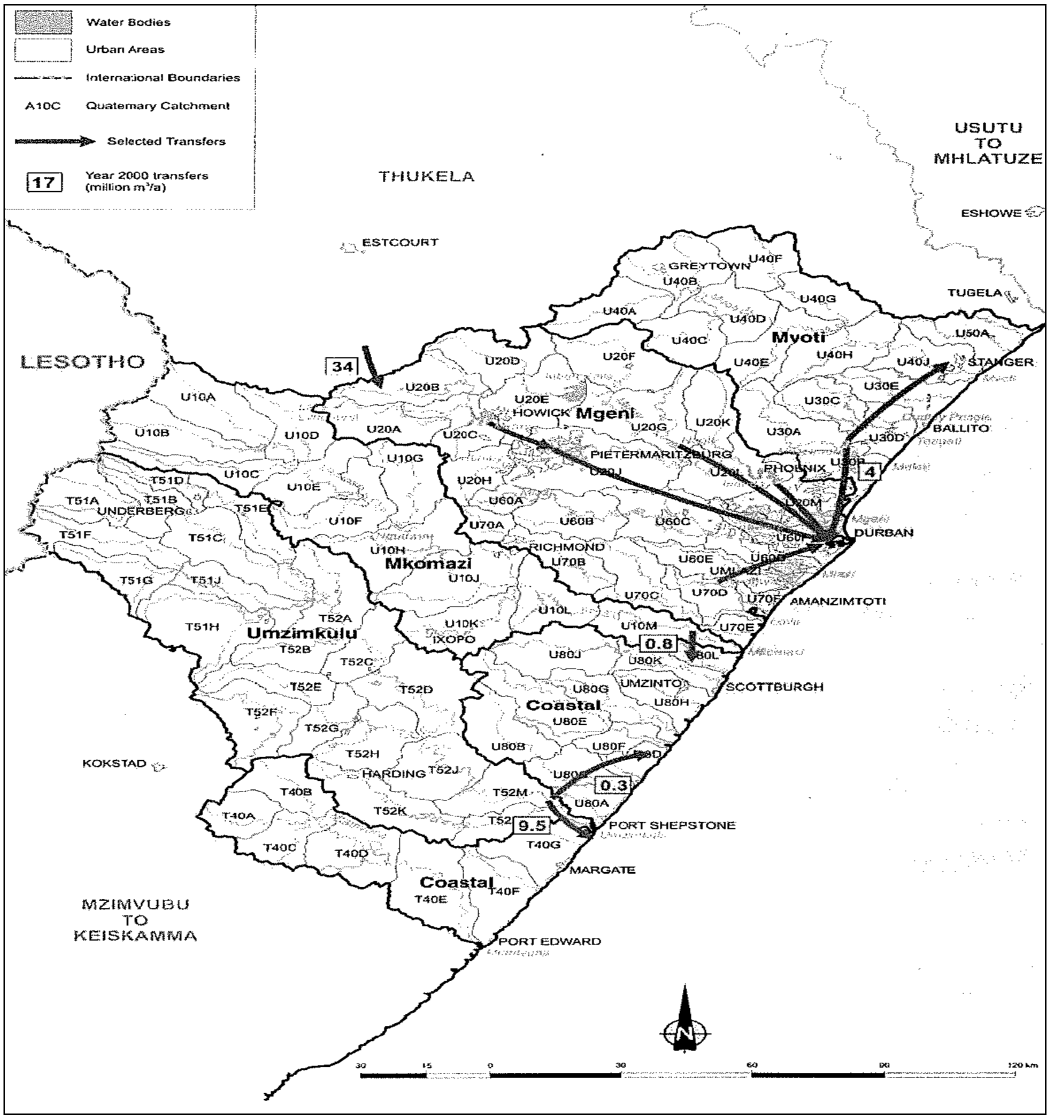


Figure 7. 5 Base map of the Mzimvubu/Keiskamma and Mvoti/Umzimkulu water management areas (DWAF, 2004)

o ***Crocodile west water management area (Brits/Rustenburg area)***

The Crocodile west and Marico water management areas border on Botswana to the northwest (Figure 7.6). The main rivers, the Crocodile and Marico, give rise to the Limpopo at their confluence. Extensive irrigation development occurs along the Crocodile River and in the Brits /Rustenburg area farmers produce mainly citrus, table grapes and deciduous fruit as permanent crops. Cash crops like wheat and vegetables are produced during the winter and soybeans, vegetables and maize during summer months. The local citrus and grain cooperatives as well as the Northwest Department of Agriculture in Brits play a major role regarding the irrigation management support services rendered to farmers. The project team interviewed fourteen farmers from this area after consultation with officials from the local citrus cooperative and from the Northwest Department of Agriculture.

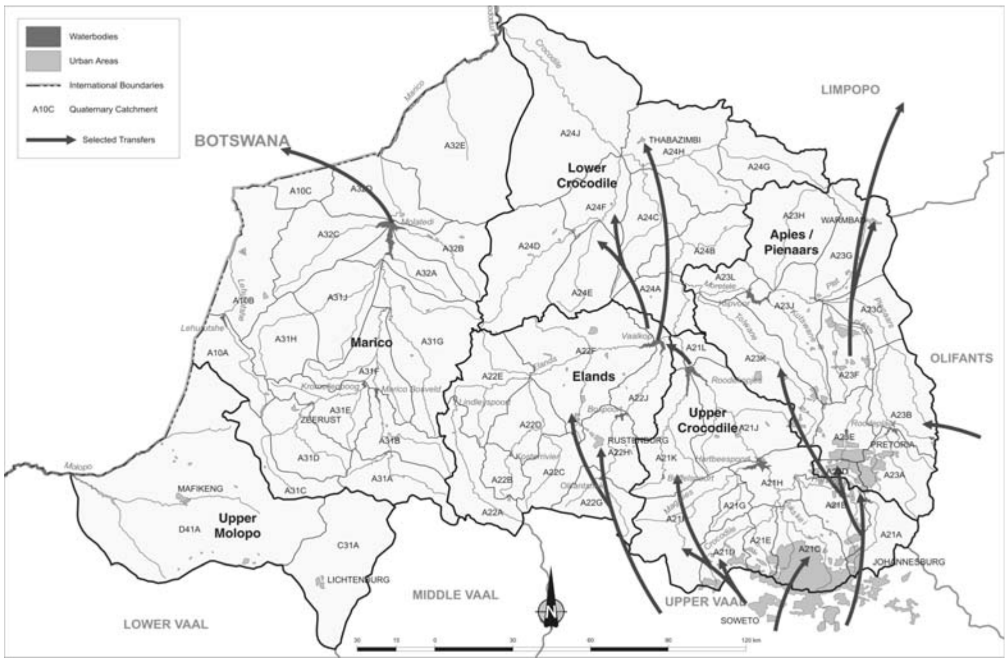


Figure 7. 6: Base map of the Crocodile and Marico water management area (DWAF, 2004)

o ***Middle Vaal water management area: Sand-Vet sub area***

The Middle Vaal water management area is situated in the Free State and Northwest Provinces in the central part of South Africa. It covers the middle reaches of the Vaal River, between the Upper Vaal and the Lower Vaal water management areas (Figure 7.7). The Sand-Vet Irrigation scheme is one of the three sub-areas of the Middle Vaal water management area. It consists of several different areas, served by a network of different channels. Seven farmers, mainly involved with the growing of cereal crops i.e. maize, wheat, soybeans, dry beans, on the Sand and Vet canals, was interviewed. These seven farmers were randomly selected after consultation with the scheme manager at Sand-Vet Irrigation scheme from a list of farmers involved in irrigation scheduling as well as those who were not using irrigation scheduling.

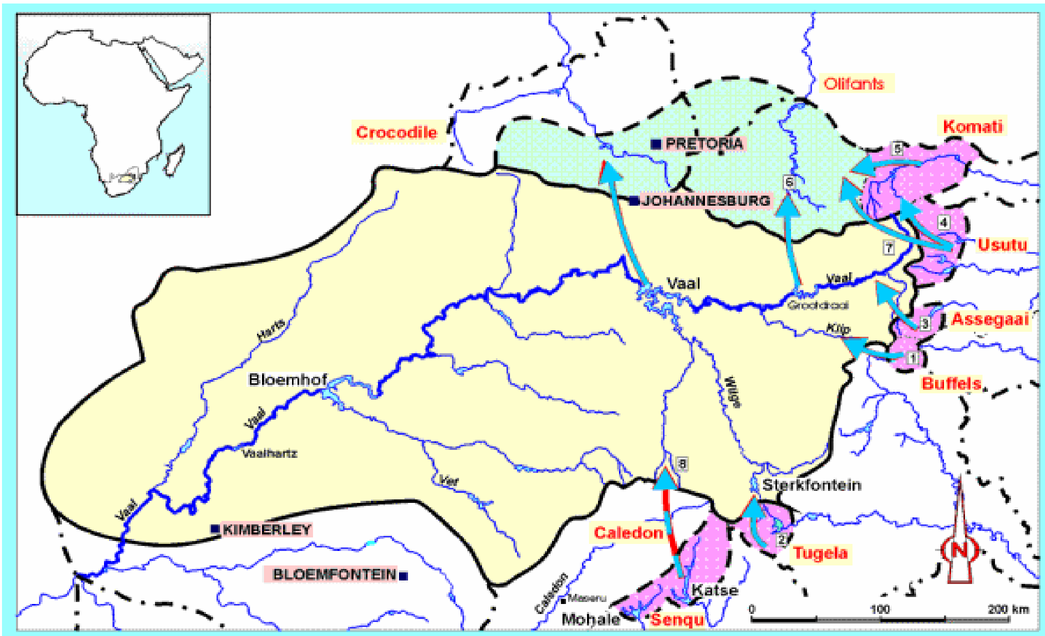


Figure 7. 7: Location map of the Middle Vaal water management area (DWAF, 2004)

o ***Breede water management area***

The Breede water management area is the southern most water management area in South Africa, and lies entirely in the Western Cape Province. The Breede River and its main tributary, the Riviersonderend River drains most of the water management area as indicated in Figure 7.8. The economy of the region is mainly agricultural based, and vineyards and fruit orchards are grown under irrigation.

Ten randomly selected respondents from the Worcester, Monatgu, and Riebeeck Wes area were interviewed. These ten respondents were selected after discussions with the scheme manager of the Breëriver Irrigation Board.

These irrigation farmers were involved with the production of table grapes, wine grapes and deciduous fruit for export or canning.

Figure 7. 8 Base map of the Breede water management area (DWAF, 2004)

o ***Levuvhu/Letaba water management area***

The Levuvhu/Letaba water management area lies in the Limpopo Province. The Letaba River flows into the Olifants River, which is a tributary to the Limpopo River (Figure 7.9).

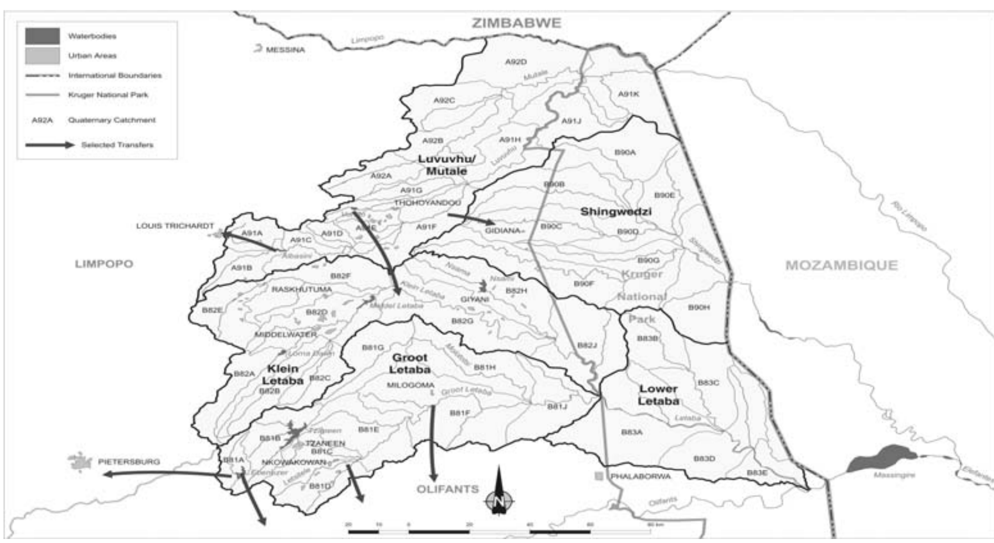


Figure 7. 9: Base map of the Luvuvhu/Letaba water management area (DWAF, 2004)

Nine respondents were randomly selected, seven from the Letaba irrigation area and two from the Settlers area. The two respondents from the Settlers area irrigate mainly from boreholes (private irrigation) and do not belong to a traditional irrigation board scheme or government irrigation scheme. The Levuvhu/Letaba water management area lies in the Limpopo Province.

7.2.2 Data collection and analysis

The field survey for this part of the study was conducted by means of structured and semi-structured interview schedule where respondents were asked questions orally and responses recorded by the researcher. This was done in a face-to-face encounter, but in some cases respondents were also telephonically interviewed. Before the investigation commenced semi-structured interviews were conducted with respective government officials, irrigation scheme managers, members of the local farmers' association, private consultants and commodity institutions active in the different areas. The information gathered from the semi-structured interviews helped with the identification of possible factors that may influence the adoption of irrigation scheduling. Once the variables assumed to influence the adoption behaviour of irrigation farmers were identified, scales were developed for the purpose of quantification and for providing a basis for analysing relationships. The draft questionnaire was tested with several irrigation and extension specialists after it was adapted as required.

The main objectives of the questionnaire for irrigation farmers were:

- To assess the demographics of the respondents and present an overview of irrigation practices.

- To assess the perception of the irrigation farmers regarding the practice of irrigation scheduling in general and the comparison between old and new irrigation scheduling technology.

- Identify the specific irrigation scheduling methods used on farms as well the reasons, perceptions and attitudes of farmers.

- Determine the human and environmental factors, which influence the adoption or discontinuation of irrigation scheduling methods and models.

- Identify the learning and information sources that irrigation farmers normally use.

Table 7.1 provides an overview of the distribution of respondents according to location that were involved in the survey for this part of the study.

Table 7. 1: Distribution of respondents according to province and irrigation area (N=134)

Province	Irrigation area	Number of respondents selected
Free State	Sand/Vet Irrigation Scheme	7
KwaZulu Natal /Eastern Cape	Underberg& Kokstad area	17
Mpumalanga	Onderberg /Komati & Lomatiriver Irrigation Schemes	17
Northern Cape	Orange Riet River WUA/ vd Kloof Irrigation Scheme/ Rust Irrigation Scheme/Lower Orange Irrigation Scheme	37
Eastern Cape	Gamtoos & Sundaysriver Irrigation schemes	23
Western Cape	Worcester, Hexriver & Riebeeck Kasteel Irrigation Schemes	10
Limpopo	Letaba & Settlers irrigation area	9
Northwest	Brits & Rustenburg-area	14
Total		**134**

Many of the questions are open-ended so as to minimize external influences and to allow the respondents to motivate their responses. The data analysis involved the use of Statistical Package for Social Science (SPSS version 10). Before analysis, the data was captured on a computer, which involved coding, data cleansing and editing, and finally modifications and collapse of data into variables.

CHAPTER 8

SOCIO-ECONOMIC FACTORS ASSOCIATED WITH THE ADOPTION OF IRRIGATION SCHEDULING

The following socio-economic factors as independent variables (personal and environmental factors) were assumed to influence the farmers' adoption decision, albeit indirectly through intervening variables like the irrigation farmer's subjective perceptions; attitudes and beliefs.

8.1 AGE

The relative age of decision-makers is a key factor in determining the life cycle "disposition" (VanClay, 2003). Several studies (Bembridge & Williams, 1999; Alene *et al.*, 2000; Mahabile *et al.*, 2002) indicated that age is negatively related with the adoption behaviour and production efficiency of farmers. This led to the hypothesis that younger farmers tend to be more inclined to adopt objective irrigation scheduling to increase the overall water use efficiency on the farm and that there is a negative relationship between age and the adoption behaviour (Hypothesis 1).

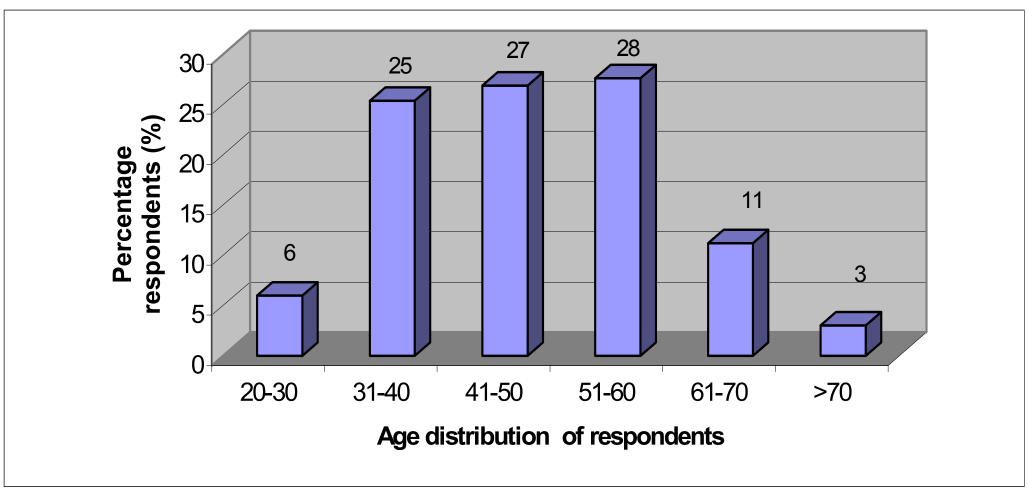


Figure 8. 1 Percentage distribution of respondents according to age (N=134)

Figure 8.1 indicates that 42% of the respondents are older than 50 years, which also reflects a significant pool of first-hand irrigation management experience and knowledge amongst the respondents. Thirty one percent of the respondents are younger than 40 years.

The relationship between age and the selected irrigation scheduling method by farmers was tested by using the independent samples t-test and to compare the willingness of farmers to implement the objective irrigation scheduling methods below 30 years and older than 60 year farmers. There is a significant difference in the scores for young farmers (M=3.3, SD=0.51) and elder farmers (M=1.87, SD=0.35; t (21) =2.7, p=0.013).

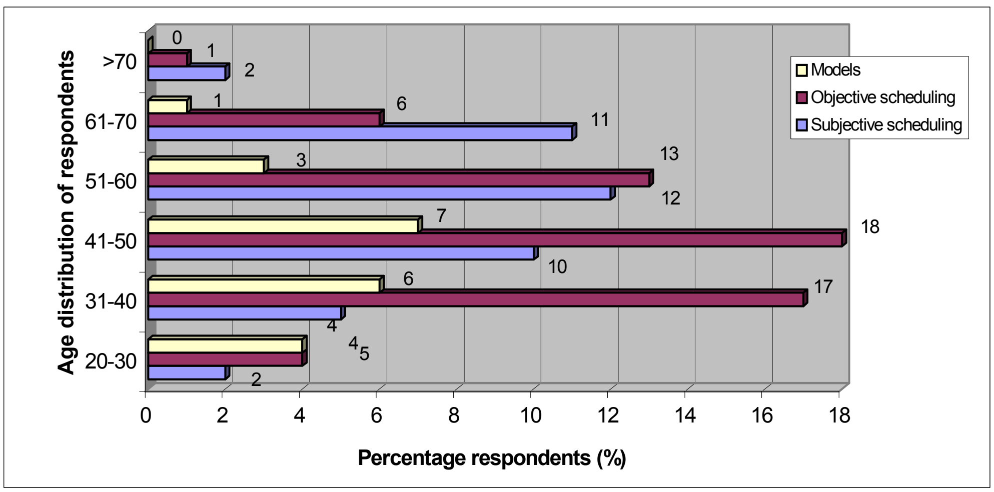


Figure 8. 2: Distribution of respondents according to age and the implementation of irrigation scheduling (N=134)

The results suggest a reduction in the willingness to invest in practices like objective irrigation scheduling (risk aversion) and an increase in the use of intuition and a fixed /semi-fixed rotational scheduling program as a method of scheduling (Figure 8.2). A significant negative relationship (Cramer's V=0.521, p=0.000) exists between age and the use of soil water content measurement, which provides evidence in support of Hypothesis 1.1 namely that an increase in age is negatively correlated with the use of objective irrigation scheduling practices.

A similar tendency is found in the case of the adoption of computer models, where a negative relationship (r=–0.253; p=0.004) provides evidence in support of Hypothesis 1, namely that the age of the farmer influences the preparedness of farmers to engage in the use of computer models for more precise irrigation scheduling on the farm. Younger farmers are more willing to use irrigation scheduling models, probably because of their computer literacy levels, and their willingness to use computer programs for farm management plans and budgets in which irrigation management is often reflected.

8.2 EDUCATION AND TRAINING

Mixed evidence regarding the relationship between farmers' education levels and the adoption of agricultural practices exists. Studies by Rossouw (1989), Bembridge & Williams (1990), Alene *et al.*, (2000) and Alene & Hassan, (2003) found that education is positively related to adoption behaviour of farmers. The findings of these empirical studies led to the hypothesis that education is positively associated to the adoption behaviour of irrigation farmers (Hypothesis 1.1).

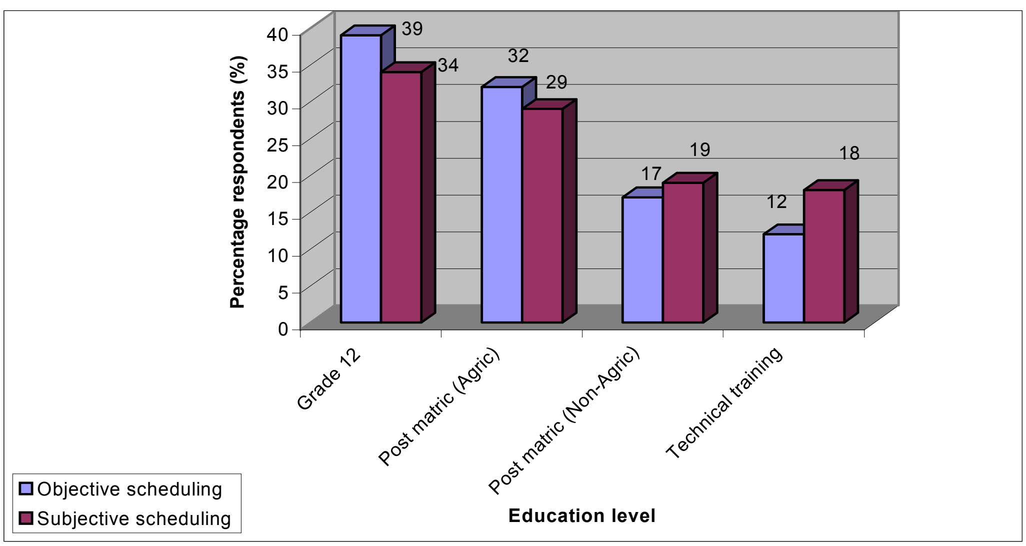


Figure 8. 3: Percentage distribution of the adoption of irrigation scheduling methods according to the education levels of respondents (N=134)

According to Figure 8.3, which presents the formal education profile of irrigation farmers, it appears that no significant difference in formal education exists between respondents using objective and subjective scheduling methods. Higher educational levels are correlated positively with adult training as been reflected through the preparedness of farmers to attend training courses in irrigation management (F=5.9; p=0.008).

There is tendency that higher education is associated with more positive attitude towards the implementation of irrigation scheduling models as supported by the significant Cramer's V value (Cramer's V=0.297, p=0.041).

Table 8. 1: Percentage distribution of respondents according to the attendance of training courses in irrigation management and irrigation scheduling implementation (N=134)

Training	Objective scheduling		Subjective scheduling		Total	
	(n)	%	(n)	%	(N)	%
Short course in irrigation management	57	71	19	35	76	57
No short course in irrigation management	23	29	36	65	58	43
Total	80	100	54	100	134	100

Training is clearly an important contributor to an individual's perception and capacity to change irrigation management practices (X^2=3.4, df=1, p=0.048). Involvement in irrigation management training courses is significantly associated with farmers' willingness to implement on-farm objective irrigation scheduling practices, as 71% of the irrigation farmers who used objective on-farm irrigation scheduling methods also attended short courses in irrigation management. It seems that farmers that had not attended any training courses in irrigation management are more likely to adopt subjective scheduling methods (Table 8.1).

These findings supply evidence in support of Hypothesis 1, namely that the attendance of more training courses in irrigation management is associated with the adoption of precise irrigation scheduling practices. This confirms the study results of Mues, Chapman & van Hilst (1998), where training was positively associated with practice adoption. Training may alleviate technical concerns that farmers have about irrigation scheduling practices.

8.3 PROPERTY SIZE AND IRRIGATION SCHEDULING

Rogers (1983) has generalized that early adopters have a larger farm-size unit than late adopters. Various authors like Cary (1992), Curtis *et al.*, (2000); Mahabile *et al.*, (2002) and Alene *et al.*, (2003) supported this.

In the case of irrigation farming, the same tendency can be expected. In fact, many irrigation farmers and consultants are of the opinion that the scale of irrigation operation is an important factor, which can influence the choice of on-farm irrigation scheduling practices. The findings regarding the relationship between farm size and implementation of irrigation scheduling models are shown in Figure 8.4.

There are significant differences in the implementation of objective scheduling methods with regard to the different categories of areas under irrigation ($F=5.91$; $p=0.016$). Fifty-five percent of the farmers that use scheduling models for irrigation scheduling are farming on a relatively big irrigation plot of bigger than 101 hectares. A positive correlation exists between the size of irrigation and the use of the use of computer models ($r=0.291$; $p=0.035$).

However, the relationship between the practicing of subjective irrigation methods and the size of irrigation area is not significant ($r=0.137$; $p=0.181$). This suggests that there are other factors involved in influencing the subjective irrigation scheduling behaviour of farmers, which need more careful analysis of the adoption behaviour of these farmers.

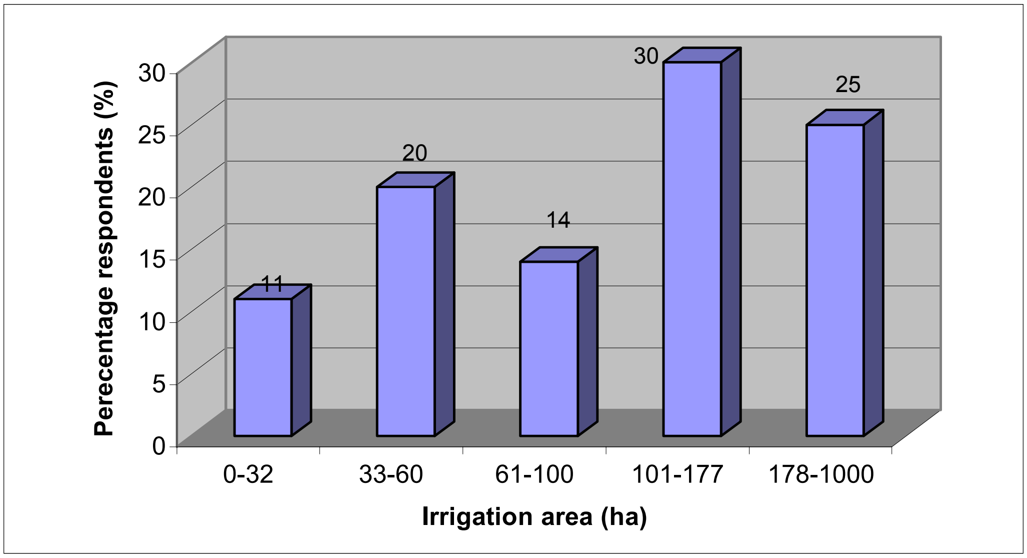


Figure 8. 4: Interrelationship between irrigation area and implementation of irrigation scheduling models (N=134)

8.4 FARMING EXPERIENCE

A general assumption is that a positive association exists between farming experience and the adoption behaviour of irrigation farmers. Experience is considered to be an accumulation of human capital, because with the accumulation of experience farmers are building confidence and knowledge over time, which in addition to the experience gained from other farmers, can become a powerful factor in addressing the best irrigation management practice.

Figure 8.5 illustrates that farmers with relative more farming experience are inclined to make use of subjective scheduling methods. Fifty-two percent of the respondents with more than 20 years farming experience use subjective scheduling methods, while 49 percent of the farmers with less than 10 years farming experience implement objective scheduling methods ($F=6.27$, $p=0.018$). The negative relationship between farming experience and the adoption of objective irrigation scheduling practices is supported by the significant negative correlations between an increase in farming experience and the use of on-farm soil water measurement techniques ($r=-0.549$;

p=0.049) as well as the use of computer models (r=-0.209; p=0.018). These findings are not in accordance with expectations (Hypothesis 1.1), and illustrate that farmers with relatively more irrigation farming experience are more prepared to rely on their local experience, observation and intuition instead of making use of objective irrigation scheduling methods

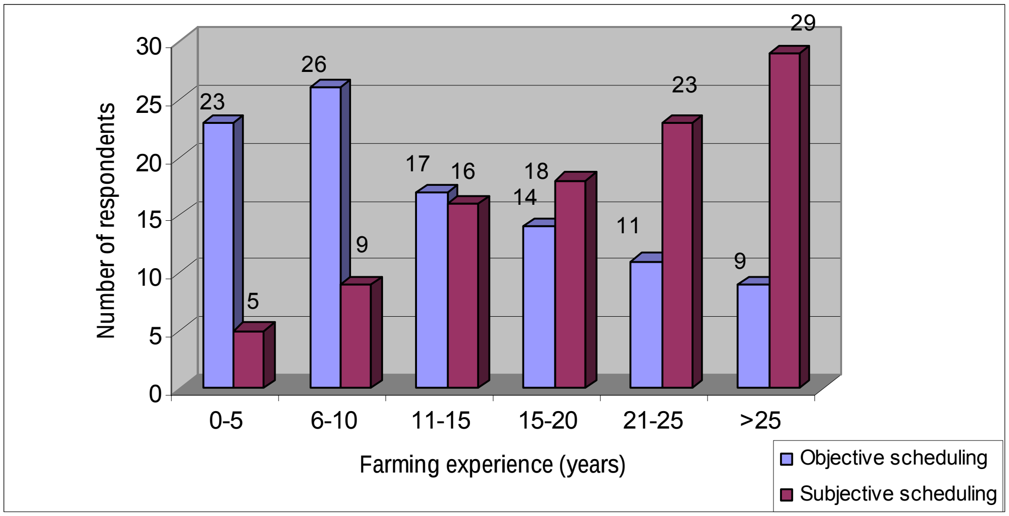


Figure 8. 5: Percentage distribution of irrigation farmers according to their farming experience and implementation of irrigation scheduling practices (N=134)

8.5 NON-FARMING EXPERIENCE

It is noteworthy that 62% of the respondents' experience is limited to that of farming, while the rest of the respondents exist over a wide range of experiences, which includes education, commerce, industry, business and the technical field. Interviews with irrigation consultants and advisors, as reflected upon in Part 5, revealed that there is a tendency that farmers with experience in other careers apart from farming are more open to agricultural innovation and more likely to seek objective advice as part of their decision-making process.

Table 8. 2: **Percentage distribution of respondents according to their non-farming experience and the association with irrigation scheduling implementation (N=50)**

Non-farming experience	Objective scheduling (n=30)		Subjective scheduling (n=58)	
	(n)	(%)	(n)	(%)
Technical field	5	17	5	25
Professional career	10	33	5	25
Commerce & business	7	23	5	25
Education	5	17	0	0
Administration	3	10	5	25
Total	30	100	20	100

Table 8.2 illustrates that 60% of the farmers with experience in other careers are prepared to implement objective scheduling methods on the farm. Fifty-five percent of these farmers are either professional people or businessmen that have started with irrigation farming. Although a relatively high percentage respondents with experience in other careers show interest for the implementation of objective scheduling methods, no significant relationship exists between the implementation of objective scheduling methods and farmers with experience in other careers (X^2=9.46, p=0.149; r=0.018, p=0.083).

8.6 SUMMARY

The study reveals that the following independent variables or socio-economic factors influence the implementation of on-farm irrigation scheduling:

- The increase in age and experience of irrigation farmers suggest a shift in reduction of their general willingness to invest and practise objective irrigation scheduling methods, although no statistical correlation exists. It is clear, however, that a tendency exists that younger farmers are more willing to use computer models because of their higher computer literacy levels and attitude towards the use of computers.

- A positive relationship exists between the educational level of farmers and their general attitude towards the attendance of short courses in irrigation management and the implementation of objective scheduling methods like irrigation scheduling models.
- The relationship between the size of irrigated area and the adoption of objective irrigation scheduling reveals positive relationships with a tendency for the implementation of irrigation scheduling models to increase with an increase in the size of the irrigated area.

CHAPTER 9
INFLUENCE OF INTERVENING VARIABLES ON THE ACCEPTABILITY OF IRRIGATION SCHEDULING

9.1 INTRODUCTION

In view of Hypothesis 1, which states that the influence of intervening variables on the adoption behaviour is higher than the independent variables, the influence of the intervening variables will now be assessed in this chapter. Their influence will be evaluated by using the normative classical five-stage adoption process (NSRC, 1955) as a conceptual framework for the identification of the role of perception, knowledge and needs to solve particular problems in irrigation management.

According to the classical five-stage model (NSRC, 1961) the adoption process is a rational decision-making process that extends over a period of time and implies a sequence of phases. Farmers, however, are not always strictly adhering to rational decision-making procedures (Simon, 1976), but rather regard decision-making as learning process with variation in deliberation and consciousness (Giddens, 1984). Therefore, Leeuwis (2004) refers to the different stages of the adoption process as aspects of learning, since the order in which awareness, interest and experiential learning through trialling occur may vary between different farmers.

The acceptability of a specific irrigation scheduling practice or the change from one irrigation scheduling practice to another, usually involves the following aspects of learning:

1. Awareness: Where the individual becomes aware of an innovation or the problematic situation.

2. Interest: The individual becomes more interested in the new idea and seeks additional information. This is where irrigation farmers select various information and learning sources.

3. Evaluation: The individual mentally applies innovation to his present and anticipated future situation, and then decides whether to try it or not.

4. Trialling: Where the individual becomes actively involved in experiential learning and makes full use of the innovation within his or her current situation.

5. Adoption or Rejection: The individual seeks reinforcement for making decisions - leading to the continuation or discontinuance of an innovation.

9.2 AWARENESS OF THE NEED FOR IRRIGATION SCHEDULING

In this context, "awareness" means not just awareness of the existence of an innovation, but also an awareness of its potential or practical value to the farmer. According to Ghadim & Pannell (1999), when a farmer reaches the stage where the potential value of the innovation is recognised, it serves as a trigger, which prompts the farmer to be willing to "open his ears and eyes". The farmer will commence by noting and collecting information about the specific innovation in order to decide whether or not to proceed to the next step of adoption, namely trialling of the specific innovation.

All but one of the farmers indicated that they had heard about irrigation scheduling before the survey. The information sources used by farmers in the study areas include the local agricultural cooperatives, private consultants and advisors from wine cellars and commodity institutions like the sugar, citrus, subtropical fruit and deciduous industries, fellow farmers and family members, universities and tertiary institutions, field days by ARC extensionists from Department of Agriculture, and representatives of seed, fertilizer and agrochemical companies. The frequencies, with which these sources are used, are summarized in Table 9.1.

Table 9. 1: Information sources through which farmers become aware of irrigation scheduling (N=134)

Sources of awareness	Objective scheduling		Subjective scheduling		Total number of respondents	
	(n)	(%)	(n)	(%)	(N)	(%)
Cooperatives	25	33	12	21	37	28
Private consultants/advisors	22	29	6	10	28	21
Fellow farmers	11	15	16	28	27	20
Universities	7	9	11	19	18	13
Departmental extensionists	5	7	6	10	11	8
ARC Institutes	5	6	3	5	8	6
Representatives (seed, fertilizer and agrochemical companies)	1	1	3	5	4	3
Missing			1	2	1	
Total	**76**	**100**	**58**	**100**	**134**	**100**

Based on the frequencies, it is clear that local agriculture cooperatives (grain, citrus and cellars), private consultants from the various industries and fellow farmers are important information sources that create awareness about on-farm implementation of irrigation scheduling.

Private irrigation consultants and advisors (29%) from wine cellars and commodity institutions like the sugar, citrus, subtropical fruit and deciduous fruit industries as well as cooperatives (33%) play a significant role in raising awareness among farmers to start with the implementation of on-farm objective irrigation scheduling techniques. Fellow farmers (28%) play an important role to raise awareness of the use of subjective irrigation scheduling methods. Although a tendency exists that different information sources are responsible for raising awareness of irrigation scheduling, no statistical significant relationship (F=1.43, p=0.233; r=0.108, p=0.177) exists between the source of information used and the on-farm irrigation scheduling method implemented.

9.2.1 Perception of the concept “irrigation scheduling”

Respondents were assessed regarding the “technical correctness” of their perception with respect to the principles that apply to the concept “irrigation scheduling” as commonly used by scientists. These perceptions of irrigation farmers reflect their attitude and beliefs towards irrigation science. According to Table 9.2, only 22 percent of the respondents fully understand the definition of irrigation scheduling; which implies that farmers could referred to the relationship between soil, plant and atmospheric. Seventy-two percent could only partially refer to the major principles included in the definition.

Table 9. 2: Percentage distribution of respondents according to their perceived understanding of the definition irrigation scheduling (N= 134

Perception regarding the definition “irrigation scheduling”	Objective scheduling (n=76)		Subjective scheduling (n=58)		Total (N=134)	
	n	**(%)**	**n**	**(%)**	**N**	**(%)**
Fully understand the definition	21	28	9	16	30	22
Partially understand the definition	53	69	43	74	96	72
No understanding of the definition	2	3	4	7	6	4
Did not answer the question			2	3	2	2
Total	**76**	**100**	**58**	**100**	**134**	**100**

Table 9.2 shows significant differences between the categories of understanding of the concept “irrigation scheduling” (X^2=3.65, df=2, p=0.016). Irrigation farmers using objective scheduling methods show more insight into the understanding of the concept than irrigation farmers using subjective scheduling methods. A significant positive Spearman correlation (r=0.179, p=0.041) confirms this association between perception about irrigation

scheduling and the implementation of objective irrigation scheduling methods. This finding emphasizes the important role that competent extensionists and irrigation institutions have to play in training and informing irrigators in this regard.

9.2.2 Perceived need for on-farm implementation of irrigation scheduling

The incentive or need related motive of a problem lies primarily in the perceived discrepancy between the current and desired or potential situation. Düvel (1991) referred to this as the need tension or need potential, and the influence of this factor is well documented in various research findings (Koch, 1985; Düvel & Scholtz, 1986; Koch, 1987; Louw & Düvel, 1993; Botha, 1997; Düvel & Botha, 1999). The need potential as illustrated through the perceived importance of implementing irrigation scheduling is illustrated in Figure 9.1.

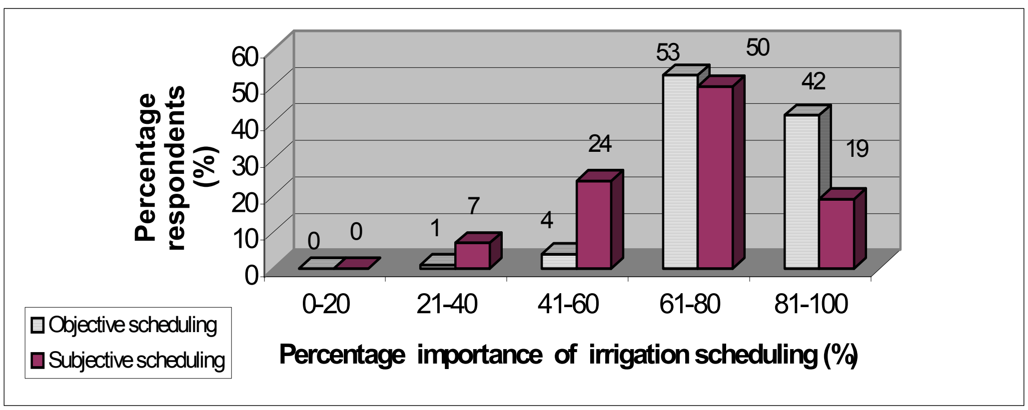


Figure 9. 1 Percentage distribution of respondents according to their perception regarding the importance of irrigation scheduling and their application of different irrigation scheduling methods (N=134)

The majority of respondents (85%) rated irrigation scheduling as an important practice on the farm for sound irrigation management, with a clear tendency of farmers implementing objective scheduling methods to be more convinced about the importance of irrigation scheduling than those farmers using subjective scheduling (Figure 9.1). This association between perception of the importance of the implementation of on-farm irrigation scheduling and the implementation of objective irrigation scheduling is supported by significant differences (χ^2=21.45, df=7, p=0.003).

Farmers involved with the practicing of objective irrigation scheduling rated the importance of implementation of on-farm irrigation scheduling higher than farmers involve in subjective irrigation scheduling. Forty-two percent of the farmers involved with the implementation of objective scheduling methods perceived irrigation scheduling to be highly important (>80%), while only 19% of farmers applying subjective scheduling methods shared the same perception. A significant correlation (r=0.424, p=0.000) exists between the perceived importance of on-farm irrigation scheduling and adoption of objective scheduling methods. This finding provides supporting evidence for Hypothesis 1.2, namely that the adoption of irrigation scheduling is directly correlated with the perceived importance of on farm irrigation scheduling.

9.2.3 Perceived need for the implementation of irrigation scheduling by fellow farmers

Sometimes the simultaneous learning of interdependent stakeholders is necessary, to arrive at coherent innovations and practices, which authors like Röling (2002) and Woodhill (2002) have labelled as “social learning”. Röling (2002) defines social learning where collective or distributed cognition is taking place, and where the different stakeholders may work together and engage in complementary practices while significant differences in perception remain. Farmers were asked to rate the importance of the practising of irrigation scheduling by their fellow irrigation farmers in an irrigation area.

Approximately 84% of the respondents regarded the implementation of irrigation scheduling by fellow farmers to be important for sound irrigation management (Table 9.3). There is an indication of a slightly higher expectation among irrigation farmers who implement objective irrigation scheduling (χ^2=16.04, df=8, p=0.042; r=0.216, p=0.013). Irrigation water is generally perceived as a common property, which necessitates stakeholders to focus on more than one system level. Therefore, it is not enough for farmers that sustainable water management principles are applied at the farm-level only, but it necessitates that stakeholders at an irrigation scheme level need to work collectively to ensure effective water management.

Table 9. 3 Percentage distribution of respondents according to their perceived importance of the implementation of irrigation scheduling by fellow farmers and their on-farm irrigation scheduling (N= 134)

Importance of irrigation scheduling by fellow farmers	Objective scheduling (n-76)		Subjective scheduling (n=58)		Total number of respondents	
	(n)	%	(n)	%	(N)	%
0-20	0	0	10	17	10	8
21-40	0	0	4	7	4	3
41-60	5	6	3	6	8	6
61-80	46	61	24	41	70	52
81-100	25	33	17	29	42	31
Total	**76**	**100**	**58**	**100**	**134**	**100**

9.2.4 Perceived reasons for implementation of irrigation scheduling

Showing interest in an innovation is an aspect of learning where the farmer collects information to decide about the possible opportunities, threats and personal consequences attached to the innovation. The motivation of farmers to learn about irrigation scheduling will depend on the priority or urgency of solving the identified problem and the magnitude of the tension between the desired and current state of affairs (Leeuwis, 2004).

The reasons provided by farmers for their initial interest shown in the implementation of irrigation scheduling (Table 9.4) reveal significant variation in the need potential of irrigation farmers ($F=6.46$, $p=0.013$). The majority of respondents (64%) maintain that the main purpose for the implementation of objective irrigation scheduling was to ensure efficient use of water on the farm and in the field according to the crop water requirements.

Table 9. 4 Percentage distribution of respondents according to the perceived reasons for the implementation of irrigation scheduling practices (N= 134)

Most important reasons for the application of irrigation scheduling	Objective scheduling (n=76)		Subjective scheduling (n=58)		Total (N=134)	
	n	%	n	%	N	%
Optimum water use on the farm ("Can't farm without it")	49	65	38	66	87	64
Control of nutrient leaching	36	47	21	36	57	43
Improved quality of crops	36	47	19	33	55	41
Electrical costs too high	16	21	11	19	27	20
Profit maximization	8	10	5	9	13	10
Application of water according to crop water requirements and maintain a full profile	8	10	4	7	12	9
Follow in the footsteps of father	2	3	8	14	10	7
To meet export standards (Eurepgap, ISO standards)	7	9	0	0	7	5
Popular and socially acceptable	2	3	0	0	2	1

Forty-seven percent farmers involved with the production of high value/high input crops, perceived the implementation of objective irrigation scheduling as a means of ensuring improved quality of crop and the prevention of nutrient leaching. The need potential of the subjective irrigation scheduling group on the other hand was less, in that only 36 percent of farmers perceived controlling of nutrient leaching and 33 percent perceived improved quality of crops as important reasons for the implementation of on-farm irrigation scheduling. Nine percent of irrigators from the objective irrigation scheduling group perceived precise irrigation scheduling practices as important to qualify in terms of Eurepgap and ISO standards that prevail as the minimum standards for good agricultural practices of export horticultural products like fruit and certain commodities like tobacco and citrus.

From the findings presented in Table 9.4, it is interesting that 14 percent of the respondents using subjective scheduling methods indicated that they are following in their fathers' footsteps in this regard. This illustrates the important role that indigenous knowledge systems play in irrigation management. It is imperative for irrigation extensionists and advisors to recognize this knowledge system as it has often evolved from years of experience and trial-and-error problem solving by irrigators. These expressed reasons provided for the implementation of irrigation scheduling differ significantly (χ^2=8.63, df=2, p=0.013) between the objective and subjective scheduling groups. This finding supports Hypothesis 1.2, which implies that there is a significant relationship between perceived need for on-farm irrigation scheduling and the implementation of irrigation scheduling.

9.3 INFLUENCE OF PERCEIVED IRRIGATION SCHEDULING EFFICIENCY ON ADOPTION BEHAVIOUR

Irrigation efficiency and the adoption behaviour of irrigation farmers are hypothesized to be a function of personal and environmental factors, which are in turn divided into independent and intervening variables. One of the intervening variables identified by Düvel (1975) as a behaviour determinant is the perceived current efficiency of irrigation scheduling adoption. The more accurately a farmer perceives his or her problem, the more likely he or she is to appreciate the improvement potential, and the more willing is he to change his behaviour.

9.3.1 Perception regarding the efficiency of on-farm irrigation scheduling

The perception of irrigation farmers regarding their level of irrigation accuracy is reflected in Table 9.5. Farmers were asked to rate the accuracy of their current irrigation scheduling on the farm, using a ten-point semantic scale.

The majority respondents (66%) rated the accuracy of their on-farm irrigation scheduling practises relatively high (between 70-80%). There is a tendency for respondents implementing objective irrigation scheduling to be more convinced of the accuracy level of their method than is the case with those using subjective scheduling, although the differences are not statistical significant (F=2.517, p=0.116). Ninety percent of the farmers implementing objective irrigation scheduling methods rated their current accuracy of on farm irrigation scheduling between 70-90%, while 71 percent of respondents from the subjective scheduling group provided the same assessment.

Table 9. 5: Percentage distribution of respondents perception of the accuracy level of on-farm implementation of irrigation scheduling (N=134)

% Accuracy irrigation scheduling	Objective Scheduling (n=76)		Subjective scheduling (n=58)		Total (N=134)	
	n	%	n	%	n	%
20	0	0	2	3	2	1
50	1	1	3	5	4	3
60	7	9	11	19	18	13
70	28	37	19	33	47	35
80	26	34	15	26	41	31
90	14	19	7	12	21	16
100	0	0	1	2	1	1
Total	**76**	**100**	**58**	**100**	**134**	**100**

As far as the perception of accuracy of on-farm irrigation scheduling is concerned, a significant relationship (Cramer's V=0.410, p=0.000) exists between the use of soil water measurement techniques and the accuracy of on-farm irrigation scheduling. However, the relationship between the perception of accuracy of on-farm irrigation scheduling and the use of computer irrigation scheduling models is not significant (Cramer's V=0.228, p=0.569).

9.3.2 Perceived satisfaction with current level of on-farm irrigation scheduling

It is only because of an existing need that a person can have a goal or a goal appears to be attractive (Düvel, 1990). The level of satisfaction with the current method of irrigation scheduling will determine the perceived improvement potential, which can influence the willingness of the farmer to change his behaviour and thereby improve the efficiency of irrigation scheduling. This assumption (Düvel, 1991) has led to the hypothesis that the need tension is positively associated with adoption behaviour.

In response to a question as to how satisfied respondents are with the current accuracy of implementation of irrigation scheduling, it appears as if the farmer group using subjective scheduling methods is relatively more satisfied than farmers using objective irrigation scheduling methods (Figure 9.2).

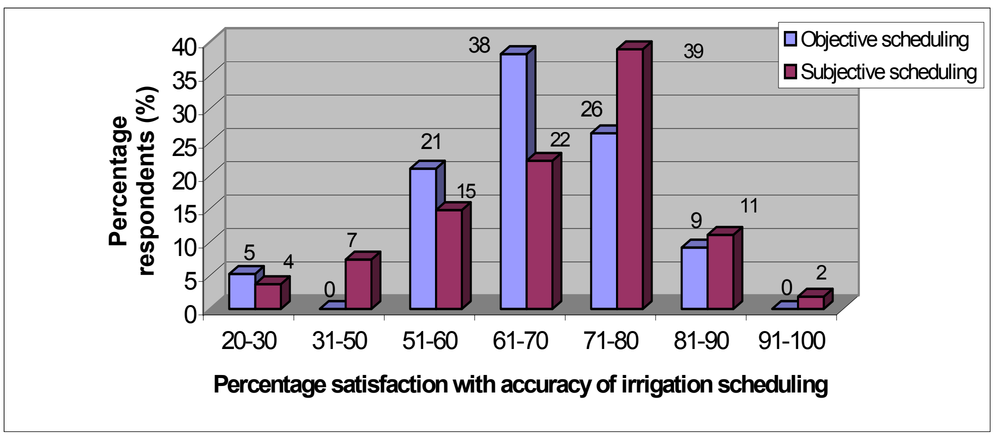


Figure 9. 2: Percentage distribution of respondents according to their perceived satisfaction with on-farm irrigation scheduling and the implementation of different irrigation scheduling methods (N=134)

Thirty five percent of the respondents that use objective irrigation scheduling methods rate their satisfaction with the accuracy of the on-farm irrigation scheduling at more than 70%. This percentage satisfaction is 52 percent in the group of respondents using subjective methods.

There is a clear indication of a higher need tension among the objective scheduling group (r= -0.234, p=0.048), which is in accordance with what has been hypothesized (Hypothesis 1.2). The explanation for this is the fact that farmers that belong to the subjective scheduling group had overrated their current level of efficiency, while farmers from the objective scheduling group are more realistic and even underrated their level of irrigation efficiency. This is an important finding for the extensionists and irrigation consultants to take cognizance of, as it illustrates the difference of the need potential as perceived between the objective and subjective scheduling groups. The more accurately a farmer perceives his efficiency of on-farm irrigation scheduling, the more likely he is to appreciate the improvement potential, and the more likely he is to alter his behaviour and thereby improve the on-farm irrigation management.

9.4 PERCEPTION REGARDING IRRIGATION OPERATIONAL COSTS

Irrigation water application costs are related to the actual cost of water, interest on capital equipment, energy (electricity or diesel), labour and also opportunity costs, especially if water is limited. In an effort to determine the need related motive for the adoption of irrigation scheduling, farmers were asked to indicate the operational cost of irrigation in relation to the other production cost items applicable to various crops and whether they experience the tariffs of irrigation water to be expensive. Seventy percent of the respondents perceived the actual tariff of irrigation water to be expensive.

Table 9.6 provides an overview of the distribution of the operational cost of irrigation water as perceived by the respondents involved in the production of cash crops (like maize, wheat, cotton, sugar cane, etc.) and intensive, high value crops (like deciduous fruit, table grapes, wine grapes, citrus, subtropical fruit, vegetable seed, etc.) respectively.

Table 9. 6: Percentage distribution of perceived irrigation operational irrigation costs with regard to the production of cash and high value/high input crops. (N=134)

Cash crops			Intensive or high value crops		
Percentage of total production cost/ha	**n**	**%**	**Percentage of total production cost/ha**	**n**	**%**
0-5%	3	3	0-5%	22	28
6-10%	29	31	6-10%	31	40
11-20%	32	34	11-20%	19	24
21-30%	29	31	21-30%	6	8
Total	**93**	**100**	**Total**	**78**	**100**

Table 9.6 illustrates highly significant differences with regard to the perceived operational irrigation costs (X^2=9.109, df=3, p=0.028) between cash and high value crop producers. Irrigation water as an operational cost proportionate to the total production costs per hectare of cash crops and high value/ high input crops like deciduous fruit, table grapes, wine grapes, and sub tropical fruit are found to be relatively small. Sixty eight percent of the respondents involved in the growing of high input crops reflected the operational cost of irrigation to be between 0-10% of the total production costs per hectare. Whereas, the relationship between the perceptions of irrigation operational costs proportionate to the total production costs of high value/intensive crops per hectare and the adoption of objective irrigation scheduling is significant (r=0.302, p=0.007).

However, although 65% of the cash crop farmers indicated the operational cost of irrigation to be between 11-30% of the total production cost per hectare, no significant relationship exists with the adoption of objective irrigation scheduling (r=0.208, p=0.265). These findings illustrate that the major advantages by the implementation of objective irrigation scheduling is not perceive to be demonstrated in terms of the possible saving on irrigation water and irrigation operational costs by cash crop farmers alone. This finding illustrates that cash crop farmers are probably underrating the effect of the operational irrigation costs on their production efficiency, and thereby supporting Hypothesis 3, which states that the specific farm business characteristics influence the irrigation farmers' willingness to adopt more precise irrigation scheduling methods.

Farmers were asked to identify the most important production inputs and rank them in order of importance with regard to their respective contribution to the total crop enterprise budget. Although farmers are generally aware of the importance of water as a primary constraint to production, they do not perceive irrigation operational costs as the most important contributor to the total production input costs for cash and intensive crop production (Table 9.7).

Table 9. 7 The perceived importance rank order of operational irrigation costs relative to the other production cost factors in terms of cash and high value crop production as expressed by weighted average score * (N=134)

Production input	Cash crops (n=92)		High value/high input crops (n=76)	
	Weighted average score	Rank order position	Weighted average score	Rank order position
Fertilizers	2.49	1	1.20	2
Seed	0.64	3		
Labour	0.79	2	1.52	1
Pest and weed control	0.23	4	0.65	4
Mechanization	0.17	6	0.09	7
Marketing	0.19	5	0.93	3
Packaging			0.60	5
Irrigation	0.14	7	0.13	6

** Weighted average score is the sum of the rank order frequencies multiplied respectively by 7 for the first position, 6 for the second position, 5 for the third position, 4 for the fourth position 3 for the fifth position, 2 for sixth position, 1 for seventh position and divided by the number of farmers expressed as percentage.*

Cash crop irrigation farmers ranked the production input costs of fertilizers, seed and labour as overwhelmingly important, with the production costs of irrigation ranked relatively low (position seven as weighted score). Also high value crop farmers ranked irrigation operational costs relatively low (position six as weighted score), which illustrates that other inputs like fertilizers, labour, marketing and timeous controlling of pest and diseases are more expensive than irrigation water.

These findings provide a possible explanation why farmers illustrate a higher need tension to spend time, money and skills to monitor production inputs like fertilisers, seed, labour, etc. more accurately than they do with regard to the adoption of more precise on-farm irrigation scheduling methods.

9.4.1 Relationship between source of irrigation and irrigation operational costs

The operational cost of irrigation could vary considerably depending on whether a farmer receives water from a canal distribution system within an irrigation scheme, or whether the farmer is pumping water directly from a river. Seventy-six percent of the respondents indicated that they receive water from a canal delivery system, while 15 % respondents pump water directly from a river. Nine percent of the respondents use boreholes as their water source.

Farmers, who pump water directly from a river or borehole, can expect to experience relatively higher electricity operational costs than farmers receiving irrigation water from a canal delivering system. Table 9.8 reveals the analysis of the differential irrigation operational costs that farmers' experience where different water sources and irrigation systems are used for the production of wheat in the Northwest province. The unit operational cost of irrigation as calculated in Table 9.8 reflects only the actual water cost, electricity and an average labour costs of R275/ha as assumed for this exercise.

Table 9. 8 Irrigation operational costs for the production of wheat with a target yield of 6t/ha and a crop water requirement of 540 mm/ha, using different water sources and irrigation systems in the Northwest Province (2003)

Source of irrigation water	Irrigation system	Tariff of irrigation water (R/ha/ annum)	Elec-tricity cost (R/ha)	Cost /unit irrigation water (R/mm)	Total irrigation cost/ season /ha (R/ha)
River	Centre pivot (Low pressure)	64.28	287.95	2.08	1123
River	Centre pivot (High pressure)	64.28	374.33	2.53	1366
Canal	Centre pivot (Low pressure)	700	287.95	2.20	1188

Table 9.8 shows a substantial difference (R243/ha) that exists regarding the total irrigation cost/season/ha between the uses of low *versus* high-pressure centre pivots, mainly because of the differential electricity consumption between these two irrigation systems. Variation is illustrated regarding the total operational costs for irrigation per hectare per season where irrigation water is directly pumped from a river compared to irrigation water received from a canal within an irrigation scheme. A significant relationship (r=0.319, p=0.004) exists between the source of irrigation used by irrigation farmers and the irrigation operational irrigation costs experienced. These findings emphasize the importance of the correct design and selection of irrigation systems that are appropriate for specific farm situations (soil, climate, management capacity etc.).

9.4.2 Perception regarding implementation of volumetric irrigation water tariffs

The Water Demand Management (WDM) as incorporated into the National Water Resources Strategy (NWRS), is an innovative strategy implemented to help manage water resources efficiently in southern Africa (de Lange *et al.*, 2002). The Water Management Plans of WUAs must therefore illustrate the current and expected water demand as well as proposed water conservation measures. Water measurement is considered to be of fundamental importance for the implementation of these plans, and except for the legislative reasons for the measuring of irrigation water, many other benefits related to practical water management are perceived from the upgrading of water measurement programs and systems (United States Bureau of Reclamation, 1997).

One way to achieve an efficient allocation of water is to price its consumption correctly. A variety of methods for pricing water have been developed, depending on natural and economic conditions. These include volumetric pricing, non-volumetric pricing and market-based methods. Volumetric pricing mechanisms charge for irrigation water based on consumption of actual quantities of water. This requires information on the volume of water used by each user or some other way to infer a measurement of water consumption. Implementation costs associated with volumetric pricing are relatively high and require a water user association (WUA) to set the price, monitor use and collect fees (Knoetze, 2003).

As illustrated in Part Two, on the majority of schemes non-volumetric pricing is exploited where the individual abstraction of irrigation water is not measured, and irrigators generally pay water tariffs that are based on irrigated area. Bos & Walters (1990) in their global survey of farmers on 12 million ha, found that in more than 60% of the cases water is charged on a per unit area basis. Under this pricing mechanism users are charged for water used per irrigated area, often depending on crop choice, extent of crop irrigated, irrigation method and season. Rates are typically greater for pumped water from a storage facility than for gravity flow from stream diversion. Consequently there are little financial and social incentives for the implementation of non-volumetric pricing.

Market-based methods have recently arisen as a need to address water-pricing inefficiencies inherent in existing irrigation institutions. Markets are far better than bureaucrats at capturing this opportunity cost, so government should encourage the establishment of markets in order to determine the most economically beneficial use of water sources (De Lange & Maritz, 1998). Formal water markets can only work if there are "buyable" and "sellable" water rights, and willing irrigation farmers to make use of this opportunity during critical crop growth stages. Water markets are, however, localized in nature because it is expensive to transport and therefore the number of suppliers and users are limited. The general perception of farmers regarding the volumetric measurement of water at farm off-takes was tested.

It was generally found that farmers have a positive attitude towards the implementation of volumetric water tariffs and water measurement at individual abstractions (Figure 9.3). Many farmers, however, indicated that they lack the necessary financial incentives for the implementation of irrigation scheduling and efficient use of water on the farm with the current water allocation and non-volumetric tariff system in use by water organisations.

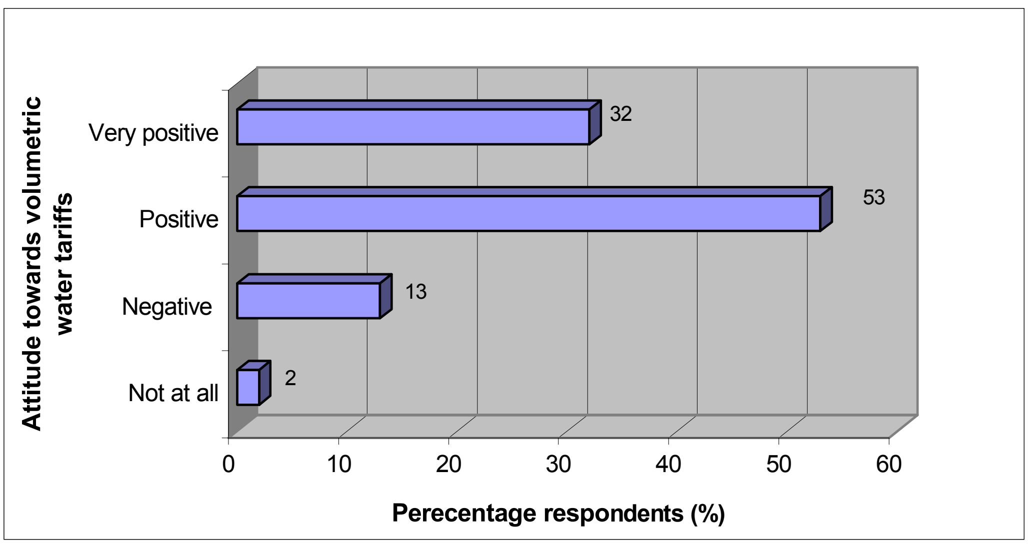


Figure 9. 3: Percentage distribution of respondents according to their attitudes towards the application of volumetric water tariffs (N=134)

Although 85 percent of farmers showed relative positive attitudes towards the application of volumetric water tariffs with the placement of water meters at each individual abstraction point, no significant relationship exists with the adoption of on-farm objective irrigation scheduling ($r=0.136$, $p=0.162$). Thirteen percent of the farmers indicated concern about the accuracy and the practical application of this technology. Common causes of meter defects perceived by farmers are defective flow meters (resulting in providing incorrect information), ageing technology and meter tempering. Often physical impurities include water grass, sticks, frogs, silt and any other object or substance conveyed by water, which can affect the meter accuracy. Therefore, the limited number of water measurement devices currently installed in the field is not perceived to be successful by farmers, and several questions regarding the practical implementation of the concept were raised.

A commercially available mechanical meter could be bought and installed for less than R8000 on most irrigation pipes smaller than 300mm in diameter (vd Stoep, 2004). However, farmers are often using more than one pump on the farm to abstract water, and therefore will need more than one device to be installed. Thirty seven percent of the respondents, who indicated a positive attitude towards the implementation of volumetric measurement, were concerned with regard to the initial cost of the device or meter and the installation of it. Although the cost of the device is relatively small in comparison with many items of the crop budgets applicable for summer and winter crops, the necessary financial incentives through the potential increasing of water use efficiency on the farm was not perceived enough for the justification of the additional costs. Respondents had raised concern about the financial responsibility for installing and buying of measurement or equipment (farmers or the responsible water organization or Department of Water Affairs?).

9.5 INFLUENCE OF PERCEIVED INNOVATION CHARACTERISTICS ON IRRIGATION SCHEDULING ADOPTION

For irrigation farmers to adopt certain irrigation scheduling practices requires an understanding of their current situation, the improvements possible, and the degree of complexity of improvements to meet the identified need potential. This implies that the adoption of irrigation scheduling technology as a practice must be regarded as a multi-stage decision process involving information acquisition and learning-by-doing. The degree to which an innovation may be experimented with on a limited scale prior to full implementation is critical in the adoption or learning process as it helps to organize and provide feedback to the farmer (Rogers, 1983, Bembridge, 1991, Leeuwis, 2004). Therefore, small-scale trials and evaluation of a new on-farm irrigation scheduling practice can provide valuable information to the farmers. This can reduce uncertainty and help with the judging or assessment of specific technology. Even financially and socially secure farmers are unlikely to plunge blindly into a new practice, but prefer to limit their risk as much as possible by gathering information and extending knowledge in a cautious way. If possible, they prefer a phased implementation of new irrigation scheduling practices, adjusting the scale either upwards towards full adoption, or downwards towards rejection as they gain knowledge, experience and confidence in their perceptions about the performance (Stirzaker *et al.*, 2004.)

9.5.1 Perception regarding irrigation technology attributes

According to Düvel (1975), all potential forces of behaviour change can be directly traced back to the perception of the psychological field. Several research studies (Louw & Düvel, 1973; Düvel, 1975; Koch, 1985; Botha, 1986; Koch, 1986; Botha, 1999) present evidence of this and led to the hypothesis (Hypothesis 1.2) that the implementation of irrigation scheduling is positively associated with the perception of irrigation scheduling technology attributes.

Linder (1987) highlighted the importance of the characteristics of a specific technology in the adoption of agricultural practices. Important attributes found to influence the rate of adoption of objective irrigation scheduling technology by farmers are the relative advantage, complexity, compatibility, trialability and the observability (Rogers, 1983). Leeuwis (2004) refers to these as characteristics of learning areas that help to understand why some learning occurs easily, or not.

Irrigation farmers usually evaluate the new irrigation scheduling devices and recommended practices in terms of the relative complexity to use or apply them, the relative risk involved and the investment characteristics relative to traditional technology. Table 9.9 provides information of the difference in perception of irrigation farmers who implement objective and subjective irrigation scheduling with regard to perceived characteristics of the ideal irrigation scheduling technology are reflected in terms of:

- Risk characteristics: some technologies have risk reducing effects in a high-risk environment, where others have no effect on risk or even increase it.

- Relative management complexity: relative management complexity refers to the flexibility characteristics of the irrigation scheduling technology or the ability to function under a variety of irrigation farming systems,

- Initial capital costs: the initial capital costs to be spent before the device can be implemented will determine adoption decisions, especially in the case of resource poor farmers.

- Relative profitability of technologies: farmers will be more willing to adopt irrigation technology that gives high returns on investment.

Table 9. 9: Percentage distribution of respondents according to their perception regarding the technological characteristics of irrigation scheduling devices and their style of irrigation scheduling implementation (N=134)

Technology characteristics	Objective scheduling (n=76)	Subjective scheduling (n=58)	Number of respondents (N)	% Respondents
1. Risk characteristics of technology				
Accuracy and reliability of data	65	32	97	72
Timeliness and speed of use of data	32	12	44	33
2. Relative management complexity				
Easiness of implementation within farming system	54	28	82	61
Robustness of device	7	2	9	7
Simple technology	27	22	49	37
3. Initial costs				
Affordable (initial cost)	38	28	66	49
4. Profitability of technology				
Cost effectiveness	15	5	20	15

It is apparent from these findings in Table 9.9 that farmers' decisions to adopt or reject the use of a specific irrigation scheduling technology are likely to be determined by the perceived usefulness of the technology as characterized by the accuracy and reliability of information produced for decision-making (72%) and timeliness of data (33%). The possible explanation for this finding is that irrigation farmers are generally "risk averse" and therefore perceive accurate and trustworthy information resulting from the implementation of irrigation scheduling technology as the most important prerequisite for the adoption of irrigation scheduling.

Respondents rated characteristics regarding the adaptiveness or easiness of technology to interact and implement with other technology in the relevant farming system relatively high (61%). To benefit from the irrigation scheduling technology, these technologies have to be adapted to the local conditions before finally adopted by farmers. In general farmers found it difficult to implement irrigation scheduling models and some of the sophisticated soil water measurement techniques like the use of neutron probes and capacitance sensors without the support from extensionists and/or irrigation consultants.

The initial capital investment in a new irrigation technology was also perceived to influence the adoption of a technology, especially in the case of resource poor smallholders. Forty nine percent of the respondents perceive the initial fixed costs for the implementation of irrigation scheduling as an important characteristic of irrigation scheduling technology. This initial capital cost for the implementation of irrigation scheduling generates an “option“ for some farmers to delay the implementation of such an investment as in the case of some of the more sophisticated scheduling methods. Farmers therefore have to decide whether the long-term investment will pay off and if the necessary incentives are inevitable to adopt such a technology.

The decision to adopt or reject an innovation is largely determined by a farmer’s self-interest. Profitability of a practice is an important element of self-interest, but self-interest also includes the farmer’s attitude to risk and conservation of the environment, as well as his general perception of success and failure. A practice like the implementation of objective irrigation scheduling was found to vary in terms of its relative profitability and appropriateness depending on the particular farming system (locality, different technical, soil, and climatic endowments and cropping system. Although the profitability of irrigation scheduling technologies were perhaps not rated as high as expected by the farmers (15%), it is known from the literature (Pannell & Glenn, 2000) on adoption studies, that this characteristic is usually a critical factor in farmers’ decision making. The value of on-farm trials and experimentation to obtain information for the reduction in uncertainty about the profitability of irrigation scheduling technology is important.

The perception regarding the technology characteristics of irrigation scheduling technology vary significantly between farmers who apply objective and subjective scheduling methods (X^2=13.44, df=5, p=0.020; r=0.178, p=0.043). This finding supports Hypothesis 1.2, which states that the perceptions of irrigation farmers with regard to the irrigation scheduling technology attributes influence irrigation farmers' adoption behaviour.

9.5.2 Perception regarding the potential benefits with the implementation of irrigation scheduling

Innovations can either be adopted or rejected, and most often like in the case of the adoption of objective irrigation scheduling techniques, the implementation of this decision requires considerable additional learning before it can be effectively implemented. In this instance we are not dealing with the adoption of one innovation only, but rather a package of innovations offered to the farmer, which includes both technical and socio-organisational elements. The adoption of on-farm irrigation scheduling can only be effective in conjunction with effective management of the irrigation system and proper cultivation practices to name a few.

As farmers interact with technology, so their knowledge increases through experimentation and trialling on the farm. This is likely to affect the overall perceptions of the attractiveness of the innovation and also reduces the uncertainty about its potential benefits. The relative advantages of alternative on-farm irrigation scheduling practices should be observable, to enhance adoption of a new practice. Relative advantage of an innovation means the degree to which a new technology or practice is perceived as better than the one it supersedes (Rogers, 1983).

Farmers rated the perceived relative advantages of using irrigation scheduling methods on a ten-point semantic scale regarding the following production aspects:

- Conservation of water on the farm
- Possible increase of production yields
- Improvement of the quality of the crops (fruit and grain)
- Saving of operational costs of electricity or alternative energy sources

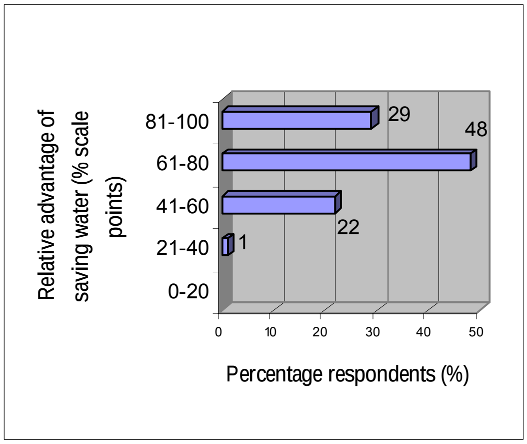
- Optimization of nitrogen use and the prevention of nitrogen leaching
- Maximization of profit on the farm.

In Figure 9.4, the perceived potential benefits with regard to the implementation of on-farm irrigation scheduling are summarized, which indicate significant differences (X^2=15.84,df=7,p=0.027). Although the conservation of on-farm water is perceived as an important production factor to farmers, only 77 percent perceived the relative advantages of the implementation of irrigation scheduling as the saving of water *per se* compared to the 97, 91, 87, 86 and 83 percent perceived improvement of profitability, optimum use of nitrogen, improvement in production yields of crops, saving on electricity costs and improvement of crop quality. This implies that irrigation farmers perceive the investment with regard to more precise on-farm irrigation scheduling primarily in terms of potential improvement of profitability of the farming concern through the improvement of crop yields, improvement of crop quality, optimizing of nitrogen use and the potential saving on electricity operational costs.

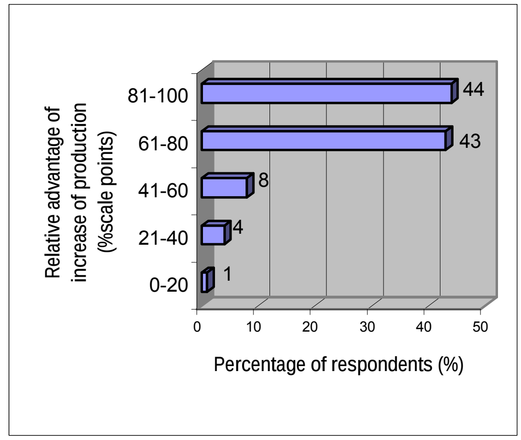
For most of the irrigators in South Africa irrigation water is the major production constraint, and the potential saving of water through on-farm irrigation scheduling entail additional irrigation area that could be irrigated with the potential increase in total net income. Also the practices of double cropping common amongst irrigation crop farmers were perceived as an observable advantage due to the implementation of irrigation scheduling.

The implementation of irrigation scheduling often necessitates small-scale farmers to irrigate bigger volumes of water, more regularly. This practice also implies the use of more resources in terms of labour and time. Therefore the implementation of more precise irrigation scheduling methods are not always perceived to be advantageous to all small-scale farmers, since many of them are often guilty of under-watering their crops.

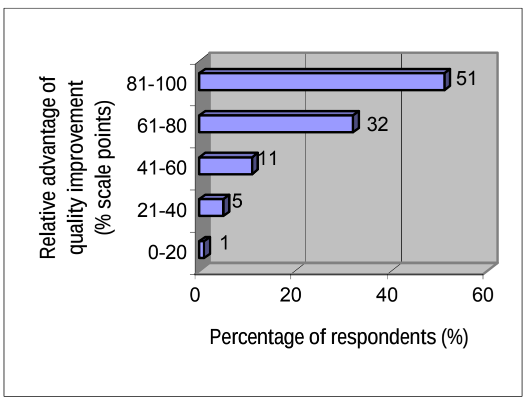
(a) Saving of water on the farm



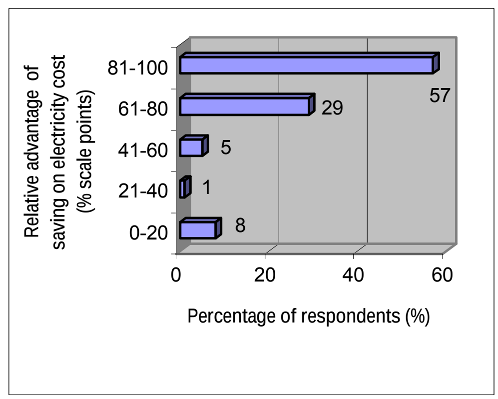
(b) Increasing of production yields



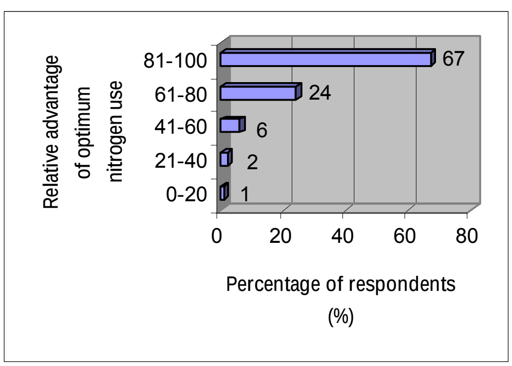
(c) Improving of crop quality



(d) Saving on electricity operational costs



(e) Efficient use of nitrogen



(f) Increase of profitability

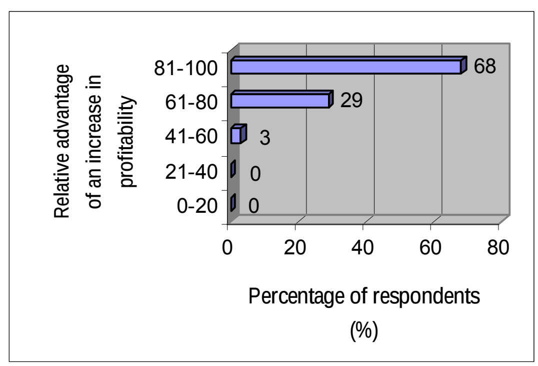


Figure 9. 4: Percentage distribution of respondents according to their perceived relative advantages with regard to on-farm irrigation scheduling based on a 10-point semantic scale (N=134)

Eight percent of the respondents indicated the saving of electricity as not important, due to the fact that they either use surface irrigation methods or the fact that they are situated beneath the canal system for the delivering of irrigation water, and are therefore using gravitational irrigation, i.e. van der Kloof irrigation scheme. A significant Spearman relationship (r=0.355; p=0.038) exists between the implementation of on-farm irrigation scheduling and the potential saving of electricity costs, which provides evidence in support of Hypothesis 2, namely that precise irrigation scheduling is perceived to improve production efficiency.

Electricity is usually charged at prices that vary for peak, standard and low demand (Ruraflex) periods. The Ruraflex rates apply during the off-peak hours of the night and over the weekend so that some degree of automated control is usually desirable. In general farmers involved in the growing of crops like wheat, maize, etc are more aware of Ruraflex since electricity operational costs form a significant percentage of the total production costs of these crops.

Irrigation usually removes the primary constraint to productivity, namely water, but nutrition, and specifically nitrogen availability is quickly revealed as the next constraint of fast growing, shallow rooted crops (Stirzaker, 2004). The optimum use of nitrogen, as indicated in Figure 9.4, is a prime motivator for the implementation of objective irrigation scheduling especially among farmers involved in “Open Hydroponic Systems” (OHS) and farmers involved in the growing of high value crops as been indicated by the significant Spearman correlation (r=0. 298, p=0.046).

The questionnaire used in the survey also allowed respondents the opportunity to list and rate additional advantages they perceived with the implementation of on-farm irrigation scheduling. Fourteen percent of the respondents indicated “peace of mind” since they are sure that the correct amount of irrigation water at the right time of the crop growth stage is applied with the practicing of irrigation scheduling.

a) Visibility of the wetting front

In many instances the awareness of a problem can be restricted because the process involved cannot be observed. The wetting front (line which separates wet and dry soil) is usually not observable for many of the irrigation farmers, unless they make use of a soil auger or spade to monitor their irrigation practices. Therefore, many irrigation farmers base their decisions on the observation of certain plant stress indicators or on the measurement of soil water content.

Respondents were asked to rate the importance of the visibility of a wetting front for water management decisions on a ten-point semantic scale. The majority of respondents (98%) perceived the visibility of the wetting front important for irrigation management decisions, and a significant Spearman correlation (r=0.376; p=0.000) supports the relationship between visibility of the wetting front and objective monitoring of soil water content.

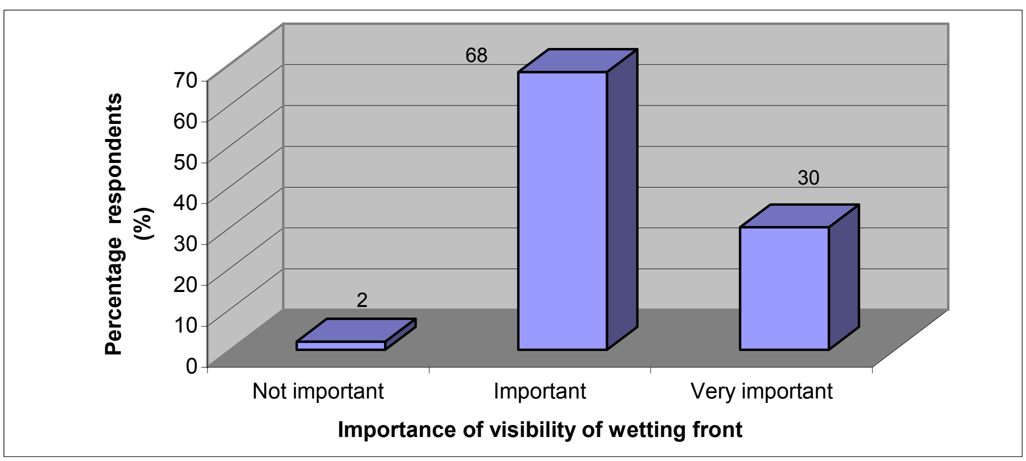


Figure 9. 5: Percentage distributions of respondents regarding their perceived importance of the visibility of the wetting front after irrigation. (N=134)

Farmers traditionally make use of a spade or soil auger to monitor the depth of the wetting front since the last application of irrigation. The finding in Figure 9.5 explains why 11 % of the farmers indicated their return from the implementation of sophisticated scheduling methods to the use of this simple and valuable irrigation scheduling method. The development of an irrigation scheduling device like the wetting front detector by CSIRO, Australia will help farmers to overcome this problem.

b) Perceived improvement regarding production efficiency

A specific innovation like irrigation scheduling is not compatible with the individuals' need, if it is not perceived as need related or a means towards achieving it (Düvel, 1991). Need compatibility is therefore positively associated with adoption behaviour and the corresponding improvement in production efficiency (Hypothesis 1.2). Düvel & Botha (1999) provided evidence of this relationship, namely that non-adoption by farmers is usually related to incompatibility of an innovation.

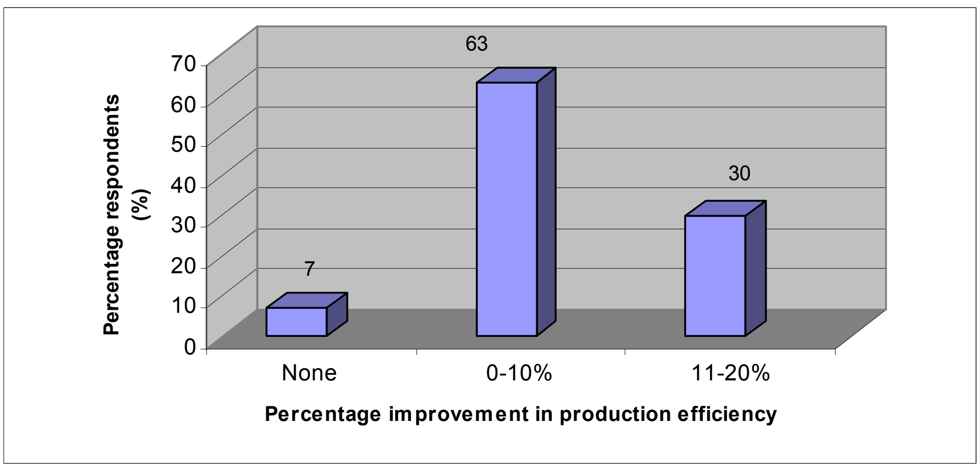


Figure 9. 6: Percentage distribution of respondents according to the perceived improvement in production efficiency since adoption of on-farm irrigation scheduling (N=84)

As far as perceived improvement with regard to production efficiency is concerned, a significant variation exists among the respondents (X^2=8.62; df=2; p=0.013). Sixty three percent of respondents indicated an improvement of production efficiency between 0-10 percent, while 30 percent perceived 11-

20% improvement in efficiency subsequent to the adoption of on-farm irrigation scheduling (Figure 9.6). Respondents, who did not respond to the question, were either too shortly involved with objective irrigation scheduling to have observed any changes or perceived the changes in production efficiency to the introduction of improved irrigation systems (changing from flood irrigation to sprinkler or centre pivot irrigation).

Seven percent of respondents, perceived no change in production efficiency subsequent to their adoption of the objective irrigation scheduling on-farm. These respondents were either newly introduced to objective irrigation scheduling or were farmers involved in the growing of pastures. Farmers involved in the growing of pastures generally make use of a fixed or semi-fixed program, and only a few of them indicated the regular monitoring of soil water to help them with decision-making.

An assessment of the perceived contribution of on-farm irrigation scheduling to production efficiency on the farm was made by requesting respondents to judge the contribution of different aspects of irrigation scheduling, using a ten point semantic scale. The main aspects of production improvement perceived in the production of cash crops (cereals, cotton, sugar cane, etc.) with the implementation of irrigation scheduling are in order of importance as indicated in Table 9.10: an increase in production yield, saving on nitrogen input costs and saving on the electricity operational cost of irrigation.

One of the farmers referred to an average improvement of 1ton/ha in the production of wheat between irrigation fields scheduled *versus* those that were not scheduled. Many of the cash crop farmers involved in the growing of maize and wheat in the Northern Cape indicated savings on the annual irrigation requirements of between 60-70 mm/ha for the growing of maize (average production yield = 12t/ha) and approximately 100 mm for wheat (average production yield = 6t/ha). It was however found that farmers do not schedule all their fields due to relative high consultancy fees perceived, but rather tend to schedule one or two fields that are representative of the rest, and then use these measurements and recommendations for irrigation management decisions.

Table 9. 10: The perceived contribution of aspects of on-farm irrigation scheduling to on-farm production efficiency expressed as mean scale point (*)(N= 134)

Contributors that influence production efficiency	Cash crops (n=92)	Intensive/ high value crops (n=76)	Pastures (n=16)
Saving on irrigation water	6.6	6.5	6.0
Increasing of production yields	8.4	7.6	4.8
Improvement of quality of crops	5.1	7.9	4.4
Saving on electricity operational costs	6.7	7.2	5.7
Increase of profitability	6.8	7.4	4.5
Optimal use of nitrogen	7.0	7.3	5.1

**10 point semantic scale with 1=not important, 10=very important*

Fruit growers and producers of high value/high input crops perceived mainly the improvement of quality and shelve life of the crop, increasing of production yields and improvement of efficiency of the management of nutrients in the orchards as main contributors to production efficiency subsequent to the introduction of on-farm irrigation scheduling (Table 9.10). Opinion leaders and advisors in the fruit industry referred to the ineffective water management practices of some of the fruit growers especially during spring when the majority of growers are either under or over irrigating. "*The most common mistake made by many fruit growers is the tendency to over estimate spring water use by the crop and apply too much water. Spring is a difficult time of the year to make irrigation management decisions as it is complicated by varying weather conditions, relative low vine and fruit water use and together with differences in soil types between the different production fields, impacts on the soil readily available water (RAW). This usually leads to a position where a farmer "runs out of irrigation water" (exhausting water allocation).*

Careful spring irrigation management is critical for the successful production of fruit and grapes (wine and table)" (Stander, 2004).

Farmers growing pastures perceived the saving of water, saving on electrical operational costs and efficient use of fertilisers as the major contributors to production efficiency subsequent to the implementation of irrigation scheduling (Table 9.10).

Irrigation farmers and managers enter a learning cycle as soon as they adopt the application of objective irrigation scheduling. For many farmers the learning curve is perhaps too steep, and they cannot learn and apply what is expected from the recommended irrigation scheduling approach, while others quickly benefit from the new approach and adapt their management system accordingly. One such farmer is a citrus/table grape grower in the Western Cape, who made use of tensiometers installed on three different depths in the orchard. This farmer perceived an increase in average production of approximately 10% and an improvement of quality of fruit between 10-15% since irrigation scheduling 8 years ago. This is one of the exceptional cases where an irrigator was found to be very positive about the use of tensiometers and was still willing to use them for his daily irrigation management decisions.

c) Interrelationship between perceived improvement of production efficiency and on-farm irrigation method

Irrigation scheduling forms part of a package of innovations that a farmer must adopt, and the selection of appropriate irrigation systems is but one of these innovations that determine the success of the implementation of on-farm irrigation scheduling. The relationship between the perceived improvement of production efficiency and the on-farm irrigation method used was tested and is indicated in Figure 9.7.

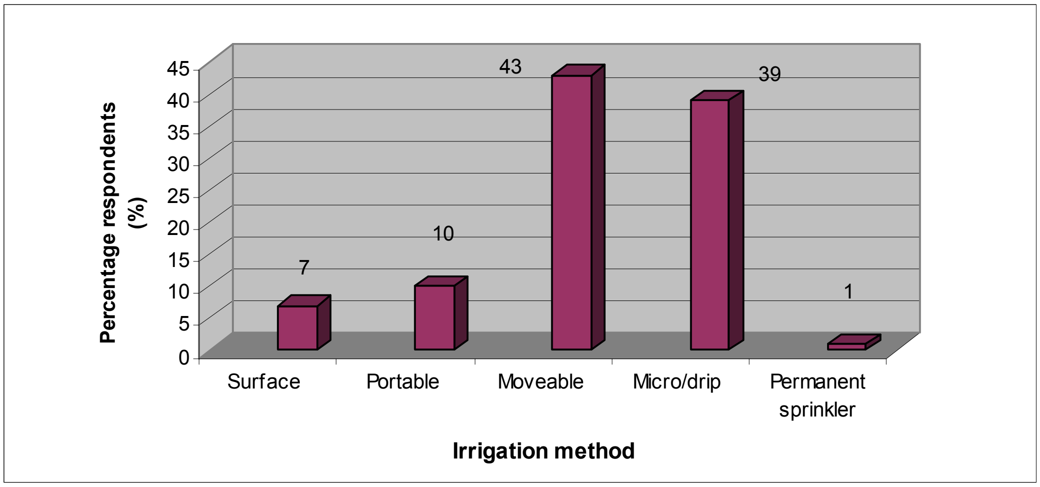


Figure 9. 7: Percentage distribution of respondents according to their perceived improvement of production efficiency and irrigation methods used on the farm (N=84)

It is clear from the findings in Figure 9.7, that it was mainly respondents irrigating with moveable irrigation systems like centre pivots (43%) and micro or drip irrigation systems (39%) that perceived improvements in production efficiency since the introduction of objective irrigation scheduling on the farm. These irrigation systems belong to the group called short cycle irrigation systems, which have greatly simplified irrigation management. The relationship between perceived improvement of production efficiency and the on-farm irrigation method is shown (Table 9.11).

Table 9. 11: Relationship between perceived improvement of production efficiency and on-farm irrigation method as reflected in a test of association (N=134)

Irrigation method	Association				
	X^2	df	p	r	P
Furrow/flood irrigation system	5.1	3	0.433	0.319	0.339
Portable irrigation system	6.2	3	0.188	0.512	0.089
Moveable irrigation system	4.6	3	0.036	0.186	0.046
Micro /drip irrigation system	6.4	3	0.072	0.264	0.017
Permanent irrigation system	Not calculated			Not calculated	

Table 9.11 shows that significant relationships exist between the perceived improvement of production efficiency subsequent to the implementation of on-farm irrigation scheduling and the use of moveable irrigation systems for example centre pivots (r=0.186, p=0.046) as well as the use of micro/drip irrigation systems (r=0.264, p=0.017). These associations provide evidence in support of Hypothesis 1.1, which states that environmental factors like the type of on-farm irrigation method selected by the farmer influence the adoption behaviour of the farmer with regard to on-farm irrigation scheduling.

d) Farmers' awareness of in-field application efficiency

Part of the innovation package implies the application of water in the most efficient way possible to prevent unnecessary losses and water wastage. In order to achieve this, the uniformity with which irrigation systems apply water will have to be high and the distribution uniform (Reinders, 2003). Poor maintenance of irrigation systems in general will increase the operational costs of irrigation and also influence the efficiency of irrigation efficiency.

Often a farmer is unaware of the performance capability of the irrigation system on the farm. This can induce severe variance between the amount needed to apply as determined with the help of objective irrigation scheduling methods (soil water measurement) and the actual amount of water applied. Farmers' perception in regard to awareness and inclusion of regular monitoring and evaluation of irrigation distribution uniformity and the application rate on pressurized irrigation systems are shown in Table. 9.12.

Thirty eight percent of the respondents indicated that distribution uniformity is evaluated only once a season, while 20 % of respondents, mainly those farmers using objective scheduling methods, indicated more regular frequency of evaluation (Table 9.12). Eighteen percent of the respondents reported no evaluation of distribution uniformity, of which 78 percent respondents make use of subjective scheduling methods. It was obvious that although farmers in general were aware of the need for regular evaluation and maintenance of their irrigation systems, many failed to implement it.

Table 9. 12: Percentage distribution of respondents according to their frequency of testing for distribution uniformity (N=122)

Intervals between measuring distribution uniformity (C_u)	Objective scheduling		Subjective scheduling		Total number respondents	
	(n)	%	(n)	%	(N)	%
More frequently than once per season	16	21	8	17	24	20
Once per season	30	49	16	35	46	38
Once per 3 years	7	9	5	11	12	9
Once per 5 years	15	20	3	7	18	15
Not at all	8	11	14	30	22	18
Total	**76**	**100**	**46**	**100**	**122**	**100**

This was confirmed by a specific respondent who had two centre pivots on the farm operating for the last 13 years without the replacement of the sprinkler packages. This farmer also admitted that he had never evaluated the application rate or distribution uniformity of the irrigation systems although he was aware of the importance and advantages thereof. A positive association exists between the implementation of objective irrigation scheduling methods and the implementation of regular irrigation uniformity and application monitoring (χ^2=12.6, df=5, p=0.027; r=0.136, p=0.022), which implies that farmers who make use of this scheduling method tend to be more aware of regular maintenance of their irrigation systems.

Reinders (2003) is of the opinion that regular monitoring of the functioning of sprinklers, and the wear and tear on nozzles, which irrigation farmers often neglect, is one of the most important irrigation management practices. Effective farm irrigation management requires that an irrigation system is capable of applying water in sufficient quantities and with high uniformity and minimum wastage to meet the crop's water requirements. Irrigation systems are more expensive if they are designed to provide a high degree of uniformity. Thus, there is a tendency to sacrifice uniformity when systems are purchased on the basis of competitive bids. The irrigation farmer should recognize that operational costs and possible yield losses would be higher when a system does not apply water uniformly. A lower initial cost system, which sacrifices uniformity of water application, may be false economy according to Reinders (2003).

e) Locality differentials in relative advantage

It is often assumed that the perception of the relative advantage of an agricultural practice like irrigation scheduling, whether positive or negative, is of the same order or magnitude amongst all clients irrespective of locality or community. This is unlikely to be the case and was tested by asking farmers from different localities to indicate the perceived improvement in production efficiency since their adoption of objective irrigation scheduling practices.

Figure 9.8 reveals how farmers from the various provinces and localities differ in their respective perceptions regarding the relative improvement of production efficiency subsequent to the implementation of objective irrigation scheduling on farm. Significant differences exist between irrigators in the different provinces regarding the perceived improvement of production efficiency subsequent to the implementation of objective irrigation scheduling on the farm (X^2=21.71, df=7, p=0.020). Seven percent of respondents in the Western Cape (mainly fruit and wine grape growers) and six percent of the respondents involved in the production of mainly maize and wheat in the Free State as illustrated in Figure 9.8 perceived substantial improvement in production efficiency (between 11-20%) subsequent to the introduction of objective irrigation scheduling. Thirteen percent respondents from the Eastern Cape and 12 percent respondents from the Northern Cape perceived less than 10% increase in production efficiency subsequent to the introduction of irrigation scheduling. A possible explanation for this finding is that precursor problems like water availability and limitations to the on-farm irrigation methods used by farmers must be dealt with first, before irrigation scheduling could show improvement in production efficiency.

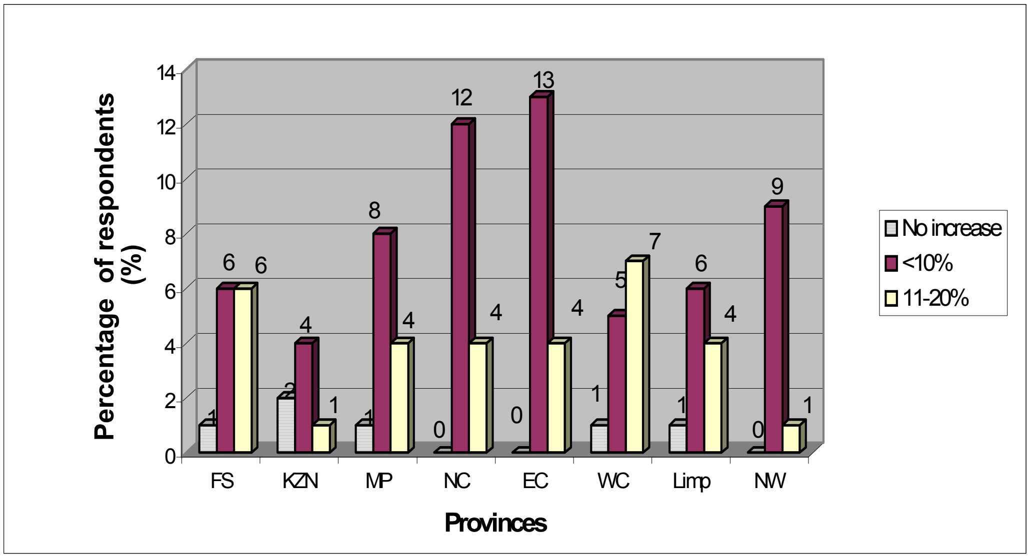


Figure 9. 8 Percentage distribution of respondents from provinces according to their perceived increase in production efficiency due to the implementation of irrigation scheduling (N=84)

9.5.3 Perception regarding the complexity of irrigation scheduling practices

The motivation of a farmer to solve a specific problem or to change current irrigation scheduling practices is affected by the confidence a person has in his own capacity with regard to problem-solving and his perceived self-efficacy (Leeuwis, 2004). Sometimes recommended agricultural practices which appear simple may in fact imply significant and complex changes to the farm production system. How difficult is the new technology to understand and apply? How much additional learning is required? Complexity is clearly related to the level of learning required, and the more difficult it is to understand or to implement the technology, the slower the adoption process is likely to be. Complexity increases the risk of failure and it introduces increased costs in gaining knowledge (Vanclay, 2003).

a) Scale of difficulty

Respondents were asked to indicate the relative easiness of the application of irrigation scheduling on a ten-point scale. The response to this question is illustrated in Table 9.13.

Table 9. 13: The perceptions of respondents related to the easiness of the implementation of irrigation scheduling (N=134)

Perception of the relative scale of easiness of implementation of irrigation scheduling	Number of respondents				Total number of respondents	
	Objective scheduling		Subjective scheduling			
	n	%	n	%	N	%
Very easy	9	12	5	9	14	10
Easy	53	70	27	46	80	60
Difficult	14	18	22	38	36	27
No response			4	7	4	3
Total	**76**	**100**	**58**	**100**	**134**	**100**

Table 9.13 reveals that the majority of farmers (70%) perceived irrigation scheduling as relatively easy to implement, while 27% perceived it to be difficult to implement. The perceived scale of easiness of implementation of on-farm irrigation scheduling differs between the objective and subjective scheduling groups (X^2=49.06, df=5, p=0.000). Eighty two percent of the objective scheduling group perceives the implementation of on-farm irrigation scheduling to be easy to implement while only 55 percent of the subjective scheduling group share the same opinion.

Although the X^{2-}tests reflect highly significant differences between the scheduling groups, no statistical significant relationship exists between perceived easiness and the implementation of soil water monitoring on the farm (r=0.046, p=0.092). However, a significant negative relationship (r=-0.248; p=0.004) exists between the perceived easiness of implementing irrigation scheduling and the use of scheduling models on the farm, which implies that irrigation farmers without the support of competent professionals cannot apply irrigation scheduling models.

b) Knowledge level needed for the implementation of irrigation scheduling

Knowledge can be seen as the basic means through which we understand and give meaning to the world around us. According to Leeuwis (2004), concepts like “perception”, “interpretation” and “understanding” all refer to the outcome or applying of knowledge. It is generally accepted that farmers or irrigation managers responsible for irrigation scheduling should at least have a workable knowledge of the following aspects: plant-soil-atmosphere continuum, operation and capacity of the irrigation system and essential managerial skills necessary for the implementation of appropriate irrigation management practices. The perception of respondents regarding the minimum required knowledge level for the efficient implementation of irrigation scheduling was tested across the two categories, objective and subjective irrigation scheduling. Four different knowledge levels were identified as items of a knowledge scale:

- **Knowledge level 1:** no special knowledge required for application of irrigation scheduling (“common sense”)

- **Knowledge level 2:** where one of the four elements (soil, plant, water and management) for an effective knowledge basis was mentioned

- **Knowledge level 3:** where at least three of the four elements of an effective knowledge basis were mentioned

- **Knowledge level 4**: where all four elements of an appropriate knowledge level were mentioned

Table 9. 14: Percentage distribution of respondents' perception regarding the required level of knowledge needed for effective on-farm irrigation scheduling (N=134)

Knowledge level of irrigation scheduling	**Number of respondents**				**Totalnumber of respondents (N=134)**	
	Objective scheduling (n=76)		**Subjective scheduling (n=58)**			
	n	**%**	**n**	**%**	**N**	**%**
Knowledge level 1	6	8	9	16	15	11
Knowledge level 2	34	45	33	57	67	50
Knowledge level 3	26	34	16	27	42	31
Knowledge level 4	10	13	0	0	10	8
Total	**76**	**100**	**58**	**100**	**134**	**100**

The findings reflected in Table 9.14 reveal that different groups of farmers perceived different prerequisite levels of knowledge to be successful in the implementation of irrigation scheduling (X^2=148.1, df=8, p=0.000). As far as the minimum expected knowledge level for the efficient implementation of irrigation scheduling is concerned (Table 9.14), 73 percent of farmers from the subjective scheduling group perceive either no special knowledge or limited knowledge is required. In comparison, 47 percent of the farmers involved in objective irrigation scheduling perceive a more specialized knowledge level required for the successful implementation of irrigation scheduling.

This positive association between the implementation of objective scheduling and the perceived required knowledge level for implementation is supported with a significant correlation (r=0.223, p=0.011). These findings illustrate that different irrigation scheduling groups have different "theories of knowing" or epistemic cultures (Knorr-Cetina, 1981), which provides evidence in support of Hypothesis 3, namely that these different epistemic cultures of farmers determine farmers approaches to problem solving, and therefore the on-farm irrigation scheduling.

9.5.4 Perception regarding the compatibility of irrigation scheduling practices

Another critical aspect of the farmers' perception is whether the innovation is perceived to be compatible with the farmer's personal objectives? This refers to the extent to which a new practice fits in with the existing knowledge and social practice. If a new idea fits in easily into an existing system it will be adopted more quickly.

There are usually two systems according to Vanclay (2003) against which the farmer judges the compatibility of irrigation scheduling: the current system of farming (biophysical) and the social system embracing the farming community or broader cultural beliefs and values. An apparent example of objective irrigation scheduling practices not compatible was observed amongst farmers in the Upper Orange water management area who have fixed water turns that occur according to a predetermined timetable of water distribution in the canal. Respondents were asked to indicate some of the problems (barriers) that they experience with the implementation of on-farm irrigation scheduling methods in an attempt to determine the perceived compatibility of the selected irrigation scheduling practice (Table 9.15).

Table 9.15 shows that 57 percent respondents indicated that they were satisfied with the current irrigation scheduling methods and tools implemented on the farm and that it was compatible with the current farming system. Significant differences exist with regard to the perceived problems experience with the implementation of on-farm irrigation scheduling between irrigation farmers from the objective and subjective scheduling groups (χ^2=8.62, df=2, p=0.013). Eighty four percent farmers from the subjective scheduling group perceived no problems with the implementation of on-farm irrigation scheduling practices, while only 35 percent of the objective scheduling group indicated their satisfaction with implementation of on-farm irrigation scheduling.

Table 9. 15: Percentage distribution of respondents according to the perceived problems experienced with the use of on-farm irrigation scheduling methods (N=134)

Perceived problems with implementation of irrigation scheduling	Objective scheduling (n=76)		Subjective scheduling (n=58)		Number of respondents	
	(n)	%	(n)	%	(N)	%
No problems experience with implementation	27	35	49	84	76	57
Uncertain about the accuracy of measurement	30	39	8	14	38	28
Not easy to understand and apply on the farm	15	20	6	10	21	16
Variability in climate and soil types on the farm complicate the efficient use and interpretation of data	8	11	4	7	12	9
Very expensive	6	8	2	3	8	6
Uncertainty - novelist to irrigation scheduling	2	3	0	0	2	2
Not enough time available	3	4	0	0	3	2
Lack of flexibility (irrigation system, management)	2	3	0	0	2	2
No support or help available from irrigation consultants	1	1	0	0	1	1
New extensionist (personality, communication skills)	1	1	0	0	1	1
Health risk (i.e. neutron probe)	1	1	0	0	1	1

An important finding is the fact that 39 percent of farmers using objective scheduling techniques are uncertain about the accuracy of measurement. These farmers often use an objective scheduling method as second opinion, to confirm their intuitive decisions. This was a most common perception amongst farmers who made use of irrigation consultants who were still new to a specific irrigation area and where credibility was still lacking. Many of this latter group of farmers therefore implement “insurance irrigation” by applying a little more irrigation water than was recommended by consultants, to avoid any risk be taken.

9.6 ADOPTION AND/OR DISCONTINUANCE OF ON-FARM IRRIGATION SCHEDULING

Farmer's decision to adopt new agricultural technology depends on complex factors after analyzing and trialling and is indeed a social process. Adoption according to Vanclay (2003) is not only including irrational responses to new information but also a deliberate decision by an individual farmer in response to a wide range of issues.

9.6.1 Perceived usefulness of irrigation scheduling models

Irrigation scheduling models can either be used for tactical or strategic purposes. In the first instance, the question is: how large an area to irrigate, which crop to plant, and how to distribute the available water supply over or during the season (Huygen *et al.,* 1995)? For the majority of crop farmers this is a major problem they are encountering, and real time scheduling is found to be even more important where farmers are scheduling high valued crops like table grapes, deciduous fruit, subtropical fruit and cut flowers. Hubona & Gertz (1997) indicated that farmers adopt irrigation scheduling models for tactical decisions, if enough compatibility exists between technology characteristics, perceived task to be completed and individual needs.

Twenty six percent of the commercial farmers that implement objective scheduling on the farm indicated the use of irrigation scheduling models either for trial basis or for full implementation (Table 9.16). Although all the farmers interviewed have access to a computer, farmers are more likely to routinely use simple monitoring techniques like the soil auger or shovel to determine the soil water content. Farmers, however, indicated that they have difficulty in using models for real time decision-making, and therefore the majority of them need professional support to be able to apply models at a farm-level (Chapter 4). Farmers in general clearly indicated that the use of irrigation scheduling models are dependent upon capable and willing irrigation consultants and extensionists to help and support the farmer with the use of the model and computer program as well as with the interpretation of the data to be used for irrigation management decisions. Some models were perceived by some respondents to be easier to understand and to apply than others.

Table 9. 16: Percentage distribution of respondents' use of computer models and programs for on-farm irrigation scheduling (N = 20)

Use of computer irrigation scheduling models	Objective scheduling (n=76)	
	n	**%**
Use computer model as part of on-farm objective scheduling	20	26
Computer models not used on-farm	56	74
Total	**76**	**100**

Significant differences in the general awareness about irrigation scheduling models available for irrigation scheduling exist between farmers involved with objective irrigation scheduling and those involved in subjective irrigation scheduling (X^2=6.92,df=1,p=0.008). Twenty nine percent of the respondents using objective irrigation scheduling are aware of the relevant models for irrigation scheduling, while only five percent of the farmers involved in subjective scheduling could mention any model or computer program available for irrigation scheduling. The irrigation farmers involved with the production of high value crops are in general more positive about the use of irrigation scheduling models than irrigation farmers involved in cash crop production (X^2=58.19,df=8, p=0.049). These findings provide evidence in support of Hypothesis 3, namely that the business characteristic as well as the technology level of the farmer determines the approach to on-farm irrigation scheduling.

a) Need tension with regard to the use of computer models and programs for use in irrigation scheduling

Figure 9.9 illustrates that farmers perceived the effectiveness and accuracy of irrigation scheduling models relatively low as an irrigation scheduling aid. Sixty two percent respondents rated the effectiveness of scheduling models as decision support systems for on-farm irrigation management below 40 %, with only 25% of the respondents perceiving it to be effective (>60%). These differences are highly significant (X^2=21.99, df=8, p=0.005).

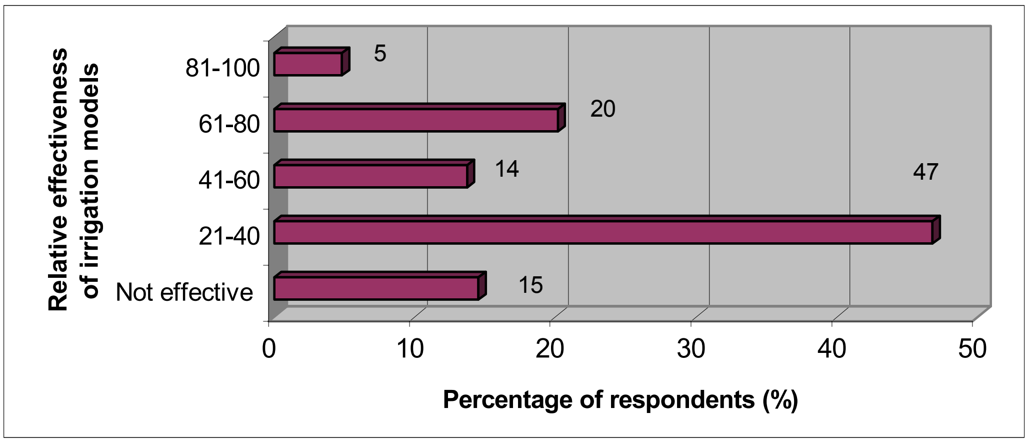


Figure 9. 9: Percentage distribution of respondents according to their perceived effectiveness of irrigation scheduling models (N = 76)

Fifteen percent of the respondents condemn the use of models and computer program as being inappropriate for implementation on the farm. This group of respondents is of the opinion that models and computer programs can only provide generic guidelines to the potential user and are not flexible to suit actual farm contextual factors. They are of the opinion that models and programs are generally not adapted and flexible enough for specific situations and conditions on the farm and need to be more flexible to fit the specific farming system, and management capacity of the farmer. This group of respondents is of the opinion that models often include various assumptions (e.g. about the biophysical processes and the interrelations) that may be valid for the locality of those that developed the model, but which are not always accurate in other contexts. These respondents also indicated that they be short of the necessary trust and confidence in irrigation consultants and extensionists for their interpretation of the data for making daily irrigation management decisions.

b) Reasons for general lack of aspiration to use computer models and programs

Farmers who are not using irrigation models provided the following reasons why they lacked any aspiration or need to introduce irrigation models on the farm. Table 9.17 reflects some of the perceptions of the respondents in this regard.

Table 9. 17: Percentage distribution of respondents according to their perceived reasons for the lack of aspiration to use computer models for on-farm irrigation scheduling (N=99)

Reason for the lack of aspiration to use models for irrigation scheduling	% Respondents
Too difficult for the farmer to use	37
Not practical enough for application on farm-level	35
Lack the necessary computer skills	25
Not aware of appropriate models	12
Time consuming	10
Not enough professional support available to help with the implementation on the farm	7
No need – satisfied with current information sources	6
Unit of farming too small to implement models	3
Too expensive	3
Lack of flexibility (irrigation system)	2

It is apparent from Table 9.17 that respondents who have no aspiration to use irrigation scheduling models, either perceive them as being too difficult (complex) to use and to implement on the farm (37%) or perceive the models as a “black box” and not useful for implementation because of the problems experienced with the interfacing with the on-farm situation and the terminology used in the models and scheduling programs (35%). The need was expressed to incorporate more farmer-friendly language in the programs. Some of the measurements used in irrigation scheduling programs are often not familiar to farmers like “litres per second” rather than m^3/ha. The interpretation of the inputs and outputs of the model or programme used, often cause problems to some farmers and therefore make it difficult for them to understand the concepts used in the program and to learn from them. The use of visual imagery and interpretation of the output of many of the programs help users to better understand some of the recommendations made for a specific field situation. These farmers commented that many of the irrigation software packages offered could not be incorporated into other farm management computer software packages and therefore are limited in their use and purpose.

Twenty five percent of the respondents indicated their general lack of the necessary computer skills to apply the recommended models. Many of the latter group of respondents belong to the age group of fifty one and older and a significant negative relationship exists between the age of farmers and the perceived effectiveness of computer models on-farm with regard to irrigation management (X^2=9.69, df=5, p=0.076; r= -0.243; p=0.005). Also included in this group of farmers are those who favour working outside and this group in general perceives office work and the use of computers as not “real farm work”. Perhaps this perceived split between “inside” and “outside” work explains why some farmers are willing to integrate computers in their daily farm management and why others only use computers for daily bookkeeping.

Twelve percent of the respondents were unaware of appropriate computer programs and models available for use in irrigation scheduling. This finding emphasizes the need for improved information channels of communication to effectively disseminate information regarding irrigation management. The majority of commercial irrigation farmers rely on extensionists from agricultural cooperatives (or private companies currently), fellow farmers, private consultants and sales representatives from irrigation companies to inform them on new irrigation technologies (Part Five). These service providers play an important role in the deployment of research findings, especially in the case of irrigation scheduling practices and tools.

9.6.2 Reasons for changing irrigation scheduling practices

Farmers' perception with regard to the importance of the implementation of objective scheduling on the farm and their need tension change as farmers go through the learning process of evaluation, trialling and appraising whether a specific irrigation scheduling method is suitable for the specific farming system and whether it would help them to reach their personal goals.

Fifty nine percent of the respondents indicate that their perceptions had changed since they started with irrigation scheduling. The majority (71%) of farmers, who changed their irrigation scheduling methods subsequent to the introduction of it, belong to the group using objective irrigation scheduling. Figure 9.10 shows the time lapse since respondents started to implement irrigation scheduling practices and a significant change in implementation of objective and subjective irrigation scheduling approaches over different periods of time happened (X_1^2=8.07, df=1, p=0.004).

A clear tendency exists with farmers who usually start with the use of more objective scheduling methods but gradually change to rely more on the use of intuition than on objective scheduling as more first–hand experience, confidence and experiential knowledge is gained. Relatively more experienced farmers often use objective scheduling methods only to monitor their current irrigation management practices and to confirm that current irrigation practices and decisions are satisfactory in terms of what the crop water requirements demand.

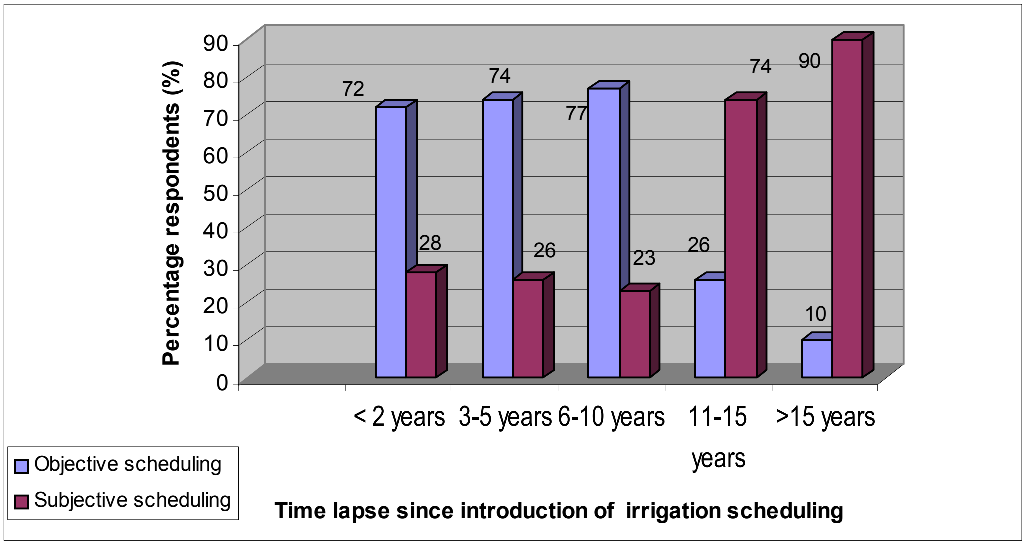


Figure 9. 10: Percentage distribution of respondents according to the time lapse since the inception of irrigation scheduling (N=90)

Consultants also reported that farmers often are more prepared to make use of scheduling consultancy services due to the uncertainty and risk that prevail during the start of a drought or when climatic conditions are subnormal. Many farmers interviewed are of the opinion that the service of consultants and use of objective irrigation scheduling is of utmost importance especially for a new farmer in irrigation or where enterprises changed from rain fed to irrigation. The tendency reflected in Figure 9.10 is that the respondents perceived approximately ten years to be a definite turning point from the use of predominantly objective scheduling methods to a situation where irrigators will rely more on the use of subjective irrigation scheduling. This is a general tendency that will differ from one situation to another and from person-to-person depending on the learning curve a farmer is willing and able to follow.

Respondents were asked to indicate reasons for changing irrigation scheduling methods, either from a subjective approach to a more objective approach, or *vice versa.* The findings are illustrated in Table 9.18.

Table 9. 18: Percentage distribution of respondents' perceived reasons for the need to change irrigation scheduling practices (N=134)

Reasons perceived for changing irrigation scheduling	Objective scheduling	Subjective scheduling	Total number of respondents	
	(n)	(n)	(N)	%
Measurement and/or predictions not accurate (tensiometers and certain computer irrigation models)	54	12	66	49
Too much irrigation recommended with some computer programs and specific situations and daily atmospheric fluctuations not taken into account	44	10	44	33
Time consuming	21	9	30	22
Capital and operational cost of irrigation scheduling too high	18	7	25	19
Irrigation scheduling method too complicated	15	5	20	15
No perceived advantages from practicing irrigation scheduling	11	4	15	11
Gained enough experience and knowledge	6	9	15	11
Size of property increased and necessitated change	0	5	5	4
Lost interest in specific method and returned to "traditional method"	0	4	4	3
Change of on-farm irrigation method	2	1	3	2
Health risk associated with specific method (neutron probe)	1	1	1	1

According to Table 9.18 significant differences occur between farmers that make use of objective versus subjective scheduling irrigation scheduling methods with regard to the perceive reasons for changing from on-farm irrigation scheduling methods (X^2=18.08, df=8, p=0.021). The majority of respondents (49%) changed practices because of the change in perception with regard to the accuracy of irrigation scheduling. Eighty percent of this group respondent makes use of objective irrigation scheduling and referred to their rather disappointing experiences with the use of tensiometers in the past. Apart from being site specific it was clear that many farmers struggled to learn enough to gain confidence in the use of tensiometers for making daily irrigation management decisions.

Thirty three percent of the respondents perceive some computer models and programs to have "misled" farmers in the past with recommendations not adapted to a specific farming system and for a specific area. The perception among these respondents is that some models underestimate evaporation grossly for warmer areas and crops like certain fruit tree cultivars that have higher water requirements than predicted by the model. Respondents also referred to recommendations with regard to irrigation that were made without taking into account a specific irrigation systems' capacity as well as the management capacity of farmers. These changes in perception as experienced by farmers through experience and on-farm trialling, is showing significant variation.

Twenty two percent of the respondents also emphasized that sophisticated irrigation scheduling practices were very time consuming, while 19 percent indicated that the cost effectiveness of objective scheduling was perceived to be low. If farmers are unable to perceive any observable relative advantages (as been reflected in Figure 9.4) for their effort put into this exercise, they are likely to opt for an alternative that is more compatible with their personal needs. These findings confirm the conclusions reached by Kaine *et al.*, (2005) and Lineham, Kristic & Kaine*.* (2005), who showed that farmers are more interested in saving time and increase flexibility than saving water on the farm.

9.6.3 Reasons for discontinuing objective irrigation scheduling methods

Discontinuance is a decision to reject irrigation scheduling after having previously adopted it. Two types of discontinuance of irrigation scheduling were observed:

- The first type is where an irrigation scheduling method was rejected in order to adopt another method that supersedes the previous one.

- The second type of discontinuance is the decision to reject irrigation scheduling as a result of dissatisfaction with its performance (inappropriateness or the farmer did not perceive any relative advantages attached to the specific scheduling method).

Twelve percent of the respondents indicated their discontinuance of objective irrigation scheduling because of the reasons indicated in Table 9.19.

Table 9.19: Reasons given by respondents for their discontinuance of objective irrigation scheduling (N=16)

Reason for discontinuing of irrigation scheduling	% Respondents
Gained enough experience, confidence and experiential knowledge regarding irrigation scheduling	69
Not practical enough for implementation on farm	63
Time consuming	50
No relative advantages perceived	44
Too expensive to continue	31
Too difficult to apply	25
Need professional support to be able to implement on the farm- not available	19
Not accurate enough and too fragile device for practical implementation	13
Discontinued when consultancy came to a halt	12
ET ref figures available from WUA	6

Table 9.19 shows the perceived usefulness of the implementation of objective scheduling on the farm by farmers changed significantly over time (χ^2=66.39, df=48, p=0.040). Sixty nine percent of the respondents indicated that they had gained enough knowledge, confidence and first hand experience after a certain period of time lapse, to be able to continue without objective scheduling.

Fifty percent of the farmers indicated that irrigation scheduling is time consuming, and scheduling is low in priority compared with other activities like markets, pests and diseases and varieties, etc as indicated in Section 9.4.

Sixty three percent respondents indicated that they found the practical implementation of objective irrigation scheduling troublesome. It appears that the scientific and extension communities have not been able to demonstrate how the irrigation scheduling technology can be effectively implemented.

Thirty one percent of respondents stopped the irrigation scheduling practices because the irrigation consultancy service was perceived to be too expensive. Six percent of the respondents indicated that they discontinued the use of objective irrigation scheduling since the local WUA started with the regular provision of ET ref figures to its clients. These figures are usually incorporated in the semi-fixed programs and irrigation calendars which farmers are following.

Private consultants and extensionists are in general expected to simplify and "translate" research information and to offer of the information in an effective and understandable way to the farmers. Nineteen percent of the respondents claimed that appropriate consultancy are lacking is some areas. Furthermore some advisors often lack the necessary capabilities (technical knowledge and communication skills) and were unable to help farmers to interpret and adapt data for the use in daily irrigation decisions.

9.7 SUMMARY

Irrigation farmers and farmers in general have traditionally been able to achieve productivity gains through the adoption of new technical products and processes. Increases in efficiency must however be pursued on a much wider front if productivity growth and sound water management are to be achieved. The farming environment has become more complex. In addition to the adoption of new irrigation technologies, irrigation farmers must also pay attention to investment in human skills, the uptake, analysis, and use of information, the management of risk, the production, quality and marketing of their products, the financial and personal management skills of their staff, and the institutional organization and structuring of their industry. This involves complicated social, institutional and economic decisions and requires a mind shift in the case of some farmers, but more importantly they must be prepared to engage in continuous, lifelong learning. This will also require a new willingness from support workers and organizations to enter into a cooperative dialogue and networking with the farmers and groups of common interest.

The findings indicated that farmers not merely perceive the implementation of irrigation scheduling as a technical issue, but also it must make sense within the social, economic and wider structural constraints of the society (institutions):

- Farmer-related factors include beliefs and opinions of the irrigation scheduling practice, perception of relevance, motivation and attitude to risk. It was evident that farmers with relatively more experience are more willing to rely on their own first-hand experience, knowledge, observations and intuition than on using objective scheduling methods. A minority of irrigation farmers were found that really understand and schedule according to the strict definition as been developed by science.

- The majority of respondents (60%) perceived the efficient use of irrigation water on the farm and not water saving *per se*, as the main reason for the implementation of irrigation scheduling. The improvement of the quality of the crop, saving on electricity costs and the effective management of nutrients were perceived as being important motivational “drivers” for the implementation of objective irrigation scheduling.

- Accuracy, reliability, easiness of implementation, affordability and initial capital costs involved, are some of the important technology characteristics of scheduling methods and devices which were identified to influence the adoption of a specific irrigation scheduling method. The characteristics were analyzed with respect to relative risk, investment, complexity and profitability of the new technology compared to the traditional methods used on the farm.

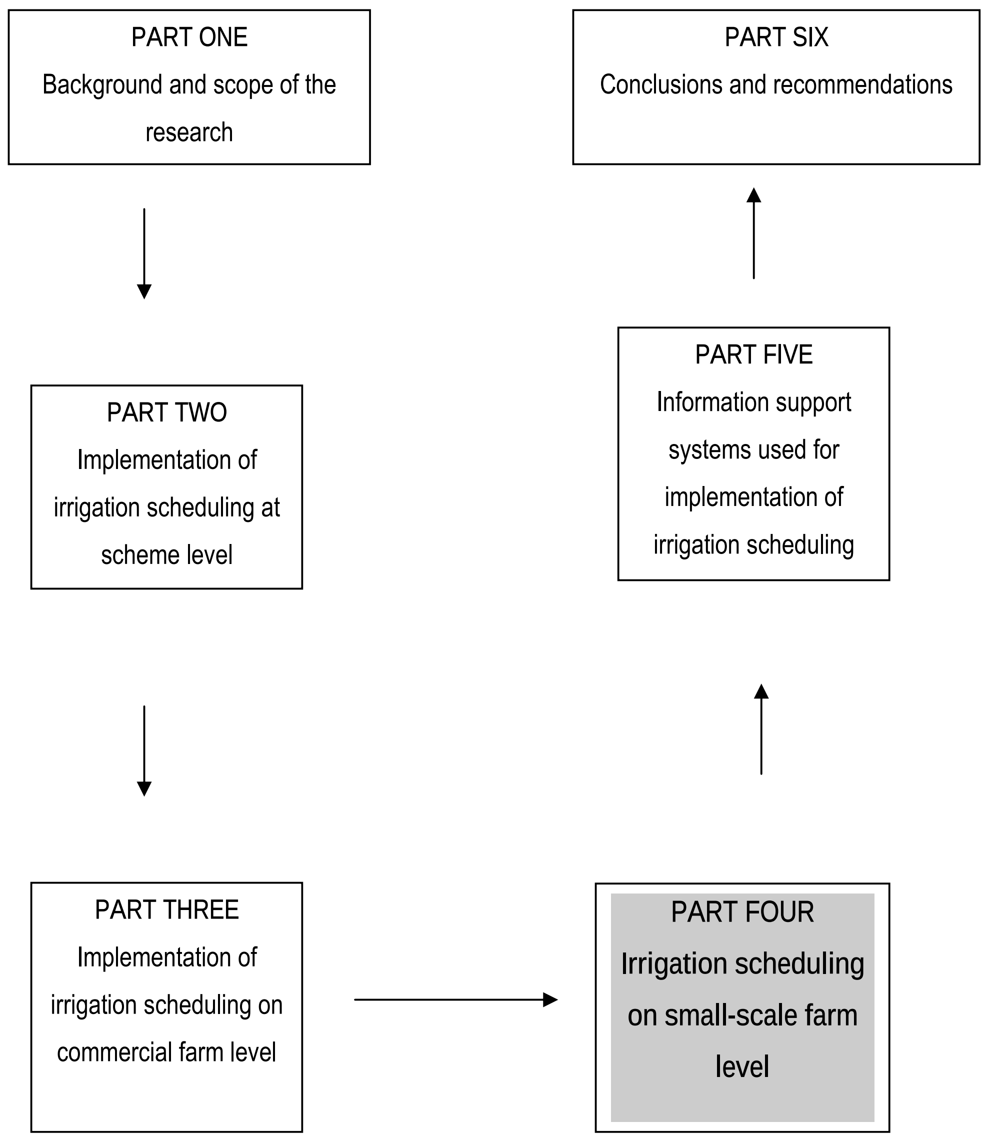
- Cash crop growers and producers of high value crops have differential perceptions with regard to the substantial improvement of production efficiency since the introduction of objective irrigation scheduling practices.

- Irrigation farmers usually start off by using proportionately more objective scheduling methods in an approach to gain experience and knowledge regarding irrigation scheduling. However, as farmers gradually gain more confidence, experience and knowledge in the application of irrigation scheduling they are prepared to make more use of intuition. Many of the experienced farmers reveal that they often used objective scheduling methods only to monitor their present irrigation practices and if necessary to do the required attuning to the scheduling program.

- Significant differences exist in the general awareness about computer models between farmers belonging to the objective irrigation-scheduling group and farmers from the subjective irrigation scheduling group. Some of the models that exist for implementation of irrigation scheduling were perceived by some respondents to be easier to apply than others. The majority of computer models and programmes available to irrigators, however, reflect implicitly the modes, reasoning, concerns and context of those that developed them (usually scientists) and are perceived to fail to anticipate the diverse logic and local context of irrigation farmers. The important role of competent professional advisors to support and guide irrigation farmers with the implementation of scheduling models was emphasized, since it cannot function in a *stand-alone mode*.

PART FOUR:

IRRIGATION SCHEDULING ON SMALL-SCALE FARM LEVEL



CHAPTER 10
BACKGROUND AND RESEARCH METHODOLOGY

10.1 INTRODUCTION AND BACKGROUND

This section deals with the current implementation status of irrigation scheduling practices by small-scale farmers in South Africa and identifies the factors and constraints that influence their adoption behaviour.

Irrigation has long been seen as an option to improve and sustain rural livelihoods by increasing crop production. Sustainable agriculture and irrigation development is defined as “agriculture, which meets today’s livelihood needs without preventing the needs of neighbours or future generation from being met” (Pretty, 1994). This definition implies a combination of ecological, economic, and social dimensions to be included in development programs and policies focused on the small-scale irrigation farmer. It also poses a challenge for professionals trained in the more conventional reductionistic scientific paradigm.

A review of the literature done by Bembridge (1996) indicates that, with a few exceptions, the economic success of small-scale irrigation schemes in South Africa falls far short of the expectations of planners, politicians, development agencies and the farmers themselves. According to a World Bank study the performance of small-scale farmer irrigation systems has generally been below expectations with low economic and financial returns (Serageldin, 1995). Small-scale irrigation in South Africa, according to Crosby *et al.* (2000), can be categorized in terms of their water supply as follows:

- Commercial and small-scale farmers on irrigation schemes
- Vegetable gardeners (served by communal water supply infrastructures)
- Independent farmers, each with “private“ water supply

It is also important to distinguish between full-time and part-time farmers in order to understand the irrigation technology requirements. Irrigated agriculture amongst the small-scale farmers is invariably aimed at the generation of a cash income or at least to supply some food for the household (food security). As far as can be ascertained from a survey done by Backeberg *et al.* (1996), there are 202 small-scale farmer irrigation schemes (SIS) in South Africa comprising approximately 46 000 to 47 500 ha under irrigation and about 50 000 ha as food garden schemes and food plots. De Lange (2004) adapted these figures as indicated in Table 10.1:

Table 10. 1: Small-scale farming in South Africa (de Lange, 2004)

	Homestead gardens	Rain fed fields	Irrigation fields	Grazing and livestock watering
No of households	2 400 000	1 700 000	56 000	1 700 000
Total area (ha)	200 000	2 000 000	100 000	12 000 000

Of the 202 small-scale irritation schemes, 79% are in the Eastern Cape, KwaZulu Natal and the Limpopo Province. As a whole, these schemes account for 4% of the irrigated areas of SA and from a rural and socio-economic point of view are of cardinal importance.

Small-scale farmer irrigation schemes in South Africa conform to one of five types (Bembridge, 2000):

- *Top-down bureaucratically managed smallholder schemes* fully administered by government or an agency of government. The management committee carries out farming operations on behalf of the irrigators. There is also no selection of farmers on the basis of “farming potential” and the majority of irrigation conforms in varying degrees to this category.

- *Jointly managed schemes* in which some of the functions are performed by the irrigation development agency, while others are the responsibility of the project participants. Such schemes are usually aimed at eventually developing farmers to produce their own food and a surplus for sale. Little selection of farmers on farming ability is evident.

- *Community schemes* which are usually small in size, operated and maintained by the water users themselves. There are relatively few of these schemes.

- *State or corporation financed schemes***,** such as those under sugarcane production, where the farmers are selected on entrepreneurial and farming ability, as well as on their financial and other resources. Government provides infrastructure to field edge and farmers pay a subsidised water charge and are responsible for their own decisions and management.

- Lastly, there are a few *large estate schemes,* which are state or private sector financed, often managed by agents at maximum use of resources through the production of high return cash crops like tea, coffee, various fruit and vegetable crops. Although there are some schemes where out growers participate on a pilot scheme basis, there is generally little farmer participation, except in the form of supervised labour.

The full range of irrigation systems is often found on the small-scale irrigation schemes, viz. flood, sprinkler, centre pivot, micro and drip irrigation (Crosby et al., 2000). Sprinkler irrigation is used on approximately 5% of irrigated land throughout the world (FAO, 2001), and in South Africa often found on relatively more modern irrigation schemes, which have recently been developed or revitalized. Flood irrigation is most widely used on the older schemes and in community gardens. A flood irrigation system that is indigenous to South Africa comprises short furrows, which are very popular because of the easiness to manage and maintain (Stimie, 2003). This system is an indigenous adaptation of the conventional long-furrow and basin systems used in commercial agriculture. A typical layout of a short furrow scheme is shown in Figure 10.1 It is highly manageable and requires comparatively little in terms of permanent infrastructure and maintenance. However, this simplicity of operation is only possible which correct system design, requiring a balance between water flow rates, furrow slope and length for the specific soil. On the community food gardens many of the farmers are making use of short furrow irrigation in vegetable crop production.

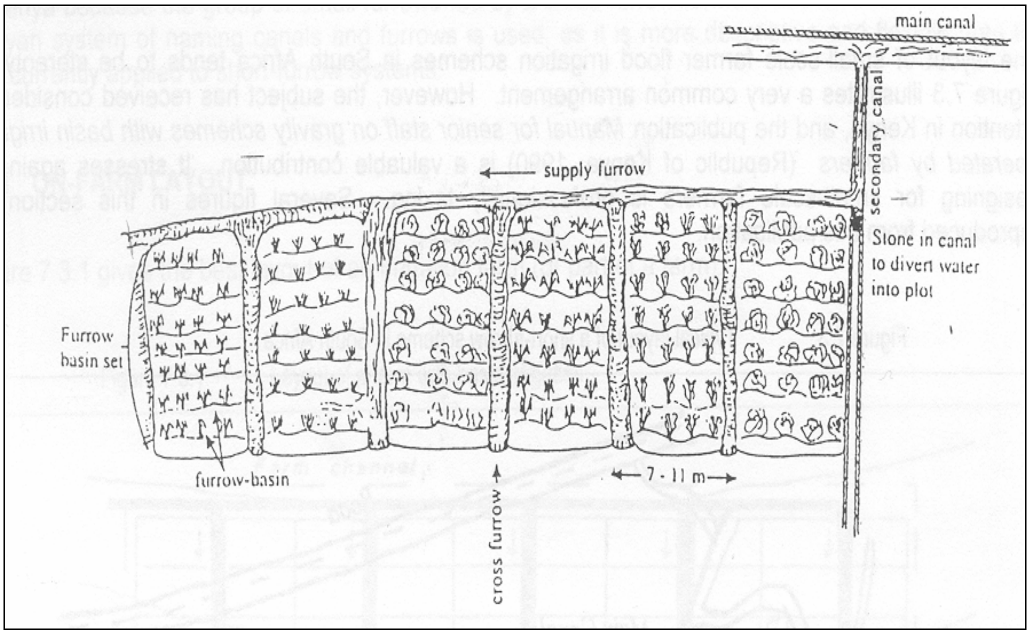


Figure 10. 1: Typical layout of a short-furrow irrigation scheme (Crosby *et al.*, 2000)

10.2 RESEARCH METHODOLOGY

The aim of this part of the study was to investigate and describe the irrigation practices and irrigation scheduling methods, which small-scale farmers are using in South Africa as well as their perceptions, and possible reasons why farmers have adopted or rejected the use of irrigation scheduling methods. This study consists of two phases. During the first phase a comprehensive literature study was done covering appraisals of the current situation of irrigation and scheduling, as well as the socio-economic and various technologies that influence small-scale irrigation farming. The interviewing of various key-informants on several of the small-scale irrigation schemes throughout the country comprised the second phase. The questions were aimed at gaining an in-depth understanding of the dynamics of irrigation management and obtaining important feedback about the farm conditions, management practices and farmers' needs. This required investigating the everyday irrigation practices of a sample of the small-scale irrigation farmers, and their interactions with other role players, and the interpreting of these relations in the relevant context.

The obvious research tradition that allows such a contextual analysis of human interaction is a case- study approach. Van Velsen (1967) refers to this as the "extended case study method" or situational analysis. In order to answer this kind of research problem, the analysis of only a single case-study is not appropriate, and therefore it was necessary to purposefully select and compare a few of the case studies (Yin, 1994). After consultation with the steering committee and several key informants, five small-scale irrigation schemes were selected for case study surveying namely:

- Zanyokwe Irrigation Scheme, Eastern Cape Province
- Tshiombo, Limpopo Province.
- Taung in the Northwest Province
- Nkomazi east (Walda, Boschfontein, Low's Creek, Figtree), Mpumalanga Province
- Bethlehem Apple Project, Free State Province

Primarily the qualitative research method (semi-structured interviewing, qualitative content analysis, analysis of narratives, history of irrigation scheme development, etc) was used to collect information to allow maximum farmer participation. The methods used range from visualization, to interviewing to evaluation of irrigation practices. Several participatory approaches have been used where farmers, extension officers and several key stakeholders participated in identifying farmer needs and possible solutions to problems faced. Knorr-Cetina (1981) refers to this method as a "sensitive method" as this approach ensures that the complex dynamics and interrelationships of a specific small-scale irrigation scheme can be understood and interpreted in their relevant context. The common theme is the promotion of interactive learning, shared knowledge and flexible, yet structured analysis.

The participants in these case studies were limited to 1) the farmers who practice farming at the specific irrigation schemes selected for the more intensive studying of irrigation practices and 2) extension officers and other key stakeholders who serve and work with these farmers at each scheme. At each site the number of participants was not predetermined, but the final sample size at each site consisted of active farmers and extension officers.

CHAPTER 11

IRRIGATION SCHEDULING IN THE EASTERN CAPE: CASE STUDY 1

11.1 EASTERN CAPE SMALL-SCALE IRRIGATION

According to Bembridge (2000) there are fifty small-scale irrigation schemes in the Eastern Cape comprising 9 527 ha with 6 349 participants. Table 11.1 indicates the information as collected by Bembridge (2000) as well as additional information collected by Eloff (2001) and Williams (2004).

Table 11. 1: Eastern Cape Irrigation Schemes (Bembridge, 2000; Eloff, 2001 and Williams, 2004)

Scheme	Area irriga-ted	Paticipants		Total	Major crops	Water source	Irrigation method	Energy source	Manage-ment agency
		CF	FPH						
Ngonyameni	17	1	0	1	Maize, Veg	River	Sprinkler	Diesel	Farmer Ass
Mzomtsha	1.5	0	9	9	Veg	River	Not implemented	Diesel	ECATU
Pakamisizwe	4	0	8	8	Veg	River	Sprinkler/ Dragline	Diesel	ECATU
Orange Grove	12.5	0	19	19	Veg	River	Not implemented	Diesel	ECATU
Phambili	3.5	0	5	5	Veg, maize	River	Not implemented		ECATU
Izikoletho	37	0	12	12	Veg, maize	River	Sprinkler/ Dragline		Private comp
Ngqubusini	3		18	18	Veg	River	Not implemented	Diesel	ECATU
Matakatye	5		6	6	Veg, maize	River	Sprinkler/ Dragline	Diesel	Num
Mjikweni	5.3		10	10	Veg	River		Diesel	-
Vukani	4		7	7	Veg	River	Sprinkler/ Dragline	Diesel	-
Lingelethu	0.8		14	14	Veg	Dam	Dragline	Diesel	ECATU
Ntsaka comm.	3		15	15	Veg	River	Dragline	Diesel	Private comp.
Xhefu	5	5	7	5	Veg	River	Sprinkler/ Dragline	Diesel	ECATU
Mngazi	32	1	0	1	Veg	River	Sprinkler	Diesel	Comm farmers
Tyefu	641	32	1646	1678	Veg, maize	River	Sprinkler/ Dragline		Comm farmers

Scheme	Area irriga-ted	Paticipants		Total	Major crops	Water source	Irrigation method	Energy source	Manage-ment agency
		CF	FPH						
Zanyokwe	471	58	146	204	Veg, maize	Dam	Sprinkler		Farmers ass
Horsehoe	56	18	0	18	Veg, maize	River	Sprinkler		Farmers ass
Keiskammahoek	744	45	102	147	Veg	Dam	Sprinkler	Diesel	Irrigation board
Mthombe	50	50	0	50	Veg, maize	River	Sprinkler		Farmers ass
Malenge	243	168	0	168	Veg, maize	River	Flood		Community
Joy comm.	1.5		36	36	Veg	Borehole	Flood		Management comm.
Masizahke	17		143	143	Veg	River	Sprinkler/ dragline		Management comm.
Occupation post	1200					Dam	Sprinkler	Diesel	
Ncora	2490	16	256	272	Veg, maize	Dam	Sprinkler/ dragline		Farmers ass
Qamata	1959	1000	0	1000	Veg, maize	Dam	Flood. sprinkler		Farmers ass
Xonxa	780	30	0	30	Veg, maize	Dam	Centre pivot	Electricity	Farmers ass
Xonxa pilot	340		0	0		River	Sprinkler	Diesel	
Thornhill	27.5		110	110	Veg, maize	River	Sprinkler/ dragline	Diesel	Tribal auth.
Tendergate	100		400	400	Veg, maize	Dam	Flood		Community
Spring Grove 2	15		60	60	Veg, maize	Dam	Sprinkler	Diesel	Community
Spring Grove 1	43		172	172	Veg, maize	Dam	Sprinkler/ dragline	Diesel	Community
Rocklands B	70		280	280	Veg, maize	River	Sprinkler/ dragline	Diesel	Community
Rocklands A	18		72	72	Veg, maize	River	Sprinkler/ dragline	Diesel	Community
Mitford	77		308	308	Veg, maize	Dam	Sprinkler/ dragline	Diesel	Management comm.
Loudon	26		104	104	Veg, maize	Borehole	Sprinkler/ dragline	Diesel	Tribal auth.
Hinana	40		160	160	Veg, maize	River	Sprinkler/ dragline	Diesel	Tribal auth.
Glenbrook 3	50		0	0	Veg, maize	Dam	Sprinkler	Diesel	Tribal auth. / Farmer. Ass.
Glenbrook 2	50		0	0	Veg, maize	Dam	Sprinkler	Diesel	Tribal auth. / Farmer. Ass.
Glenbrook 1	12		0	0	Veg	Dam	Flood		Tribal auth. / Farmer. Ass.
Beccles farm	22		0	0	Veg, maize	River	Sprinkler	Diesel	Tribal auth. / Farmer. Ass.
Yonda	16		64	64	Veg, maize, wheat	Dam	Sprinkler/ dragline		Tribal auth.
Shiloh	455	15	263	278	Veg, maize	Dam/river		Electricity	Farmers ass

Scheme	Area irriga-ted	Paticipants		Total	Major crops	Water source	Irrigation method	Energy source	Manage-ment agency
		CF	FPH						
Prices Dale 2	29		117	117	Veg, maize, wheat	Dam/river	Sprinkler/ dragline		Farmers ass
Prices Dale 1	106.5		213	213	Veg, maize, wheat	Dam/river	Sprinkler	Diesel	Tribal auth.
Oxton Manor	60		0		Veg, maize, wheat	Dam/river	Sprinkler		Tribal auth.
Oxton	49		196	196	Veg, maize, wheat	Dam/river	Sprinkler		Community
Ngojini	18.5		74	74	Veg, maize	Dam	Sprinkler	Electricity	Farmer ass.
Mbekweni	42		84	84	Veg, maize, wheat	Dam/river	Sprinkler		Management comm.
Haytor	19		76	76	Veg, maize	Dam/river	Sprinkler/ dragline	Electricity	Farmers ass
Bushy Park	23		92	92	Veg, maize, wheat	Dam/river	Sprinkler/ dragline	Diesel	Management comm.
Katriver	1120	24	-	24	Citrus	River	Micro/ sprinkler	Electricity	Management comm.
Total	11 582	1 463	4 910	6 373					

Veg= vegetables; Farmer ass. = Farmer association; Management comm. = Management committee; Tribal auth. =Tribal authority; ECATU= Eastern Cape Appropriate Technology Unit; FPH = Food plot household; CF= Commercial farmer.

Eloff (2001) indicates that many of the schemes are either no longer in production or only partially in production. Most of these farmers, according to Bembridge (2000), are carrying a high debt load, mainly on account of poor financial management. The recent withdrawal from management from these schemes by the Department of Agriculture, the changing scenario in government financed irrigation schemes in the last couple of years and theft and vandalism of the irrigation equipment also contributed to the general poor state of in-field irrigation infrastructure. The rehabilitation of the irrigation infrastructure is currently addressed under the Comprehensive Agricultural Support Programme (CASP) and the Eastern Cape Department of Agriculture (ECDA) acknowledges the fact that the irrigation schemes need to be fully functional before it can be handed over to farmers for self-management. However to access funding from CASP, farmers have to organize themselves into legal farmer groups. In some areas farmers have successfully formed cooperatives and trusts, but in general they are lacking the necessary capacity to run and manage these institutions.

The Kat River Valley as indicated in Table 11.1 is a relative big irrigation scheme in the Eastern Cape and is well known for its citrus production. During the early 90's,some of the more productive citrus farms were taken over by a Ciskei parastatal, Ulimocor, and placed under the management of small-scale farmers. By 1994, many of the state run Ulimocor citrus farms further down the valley became unproductive, with the exception of a few farms, which were scheduled for irrigation and were licensed for water use (Eloff, 2001). In the "middle" and "lower" Kat River valley, commercial white and black farmers had continued to run commercial citrus farms, mostly for export markets that relied on irrigation water from the Kat River. These citrus farmers are members of the Kat River Cooperative, which is responsible for production inputs and helps with the marketing of the citrus. A full time extensionist is employed by the cooperative to support farmers with their day-to-day decisions on management and production. These farmers at present use no objective scheduling method, although tensiometers were used in the past. Farmers now make use of a fixed irrigation schedule as provided by the local citrus cooperative. These farmers formed the Kat River WUA during December 2001, when the Minister of Water Affairs and Forestry gazetted its constitution.

Farmers' major problems experienced on the irrigation schemes in the Eastern Cape are indicated in Table 11.2, as cited by Bembridge (2000) and confirmed by extension officers employed on some of the irrigation schemes in the Eastern Cape (Zanyokwe, Keiskammahoek and Qamata) through participation in a pair wise ranking exercise.

On many of the small-scale irrigation schemes in the Eastern Cape, farmers are experiencing problems with poorly maintained irrigation infrastructure where often hydrants, reservoirs, valves and water ways need attention. The lack of appropriate training of farmers to improve their technical and managerial capacity on the farm was also identified as stumbling blocks in the production of crops under irrigation.

Table 11. 2: Rank order of the major problems that farmers experience on the Eastern Cape irrigation schemes (Bembridge, 2000, Vusani, 2004; Dlulane, 2004, Dlovo, 2005)

Scheme problems	Rank position
Poor maintenance of infrastructure and equipment.	1
Lack of farmer training.	2
Local and political conflict.	3
High pumping and maintenance costs.	4
Lack of credit.	5
Poor market opportunities.	6

In 54 percent of the schemes listed in Table 11.1, farmers pump irrigation water using mainly diesel as source of energy. According to Bembridge (2000) and Williams (2004) many of the crop losses farmers experience are due to engine breakdowns. It seems from the rank order of problems (Table 11.2) that farmers on the relative bigger irrigation plots (>50ha) are more aware of the irrigation operational costs (Stimie, 2004).

11.2 CASE STUDY 1: ZANYOKWE IRRIGATION SCHEME

The first case study refers to a small-scale irrigation scheme namely Zanyokwe Irrigation Scheme, in the Eastern Cape. This scheme is reflecting a typical development project planned by the Ciskei Government in consultation with the community in an attempt to improve the standard of living, and to create job opportunities.

11.2.1 Background

The scheme was planned during the early 1980's and was named after Zanyokwe village, which is situated on the southern part of the scheme across the road to Keiskammahoek. Before 1984, the Ciskei government negotiated with Zanyokwe residents about the possibility of establishing an irrigation scheme for which the arable land that belonged to Zanyokwe would be used. The Development Bank of SA (DBSA) financed the project and the Ciskei government funded it. The engineering related planning and design at the scheme was done at a high standard, which can be seen from the technical reports that are available. During the establishment of the irrigation scheme, government owned and managed the entire infrastructure and this responsibility has only been transferred to the Zanyokwe Agricultural Trust recently (ATS Rural Dev. Services, 2002).

In 1984, the scheme was established with 48 members. At that time, the Ciskei government had a strong relationship with Israel. The two governments signed a five-year contract whereby the Israelis with their skills and experience would run the scheme. The main objective was for the local farmers to learn from these advanced farmers. When the Israelis left the scheme in 1989, the ECDA helped farmers with the formation of an association with surrounding communities namely Lower Ngqumeya, Zingcuka and Cwar-Kamma Furrow (ATS Rural Dev. Services, 2002).

The scheme has an irrigated (or previously irrigated) area of 471 ha. This consists of individual holdings, ranging from 0.1 to 20 ha and some communal areas and food plots. It is estimated that less than 50% of the scheme is under active production (Dlovo, 2005). The scheme is located between King Williams Town and Fort Beaufort and stretches from the Sandile dam to Middledrift in the foothills of the Amatola Mountains and receives its water from the Sandile dam. Water for irrigation is received *via* a pipeline from the Sandile dam and most of fields on the irrigation scheme are irrigated by gravity from the pipeline on an *ad hoc* basis when the plants need irrigation or when the farmer is of the opinion that he/she must irrigate. There are booster pump stations for areas where gravitational pressure is not enough, and these farmers are paying for the electricity used.

The scheme is made up of six sections as illustrated in the locality map (Figure 11.1) namely Lenye, Burnshill, Lower Ngqumeya, Zingcuka, Kamma Furrow and Zanyokwe. In Zanyokwe, little development has taken place yet al.though the Kamma Furrow section forms part of the scheme; it appears that the members of the community are slowly pulling out of the scheme. This is because of the new municipality demarcation, where Kamma Furrow falls under Nkonkobe municipality, while the rest falls under the Amahlati municipality (Nyangwa, 2004). As a result these farmers are no longer attending farmer group meetings nor participate in field days as intended for the scheme.

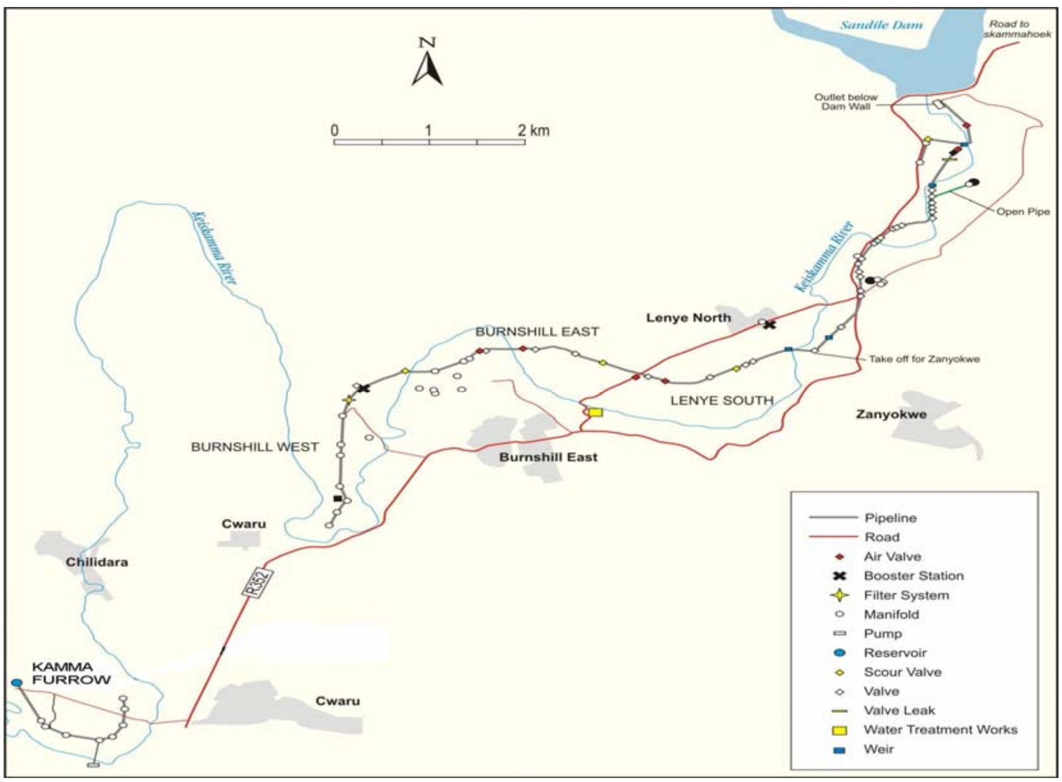


Figure 11. 1: Schematic diagram of Zanyokwe Irrigation Scheme

The scheme was supposed to be managed by a Board of Trustees, but apparently there were complications during the registration (the trust deed was not yet registered with the relevant authority), and therefore the Trust has no authority to run the scheme.

11.2.2 Irrigation methods and scheduling

Apart from Kamma Furrow the scheme receives irrigation water *via* an 800-mm pipeline from the Sandile dam. The pipeline tapers down to a smaller diameter towards the end of the scheme. Kamma Furrow is at the far end of the scheme and has a separate pump unit to pump water from the Keiskamma River into their reservoir or directly into the distribution system. Because the dam also supplies domestic water, Amatola Water Board on behalf of the Department of Water Affairs maintains the dam and pipeline. The assured yield from the dam is 12.7 million cubic meters and its capacity is 30.7 million cubic meters (Rural Urban Cons., 2001). The outlet of the dam is fitted with state-of-the-art control and measuring equipment that is in a good working order (Stimie, 2004).

There are nine main off-take points along the pipeline to distribute water to the scheme. The water supply is designed with a duty of about 0.9 litres/second per hectare. This is considered to be adequate at this level of scheme utilization (Rural Urban Cons., 2001). Each take-off was originally fitted with a flow meter, pressure gauges and filters, but currently these devices are no longer functioning any more and many pipes are leaking.

Farmers in Zanyokwe use sprinkler irrigation systems but the general maintenance of the systems is not adequate (pipes are damaged, hydrant pipes are leaking, valves are not working). Most of the irrigation fields are irrigated by gravity from the pipeline, except for Lenye North where water has to be pumped to reservoir, from where irrigation is done by gravity. About 10 farmers depend on this irrigation method. Van Averbeke *et al.* (1998) argue that the difference in height between the Sandile dam and the irrigation fields are not sufficient to provide adequate hydraulic head to operate pressurized irrigation system like sprinkler irrigation. As a result, there was a need to build storage reservoirs to be fed from the main pipeline linking Zanyokwe with Sandile dam.

With regard to water rights, farmers don't pay for the water, except for the Lenye North farmers who pay R170 per month. A management committee manages the scheme's resources and infrastructure, while the tribal authority appears to play a minor role in scheme matters. According to the farmers, the infrastructure on the irrigation scheme (buildings, irrigation infrastructure and tractors) belongs to the Zanyokwe Agricultural Trust, but it could not be verified with the Department of Agriculture. The Trust owns a tractor that is rented to farmers for the preparation of their irrigation fields (approximately R400 /ha for primary seedbed preparation).

The soils that occur on Zanyokwe are classified as having a moderate to low potential for irrigation due to the heavy texture and high percentage of sand and silt (Laker, 2002). Cultivation difficulties and slow permeability occur on some of the heavier soils. This clearly shows that irrigation management should be carefully managed to avoid soil-related problems.

According to Stewart Scott Inc. (1998), the general inefficient water management practised by many of the small-scale farmers are due to under-designed pipelines, lack of know-how of extension officers and farmers, leaks in the irrigation system, incorrect nozzle sizes and low pump efficiencies. The consequences of poor maintenance of irrigation equipment like sprinkler irrigation systems often lead to yield losses and increased pumping costs. The field evaluation as part of the case study of Zanyokwe illustrates that the irrigation systems indeed have not been well maintained.

- *Sprinkler spacing and nozzle sizes*

Great technical variation was found as apparent in different standpipe lengths, different types of sprinklers and nozzles used in a single lateral, which have an effect on the efficiency of the system. Photo 11.1 shows a single lateral with different lengths of standpipes in use at Zanyokwe.

Photo 11. 1: Sprinkler lateral with different standpipe lengths in use at Zanyokwe

The spacing of sprinklers was designed to be 12m by 12m because of prevailing strong winds in the area. For vegetables, the design operating pressure at the sprinklers is 250 kPa and the required discharge of each sprinkler is 0.97 m^3/h. The system was designed to give a net application of 5.4mm/day and a gross application of 7.2 mm/day. The stand time was designed to be 5.3 hours to give a gross irrigation of 35mm (Rural Urban Cons., 2001).

It was found that farmers are using a variation of nozzles on the same line (Photo 11.2); some were CDS (CDS nozzles are special low-pressure nozzles manufactured from nylon) some were single and some were double nozzles. This means that the distribution on that line is very uneven. CDS nozzles are prone to blockages and are easily damaged when unclogged.

Photo 11. 2: Different sprinkler nozzles (a) CDS and (b) ordinary in use by a farmer in Zanyokwe (2004)

o *Distribution and application efficiency of irrigation systems*

During the field evaluations performed on irrigation plots in the Zanyokwe Irrigation Scheme (2005), irrigation distribution tests were done by setting up catch cans in a 3 m x 3 m grid between the sprinklers and recording the amount of water collected in each can within a set period of time.

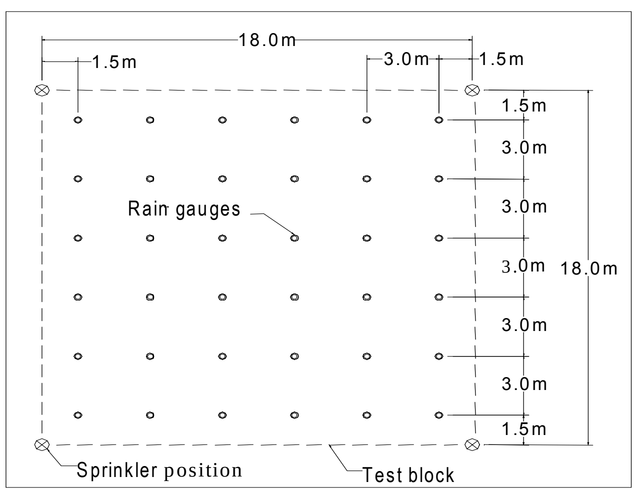


Figure 11. 2: Example of the rain gauge layout used for distribution tests at Zanyokwe irrigation plots

The collected data was used to calculate a number of water use efficiency performance indicators, including the uniformity coefficient, distribution uniformity, application efficiency and system efficiency. The results of the measurements indicated that both irrigation systems performed below average because of the following reasons:

- *Christiansen uniformity coefficient (CU)*

Since CU is a function of sprinkler type and sprinkler spacing, farmers who are not following the recommended 12 m by 12 m sprinkler spacing but rather use 12 m by 18 m spacing, experience problems with regard to sprinkler uniformity.

- *Distribution uniformity (DU_{lq})*

The amount of water collected in the catch cans varied from 3.2 to 8.9 mm, with an average application of 6.1 mm. This indicates poor distribution uniformity because of the variation both in the spacing of the sprinklers as well as the system pressure. The effect of this is a huge variation in the amount of water received by the plants in different sections of the field.

- *Application efficiency (AE)*

With regard to the evaluation of application efficiency, some farmers' system performance was well below the norm, which indicates that a considerable amount of water is lost between the sprinkler's nozzle and the soil surface. The average irrigation application (mm/h) varied between 6.05 mm/h and 2.87 mm/h, while the gross application (mm/h) varied between 10.14mm/h and 5.81 mm/h.

The field tests of the ARC (1997) indicated that evaporation losses could be expected to be as high as 40%, due to system pressure, wind speed and temperature. If irrigation is done at nighttime, the losses can be reduced to less than five percent. Trials indicate that more than half of the daily losses occur between 10h00 and 16h00 (Reinders, 2003). The majority of farmers on Zanyokwe irrigate according to a fixed irrigation schedule, three hours standing time every four days, between 6h00 and 18h00.

Farmers at Zanyokwe do not use objective scheduling methods, but make use of a combination of plant observation method and the "feel method". Although departmental extension officers are responsible for the delivery of technical support on cropping systems and help with regard to the preparation of business plans and management of irrigation, they are in general perceived to lack the necessary competency and technical skills to support farmers with regard to irrigation management.

Following a focused group discussion and presentations of problems by the irrigation farmers of Zanyokwe, the following problems were identified and ranked accordingly as presented in Table 11.3

Table 11. 3 Preferential ranking of problems that influence optimum crop production of irrigation farmers from Zanyokwe (N=20)

Problem	Problem code	Pair wise score	Preferential ranking
Weak farmer organization.	Fo	14	1
Land tenure system.	Lt	12	2
Inappropriate markets.	Ma	11	3
General poor state of irrigation infrastructure.	Irr	10	4
Poor irrigation management skills.	Im	10	4
Cropping patterns (especially during the winter).	Cp	8	5
Crop production below personal expectancy.	Prod	7	6
Lack of credit and capital.	Cr	5	7
Lack of appropriate technology.	Tech	3	8

11.2.3 Lessons learned

1. Effective institutional arrangements and leadership conducive for the implementation of irrigation scheduling

The findings in Table 11.3 illustrated that weak farmer organizations are perceived as farmers' biggest problem. The Zanyokwe irrigation scheme was supposed to be managed by a 12-member board of trustees elected to represent the different sections of the scheme. This has however not materialized, and currently a management committee manages the different affairs of the irrigation scheme. However due to a general lack of leadership skills, everybody is not satisfied with the management of the scheme and appropriate training of newly elected executive members of the management committee was suggested. The implementation of effective irrigation schedules and best management irrigation farming practices according to the on-farm constraints are perceived not to be possible due to inappropriate institutional arrangements. This supports partially the assumption that independent environmental variables like institutional arrangements can influence the adoption behaviour of small-scale irrigation farmers (Hypothesis 1.1).

2. Social and cultural constraints influence on the attitude and perceptions of farmers

The land tenure system of Zanyokwe is complex (Loxton Venn and Associates, 1984) and according to the extension officers and farmers, some irrigable land at Zanyokwe has not been farmed for many years, in spite of irrigation water being available. This happened apparently because landowners or occupiers rather preferred to rent the land to outsiders not always interested in crop production.

Clarification of land tenure arrangements of irrigation farmers could increase farmers' incentive to invest in their land and irrigation systems. Extension education is a useful tool in helping farmers to adopt appropriate irrigation management practices, but this research suggests land ownership in some areas impose strong limits on its effectiveness.

A steering committee comprised of farmers, the Department of Agriculture (DoA), Agricultural and Rural Development Research Institute of the University of Fort Hare (ARDRI), United States of America Department of International Aid (USAID), Starke Ayres and Kynoch was established to promote market linkage with Pick and Pay supermarket. However farmers in general experience problems to comply with negotiated market contracts (like for instance Pick and Pay) because of inappropriate crop planning. The support of competent extension officers in this regard is urgently needed. The Massive Food Project (MFP) is a funding programme offered by the Department of Agriculture. Several problems are experienced with the implementation of the support programme, of which the lack of proper organized farmer organizations is but one (Manona, 2005).

3. Availability of water supply to the field

Farmers ranked the general poor state of the irrigation infrastructure and lack of irrigation management skills as problem four (Table 11.3). They suggested that the Eastern Cape Department of Agriculture should assist with the repairing of infrastructure, where after the maintenance will become the farmers' responsibility. This support the assumption that unless precursor problems like infrastructure and farm layout as independent environmental factors are dealt with first, farmers will not be prepared to focus on irrigation scheduling (Hypothesis 1.1).

4. Potential benefits attached to the implementation of more accurate irrigation management should be visible

Some farmers make use of electricity to pump water to reservoirs and for higher inline water pressure where the gravitation is not adequate for irrigation. These farmers are in general more aware of the potential operational cost attached to the delivering of irrigation water to the irrigation field. It was found that they were also more prepared and willing to learn about the correct procedure of irrigation scheduling.

Many of the farmers from Burnshill East and Lower Ngqumeya cannot pay their electricity bills every month, and have requested government to help them. These farmers are also more aware of the fact that they should not all irrigate at the same time, since it tends to undermine the inline water pressure. However, farmers struggle to adjust to this since they are not properly organized into a functional farmer organization.

5. On-farm irrigation techniques as constraints to the implementation of scheduling methods: Sprinkler irrigation

Sprinkler irrigation is often considered as being very effective compared to surface irrigation because it enables better control of water application. However, the control is dependent on proper irrigation system design and informed selection of equipment, and also requires that farmers develop appropriate skills for managing their systems (knowledge and control of system pressure and flow that enables the system to distribute water uniformly over the field).

It is clear from the field evaluation that some farmers are struggling with the managerial challenges, because of a lack of skills and poor knowledge of system operating requirements and the regular maintenance of irrigation systems. The current situation can be improved through appropriate training and information for farmers and extension officers to improve skills in controlling and management of irrigation systems at field level (setting of equipment, operation of systems, using sensors to check and monitor distribution uniformity and application efficiency). As outlined in Part Three, irrigation scheduling is perceived to be a complex concept and therefore hard to implement even by commercial farmers.

6. Requirements for interactive communication between researchers, extensionists and farmers

The general perception of farmers about the role that extension officers could play in the day-to-day solving of problems needs to be mentioned. They do not perceive extension officers only to provide them with technical advice, but expect extension officers to play a more definite role in terms of support in the operation of farmer organizations. Farmers complained in general about the irregular visits by extension officers to the irrigation scheme. These irregular visits are according to the extension office caused due to a lack of available transport facilities.

The traditional scientific framework used by extension to help irrigation farmers often follows the linear transfer of technology approach. This approach assumes that the problem will be solved once the target audience implements the practice of irrigation scheduling. However, according to Blacket (1996), the extension and research programs offered to farmers have been based on worldviews of problem solvers rather than their clients. Therefore effective dialogue between research, extension and farmers is identified as a precursor for change in irrigation management practices at Zanyokwe. Extension should form an integrated part of every irrigation project, and the ultimate efficiency is often determined by the quality of personnel, the extension approach, organization and management. This finding provides support for the assumption that effective dialogue between extensionists, researchers and farmers is necessary in the simplifying of research information and delivering it to farmers in an effective and easily understandable manner (Hypothesis 5).

CHAPTER 12
IRRIGATION SCHEDULING IN THE LIMPOPO: CASE STUDY 2

12.1 LIMPOPO SMALL-SCALE IRRIGATION

Up-dated information on the status of the small-scale farmer irrigation schemes (SSI) in the Limpopo Province was obtained from the LPDA (Limpopo Province Department of Agriculture). There are 171 irrigation schemes identified in the Limpopo Province and these schemes comprise a total of 51 091 hectares with 7 307 participating farmers.

Hundred and fourteen schemes with a total irrigable area of 18 629 ha are included in the Revitalising Program of Small-scale Irrigation Schemes (RESIS) that the Limpopo Province Department of Agriculture (LPDA) has embarked on. The main objective with this program is the transfer of ownership of irrigation schemes and the empowerment of farmers. This program commenced in 1998, and a total of 28 irrigation schemes have since undergone the revitalization program or are in the process of implementing the program. The program entails the rehabilitation of infrastructure, the construction of conservation works and the proper management of the infrastructure and conservation works. Farmers are assisted in the establishment of appropriate institutional structures for the sustainable management of the schemes. The establishment of farmer groups and Water User Associations with their respective management committees enable the farmers to operate as a legal entity and to apply for access to the DWAF grant for additional infrastructure rehabilitation that may be necessary. However, it is expected of LPDA to take care of the follow-up support and mentorship after the formal intervention of rehabilitation is completed. Table 12.1 provides an overview of the major crop types found on the small-scale irrigation schemes in the Limpopo.

Table 12. 1: Percentage distribution of crop types found on the Small-scale Irrigation (SSI) in the Limpopo (N=171)

Crop type	Percentage irrigation schemes
Citrus	8
Subtropical fruit	12
Cash crops	72
Vegetables	4
Coffee	2
Grapes	0.5
Deciduous fruit	1
Rice	0.5
Total	**100**

Table 12.1 shows that small-scale irrigation farmers in the Limpopo are mainly engaged with the production of cash crops like cereals and cotton on the small-scale irrigation schemes. The following categories of small-scale irrigation methods are found on the 114 irrigation schemes earmarked for revitalization:

- Flood and furrow irrigation (mainly short furrow irrigation): 50%
- Centre pivot: 5%
- Sprinkler irrigation: 45%

On twelve of the irrigation schemes (30 634 ha), commercial farming is exercised under a government water scheme where farmers are directly responsible for the water tariff. The water regulation services (distribution and fee collection) on the 114 emerging small-scale irrigation schemes are largely found to be in the hands of the LPDA through the local extension agents. Farmers are in general responsible for the electricity operational costs associated with the pumping of irrigation water to the irrigation field.

12.2 CASE STUDY 2: TSHIOMBO IRRIGATION SCHEME

The second case study deals with a small-scale irrigation scheme, namely Tshiombo Irrigation Scheme located in the Limpopo Province. This scheme is reflecting a typical design that conforms to the irrigation scheme development model subscribed to by South African Government during the period 1930-1970. Physically, this model involved the establishment of a source of irrigation water, usually by means of stream diversion, and a water distribution system that consisted of concrete canals. Typically farmers were allocated 1.5-2 morgen (1.3-1.7 ha) of land (Perret, 2001).

12.2.1 Background

The Tshiombo Irrigation Scheme is situated at the northern side of Thoyandou, 40 km from Louis Trichardt in the Limpopo Province (Figure 5.4). The scheme was designed in 1990 to irrigate 1100 ha from the Mutale River with water diverted into a canal from the river by means of a weir. Approximately 930 farmers are participating in this scheme, each of them having an average plot size of 1.28 ha, subdivided into 5-6 seedbeds. Bulk water is stored in 10 storage dams that are filled on a specific night during the week. These storage dams were planned to play an important role to ensure the effective distribution of irrigation water to the four irrigation blocks of the irrigation scheme.

Hundred percent of the area is utilized and farmers use mainly short furrow irrigation to irrigate crops. Crop production is mainly for household purposes with surplus being sold to hawkers of Thoyandou and to fresh produce markets in Pretoria and Johannesburg. A wide range of crops are produced on the scheme, which include maize, cabbage, Swiss chard, chillies, beans, sweet potatoes and various other vegetables. No electricity is available, as farmers make use of gravitation irrigation from the nearby storage dams. According to the local extension officer, the majority of the farmers participating on this scheme are women (70%), while 80% of them receive a pension as an off-farm income. Farmers receive the water free of charge, while they pay R1 per month per plot rent, irrespective of the size of the plot.

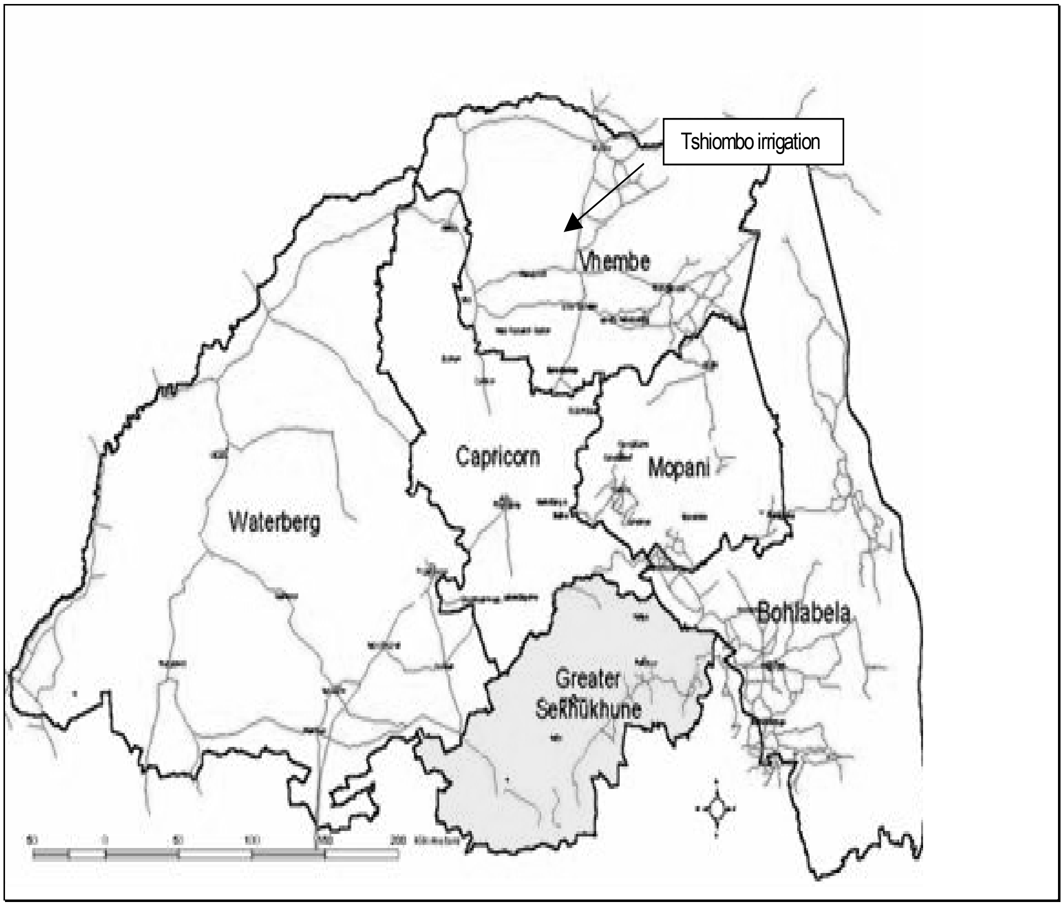


Figure 12. 1: Base map of Limpopo municipality districts indicating the location of Tshiombo Irrigation Scheme in the Vhembe district

12.2.2 Irrigation methods and scheduling

Tshiombo Irrigation Scheme consists of four irrigation blocks. Farmers are generally organized in block committees and most farmers interviewed are satisfied with the operation of the block committees. The block committees are responsible for maintaining in-house rules and conventions at a block level, and if a farmer fails to obey the rules he/she is reported to the water bailiff. If however, the water bailiff fails to solve the problem, the executive committee of the scheme will pursue the matter further.

The main canal that is used for the bulk water conveyance has 48 take-offs, which distribute water through secondary canals to farmers. A specific timetable for bulk water distribution to the four irrigation blocks is followed on the scheme according to the filling of the seven storage dams (Table 12.2).

Table 12. 2 Timetable followed for irrigation on Tshiombo Irrigation Scheme (Netangaheni, 2003)

Day of the week	Block Number
Monday	2,2A,3 & 4
Tuesday	1, 1A, 1B, 2, 2A, 3 & 4
Wednesday	1, 1A, 1B, 2, 2A, 3 & 4
Thursday	1, 1A, 1B, 2, 2A, 3 & 4
Friday	1, 1A, 1B, 2, 2A, 3 & 4
Saturday	1, 1A, 1B, 2, 2A, 3 & 4
Sunday	1, 1A, 1B, 2, 2A, 3 & 4

During a survey conducted by the ARC-IAE in 1997, it was found that the application efficiency in short furrows is generally relatively high. This means that most of the water in the short furrows actually reaches the roots of the plants being irrigated. Distribution uniformity in the short furrows can achieve 80–90%. This is a property of small-basin and short-furrow irrigation, provided the basins/furrows have a fall of less than 1:300. On a steep gradient of 1:100, the uniformity of distribution was below 40%, largely due to unequal damming in the short furrow.

Interviews with farmers from blocks 1 and 2 revealed that they do not experience problems with bulk water supply. However farmers from block 3 and 4, which are located further away from the weir, experience water shortages at critical periods of crop production, which can negatively effects their crop management and potential income. For this reason it is important that the supply canals used on the irrigation blocks are properly maintained, which is the responsibility of farmers. If a farmer maintains secondary canals on a particular day when water is scheduled for his specific block, his or her neighbour would be allowed to use water during the time. This approach works well as farmers are prepared to take up the responsibility for the maintenance of supply furrows and to organize and schedule appropriate irrigation distribution for a specific block.

Farmers from block 1 and 2 (nearest to the weir) do not irrigate on Mondays, so that a chance is provided for farmers in block 2, 3 and 4 to irrigate (Table 12.2). This time schedule for water delivery is designed especially for the farmers of blocks 3 and 4, where water is stored in a dam before irrigation can take place. Only two farmers from irrigation block 1 and 2 are allowed to irrigate simultaneously, usually during the morning (6h00 till 12h00), which is then followed by irrigation during the afternoon by the rest of the farmers. This order of irrigation can change the following day, as the schedule of irrigation is not fixed and depends on good neighbouring and the specific growth stage of a crop. During a period of water shortage, farmers from blocks 1 and 2 are expected to reduce the time of irrigation in the morning to four hours instead of the normal 6 hours, to provide some opportunity for the rest of the farmers.

Farmers in blocks 3 and 4 make use of water that is stored in storage dams to irrigate. Farmers irrigate by filling a specific furrow before moving to the next, and no objective monitoring of irrigation application is used. Apart from following the fixed timetable of bulk water delivery, farmers use regular field inspection to monitor their irrigation efficiency through observation of the plants and the soil conditions. The extensionists interviewed acknowledged the fact that his technical knowledge and skills on irrigation scheduling *per se,* and the use of scheduling methods like the “feel method” and other more sophisticated methods is inadequate to support small-scale irrigation farmers.

Extensionists were asked to list the major constraints to optimal crop production in Tshiombo that they perceive (Table 12.3).

Table 12. 3: The importance rank order of perceived problems representing constraints in crop production at Tshiombo Irrigation Scheme (Netangaheni, 2003)

Constraints	Ranking
Water shortage and vandalism (blocks 3&4).	1
Flood 2000 damage to land: gullies and dongas cause operational problems with seedbed preparation.	2
Cattle roaming on the crop fields during wintertime, due to damaged fences.	3
Transport problems experienced with regard to delivering of produce to markets (expensive) and inadequate market strategy.	4
Lack of appropriate credit facilities.	5
Cooperative not addressing the needs of farmers.	6

The major constraint perceived by the extensionists that influence crop production on Tshiombo is the availability of bulk irrigation water from April till July, especially with regard to the irrigators on blocks 3 and 4. The lack of maintenance of canals (Photo 12.1) and vandalism (Photo 12.2) cause severe problems in the distribution of irrigation water and therefore influence the production of winter crops (cabbage).

Photo 12. 1: Poor maintenance of irrigation canals and excessive vegetative growth on the canal banks at Tshiombo Irrigation Scheme (irrigation blocks 3 and 4) causing inefficient water distribution

Photo 12. 2: Vandalism of irrigation delivery structures like a canal sluice gate at Tshiombo Irrigation Scheme prevent effective water distribution on the scheme (2003)

Farmers in Tshiombo are well organized into eight commodity groups of which, the Soil and Water Conservation and Soil Fertility Management groups are important for this discussion. Farmers from these two groups meet twice per month to discuss crop production aspects like seedbed preparation, fertilization and selection of cultivars. Apparently, little time is spent on irrigation management aspects, apart from discussions regarding the operational execution of the scheduled timetable of delivery and the required maintenance activities of the canals.

Lessons learned

1. *Institutional arrangements are of critical importance for the adoption of irrigation scheduling methods*

The irrigation community at Tshiombo has operational and institutional arrangements that appear to work relatively well and which stood the test of time. Institutions like block committees, commodity farmer groups, and the newly established cooperative are important institutional "vehicles" to be in place to ensure sustainable irrigation water management. The institutions mentioned provide social rights and guidelines that govern individuals and commodity groups in a community. Crosby *et al.* (2000) found that farmers' success and acceptability of small-scale irrigation schemes are closely related to the management system of the scheme. This supports partially the assumption that independent environmental variables like institutional arrangements can influence the adoption behaviour of small-scale irrigation farmers (Hypothesis 1.1).

It was clear from the discussions held with farmers and extensionists working in Tshiombo that they had differential perceptions regarding the terminology and concepts of irrigation scheduling and therefore also the degree to which irrigation scheduling occurs. For the extension officers irrigation scheduling relate mainly to the institutional and engineering concepts of irrigation scheduling (scheme level) as practiced on the Tshiombo irrigation scheme and not the farm level where agronomic concepts of when to irrigate crops and how much to apply is important for farmer decision-making. The institutional and engineering concepts include the development and implementation of the timetable of bulk water delivery and distribution as adopted on Tshiombo irrigation scheme, namely the supplier, distributor and the user. This supports the assumption that intervening variables like the perception about irrigation scheduling influence the adoption behaviour of small-scale irrigation farmers (Hypothesis 1.2).

2. Fixed water delivery schedules affects discharge at field level

Individual irrigation farmers on this scheme have very little opportunity to apply their own adapted irrigation scheduling methods based on their and specific crop needs, as the availability of irrigation water is dictated by a fixed schedule (time-table) of bulk water deliverance. Three parameters describe the local in turn bulk water delivery schedules: a) the duration of the irrigation cycle, b) the delivery pattern and c) the method of water distribution. The irrigation cycle is the period over which water returns. Ideally, the duration of the cycle should be in line with the crop requirements. Irrigation cycles that are too long complicate the cultivation of crops with short irrigation intervals.

The second parameter, the delivery pattern, arranges the sequence in which each water user will receive his turn within the irrigation cycle. Water distribution directly affects the discharges at the field level. This is an important determinant of field efficiency as flows at field level may be too large or too small to distribute across the plot. At present farmers tend to irrigate their fields in accordance with this fixed irrigation timetable, which provides support for the assumption that an independent variable like bulk water delivery influence the implementation of irrigation scheduling (Hypothesis 1.1) However, instances of transgression of the water-sharing rules by some plot holders indicate that the current water–sharing timetable is inadequate at times, which illustrates the important role that institutions should play in actively coordinating water delivery and the capacity to revise the schedules.

Some farmers are clearly more successful than others and are more adaptable to the current irrigation cycle, delivery pattern and water delivery schedule. These farmers optimized the use of available water through the reduction of evaporation from the soil surface through the use of mulching, and increased the infiltration rates of soils by applying proper seedbed preparation (prevention of the formation of a plough layer). They also are more aware of the regular maintenance of the secondary canals in the form of weed and invader control to prevent infrastructure damage as experienced in blocks 3 and 4 of the scheme (Photo 12.1).

3. *On-farm irrigation methods (surface irrigation) as constraint to the implementation of irrigation scheduling methods*

Many farmers from Tshiombo perceived “more effective and sustainable irrigation management” as synonymous with the need to change their current furrow irrigation system to either a drip or sprinkler irrigation system. According to Stimie (2003), farmers that use short furrow irrigation can also be very effective if they understand and apply sound irrigation management principles. The following challenges must be incorporated in the management of surface irrigation:

- The variability, in time and in space of infiltration characteristics of soil types is very important. Childs *et al.* (1993) indicated that this variability could play a more important role in variability of infiltrated water than the factors governing the intake opportunity time.

- The control of field levelling is difficult (Pereira, 1996). The preparation at the beginning of the irrigation season is particularly important because it conditions the homogeneity of the water distribution over the irrigated field, as well as the soil characteristics.

- The control of field intake discharges and runoff, which is a common problem for farmers, is essential to effectively control of the depths of water to be applied.

4. Attitude of farmers to participate in institutional arrangements on the scheme

Many of the farmers (especially from blocks 3 and 4) have indicated their dissatisfaction with the water availability on the scheme during April to July of every year, when water shortages are experienced. Because the scheduling of the delivery and availability of bulk water on Tshiombo is based on the cooperation and collaboration of all the water users of the scheme, the institutional arrangements required as well as the general attitude of farmers to adhere and obey these rules and regulations of water sharing are critically important. Some farmers are guilty of transgressions of the irrigation timetable. This together with a lack of commitment to regular maintain secondary the canals is contributing to this problem.

CHAPTER 13

IRRIGATION SCHEDULING IN MPUMALANGA: CASE STUDY 3

13.1 MPUMALANGA SMALL-SCALE IRRIGATION

There are 15 small-scale irrigation schemes identified in Mpumalanga, which comprises of 8109 ha with approximately 191 participants. Table 13.1 captures the information as collected in this survey.

Irrigation development on the small-scale irrigation schemes in the Mpumalanga has been based mainly on establishing commercial farmers, most of who are involved in sugarcane, maize, tobacco, vegetable, subtropical fruit and wheat production (Table 13.1). The majority of small-scale farmers make use of sprinkler irrigation (set-move and floppy sprinklers) to irrigate the variety of crops. Drip irrigation is recently introduced to some of the "newer" irrigation schemes, where farmers use it for irrigation in sugarcane production and production of a variety of subtropical fruits. The small-scale farmers of Mpumalanga are served with extension and information by the Mpumalanga Department of Agriculture, and where farmers are involved in sugarcane production, SASRI extensionists support the extension division of MPDA with "expert" knowledge on production aspects of sugarcane.

13.2 Case study 3: Nkomazi Irrigation Project (Low's Creek, Walda, Figtree, Boschfontein)

The third case study reveals the experience of small-scale sugarcane growers in Nkomazi-east who are served by extension officers of the Mpumalanga Provincial Department of Agriculture (MPDA) and extensionists of the sugar industry (TSB and SASRI) regarding irrigation management and sugarcane production aspects. This reflects on a partnership between the sugar industry and government for the sustainable production of sugarcane.

Table 13. 1: Small-scale irrigation schemes in Mpumalanga (2003)

Irrigation scheme	Size (ha)	Number of farmers	Irrigation scheduling method	Major crops	Irrigation method	Support
Hereford	189	33	Intuition	Vegetables, tobacco	Flood	*MPDA
Elands-doorn	80	50	Intuition and fixed schedule	Vegetables, maize	Sprinkler	*MPDA
Agrisiet	69	11	Intuition & fixed schedule	Vegetables	Sprinkler/centre pivot	*MPDA
Klipspruit	120	4	Fixed schedule	Maize	Sprinkler	*MPDA
Swartkoppies	157	8	Fixed schedule	Maize	Sprinkler/ centre pivot	*MPDA
Leeufontein	4	1	Fixed schedule	Maize	Sprinkler/ centre pivot	*MPDA
Litolo	24	2	Fixed schedule	Deciduous fruit, Vegetables	Sprinkler/micro	*MPDA
Gouwsberg	340	34	Fixed schedule	Maize, vegetables	Flood	Farmer & *MPDA
Mapochs-gronde	350	11	Fixed schedule	Maize, vegetables	Centre pivot, sprinkler	Farmers
Walda	833	82	Fixed schedule, neutron probe, wetting front detector	Sugarcane, vegetables, maize	Sprinkler, drip, floppy systems	*MPDA & SASRI
Buffelspoort	229	32	Neutron probeWetting front detector, fixed schedule		Dragline	*MPDA & SASRI
Low's Creek	285	35	Neutron probe, Wetting front detector, intuition fixed schedule	Sugarcane, litchis, banana	Dragline, sprinkler, drip	MPDA & SASRI
Mfunfane	490	21	Fixed schedule	Sugarcane	Dragline, sprinkle	MPDA & SASRI
Mbunu C	154	17	Fixed schedule	Sugarcane	Dragline, sprinkler	MPDA & SASRI
Magudu Irrigation Dev.	4 785	850	Neutron probe Fixed schedule	Sugarcane, maize, banana, litchi, leather fern	Dragline, sprinkle, centre pivot, flood	MPDA & SASRI
Total	**8 109**	**1 191**				

SASRI= South African Sugar Experimental Station; MPDA= Mpumalanga Department of Agriculture

13.2.1 Background

This partnership arrangement between the South African Sugar Association (SASA) and the Provincial Departments of Agriculture of Mpumalanga and

KwaZulu Natal was signed in 1994, and since then a joint extension program is undertaken to service the smallholder sugarcane growers. Extension officers were seconded to SASA to support small-scale sugar growers with the understanding and application of on-farm technical information. SASRI extensionists serve as specialists and are responsible for the appropriate training of field extension staff. This joint venture is in the interest of both parties. The sugar industry needs sugarcane for their mills at Komatipoort and Malelane, and TSB has allocated a quota of 4 500 ha to the Nkomazi small-scale farmers. The government on the other hand lacks the necessary expertise to effectively serve the small-scale sugarcane growers.

The development activities of Nkomazi Irrigation (Figure 13.1) started in 1985 with the focus on the production of crops like cotton, maize, vegetables, sisal, leather fern and some sugarcane. Since 1990 when the Nkomazi Irrigation Expansion Programme (NIEP) was implemented, the development approach was revised with the emphasis on sugarcane production. The purpose of the NIEP was to establish 19 irrigation projects to support more than 950 small-scale farmers spread over approximately 7 000 hectares of land in the Nkomazi region.

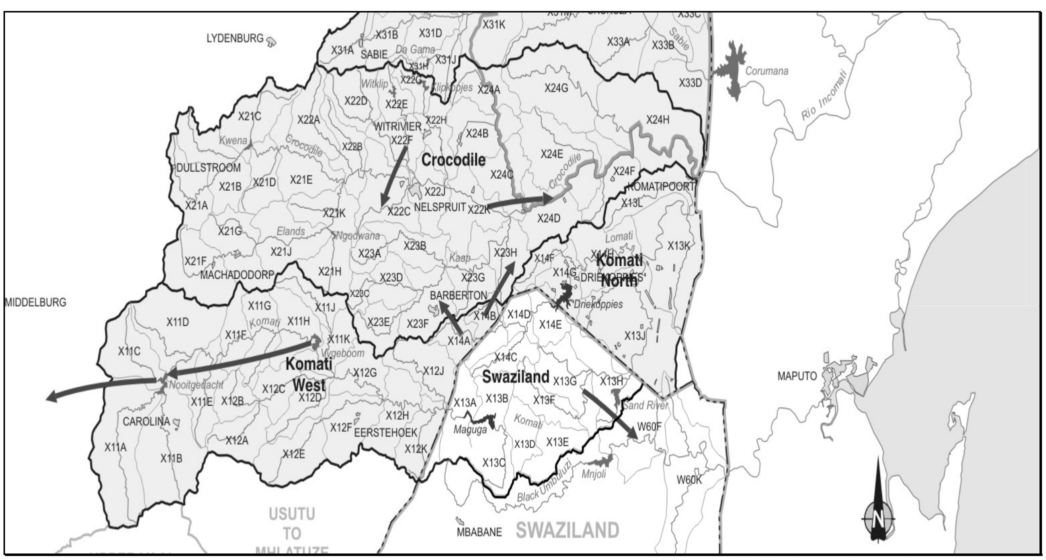


Figure 13. 1: Base map of the Nkomazi Irrigation Scheme within the Inkomati water management area (DWAF, 2004)

Since 1999, the MPDA offered an irrigation scheduling service to small-scale farmers free of charge as part of the agreement with the sugar industry. This service was rendered to some of the small-scale farmers of Walda, Buffelspoort and Low's Creek. Hundred and eight farmers were involved in this irrigation scheduling service rendered by the Division of Agriculture Engineering. Two staff members situated in the Nkomazi area was responsible for the weekly soil water measurements taken with a neutron probe. The data was regularly submitted to an agricultural engineer based in Nelspruit, who was also responsible for the interpretation of the raw data and appropriate recommendations to farmers. These recommendations on irrigation were prepared in consultation with extensionists from SASRI. In general farmers perceived this service very positively and the need was even expressed to extend the service to the rest of the growers. However, this service was discontinued by MPDA during 2002, due to a shortage of operational funds. Subsequently the majority of small-scale sugarcane growers in the Nkomazi follow a fixed irrigation schedule based on SASRI guidelines and without any objective monitoring of the soil water content.

On the irrigation schemes in Nkomazi "energy centres" or field offices have been established, where general administrative duties are taken care of like, the settlement of electricity bills, record keeping and networking where needed. It also serves as a venue for the monthly meetings of farmer groups with the executive committee of the project and it is also used for appropriate training offered by the local extensionists.

13.2.2 Walda Irrigation Scheme

The small-scale sugarcane farmers of Walda use mainly sprinkler and floppy irrigation systems to irrigate. Water availability is generally not a problem to these farmers. The average plot size per farmer is 10 ha, which is divided into 12 blocks of 0.83ha each. Farmers irrigate according to irrigation blocks and follow a three to four hour irrigation cycle every 3-4 days. The general recommendation is not to exceed a net application of 16 mm per irrigation cycle, because of the specific soil type and infiltration attributes of the soil.

Soil types in the Nkomazi area vary quite extensively, but according to Botha (2003), the majority of soil types in this area have a definite plough layer at 30 cm, which prevents the development of the root systems of sugarcane and also impedes penetration of water. The soils at Walda are also relatively high in clay content (approximately 40%), and for this reason farmers should not exceed a net application of 16 mm per irrigation cycle. Farmers usually start to irrigate at 6h00 in the morning till 18h00 when farmers leave for their homes in villages nearby. This practice often leads to relatively low irrigation efficiencies on the scheme due to the high evaporation losses experience from the irrigation between 10h00 and 16h00 as well as the general tendency of farmers to exceed the maximum recommended application rate of 16 mm per irrigation cycle.

13.2.3 Low's Creek Irrigation Scheme

This scheme (282 ha) is found in the Tikhontele village in Mpumalanga and consists of 35 farmers with the average plot size of 7 ha. A canal extracts water from the balance dam to the field. Each farmer is responsible for pumping water from the canal to his specific irrigation plot. The crops that are planted in Low's Creek Irrigation Scheme are indicated in Table 13.2.

Table 13. 2 Crops grown in the Low's Creek Irrigation Scheme

Crops	**Area (ha)**
Sugarcane	218
Litchis & bananas	62
Total	**280**

Farmers use mainly sprinkler, floppy and dragline irrigation system for sugarcane production, while a couple of farmers have changed to the use of drip irrigation. The exception is the one farmer from Low's Creek who uses flood irrigation.

These growers generally follow a fixed scheduled program of daily irrigation as provided by SASRI and with the primary purpose of improving the sucrose content (quality). They usually follow a 10-hour irrigation cycle with the overhead irrigation sprinklers and floppy irrigation system spaced at 14mx12m. For the dripper irrigation the sugarcane rows are 3m apart with one line drip tape per row. Emitters are spaced 0.75m apart and have a flow rate of 1.5l/h. Farmers usually follow a 2-hour irrigation cycle during hot summer periods and decrease it to one hour of irrigation during overcast days.

Farmers in general encountered problems to maintain the sprinklers regularly, and leaking sprinklers and worn sprinkler nozzles were observed during the field visit. All the farmers are staying in villages adjacent to the projects and are therefore not prepared to irrigate during nighttime. Most of the irrigators are old and often reluctant to accept information from the younger extension officers responsible for extension services in the area. Some farmers at the top end of the scheme i.e. furthest away from the water source experience water shortages due to lack of inline pressure because of the over pumping by farmers at the bottom end of the scheme.

13.2.4 Figtree, Boschfontein (1&2) Irrigation Scheme

Figtree and Boschfontein irrigation projects are two irrigation projects in the Magudu Irrigation Development area, situated next the Swaziland border. Farmers are responsible for their own water allocation. The Komati River Irrigation Board controls the scheduling of irrigation water during times of water shortage. The actual water tariff applicable to small-scale farmers in the Nkomazi area is R95/ha/annum.

Farmers irrigate according to irrigation blocks and usually follow a 12-hour irrigation cycle. Each farmer irrigates when it is his or her block’s turn to irrigate. They are allowed to use 11 sprinklers per field (approximately 1.8 ha), but farmers do not always adhere to this and some of the farmers were found to use more sprinklers. It was also very commonly found that sprinkler lines are extended beyond the designed length, and that irrigation cycles of 10-12 hours were found to be changed to longer nighttime irrigation cycles (14-hours) and shorter daytime irrigation cycles (6-hours). Farmers in general encountered problems to maintain the sprinklers regularly, and leaking sprinklers, worn sprinkler nozzles, different sizes of sprinkler nozzles, etc were observed during the field visit.

Farmers from Low's Creek, Figtree, Boschfontein and Walda projects were asked to identify their biggest constraint that prevent them from success with their current farming ventures? Apart from the lack of appropriate credit, relative high electricity costs per month were perceived to be their biggest constraint, which prevents them from profitable sugarcane production. Farmers on these irrigation schemes do not receive individual electricity accounts, but the scheme as the legal entity is accountable for electricity supply services. This leads to injudicious use of electricity, for instance, the unnecessary starting and stopping of pumps when shifting irrigation pipelines in between irrigation cycles.

As shown in Table 13.3, this income statement of a small-scale farmer at Walda for the 2003/2004 seasons illustrates the proportional high operational costs of electricity and irrigation water (24.8%) in comparison with other production input costs of sugarcane. This specific farmer is more progressive and therefore produces an average yield of 83 tons sugarcane per hectare, which is 8t/ha above the break-even point for sugarcane production for this specific area (Swart, 2004). According to Botha & Swart (2003), the average production yield for sugarcane by small-scale farmers in the Nkomazi area varies between 65-70t/ha. This is substantially lower than the average production of 100-110t/ha for commercial growers recorded in the same area. This case study clearly illustrates why the less successful farmers find it difficult to make a profit. These figures support the perception of many farmers on the scheme that electricity costs (and irrigation *per se*) are indeed a major input cost for sugarcane production, especially when farmers are not sensitive to the efficient use of irrigation water on the farm.

Table 13. 3: A statement of income and expenses of a small-scale sugarcane grower at Walda for the 2003/2004 season (Swart, 2004)

Farm size (ha)		4.2
Tons (t)		343
Tons/ha (t/ha)		82
RV% (%)		13.4
Tons RV (t)		45.93
RV price (R)		1 429
Gross Income (R)		65 617
Fat rate (14%)		5 189
Interest on retention		0
Gross income (R)		70 806
Costs	**Costs per ha**	
Irrigation& electricity	1 143	4 800
Hand weeding	350	470
Weed control (chemicals)	450	1 890
Fertiliser	2 300	9 660
Fertilizer application	100	420
Infield irrigation maintenance	50	210
Gapping	100	420
Consumables	100	420
Total	**4 593**	**19 290**

Other important constraints perceived by farmers within the Nkomazi area are:

- Vandalism and theft of irrigation infrastructure like irrigation pipelines, sprinklers, and other equipment during nighttime by members of the villages. According to the farmers, villagers who were not fortunate to have received land are often responsible for this. This stolen irrigation equipment is often found to be used in vegetable gardens in the villages.

- A general lack of appropriate drainage systems was found in the majority of the fields, and because of over-irrigation on many of the fields, access to the different blocks and fields of sugarcane is often perceived to be a problem.

- Farmers' inadequate knowledge of soil preparation, crop and irrigation management skills (Swart, Khosi and Mtembu, 2003).

13.2.5 Lessons learned

1. Behavioural adaptation needed

Many farmers are over-irrigating and therefore water is often observed. Although the soil types commonly found in the majority of the Nkomazi area dictate that farmers should not apply more than 16 mm net irrigation per irrigation cycle, many farmers are found to still practise a 10-12 hours irrigation cycle. This usually leads to over-irrigation and huge run-off.

Many farmers still believe in following the traditional 14-day irrigation interval with an irrigation cycle of 12 hours per position. At an application rate of 5mm/hour, and with soils that in general have a limited water holding capacity, it was found that on many farms the sugarcane crop was showing symptoms of water stress between irrigation applications. According to Swart (2003), this may be one of the reasons for the relative poor production yields that many small-scale farmers experienced.

These findings illustrate the important role that effective communication needs to play between extensionist and farmers, where extensionists and researchers need to understand the complex situation of Nkomazi farmers. This also requires that extensionists and researchers will be prepared to follow different approaches than the technology transfer approach, for instance to apply the principles of adaptive management as applied by many of the small-scale farmers. These findings support the assumption that effective dialogue between extension and Nkomazi small-scale farmers is a precursor to the implementation of irrigation scheduling (Hypothesis 5).

2. *Social constraints influence the general willingness of farmers to adopt irrigation scheduling*

Extensionists and advisors often experience that many of the farmers (owners) on these irrigation projects are part time-farmers, who work in Gauteng or elsewhere and therefore never or hardly ever attend the regular farmer meetings held at the energy centres. The labourers on the fields of these farmers, also not regularly attend monthly meetings, and therefore technology transfer and interactive communication between extensionists, researchers and farmers as decision makers are hardly possible. These social constraints create new challenges to extension and research in an effort to interact with these farmers to ensure that farmers are well informed and understand the potential benefits of irrigation scheduling practices.

3. *Credible ground level support required for implementation of irrigation scheduling*

The success of the interface between extensionists and farmers will depend on the credibility of the extensionists as illustrated through his technical competence in irrigation management. Many of the sugarcane growers in the Nkomazi complain about the technical support rendered to them by extension staff, particularly with regard to the lack of technical knowledge and skills regarding irrigation management. These findings emphasize the urgent need for appropriate training (formal and in-formal) of ground level staff in an effort to provide support to farmers through extension staff that is credible and competent. This supports the assumption that competent extension staff is needed for the implementation of irrigation scheduling (Hypothesis 4).

4. *Attitude and knowledge as important intervening variables that determine the adoption behaviour of farmers*

Apart from a limited number of farmers who were served by the MPDA in terms of weekly soil water measurements with a neutron probe, the rest of the farmers follow a fixed irrigation schedule based on general SASRI guidelines for the production of sugarcane. Much over-irrigation is evident among farmers due to the lack of appropriate knowledge and skills regarding proper irrigation management or because of the relative negative attitude of many farmers who still perceive irrigation water as a right and not a privilege. Farmers from this latter group are therefore not prepared to spend additional time, labour and capital to ensure more efficient water management on the farm, and this finding provides evidence in support of Hypothesis 1, namely that entrenched culture needs to change before they will be willing to adopt irrigation scheduling practices.

5. Inefficient use of institutional arrangements

The energy centres in Nkomazi offer excellent infrastructure and facilities for the offering of appropriate on-site training programs to farmers. However, it appears that extension officers responsible for the servicing small-scale farmers in Nkomazi do not optimally use these facilities and resources. A possible explanation for this tendency is the general lack of technical knowledge and skills of extension officers, their relative low credibility in society, but also the negative attitude and commitment found amongst some extension officers (Swart, 2004).

CHAPTER 14
IRRIGATION SCHEDULING IN NORTHERN CAPE AND FREE STATE: CASE STUDY 4

14.1 NORTHERN CAPE AND FREE STATE SMALL-SCALE IRRIGATION

In the Northern Cape and Free State, the irrigation schemes indicated in Table 14.1 are confined to the few bigger irrigation schemes. This information serves as a summary of information collected from private consultants, irrigation scheme managers, researchers and extensionists from the respective Departments of Agriculture.

Table 14.1 shows that apart from the extension and advisory services that the respective Departments of Agriculture deliver; private consultants are also involved in the training of farmers in certain production skills on table and wine grapes. However, no specific training program is in place for training of small-scale farmers regarding irrigation management. Therefore, farmers usually use fixed irrigation schedules as provided by departmental extension officers and private consultants. Both the consultants and extensionists working amongst these small-scale farmers identified the urgent need for the development of appropriate training programmes to equip them with the basic skills and knowledge in irrigation management principles.

The “mentorship program” that has been adopted by the Department of Land Affairs, was initiated at some irrigation schemes like Opperman. In this program, commercial farmers act as “mentors” to small-scale farmers to help them with the learning of appropriate production and management skills. This program has the potential of playing a very important role in the future training of farmers regarding irrigation scheduling.

Table 14. 1: Small-scale irrigation schemes in Northern Cape and Free State (2003)

Scheme	Area under irrigation (ha)	Potential area for irrigation (ha)	Number of farmers	Major crops	Irrigation method	Support
Riemvasmaak	11	600	25	Grapes, vegetables	Sprinkler, micro irrigation	*NCDA
Jacobsdal	601		17	Grapes, vegetables, wheat, maize	Sprinkler, micro irrigation	*FSDA
Kalffontein	350	350	40	Wheat, maize, cotton, groundnuts	Sprinkler	*FSDA
Bethlehem Apple project	110	110	105	Apples	Micro & drip irrigation	Afgri Trust
Eksteenskuil	620	620	117	Wine grapes	Flood & furrow	ARC Nietvoorbij & *NCDA
Iterleng community	15		8	Lucerne	Flood	*NCDA
Aganang Comm. trust	17		6	Lucerne, wheat, maize	Flood, sprinkler	*NCDA
Drie Eenheid Boerdery	60		3	Maize	Sprinkler	**NCDA
Mahau Trust	25		6	Lucerne	Flood	*NCDA
Opperman	240		48	Wheat, maize	Sprinkler	*FSDA
Zelpy	9		16	Wine grapes	Flood	*NCDA
Total	**2 058**		**391**			

** NCDA = Northern Cape Department of Agriculture; FSDA= Free State Department of Agriculture*

14.2 CASE STUDY 4: APPLE PROJECT IN BETHLEHEM

This case study illustrates how small-scale apple growers with the intensive support of an experienced “mentor” have developed adapted irrigation scheduling methods appropriate for their specific needs.

14.2.1 Background

Apples are grown on a 110 ha farm, which is situated 10 km from Bethlehem on the road (R26) towards Fouriesburg in the Free State. This agricultural development project was started in 1999 as part of a RDP initiative. A partnership agreement was made between 106 small-scale farmers who were interested in apple production, AFGRI (the local agricultural cooperative), Development Bank of South Africa (DBSA) and the municipality of Bethlehem to form a trust. The land was purchased from the municipality, and irrigation water of very good quality and at a special tariff is obtained from the municipality (Gerald dam). The availability of this irrigation water provides farmers with the necessary flexibility to apply scheduling methods that are the most appropriate for the crops grown on the farm.

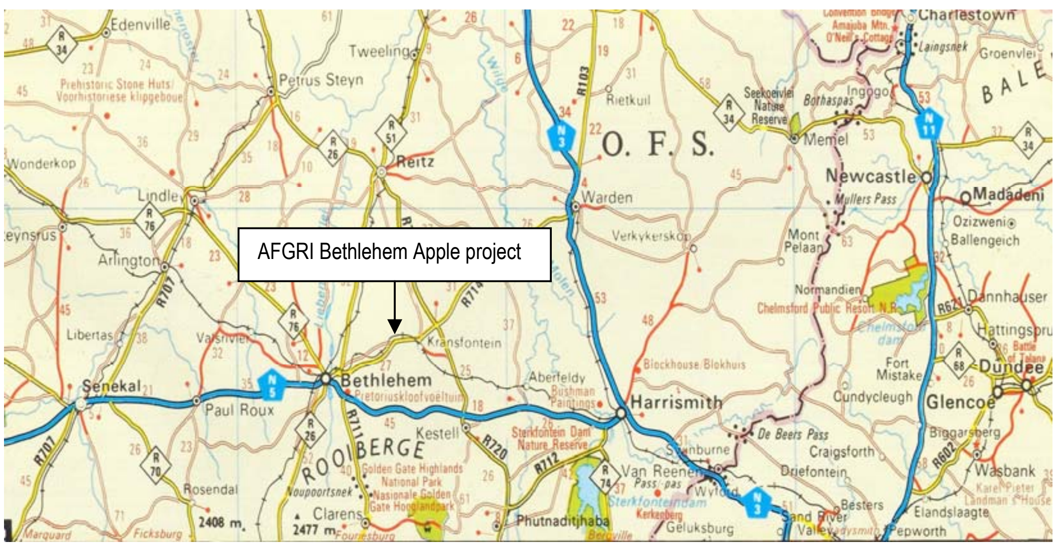


Figure 14. 1: Location map of the AFGRI Bethlehem Apple project outside Bethlehem

An experienced farmer, who had been farming for the past twenty years in the district, was appointed as a mentor to help the farmers in the propagation of apples. One hundred and six farmers were allowed to participate in this project with each participant receiving one hectare of land on which five different apple cultivars were planted. This strategic decision was taken to ensure that all the farmers have the same opportunities to gain experience in the different marketing and management requirements of the different cultivars. The 106 ha apple orchard is divided in 8 different blocks, according to different slopes, soil potential, and topography of the farm to ensure more effective management. A block manager per unit is elected, and serves on the executive committee as a representative of a specific irrigation block, which meets every week. During the weekly meetings, planning and operational management for the next week is discussed and relevant training sessions for block managers and farmers conducted. The executive committee started off under the chairmanship of the mentor, but as capacity was built, it was transferred to one of the block managers.

Each farmer is responsible for the capital investment of the establishment of one-hectare apples. Due to the fact that little or no profit was shown in the development of the project for the first couple of years, farmers were allowed to apply for “an operator’s fee”. This fee was calculated against the net production of his land. The mentor and farmers identified four hectares for experimental purposes where certain irrigation technology and fertilizer trials applicable on the farm are tested. This area also serves as a “demonstration unit” for training purposes of farmers.

14.2.2 Irrigation method and scheduling

With the initial establishment of the orchards, micro irrigation was installed on the first 56 hectares, but as from the second year of development, drip irrigation was installed on the remaining area. Apple rows are 1.5 m apart with 2 lines of drip tape per row. Emitters are spaced 0.75 m apart and have a low rate of 3l/h. In the micro irrigation, there is one line per row with the emitters spaced at 0.75m. Farmers, block managers and the mentor have indicated their preference for the use of drip irrigation for the production of apples from a management and maintenance point of view. Drip irrigation is perceived to lend itself to allow for the practising of fertigation, and therefore, more precise fertilizer management as needed for the five different cultivars.

Photo 14. 1: Apple orchards under drip irrigation in the AFGRI project for small-scale farmers outside Bethlehem (2003)

These farmers use a fully automatic Motorola computer system, which controls the irrigation on the 8 irrigation blocks. The SAPWAT model for irrigation planning and prediction of crop water requirements is also implemented on the farm. All the relevant climatic and weather data was collected until 2001 from an automatic weather station installed on the farm. However, due to vandalism and the destruction of the station on the farm by some farmers who were expelled from the project, the weather station at the Small-Grain Institute (Bethlehem) is subsequently being used. This weather data was initially used for the adaptation and attuning of the predictions made by SAPWAT regarding the crop water requirements.

The measurement of the soil water content is done through the use of tensiometers. Relatively early in the development of the project it was realized that figures alone do not mean anything to a farmer, until "practical value" is added. The soil auger together with the use of a tensiometer added meaning and interpretation to tensiometer readings in terms of "relative dryness and wetness". Since the farmers and mentor on this project experienced many problems with unreliable tensiometer readings, tensiometers were replaced by the use of gypsum blocks. Gypsum blocks were found to be more appropriate and easier to use by the farmers. According to the mentor gypsum blocks also provide more accurate readings.

Farmers are convinced that the regular use of a soil auger in monitoring the soil water status helped them to develop the irrigation management strategy currently followed.

Every week, 3-4 blocks are identified for the digging of soil pits for inspection and for validation purposes of the readings as per tensiometer or gypsum pad. These opportunities are also used to train block managers and farmers of a particular block in the use of different irrigation scheduling tools (e.g. feel method) and to illustrate practical orchard management. This learning based approach provides ideal opportunities for experiential learning of farmers, where farmers' skills and understanding of irrigation management dictate where to start with the training. These training opportunities also serve as feedback to the management system. These training sessions help to make irrigation scheduling models like SAPWAT, more appropriate for the specific conditions that prevail. According to Fourie (2002), SAPWAT was initially over-predicting the crop water requirements of the apple trees on the farm, and through intensive monitoring with soil augers and regular observations by farmers it was successfully attuned.

Farmers are expected to attend regularly the training sessions arranged for a specific block. Block managers also help the participating farmers with general dissemination of information on irrigation management. Irrigation specialists from Stellenbosch assist in this project with the evaluation of the applied irrigation management on a two yearly basis. Although the exercise was recognized as perhaps an unnecessary and expensive, block managers as well as the mentor were convinced that it added much value to this project.

14.2.3 Lessons learned

1. Farmer "ownership" a prerequisite for taking responsibility

This project illustrates the importance of the development of proper institutional structures, where farmers take ownership and are trained in several aspects of irrigation management and leadership. Small-scale farmers should participate in all phases of the irrigation scheme and should be treated as “owners” rather than as “beneficiaries” of a project. As a general rule, an innovation is better adopted if the small-scale farmer themselves participate in the setting up process and operational decision-making (Fourie, 2002). External management is not conducive to farmers’ taking responsibility for their farming enterprises. The farmers tend to neglect the maintenance of equipment if they do not see it as their responsibility.

2. Experiential learning as an alternative approach of training

The learning based approach used in this case study relies on the training of trainers or mentors (block managers), and recognizes the importance of the farmers’ role in the dissemination of information to other farmers. This approach was found to be very successful in stimulating efficient interaction between the various stakeholders (mentor, farmers and researchers). The implementation of experiential learning by farmers and the opportunities provided for feedback on their experiences to the executive committee, proved to be successful in the building of irrigation management capacity amongst block managers and farmers. These findings provide support for the assumption that effective dialogue between the small-scale farmers, mentor and professionals involved in this project is a precursor for the adoption of irrigation scheduling (Hypothesis 5).

3. Mentorship role in the changing of adoption behaviour

This project also demonstrated a possible route to be followed in the development of appropriate scheduling methods adapted for a specific farm. The important role to be played by a mentor or an extensionist in the support of new farmers (small-scale) on a daily basis cannot be over emphasized. According to de Beer (2005) “mentoring is simply someone who helps someone else to learn something the learner would otherwise have learned less well, more slowly or not at all.” Without this important support, the application of sustainable irrigation management practices by small-scale farmers is more unlikely. The importance of the selection of the right person to fulfil this job cannot be over emphasized. This person must have comprehensive expertise in order to gain the confidence of the farmers and be able to articulate terminology and concepts in a language that farmers can understand and apply. It is expected of the protégé to respect and trust the mentor to establish a caring relationship in an effort to accelerate the learning curve. The evidence collected from this case study at Bethlehem supports the assumption that competent ground level support (a mentor in this project) is conducive for the adoption of irrigation scheduling (Hypothesis 4).

4. *The need of precise irrigation scheduling techniques in the production of high value crops*

The need for embarking on the use of more precise irrigation scheduling when involved with the production of high value crops like apples were illustrated in this case study. Farmers as well as the mentor are convinced that the net benefits in spending more time, capital and resources on precise monitoring of the soil water status are positively reflected in terms of production efficiency (yield and quality of apples). This provides support for the assumption that farmers perceive an improvement in production efficiency with the implementation of precise irrigation scheduling (Hypothesis 2). The important role of quality interactive communication between research, consultants, mentor(s), block managers and farmers was illustrated in the learning that farmers undertook and the capacity that was build among the small-scale farmers.

CHAPTER 15

IRRIGATION SCHEDULING IN NORTHWEST: CASE STUDY 5

15.1 NORTHWEST SMALL-SCALE IRRIGATION

In Northwest Province, the discussion is restricted to the larger irrigation schemes that occur in the province, namely Taung and Disaneng irrigation schemes (Table 15.1). Except for the Taung and Disaneng irrigation schemes, which are commercially orientated, the majority of the 20 irrigation schemes in Northwest Province are based on vegetable growing both for food security and additional household income (Branken & de Kock, 2001). Apart from these two larger irrigation schemes, many community gardens are found in the province where farmers produce vegetables by making use of hosepipe, flood and dragline irrigation methods. The Northwest Department of Agriculture (DOA Northwest) is the main agent that supports these food plot growers. According to Swanepoel (2004), farmers are trained in relevant cultivation practices and a fixed schedule of irrigation applies for the majority of food plot growers.

Table 15. 1: Small-scale irrigation schemes in the Northwest Province (2003)

Scheme	Area under irrigation (ha)	Number of farmers	Irrigation method	Crops	Support
Taung	3580	411	Centre pivot, sprinklers	Maize, cotton, wheat, groundnuts, barley,	Northwest Dept. of Agric, Suidwes Cooperative, SA Malsters.
Disaneng	204	66	Sprinkler	Lucerne, table grapes, deciduous fruit, maize, wheat	Northwest Dept. of Agric
Total	**3 784**	**477**			

Table 15.1 shows that approximately 477 farmers are registered under these two irrigation schemes and with the exception of Taung, they use sprinkler irrigation systems to irrigate their crops. On Disaneng Irrigation Scheme, farmers produce table grapes and deciduous fruit on a very small-scale, and focus mainly on the production of lucerne and cereal crops like maize and wheat. Although this project was initiated by the Northwest Department of Agriculture, the ground level support required by farmers with regard to irrigation management is lacking because of the technical incompetence of extension officers (de Kock, 2001).

15.2 CASE STUDY 5: TAUNG IRRIGATION SCHEME, NORTHWEST

The last case study deals with a small-irrigation scheme, namely Taung Irrigation Scheme, in the Northwest Province. This scheme reflects a partnership agreement between farmers and the private industry.

15.2.1 Background

This scheme was established in the former Bophuthatswana homeland, which now forms part of the Northwest Province. It was started in 1939 with flood irrigation on two "morgen" plots and has always been known for water wastage and poor soil quality. Presently the scheme is using centre pivots irrigation systems that were introduced when Agricor developed the scheme in 1979.

The scheme is approximately 3 580 ha in size and 411 farmers are registered under the scheme. Each farmer has an average plot size of 7.5 ha. The scheme receives bulk water from the Vaal River via the Bloemhofdam. An open canal system is used from Vaalharts to Taung. The scheme has three balancing dams each with varying water-holding capacity. Water is controlled and distributed through water bailiffs. Water is ordered on a weekly basis from the main source and farmers are currently paying a yearly water tariff of R154/ha.

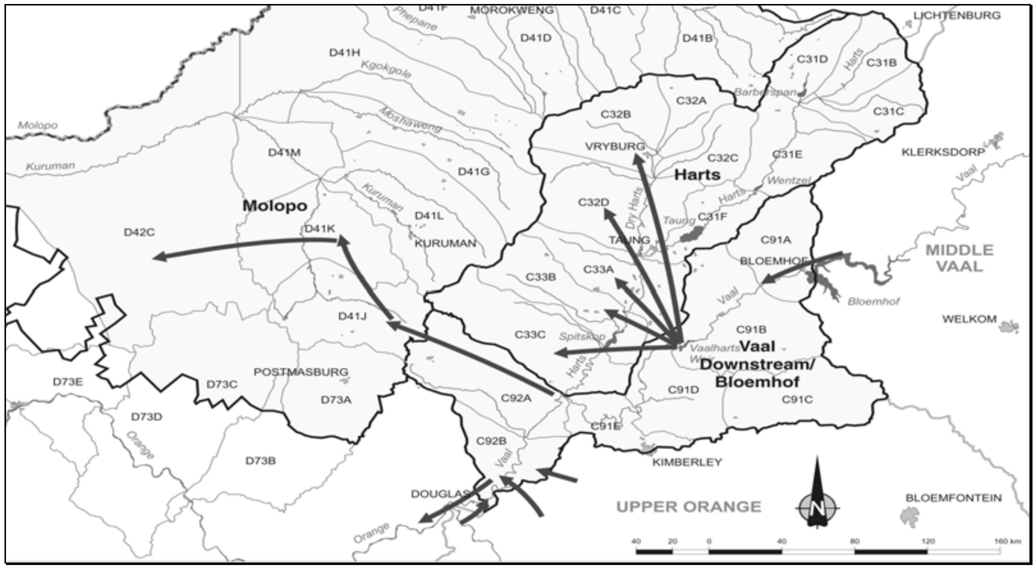


Figure 15. 1 Base map of the Taung Irrigation Scheme within the Lower Vaal water management area (DWAF, 2004)

15.2.2 Irrigation methods and scheduling

Three to four farmers usually share a centre pivot, which implies that they must plant crop types that have the same crop water requirements. There are currently 73 centre pivots in operation. A major problem found on the Taung Scheme is that the centre pivot irrigation systems were designed for 16-12 ha, but as farmers became more successful in the past, the irrigation systems were extended to the current 30 and 40 ha centre pivot irrigation systems. This however inevitably led to inefficient irrigation systems in terms of under-designed suction heads (only 3 kPa), which resulted in inefficient application and distribution of irrigation.

Since the majority of the centre pivots are 20-22 years old, the maintenance costs experienced by farmers are relatively high. Until 2000, the Department of Agriculture Northwest (DOA Northwest) was responsible for structural breakages experienced on the irrigation systems, but this has subsequently been transferred to the account of the individual farmers. Before 2000, farmers were only accountable for the maintenance of the systems in terms of sprinkler packages, pumps, motors, and maintenance of pump house. A private irrigation company is currently contracted to help farmers with the maintenance of irrigation systems, and farmers are informed to be aware of the costs in this regard (Erasmus, 2003).

Photo 15. 1: Relative old and often under-designed centre pivot irrigation systems used for crop production at Taung Irrigation Scheme (2004)

A variety of crops are planted on Taung Irrigation Scheme, with the major crops being maize, groundnuts, and cotton during the summer months and wheat and barley as winter crops. Farmers make use of the private sector to help them with the financing of their summer and winter crops. Suidwes Cooperative supported farmers with production loans for the summer crops (maize and groundnuts) during the 2002 and 2003 production seasons, while South African Malsters (SAM) provide support to 211 farmers for the production of barley. The irrigation scheduling methods that farmers follow in the production of the different crops varies as indicated in Table 15.2.

Farmers use fixed irrigation schedules for the production of summer crops like maize, groundnuts, while BEWAB and fixed irrigation schedules are used for the production of wheat. It was found that the majority of maize farmers follow a 7-day irrigation cycle.

Table 15. 2: Different irrigation scheduling methods applied on Taung Irrigation Scheme

Crop	Irrigation scheduling method
Summer crops: maize, groundnuts, lucerne	Fixed irrigation schedule
Wheat	BEWAB, fixed schedule
Barley	BEWAB, neutron probe, GWK program, SWB, irrigation calendars

In the production of barley, farmers started off with the use of the BEWAB predictions for scheduling as being practised with the production of wheat, since the industry as well the ARC in Bethlehem could not provide adapted guidelines for irrigation of barley for the Taung area. This program initially worked well until signs of over-irrigation were observed especially during the initial stages of the production season, while under-irrigation occurs during critical crop growth stages. Since 2003, the University of Pretoria has been involved in a research project to develop an irrigation scheduling program suitable for the production of barley but also adapted for the conditions of the small-scale growers in Taung. The SWB model is used to generate site-specific irrigation calendars, which can be used by the farmers for irrigation of their crops.

Apart from the on-going research, a private irrigation consultant was appointed since 2003 to measure the soil water content on a weekly basis with a neutron probe. The computer scheduling program, which the consultant is using, is similar to the one that Griekwaland Wes Cooperative uses. This scheduling service provided to the barley growers at Taung is compulsive and farmers have to pay for this service. The information provided by these weekly measurements, plus the data collected through research and the general observations made by experts from the industry helped farmers and extensionists to attune the irrigation scheduling program that is presently used.

Five Farmer Support Units (FSU) are in operation at Taung. A FSU usually comprises of 40-80 farmers, who meets regularly to discuss important aspects of crop cultivation, which also includes principles of irrigation management. Since 2001, a full time extensionist was appointed for the support of the farmers involved in barley production. This person enjoyed specialist training in the production of barley before he was appointed to support farmers involved in this project.

15.2.3 Lessons learned

1. *Competent ground level support needed for high precision irrigation technology*

It is clear from this specific case study that the use of relative high irrigation technology like centre pivots often requires the support of appropriate trained professionals to ensure efficient use of this equipment. Although this type of irrigation system is relative easy to manage, it requires farmers to understand concepts like the correct calculation and implementation of the nozzle chart of the machine, ensure that the end gun is correctly set, etc. Without intensive support and resources available to fund this type of support required, small-scale farmers usually found it difficult to complete the steep learning curve that is expected in the production of high value crops like the growing of barley under centre pivot irrigation systems. SA Malsters are offering extension support that exists in the form of a mixture of advice giving (providing a recipe on irrigation scheduling) and education or learning (proactive learning in an effort to promote independency). The experience gained with this case study at Taung supports the need for interaction or a “dance” Hayman (2001) between small-scale farmers and competent ground level support with the implementation of sound irrigation management (Hypothesis 4).

2. On-farm irrigation system as a constraint to the implementation of irrigation scheduling methods

Cognizance should be taken of the original capacity and design of an irrigation system before allowance be given to extend the irrigation systems to satisfy the need of additional farmers. This aspect is clearly illustrated at Taung where a decision to extend the centre pivots originally designed for 10-12 ha to 30 ha, not only affected the uniformity of irrigation water application but caused tremendous practical problems that neither the farmers nor the professionals could attend to. This inevitably leads to inefficient irrigation practices that could not be rectified by the implementation of irrigation scheduling alone.

3. Institutional arrangements determine the efficiency of collective irrigation management

Sharing of irrigation equipment like the 73 centre pivots at Taung is only possible with good cooperation between farmers. Farmers need to be well organized, and be able to manage and maintain their shared equipment. Five FSUs are in operation at Taung, and farmers are represented in the management committee, which is responsible for strategic decisions regarding the distribution of water and the general rules applicable in the operation of the irrigation scheme. Aspects of irrigation management are currently not discussed at FSU level, although the management committee could play an important role in changing farmers' attitude, perception and behaviour regarding the implementation of sound irrigation practices. During these monthly meeting SA Malsters capacitate farmers by offering appropriate training.

This case study also reveals that without proper institutional arrangements the changing of farmers' irrigation management behaviour will be very slow. The implementation of effective irrigation schedules and sound on-farm irrigation management is impossible if appropriate institutional arrangements do not exist. This supports partially the assumption that independent environmental variables like institutional arrangements influence the adoption behaviour of small-scale irrigation farmers (Hypothesis 1.1).

CHAPTER 16

IRRIGATION SCHEDULING IN OTHER PROVINCES

16.1 WESTERN CAPE SMALL-SCALE IRRIGATION

Small-scale farmer irrigation in the Western Cape is confined to a few schemes. The figures as presented in Table 16.1 are based on a survey completed in 58 small-scale farming communities during 2002. The Department of Agriculture, Western Cape and LANOK (Landbou Ontwikkeling Korporasie) are responsible for the rendering of extension and support to small-scale farmers in the Western Cape. LANOK is mainly responsible for the provision of production credit to farmers but also renders extension services and support where applicable to farmers regarding certain commodities.

Table 16. 1: Small-scale irrigation schemes in the Western Cape (Saaiman, 2003)

Sub region	No of schemes	Number of food plot holders	No of comm. farmers	Total number farmers	Area under irrigation (ha)	Major Crops	Irrigation method
Northwest	6	304	6	310	58	Citrus, lucerne, vegetables grapes	Sprinkler, furrow
Swartland	14	419	7	426	90	Vegetables, flowers, deciduous fruit	Sprinkler, furrow, micro
Boland	12	575	2	577	18	Vegetables, flowers, deciduous fruit	Sprinkler, furrow, micro
Klein Karoo	9	240	12	252	81	Potatoes, vegetables, deciduous fruit	Sprinkler, furrow, micro
South Coast	17	408	3	411	107	Vegetables	Sprinkler
Total	58	1 946	30	1 976	354		

According to the survey done by the Department of Agriculture (2003), 85 percent of the small-scale farmers are involved in food plot production for food security and additional household income. The relative more commercially oriented small-scale farmers earn more than R20 000/annum and are mainly involved in the production of crops like flowers, lucerne, deciduous fruit, and grapes.

According to Beukes (2002), the majority of small-scale farmers do not make use of objective irrigation scheduling methods, but rely on the use of local knowledge, experience or a fixed irrigation schedule. She is of the opinion the average small-scale fruit grower in the Western Cape lacks the basic knowledge and skills regarding proper soil preparation, cultivation of fruit and irrigation management. Only a relatively small percentage of the newly settled small-scale fruit growers are properly trained in irrigation management and have the necessary confidence to apply irrigation scheduling methods like the use of evaporation pans, feel method, etc.

Du Plessis (2002) is of the opinion that small-scale irrigation farmers' decisions regarding a specific irrigation interval and length of an irrigation cycle to follow are mainly determined by availability and reliability of irrigation water. Since irrigation water availability and reliability are often problematic in some irrigation areas, many of the small-scale fruit growers in the Western Cape are guilty of under-irrigation of their crops.

16.2 KWAZULU NATAL SMALL-SCALE IRRIGATION

In KwaZulu Natal there are 18 irrigation schemes, comprising of 6 923 ha and many community gardens that are either already established or in the process of being established (Table 16.2).

Table 16. 2: Small- scale irrigation schemes in KwaZulu Natal (2003)

Scheme	Area irriga-ted(ha)	Participants			Irrigation method	**Major Crops**	Support Agency
		CF	FPH	Total			
Bululwane	350	-	430	430	Flood	Vegetables, maize	KDA
Mzondeni	167	43		43	Sprinkler	Maize, wheat, cotton, vegetables	Illovo sugar
Ndumu B	150	11		11	Sprinkler	Sugarcane	KDA
KwaDlama	167	43		43	Sprinkler	Sugarcane	Tongaat/ Hulett
Biyela	501	277		277	Sprinkler		Tongaat/ Hulett
Ngwelezana	16	-	105	105	-	Vegetables, maize	KDA
Nzimele	338	125		125	Sprinkler	Sugarcane	Tongaat/ Hulett
Mkuphula	20	-	244	244	Flood	Vegetables, maize	KDA
Mooirivier	340	-	760	760	Flood	Vegetables, maize	KDA
Tugela Ferry	540	-	1832	1832	Flood	Vegetables, maize	Illovo
Mansomeni	186	63		63	Sprinkler	Vegetables, maize, sugarcane	Illovo
Sinamfini	272	-	176	176	Sprinkler	Vegetables, maize, sugarcane	Lima
Shinga	20	20		20	Sprinkler	Vegetables, maize	Illovo
Daka Daka	234	160		160	Sprinkler	Sugarcane	Illovo
Mthondeni	93	33		33	Flood	Sugarcane	KDA
Tukhela Estate	374	-	1275	1275	Sprinkler/ flood	Maize, wheat, vegetables	KDA
Makhatini	2 620	259		259	Sprinkler	Sugarcane, cotton, maize, vegetables, wheat	Vunesa Cotton
Impala	535	47		47	Sprinkler/semi-dragline	Sugarcane	KDA/ SASRI
Total	**6 923**			**5 903**			

KDA = KwaZulu Department of Agriculture, SASRI= South African Sugar Research Institute

FPH = Food plot household; CF= Commercial farmer.

Makhatini irrigation scheme

The Makhatini scheme is the largest in the province and has an estimated irrigation potential of 12 000 ha from the Jozini Dam. During the time of the interviews conducted with officials from ARC and Vunisa Cotton (2002), irrigation farming activities at Makhatini had been limited to 50 ha. Only five farmers were involved in the production of cotton and sugarcane under irrigation. According to Steyn (2002), the biggest constraints that irrigation farmers on Makhatini face with crop production are the fact that many of the farmers still struggle with debt accumulated from previous production seasons and access to appropriate credit facilities. Rain fed cotton production out-produced irrigated cotton production for the last couple of production seasons, and therefore many farmers switched to rain fed cotton production. The role of Vunisa Cotton is to support the cotton growers with access to credit, establishment of appropriate marketing opportunities and supply of technical support on cotton production. No objective scheduling methods are implemented by farmers who rely on a fixed schedule as provided by the industry.

Apart from the accumulated debt that farmers are struggling with, the following constraints prevent farmers from optimal crop production at Makhatini irrigation scheme as been identified by the Vunisa Cotton extensionist:

- Lack of adequate maintenance of their irrigation systems. Many nozzles and sprinkler packages were in a very poor condition, and in need of replacement.

- Cultivation practices of farmers are in general not appropriate due to lack of production knowledge and proper equipment.

- Lack of financial capacity to take care of day-to-day problems like the repairs and maintenance of machinery and irrigation equipment.

- Inadequate skills and technical knowledge of departmental extensionist regarding irrigation management.

- Vandalism and theft.

Apart from cotton and sugarcane produced on the Makhatini irrigation scheme, the other irrigation schemes mainly produce sugarcane and vegetables. SASRI, Tongaat, Illovo, and Hullet Sugar jointly deliver extension support in the production of sugarcane together with KwaZulu Natal Department of Agriculture as part of the partnership agreement, which was established in 1994. In KwaZulu Natal, two extension officers were seconded to SASA, and another two operated on a 50:50 time basis. These four extension officers supervise the extension activities of forty technicians from the Department of Agriculture. These extension officers and technicians provide technical assistance for the production of sugarcane. No official scheduling service is rendered to small-scale farmers who, in general, use fixed irrigation calendars as prepared by the sugar industry.

Tugela irrigation scheme

At Tugela Ferry Irrigation Scheme the majority of farmers (65%) are using short furrow irrigation. The supply infrastructure to the different blocks consists of parabolic concrete canal sections, reducing in size towards the end of the scheme. Water is diverted into the block with smaller lined canals and farmers receive water at a fixed time during the week. This canal-supplied short furrow system with fixed irrigation turns makes it difficult to adapt the time and quantity of water applied which are critical elements in irrigation scheduling. It is often found that most farmers apply more or less the same amount of water (mm) during the season, irrespectively of the crop water requirements.

As far as irrigation timing is concerned, a farmer has to irrigate when it is his turn. It may be that the soil still contains adequate soil water for crop production and therefore the additional irrigation application simply passes through the wetted soil profile beyond the active root zone, or it may be that the soil had already dried out beyond the allowable depletion level and that the crops have already suffered as a result. The amount of water that can be directed to the field depends on the slope and the size of the supply furrows and it is only by varying the in-flow time to each furrow that the amount of water applied to crops can be adapted.

16.3 GAUTENG SMALL-SCALE IRRIGATION

In Gauteng, apart from the many community gardens (approximately 1 200 ha) that were established or are still in the process of being established (Potgieter, 2002), Rust de Winter (Table 16.3) is the only large irrigation scheme utilized for commercial crop production. Since 1994, the problem of land tenure status of farmers has not yet been resolved, and this is still regarded by farmers as their biggest constraining factor. Short time period tenure contracts are also restricting people's investment in the property they occupy and therefore limit the level of land utilization. These socio-political issues are according to Botha *et al.*, (2000) inhibiting the normal development and functioning of the irrigation scheme.

Table 16. 3: Small-scale irrigation schemes in Gauteng (2003)

Scheme	Area under irrigation (ha)	Number of farmers	Irrigation method	Crops	Support
Rust de Winter	827	35	Centre pivot, sprinklers	Maize, cotton, wheat	Gauteng Dept. of Agric.

CHAPTER 17
SUMMARY

Certain essential factors were identified that influence the performance of small-scale irrigators namely: group cohesion, institutional support, efficiency and structure of the management committees, choice of crops and market strategy, appropriateness of technical design of irrigation systems, irrigation management capacity and the general commitment of irrigation farmers.

It is clear from the incorporated case studies that the approach to irrigation management on small-scale irrigation schemes differs between the traditional small-scale irrigation schemes and where partnership agreements with the private sector were made. These partnership agreements illustrated the necessity to take first care of precursor problems to irrigation scheduling, namely water availability, poor distribution uniformities, limitations to farm layout, identification of appropriate markets and efficient irrigation system design before farmers will be prepared to focus on irrigation scheduling.

In general it was found that the weak institutional arrangements and handling of farmers' affairs on scheme level on several small-scale irrigation schemes hampers sustainable agricultural development. Farmers in general also lack important skills such as leadership, organizational capacity, management and agribusiness skills. The challenge facing extension and rural developers in general is to build the necessary capacity of farmers and to strengthen institutional management.

The case studies illustrated that a clear set of rules and regulations for acquisition, conveyance, delivery and distribution of irrigation water to small-scale irrigation schemes apply. A framework for irrigation scheduling on a small-scale irrigation scheme (Table 17.1) distinguishes three levels of operation; the main system for irrigation water acquisition, conveyance and delivery to tertiary units, the tertiary system for water distribution among farmers and the field system for water application. Since these rules are made at different forums (main, tertiary and in-field water delivery systems) there is a need for effective communication between the various parties exist so that planned and actual water delivery as well as in-field application of irrigation water can take place in a meaningful way.

Table 17. 1: Institutional framework of water delivery necessary for irrigation scheduling

	Management responsibility	Agency responsible
1.	*Main water delivery system:* acquisition, conveyance and delivery to tertiary system.	DWAF
2.	*Tertiary system:* decide on water distribution and system management on a scheme level among farmers.	Block committees, management committees, farmer support units, Water User Associations
3.	*Field level:* the irrigation system on-farm will determine the amount of water that could be applied in the field and will influence the crop selection, use of agro inputs, irrigation scheduling method.	Farmers

Sprinkler irrigation is attractive to many of the small-scale farmers – but the finding shows that it could lead to excessive water use like in the Nkomazi. Many of the small-scale farmers are of the opinion that short furrow irrigation is inappropriate and not efficient, for sustainable food production. There is however an increasing realization amongst scientists that one should rather support farmers with their current irrigation systems and try to improve the general irrigation management efficiency (prevent water logging at the bottom of the furrow for instance) through appropriate training and efficient dialogue between farmers, research and extension.

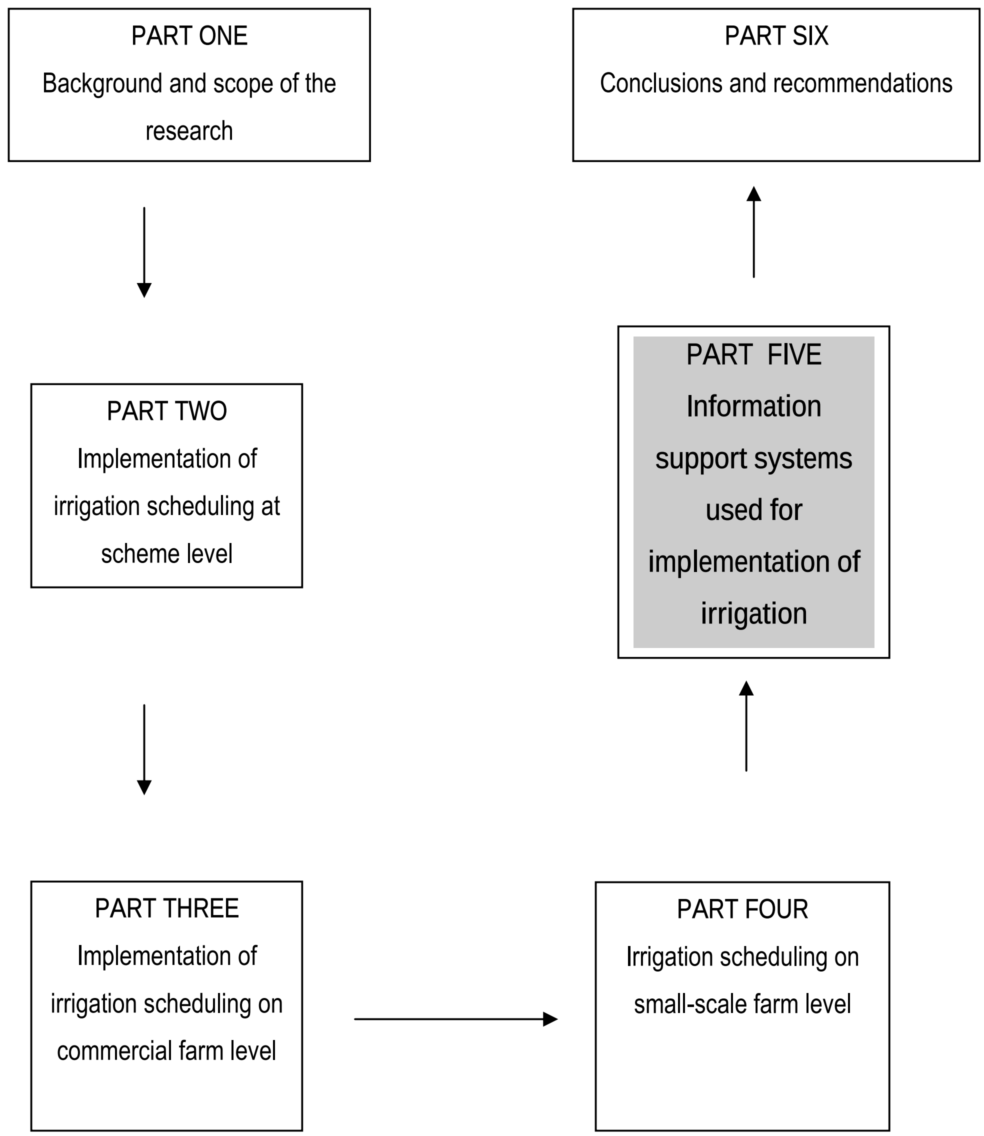
Consultants and extensionists without appropriate technical training and understanding of the situation of smallholder irrigation development should rather not participate unless they receive appropriate training beforehand. Many small-scale farmers mentioned the serious lack of competent advisors and extensionists with specialized training in irrigation. In several interviews held with extension officers it became clear that they had little to offer farmers regarding irrigation management. One of the extension officers in KwaZulu Natal even said that irrigation was not part of their job description, as his perception of "irrigation management" entailed only the engineering aspects namely water supply, distribution, and infrastructure.

Irrigation management was found to be perceived by the majority of small-scale irrigation farmers as "new technology" and it is therefore imperative that appropriate training curricula and training manuals be developed to support extensionists and advisors with the training of farmers. The innovation processes of irrigation scheduling techniques with its three main components namely, creating a technique, dissemination of the idea and the adoption of it, form a whole. The three components cannot therefore be allocated to different role players namely research who design the technique, extension services to disseminate the information and farmers to adopt the technology without effective interaction between the relevant parties. Small-scale farmers, as illustrated in the case study at Bethlehem should be included in the process of innovation and conditions should be created for them to participate.

The learning based approach used in the projects as indicated in the case studies of Bethlehem and Taung, requires extension officers and advisors to perform new roles. Illiteracy amongst many of the small-scale farmers poses specific training problems to overcome. Experiential learning can address this problem but requires people with the necessary skills and knowledge to help and support farmers. Extension officers should be equipped with the necessary skills to effectively play the facilitators' role in starting of a dialogue with farmers and in listening sympathetically to what farmers have to say.

PART FIVE

INFORMATION SUPPORT SYSTEMS USED FOR IMPLEMENTATION OF IRRIGATION SCHEDULING



CHAPTER 18

AGRICULTURAL KNOWLEDGE SUPPORT SYSTEMS USED FOR IRRIGATION SCHEDULING

18.1 INTRODUCTION

In Chapter 9 (section 9.2) the role of various actors was identified in creating awareness with regard to the potential role that irrigation scheduling can play on the farm. This intervention helps to create the conditions for learning about irrigation scheduling. This chapter identifies the role of "outsiders" (e.g. scientists, experts from industries and irrigation consultants) and "insiders" (e.g. family members, fellow farmers, opinion leaders) to inform and help farmers with the implementation of on-farm irrigation scheduling.

18.2 AGRICULTURAL KNOWLEDGE INFORMATION SYSTEMS USED BY IRRIGATION FARMERS

Farmers make use of a variety of information sources that forms part of the Agricultural Knowledge and Information System (AKIS), which links irrigation farmers and institutions to promote mutual learning and generate, share and utilize irrigation management technology, knowledge and information. The AKIS system integrates farmers, educators, extensionists and researchers as part of the agricultural knowledge triangle to harness knowledge and information from various sources for better farming (Röling, 1989; Engel & Solomon, 1997; FAO & World Bank, 2000).

Knowledge can be seen as the basic means through which farmers understand and give meaning to the world around. Knowledge and perceptions are closely intertwined with the concept information. According to Leeuwis (2004), perceptions or meanings inform us about a particular state of affairs, and this constitutes information. With the help of information, farmers reduce uncertainty and bring order to the world around them.

The process of introducing information on a new irrigation scheduling method into the farmers' psychological field or life space requires appropriate support and communication network structures between researchers, irrigation system managers, extensionists, consultants, advisors and farmers. There is an increasing recognition that in order to understand information seeking, we need to understand the social context in which it takes place and the factors that influence it (Chang & Lee, 2000; Cool, 2001; Solomon, 2002). Information seeking in its broader context is often termed "information behaviour", which is defined by Wilson (1999) as the activities a person engages in when identifying his or her own needs for information, searching for such information and using that information for decision-making. As Webster (1995) points out, the semantic definition of information implies that "information is meaningful, it has a subject, and it is intelligence or instruction about something or someone".

The opinions of family members are often incorporated into the process of decisions making in farm management and the selection of irrigation technologies (Ellis, 1993; Jackson, 1995). Beyond the household members, irrigation farmers access multiple sources of information and belong to a diversity of "learning systems" (Schön, 1983, Lundvall, 1992; Kilpatrick, 1997), which include both formal and informal information networks. Expert advisors, farmer groups and training events form part of this network and play a crucial role in adoption decisions (Chamala & Mortiss, 1990; Frank & Chamala, 1992; Pretty & Shah, 1994; Chamala & Keith, 1995).

Farmers draw from a range of sources and types of information in their interactive learning about irrigation management (Figure 18.1), which also serve as learning organizations (Senge, 1993):

- *Private irrigation consultants*, which provides consultation services, based on a user-pay system. A more detail discussion of the profile of private consultants involved in irrigation management will follow in Chapter 19.

- *Cooperative extension officials:* some of the bigger agricultural cooperatives are rendering an irrigation scheduling service that is also based on a user-pay system, where farmers are responsible for the direct cost involved with such a service (e.g. transport and basic fee per visit).

- *Representatives* of seed, fertilizer and pharmaceutical companies.

- *Fellow farmers or the farmer himself*.

- *Extension officers from the Department of Agriculture and officials from Department of Water Affairs.*

- *Farmer study groups and growers' societies* like the avocado, banana, and table grape grower's societies.

- *Representatives and advisors* from irrigation companies mainly responsible for the designing of irrigation systems and selling of irrigation technology.

- *Commodity institutions or industry specialists* like for instance Vinpro (KWV), Cape span (citrus and deciduous fruit), SASRI (South African Sugar Research Institute), etc.

- *Irrigation Board Scheme or Water Users Association officials*.

Figure 18.1 shows significant differences with regard to the information sources that irrigation farmers use to help them with irrigation management decisions (F=5.0, p=0.038). The respective role of each of these information sources as revealed in Figure 18.1 will be discussed.

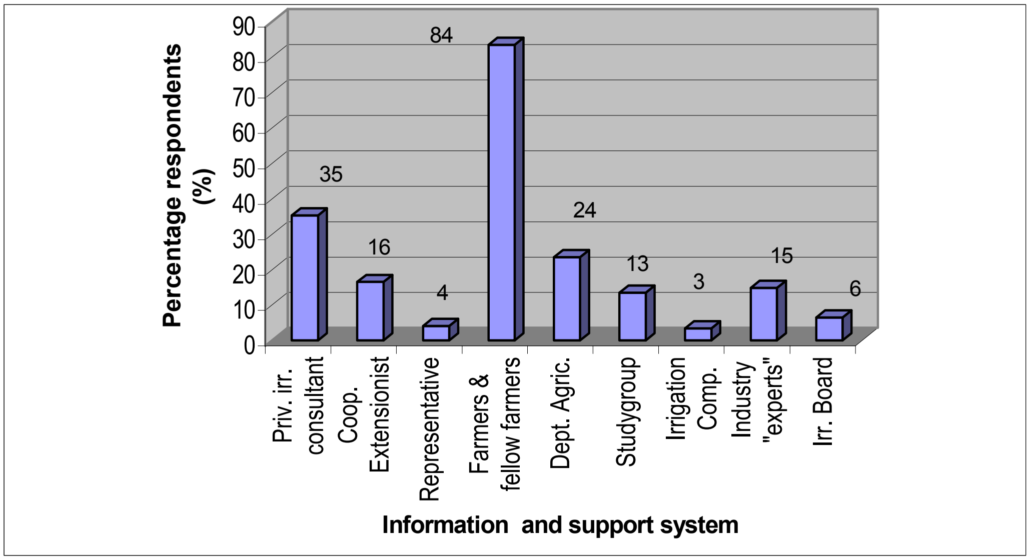


Figure 18. 1: Percentage distribution of respondents according to their use of various information and support system regarding irrigation scheduling (N=297)

o ***Role of "insiders" as agricultural information source***

The majority of farmers (84%) depend on their fellow farmers and themselves as their primary source for information and support regarding irrigation management and scheduling. Many farmers indicated that they regard their own farming experience and knowledge ("hands on experience") as more significant than the knowledge and information of industry "experts" and irrigation consultants. They often have extensive indigenous knowledge (local knowledge) of their own farming situations through close observations and experiential learning of the changes on the farm. This local farm knowledge was regarded as an imperative addition to scientific "facts" presented by the "experts" before the farmer can use advice for decision-making.

Apart from the use of the farm business as the internal learning system, farmers also seek advice from fellow farmers, perceived as "opinion leaders" or "gatekeepers" by their fellow farmers. The respondents perceive these "opinion leaders", usually experienced and relatively progressive and influential irrigation farmers, as important sources of information and learning. The role of study groups (13%) was also highlighted as an important opportunity for informal interaction and social networking but also with regard to farmer learning. Such farmer-to-farmer interactions provide opportunities for farmers to compare views on how the "new" information could be contextualized within their own situation and to test each other's values, perceptions and attitudes towards making changes based on this information.

Respondents were asked to rate the importance of fellow farmers' knowledge and opinions for decision-making in irrigation scheduling on a ten-point semantic scale (Figure 18.2). Ninety percent of the respondents regarded information shared and collected from fellow farmers to be very important.

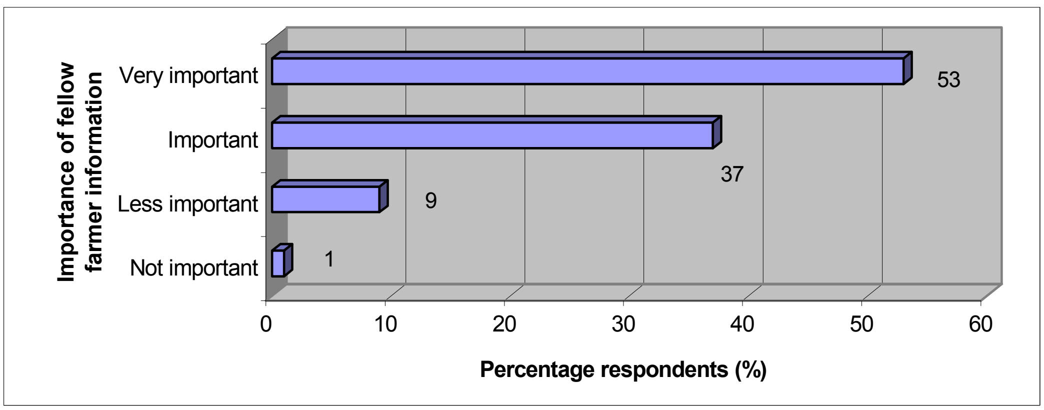


Figure 18. 2: Percentage distribution of respondents according to their perception of fellow farmers as an important information source for irrigation scheduling (N=134)

Knowledge and opinions gained from fellow farmers are perceived to be very valuable to irrigation farmers since it is local and comes from direct experience and observation over time. Many young farmers (23%) also referred to the potential "mentor role" that some of the experienced fellow farmers or "intimates" play regarding irrigation management decisions and farm management. The information and opinions of fellow farmers are perceived as an important source for both learning for change and continuous learning. This association between the support offered by fellow farmers with regard to irrigation management and the implementation of on-farm irrigation scheduling is supported by a significant correlation (r=0.866, p=0.014).

Evidence from discussions with respondents suggested that family members (especially the father of the family) often play an important role in decisions to be taken on the farm, which also includes decisions regarding irrigation scheduling. The role of "intimates" often serves as a checkpoint for information and decision-making of irrigation farmers.

o ***Role of "outsiders" as agricultural information source***

Commercial irrigation farmers in the implementation of objective scheduling practices (Figure 18.1), often use services of private irrigation consultants (35%) and other professionals from the cooperatives (16%) and industry (15%). These professionals are usually used in cases where farmers apply computer models or programs and/or highly sophisticated scheduling devices like the neutron probe, capacitance sensor, etc. The respondents specifically refer to the important role that commodity institutions like Cape span, Vinpro, and SASRI play in the learning and support rendered to farmers with irrigation scheduling.

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These experts or specialists are perceived to play an important role in closing the gap between the providers of research information and the users of it. Hargadon (1998) referred to them as "knowledge brokers". A general tendency that occurs is that "new farmers" to irrigation, especially those that do not have previous farming experience, are more prepared to rely on the support and advice of industrial experts and/or consultants than on opinions shared by fellow farmers. A significant relationship (r=0.248, p=0.049) exists between the use of irrigation consultants and the implementation of on-farm irrigation scheduling by farmers without previous farming experience. These farmers acknowledged the valuable input received from irrigation consultants and industrial experts especially during the initial phases of irrigation farming.

"Industrial experts" are taken here to include professionals that belong to a specific commodity or industry i.e. deciduous fruit, sugar, wine cellars or citrus.

The role and importance of irrigation consultants for decision-making were tested in the survey, and Figure 18.3 summarizes these findings. Sixty two percent of the respondents assessed the role of consultants to be very important for the implementation of objective irrigation scheduling. This relationship between the implementation of on-farm objective scheduling by commercial farmers and the use of private consultants as an important information support system is significant (r=0.282, p=0.040). This implies that commercial farmers perceive the service and support of irrigation consultants as important for the implementation of objective irrigation scheduling, often as complimentary or additional to the farmers' viewpoint in decision-making regarding irrigation scheduling.

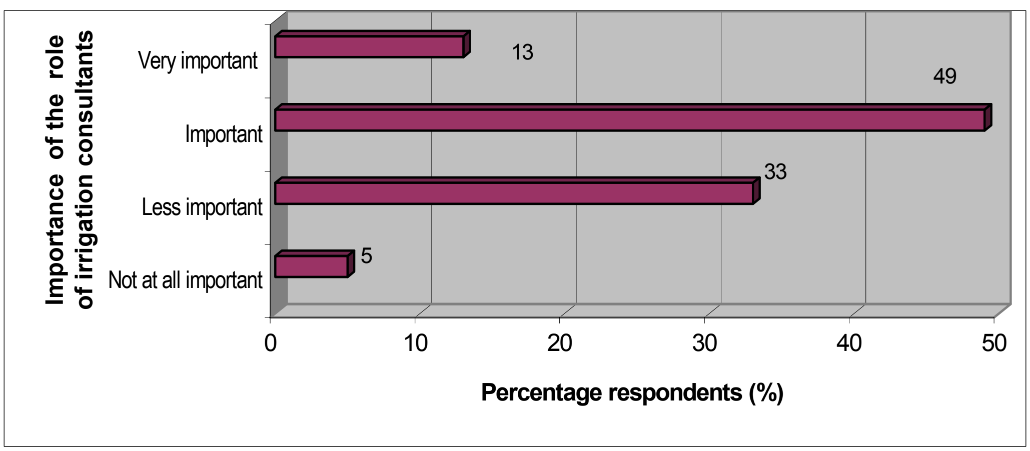


Figure 18. 3: Percentage distributions of respondents according to their assessment of the importance of irrigation consultants as information source for irrigation scheduling (N=134)

The contribution of the Department of Agriculture and Department of Water Affairs as agricultural information sources is perceived to be important for irrigation farmers. Twenty four percent of the respondents, of which 86 percent are small-scale farmers, make use of departmental information with regard to the implementation of irrigation scheduling. With the exception of irrigation schemes like the Rietrivier Irrigation Scheme and a few others, where commercial irrigation farmers are regularly meeting with both the Departments of Agriculture and Water Affairs, commercial farmers perceive little support from the Department of Agriculture with regard to the implementation of irrigation scheduling.

Amongst the small-scale farmers, government or departmental extension officers are the most frequently used learning sources for irrigation management decisions. A significantly positive relationship (r=0.254; p=0.002) exists between the use of departmental officers as information sources and the implementation of on-farm irrigation scheduling by small-scale irrigation farmers. This implies that the majority of the small-scale irrigation schemes depended upon support rendered by governmental extension officers with regard to the implementation of irrigation scheduling. This finding support the assumption that competent ground level support is necessary before farmers will implement on-farm irrigation scheduling (Hypothesis 4).

Commercial irrigation farmers also identified the relative unavailability of appropriate technical support from some research institutions in certain commodities like subtropical fruit and citrus. In these industries, farmers overcame the constraints through the establishment of respective growers' societies and study groups in the field of avocado, banana, mango and citrus. Some of these "interest specific groups" also appointed their own advisors to support farmers with different production aspects, including irrigation management and scheduling.

In some irrigation areas where local cooperative extensionists and private consultants are not rendering irrigation scheduling services and support, irrigation farmers (4%) rely on the support and consultation from representatives of fertilizer, agrochemical and seed companies (Figure 18.1). Farmers acknowledged the fact that these representatives are not irrigation "experts", but they identified them as important supportive role-players in irrigation management and excellent “information brokers” with the outside world. For many farmers this is their only link with what is happening on neighbouring farms. The relationship between the use of representatives and the implementation of objective irrigation scheduling is not significant (r=0.211, p=0.558). This implies that these information sources are usually offer farmers a “recipe” or fixed irrigation calendar based on crop growth stage and the number of days after sowing or planting, rather than an irrigation calendar that takes the phenological stage of the crop into consideration.

18.3 CATEGORIZING THE LEARNING FOCUS

Farmers generally use three categories of information sources namely: interpersonal sources, mass media and interactive electronic information systems like computers, videos, etc. Rogers (1995) defined interpersonal communication as those involving face-to-face exchange between individuals and mass media sources as those enabling one or a few individuals to reach an audience of many. The third category of communication system, namely interactive electronic information systems also categorized as “machine assisted interpersonal communication”, came into use in the early 1980 (Rogers, 1983).

Learning implies cognitive change as we act and receive feedback from our environment. It is this kind of learning, as distinct from separate educational activities and teaching, that is crucial in adult education. Learning therefore occurs and is required at various fronts in the changing of behaviour (Leeuwis, 2004). The findings in Figure 18.1 illustrate that commercial as well as small-scale irrigation farmers approach problem solving and learning in different ways (F=5.819, p=0.017). Farmers usually approach problem solving according to the different styles of farming, the farmers’ personal business and industry characteristics (Vanclay & Lawrence, 2001). Some farmers prefer listening, others reading, others observing while others learn-by-doing *(experiential learning)* (Dunn & Dunn, 1978).

Based on the different information sources that irrigation farmers have at their disposal (Figure 18.1), farmers associate with mainly four different learning groups regarding the use of irrigation information:

- *Localized information source:* The local focused group of farmers makes use of information and advice/opinions mainly from fellow farmers, study groups, local experts like departmental extension officers, irrigation board scheme officials, water user association officials, local cooperative extensionists. This group also perceived local field days and representatives of seed, representatives from agrochemical and fertilizer companies as important information sources for decision-making.

- *Specialist or expert information source:* This group of farmers' uses private irrigation consultants, specialists from the Agricultural Research Council (ARC), industry related expertise like SASRI, Cape span, Vinpro, professionals from universities or tertiary institutions, and designers and planners from irrigation companies in their learning process.

- *Formal and informal training in irrigation scheduling*: Fifty eight percent of the irrigation farmers interviewed indicated that they have attended formal or informal training in irrigation scheduling. Farmers however differ in their preference for using formal or informal training opportunities. The majority of irrigation farmers (62%) interviewed prefers informal sources of learning mainly because they are familiar with them, and they can choose learning sources, which fit their specific needs and situation (preference for independence). For example, fellow farmers and neighbours are often approached for background information and for information on practical implementation of irrigation scheduling. This group of farmers usually contacts consultants and advisors from commodity institutions for detailed technical advice needed for decision-making.

- *The use of the printed media and information technology (IT) as sources of informal learning:* The most important printed media source used by the majority of commercial farmers (72%) is either the newsletter or information leaflet from the local cooperative or relevant commodity institution like sugar, barley, or popular articles that occurs in the Farmers Weekly, Landbouweekblad or Nufarmer for the small-scale farmers. The printed media is often used to increase awareness relating to a practice like irrigation scheduling and often acts as a stimulus for further discussion and debate between farmers.

  Although computer usage by commercial farmers was found to be common, it is often not used for "learning" about irrigation management, but rather for record keeping, financial management and for obtaining quick and up to date information on marketing, weather patterns and research. The use of existing computer scheduling models and programs, often built with rigid mathematical methodology, is still limited (16%) as indicated in Part Three, and the majority of irrigation farmers found the use of computer models and programs relatively difficult to interpret and complex without the necessary ground level support.

It is of the utmost importance that clear and concise information on the costs and benefits of alternative irrigation scheduling methods are available. "Effective information" is usually generated much slower than generally assumed, and simply the "dumping" or provision of technical information about irrigation scheduling to a farmer, might not be appropriate. However not all farmers learn in the same manner as illustrated in Figure 18.1, and therefore differ in the learning sources they access for learning.

Understanding the cognitive styles of individual irrigation farmers or the individual groups of irrigation farmers can assist the extensionist or advisor to focus on the most appropriate means of offering the irrigation scheduling innovation package to farmers as part of a holistic management plan for the farm. Based on the response of respondents about the information or learning sources they accessed regarding irrigation scheduling, four distinct learning pattern groups of farmers could be identified:

- Farmers who do not consult additional information source regarding irrigation scheduling on the farm, but mainly rely on their local experience and knowledge in irrigation decisions.

- Farmers that regularly consult at least another learning source before decisions are taken on irrigation scheduling, usually within the boundaries of a specific farming area (localized knowledge).

- Farmers that consult at least two additional information sources regarding irrigation scheduling, before changing or making decisions regarding irrigation scheduling.

- Farm businesses that use a wide range of information sources (three or more additional learning sources) before decisions are taken regarding irrigation scheduling. These sources may include experts, training, fellow farmers, media and general observations.

a) Relationship between learning sources used and implementation of irrigation scheduling

Figure 18.4 reflects the degree to which farmers use a multitude of sources in the implementation of irrigation scheduling. It is clear from Figure 18.4 that 90 percent of farmers are making use of one or more additional learning sources, while 10 percent indicated that they rely only upon themselves for decision-making regarding the application of on-farm irrigation scheduling practices.

A tendency was found that younger farmers are in general more willing to make use of additional learning sources, especially computer-assisted support and publications than farmers aged 66 years and older (r=-0.394; p=0.015). This finding provides evidence in support of Hypothesis 1.2, namely that the age of farmers as an independent variable determines the perception of learning sources needed, before an innovation like irrigation scheduling will be implemented.

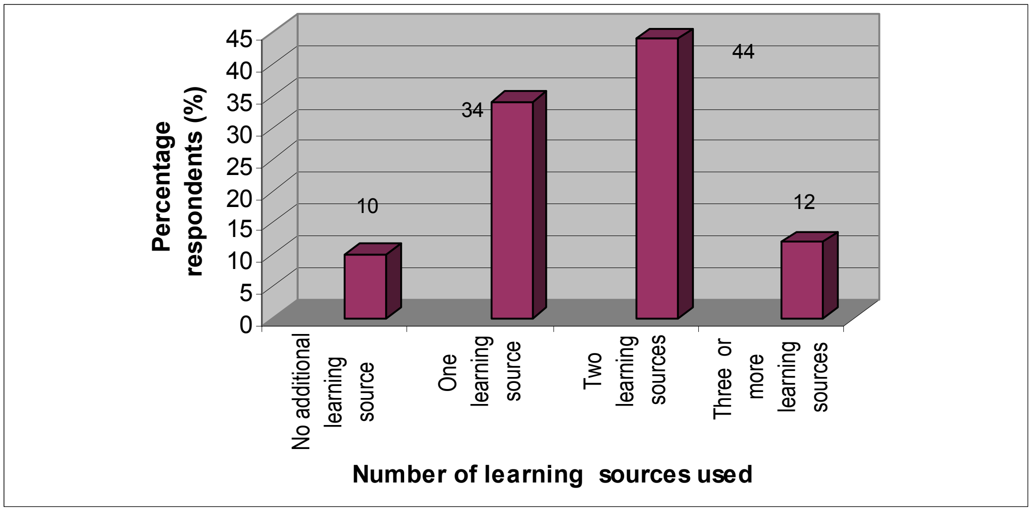


Figure 18. 4: Percentage distribution of farmers according to their use of multitudes of learning sources (N=134)

It was also found that as the size of irrigation area increase farmers are generally more prepared to use additional learning sources (r=0.230; p=0.038). This significant relationship provides evidence in support of Hypothesis 3, namely that objective irrigation scheduling is too complex, expensive and time consuming for many farmers but more appropriate for the large growers who often have higher incomes and flexibility with labour.

Figure 18.5 highlights the relationship between the number of learning sources used by farmers and the implementation of objective and subjective irrigation scheduling methods. This shows that irrigation farmers differ with regard to the number of learning sources they consult before they implement irrigation scheduling (χ^2=8.90, df=2, p=0.022). Sixty six percent of the farmers that make use of objective scheduling methods consult two or more learning sources, while 58 percent irrigation farmers involved with subjective scheduling methods consult less than two learning sources.

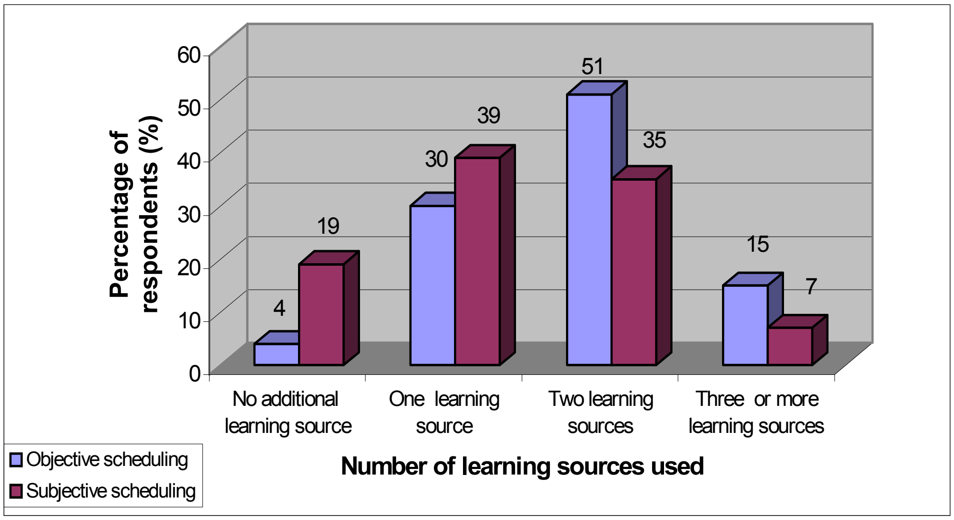


Figure 18. 5: The percentage distribution of respondents according to type of irrigation scheduling used and the number of learning sources consulted (N=134)

A significant relationship exists between the number of learning sources used and the implementation of on-farm irrigation scheduling (r=0.244, p=0.007). This implies that farmers, who apply objective scheduling methods, are more inclined to use more than one information or learning source. Irrigation farmers involved in the application of subjective scheduling methods on the other hand are more willing to rely on personal experience and perhaps the use of one additional source of information, usually within the boundaries of a specific irrigation area ("localized knowledge").

18.4 PERCEIVED ATTRIBUTES FOR EFFECTIVE KNOWLEDGE SUPPORT

The following attributes of an irrigation consultant and extensionist are, according to respondents, very important in the building of trust, credibility, delivering of an effective irrigation scheduling service (Table 18.1).

Table 18. 1: Percentage distribution of respondents according to the perceived attributes of irrigation extensionists/advisors to be critical (N=134)

Attributes of irrigation consultants	Number of respondents (n)	% Respondents
1. Technical competence	56	42
2. Affordable support service	54	40
3. Timely, focused and accurate information	47	35
4. Integrity, credibility, trustworthiness and commitment	38	28
5. Preparedness to learn from each other	26	19
6. Practical recommendations and insight into the context of application	24	18
7. Ability to interpret data as measured, and not only acts as a “dip stick” offering data	18	13
8. Availability, empathy and interpersonal sensitivity of consultant	15	11

Table 18.1 reveals that the following attributes of advisors and extensionists as identified are critical for the building of trust and credibility:

- The first qualification farmers expect of irrigation consultants/extensionists is *experience and competency in the irrigation area (42%).* The consultant must have both educational and practical knowledge of the irrigation system’s operation and management, which includes irrigation scheduling. Farmers perceive this attribute in general as an important basis for the building of long-term extension relationships.

  The advent of computer irrigation scheduling and the use of sophisticated scheduling devices like neutron probes, etc. that necessitates the use of appropriate computer software, has resulted in some activity by irrigation consultants. Computer experts without proper experience and training in irrigation management and general agricultural production are not in a position to help farmers with the interpretation of data measured in the field.

- *Timely, focused information (35%):* In general, there is an expectation that the irrigation extensionists/advisor should be able to understand the bigger picture. An advisor /extensionists should be aware of what new irrigation technology or practices have or are being developed. They must keep the farmer informed about the appropriateness of this innovation to the specific farming system. Many farmers acknowledged this attribute as the biggest advantage of an irrigation consultant or extension services.

- *Integrity and credibility (28%):* Advisors/extensionists are expected to be unbiased, trustworthy, maintain confidentiality, and be reliable.

- *Understanding the context (18%):* It is important that the irrigation extensionist /advisor must be well informed about tendencies and the latest developments of the specific industry with which the farmer is involved. They have to make recommendations that are adapted to the farming system and management style of a specific farmer, but also reconcilable with the social norms and values as applicable for the specific farmer.

- *Ability to interpret measured data and communicate effectively (13%):* One of the constraints of many of the irrigation consultancy services rendered to farmers is the fact that many of the consultants are not in a position to correctly interpret the data they have measured because of their insufficient or inappropriate formal training. Providing information alone without contextualizing it has not been perceived to be very effective to farmers. Since irrigation scheduling is about providing information concerning a living, dynamic plant-soil-atmosphere ecosystem - basic knowledge and experience in agronomy, soil physics, climate, irrigation engineering, irrigation economics and the interaction of these elements are required.

  Furthermore, it is of utmost importance that advisors and consultants understand and act on the knowledge they have gained regarding the learning preferences of the farmer. It was indicated that the manner in which the measured data and information needed for irrigation management is presented and packaged for a specific farmer will only be effective if the specific business context and the desired outcomes of the farmer is taken into account.

- *Availability, empathy and interpersonal sensitivity (11*%): The ability and availability of advisors/extensionists to identify needs and problems of clients as well as to offer support to farmers with appropriate information for decision-making are important characteristics of an efficient extensionist or advisor. The development of trust between the relevant parties through showing empathy with the needs of the farmer is an essential element for adoption of new practices.

- *Preparedness to learn from each other (19%):* Advisors and extensionists should be able and prepared to learn from each other and from the farmer as well. They should be prepared to take the responsibility for their recommendations, but also be prepared to listen, observe and interpret what farmers are saying. Many farmers indicated that they perceived the role of advisors, extensionists and consultants as being very negative. This is largely because they are inclined to impose the technology upon farmers, without adopting a participatory approach in this regard.

18.5 SUMMARY

The findings reported on this chapter revealed that farmers use different learning sources and systems in their integration of knowledge that fit the different farming styles as well as the specific stage of the lifecycle of irrigation farmers: The stage of the lifecycle of a farmer will influence his/her attitudes, perceptions and willingness to trial with new innovations.

- Some farmers indicated that they seek information and advice mainly from local experts like the local cooperative extensionists, fellow farmers, and water institutions like the irrigation board and do not regularly make use of "outside" information. Many farmers indicated that they have learned about irrigation scheduling from experience gained over time. The local knowledge of farmers, which has been gained through experience, is an important source of learning. In addition to farmers learning from their own experience, they also learn from the experience of other farmers. The majority of respondents (84%) rely on the use of fellow farmers or their own experience and knowledge in the application of irrigation scheduling. As Scarborough *et al.* (1997) point out, farmers that act, as opinion leaders tend to speak the same language, literally and culturally, as their colleagues, and are faced with similar constraints and problems as fellow farmers, which enhance the relevance and credibility of their advice and views.

- The more progressive farmers and bigger farm businesses are more likely to use the irrigation consultants and experts of industries for advice. 35% of the respondents indicated the use of consultants as their major source of information regarding irrigation scheduling. Members of this group base their information on "opinion leaders" in the farming community.

- The third group is more of an outward focused group and consults widely whenever information is needed. Furthermore, this group is likely to be already participating in other learning activities like training, study groups, and external networking.

A significant relationship exists between the attitude of a farmer to use multiple information sources and the business context and size of irrigation of a farmer. Farmers involved in the use of objective scheduling methods are more willing and prepared to seek for additional information sources outside the irrigation area than the farmers involved in subjective scheduling methods. The farmers of the latter group are more prepared to seek information from fellow farmers and local information sources. These findings also support the general expectation that the differences in farmers' goals and circumstances, the technology level and complexity of interactions and decision making by the farmer determines the choice of irrigation scheduling method selected and eventually the adoption behaviour. (Hypothesis 3)

Irrigation farmers identified several important attributes of an ideal extensionists/consultant like truthfulness; credibility as an extensionist or consultant is earned by being honest and treating people with the necessary respect. Being respectful when dealing with people involved in a change process include aspects like openness, honesty about one's intentions, making a real effort to help farmers to learn from the innovation and to respect people's decision even when they say "no".

CHAPTER 19
THE ROLE OF PRIVATE IRRIGATION CONSULTANTS AS A SOURCE OF LEARNING

19.1 INTRODUCTION

The complexity of irrigation technology, especially the use of real time irrigation scheduling methods, makes it difficult for many farmers to apply this technology on a day-by-day basis. It often necessitates refinement and the implementation of relatively sophisticated irrigation technology has generally been through support by industrial representatives, private irrigation consultants and extensionists from agricultural cooperatives. These service providers who are in regular contact with the irrigation farmers' often have considerable influence on farmers' decision making (Daniels & Chamala, 1989). The selection and evaluation of an irrigation consultant often poses a challenge for many farmers.

Presented in this chapter are some of the general perceptions and attitudes of irrigation consultants and important information concerning their training, competencies and experience that deserve consideration.

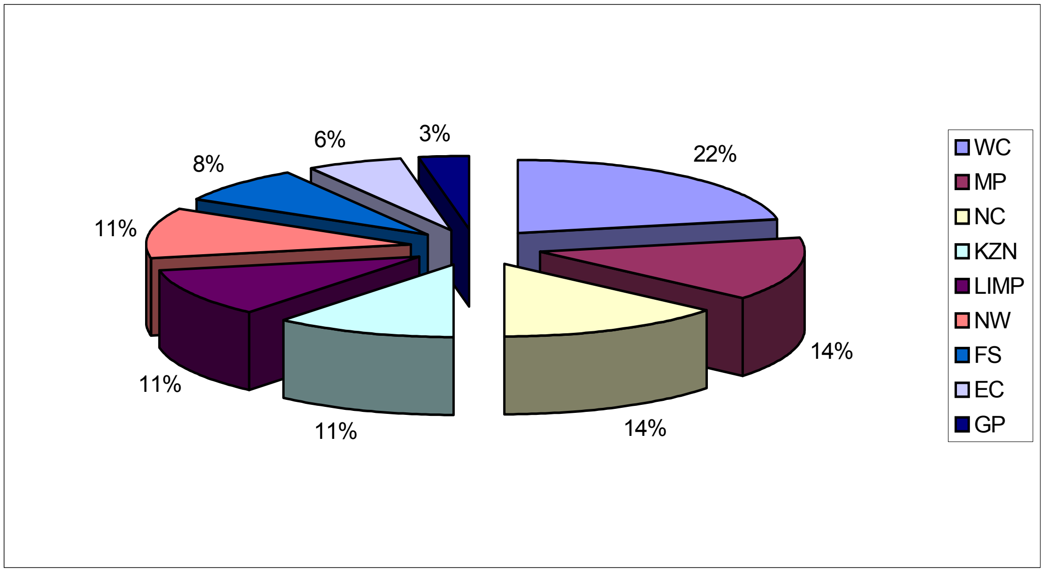
19.2 RESEARCH METHODOLOGY

A qualitative study was conducted to identify the irrigation consultants and extensionists that are supporting irrigation farmers with the implementation of objective irrigation scheduling. The qualitative interview method was designed around the semi-structured interview guide approach (Patton, 1990), which involved developing specific subject areas for the interview. This qualitative format of in-depth interview was chosen, as respondents are more willing to respond to an open-ended semi-structured dialogue in a relaxed way rather than to a formal structured questionnaire, enabling a better understanding of the factors contributing to adoption (Bickman & Rog, 1998). Raising specific questions as an entry point for discussion started the interview, but adequate space and time was left for interviewees to elaborate their views and raise new issues. This permitted questions to be customized to suit the different respondents and enabled the perspectives of the individuals to emerge. Approximately 70 semi-structured interviews were conducted with key individuals and opinion leaders within the irrigation-farming sector and included irrigation consultants and extensionists, irrigation designers, representatives of irrigation infrastructure companies and educational institutions that are regularly supporting irrigation farmers with decisions on irrigation management. The interviews with key people and opinion leaders in the irrigation industry served to identify consultants and extensionists responsible for irrigation scheduling services in the country and also helped to ensure that the desired data was being collected.

The focus of this qualitative study was confined to the thirty-seven irrigation consultants and extensionists identified and interviewed with specific reference to the use of the irrigation scheduling methods or techniques as part of their consultancy service offered to irrigation farmers and on their availability to be interviewed. The main areas covered during the semi-structured interviews were: identifying of the irrigation consultants/extensionists responsible for supporting farmers as well as the irrigation scheduling methods and techniques used; identifying of the clientele that use these services; identifying the perceptions of the necessary requirements to ensure efficient service delivery; identifying possible reasons why irrigation farmers often lack the necessary aspirations to use objective irrigation scheduling methods as well as some recommendations from the viewpoint of the consultant to keep in mind with the promotion of the practicing of objective irrigation scheduling. A single interviewer was used and each of these interviews was recorded on tape and later transcribed for analysis purposes. The approach used to analyse interview data involved observing primary patterns to sort the data into useful themes (Patton, 1990). In reviewing interview data it became clear that the utility of certain irrigation methods and techniques varied between the various respondents, but that certain common principles prevail in the effort to help farmers with irrigation managerial decision making.

19.3 GEOGRAPHICAL DISTRIBUTION

The geographical distribution of respondents in this survey (Figure 19.1) had a higher concentration of consultants operating in the relatively more intensive, high value cropping areas of the Western Cape (22%), Northern Cape (14%) and Mpumalanga (14%).



WC=Western Cape, MP=Mpumalanga, NC=Northern Cape, KZN=KwaZulu Natal, LIMP=Limpopo, NW=Northwest, FS=Free State, EC=Eastern Cape, GP=Gauteng

Figure 19. 1: Percentage distribution of irrigation consultants as per province (N=37)

19.4 TECHNICAL QUALIFICATIONS

The key factors contributing most significantly to the competence of consultants are their knowledge and level of training, whether formal or non-formal (vd Westhuizen, 2003; Childs, 2003). The formal qualifications of the consultants ranged considerably as indicated in Table 19.1, and all but one respondent have received tertiary qualifications.

Table 19. 1: Percentage distribution of the technical qualification of irrigation consultants and extensionists (N=37)

Education level	Number of respondents (n)	% Respondents
Technical diploma (Non-agriculture)	16	43
Agric. Degree	14	38
Agric. Diploma	3	8
Post matric qualification (Non-agriculture)	3	8
Grade 12	1	3
Total	**37**	**100**

The majority of irrigation consultants (51%) have a non-agricultural post-matric qualification (technical or engineering). This means the majority of consultants are technically qualified; it does not necessarily place them in a professional agricultural category. Irrigation farmers often perceive appropriate agricultural knowledge as a precondition for effective irrigation scheduling support.

19.5 EXPERIENCE

According to Table 19.2 the experience of the irrigation consultants varies considerably, with 19% of the consultants having been involved in irrigation management for more than sixteen years. Sixty percent of the consultants indicated that they have less than ten years experience in irrigation management. Since the mid 90's, many new irrigation consultancies were initiated.

Experience in irrigation management is usually associated with the acquisition of confidence and skills in observing, listening and analysing a specific situation and which is a prerequisite for providing help and support to farmers with irrigation scheduling. One of the more experienced respondents noted the following in this regard: *"It took me nearly ten years to understand what irrigation farmers really need and expect to enable them to make sound water*

Table 19. 2: Percentage distribution of the experience level of respondents in irrigation management (N=37)

Experience in irrigation management (years)	Number of respondents (n)	% Respondents
0-5	10	27
6-10	12	32
11-15	8	22
16+	7	19
Total	**37**	**100**

management decisions. This was due to the fact that in the past I always wanted to prescribe to farmers what to do and/or even tried to withhold certain management information from them to ensure them depending on my consultancy service. Subsequently I have realised that the more one can stimulate farmers to think, understand and act on the irrigation information provided, the bigger the demand for the specialised services from irrigation consultants become" (van der Westhuizen, 2003).

All of the irrigation consultants reported adequate competency in the use of computers and their ability to use appropriate software.

19.6 IRRIGATION CONSULTATION SERVICE FEE

The fee of any consulting service is highly dependent on the level and types of services available. Many consulting services (32%) not only provide irrigation scheduling services to farmers, but are also responsible for recommendations regarding fertiliser, insect control, financial management and general irrigation management (operating pressure, uniformity of deliverance, etc). 48 percent of the respondents indicated a consulting tariff charged per point of measurement, payable at the end of the production season.

According to irrigation consultants, the demand or need for irrigation scheduling services follows a seasonal pattern and is definitely more intensive when farmers experience relative low rainfall years (drought). Farmers, who in the past have discontinued the services of professional irrigation consultants, are more prepared to employ them and spend additional resources for more clarity on the exact status of the soil water content level during periods of relative low rainfall.

19.7 PROFILE OF POTENTIAL CLIENTELE

Consultants and extensionists seldom have contact with all potential clients, but usually reach out to or are approached by specific user groups depending on their perceived credibility and acceptability. The attributes and characteristics of the clientele that usually engage in irrigation scheduling consultancy are summarised (Table 19.3).

Table 19. 3: Characteristics and attributes of clientele served by irrigation consultants and extensionists (N=37)

Attributes and characteristics of farmers	Number of respondents (n)	Percentage of respondents (%)
1. Business oriented people	12	33
2. Professional people that started farming	11	31
3. Farmers involved with intensive, high valued crops	10	28
4. Farmers from all categories viz. age, education, experience, size of farming operation, etc	8	22
5. Younger farmers	4	11
6. Corporative or estate faming concerns	3	8

Thirty three percent respondents indicated in Table 19.3 that their clientele usually consist of the relative more business-oriented farmers, while 22 percent of the consultants and extensionists indicated that they have no specific clientele group that make use of their irrigation scheduling service. Business-oriented people are in general more self-reinforcing and will often seek and participate in further learning opportunities. Since the adoption of objective irrigation scheduling methods often require a significant amount of technical understanding, training and preparedness to learn about the alternative scheduling method is essential. It is clear from Table 19.3 that the majority of clients (64%) involved in the use of irrigation scheduling services offered by consultants, belong to a group of more business-oriented farmers, and/or professionals from various occupations outside agriculture that are starting irrigation farming and/or are involved in the production of high valued, intensive crops. These findings are in agreement with Hypothesis 3, namely that the business context and general approach of the farmer towards farm management and technology determine his approach to the use of precise irrigation scheduling.

Table 19.3 also illustrates that a relative low percentage (8%) of corporative or estate farming concerns do make use of irrigation consultants. This could be due to the fact that many of the corporate farming concerns often appoint their own irrigation experts to address this need.

19.8 IDEAL NUMBER OF CLIENTS

Interviewees were asked to indicate the current number of clients they are servicing and these findings are reflected in Figure 19.2.

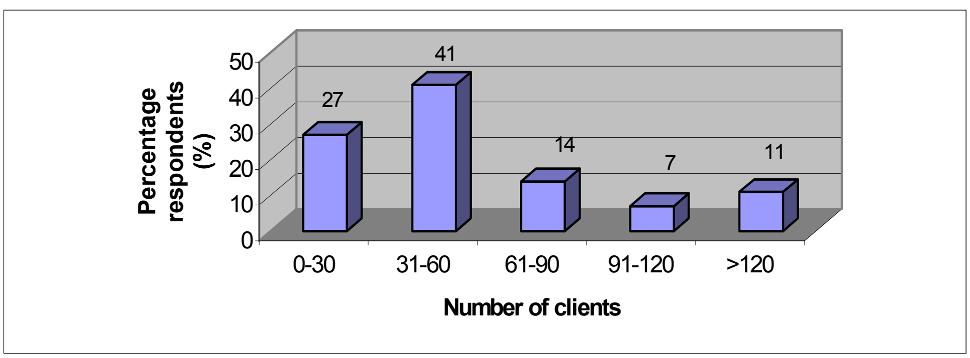


Figure 19. 2: Percentage distribution of respondents according to the number of clients served (N=37)

The majority of consultants (68%) have a clientele group of 60 farmers or less (Figure 19.2). Although all of the consultants have indicated that a certain threshold number of measuring points or tubes are necessary to offer a cost effective service, the consultants that service a bigger number of farmers also admitted that they could not consult and visit farmers as regularly as needed. The consultants involved in servicing the larger number of farmers often use “runners” or other staff to measure and supply the data to them, which are then analysed by the consultants themselves. The fact that these consultants make use of supporting staff to measure the frequency of personal and regular consultation with their clients also decreases. In general farmers expect to have regular contact with consultants, even if the time scheduled for meeting is very limited.

19.9 PROFILE OF SERVICE DELIVERY BY IRRIGATION CONSULTANTS

Important for the effective delivery of irrigation scheduling services is the regularity that the soil water content status is monitored and the relative time span between the collection of raw data and the provision of recommendation for decision-making by the farmer. Fifty four percent of the consultants interviewed have indicated that they measure soil water content every week, analyse the data and submit recommendations to farmers within 24 hours after taking the measurement. This group of consultants also indicated that they usually consult farmers every fortnight at which stage field visits and observations often form part of the consultation. Thirty one percent of respondents also indicate that they measure weekly, but consult and make recommendations on the same day that the soil water measurements are recorded.

Irrigation consultants involved with irrigation scheduling of permanent, high valued horticultural crops like deciduous fruit, table grapes, etc. reported regular measurements of the soil water content on a weekly basis during the peak growing season, but will often scale down to even once a month during the winter periods or dormant season. The minority of consultants (16%) still measure every second week, with analyses and recommendations provided within 24 hours after measurement.

19.10 REQUIREMENTS OF AN EFFECTIVE IRRIGATION SCHEDULING CONSULTANCY

Irrigation consultants identified key attributes and competencies imperative for the rendering of effective irrigation scheduling consultant services. These range from personal attributes like interpersonal communication skills to technical knowledge, expertise and ethnical competence as indicated in Table 19.4.

Table 19. 4: Competencies and personal attributes perceived by consultants necessary for delivery of a successful irrigation consultancy (N=37)

Attributes and characteristics for effective irrigation consultancy	Number of respondents (n)	% Respondents
1. The software selected by consultants, must be appropriate, accurate and relative easy to understand by both the consultant and the farmers	19	52
2. Consultants should have appropriate education, knowledge, skills and work experience to ensure credibility and the ability to interpret the measured data	16	42
3. Show commitment, persistence and focus on achieving the objectives as set together with farmers	10	26
4. Be service oriented and open minded, observant, and versatile in the recommendations to accommodate the different situations of farmers and farming systems	7	19
5. Consultants must show good communication skills and be able to listen and interface effectively with farmers	6	16
6. Consultants should show good common sense and be realistic in the approach they apply and combine it with good time management	6	16
7. Apply sound sale techniques in approaching new clientele: farmers need to buy into this new innovation	6	16
8. Display good computer skills	5	14

Fifty two percent of the respondents perceive the use of a correct and appropriate software program as a very important requisite for the delivery of an effective irrigation scheduling service (Table 19.4). Many of the consultants referred to the use of inappropriate software programs in the past that have cost them dearly in terms of clients that were unsatisfied with their services and consequently terminated the service. The perceived usefulness of an irrigation scheduling program or model used by irrigation consultants is an important consideration that was identified by irrigation farmers in Part Three (Chapter 9).

Forty two percent of the respondents identified the importance of appropriate technical qualifications and experience as prerequisites for an effective irrigation consultancy service. The credibility of the person providing the service was identified to be very important in terms of the adoption of irrigation scheduling services. Credibility is often regarded as a combination of trust, competence and integrity usually developed over time between a client and a consultant. Many of the consultants referred to the fact that they took over from another consultant because of certain personality clashes between the farmer and the specific consultant or due to the lack of the necessary skills and experience to interpret data correctly. Consultants identified attributes like service orientation, good personal communication skills, adequate computer skills, commitment and the general application of common sense to be important for successful engaging with irrigation farmers and managers. These key attributes and competencies identified through the interviews supply evidence in support of Hypothesis 4, namely that competent ground level support is a necessity for the implementation of irrigation scheduling practices.

Sixteen percent of the respondents were of the opinion that it is important to apply some of the basic skills and techniques that salesmen and representatives often use, to enable irrigation farmers to “buy into “ the use of irrigation scheduling on the farm.

19.11 PERCEIVED REASONS OFFERED BY CONSULTANTS AS TO WHY FARMERS ARE NOT MAKING USE OF IRRIGATION SCHEDULING

Respondents were asked to provide possible reasons why some farmers are not interested in the use of irrigation scheduling services and objective irrigation scheduling *per se*. The following responses of consultants in this regard are reflected in Table 19.5.

Table 19. 5: Reasons, as perceived by consultants, why farmers fail to make use of objective irrigation scheduling (N=37)

Reasons for farmers not scheduling as perceived by consultants	Number of respondents (n)	% Respondents
1. Consultants lack the necessary skills to interpret measured data into some information that could be use for decision making by the farmer	18	49
2. Not all farmers are aware of the potential benefits of irrigation scheduling	16	43
3. Cost of water relatively low compared to other production input costs, and therefore is a relative low priority to farmers	14	38
4. Farmers perceive objective irrigation scheduling in general as complicated and difficult	11	30
5. No financial incentive exists for the farmer because of flat tariff structure of water	10	27
6. Lack of flexibility (irrigation system or water delivering) prevents farmers from applying irrigation scheduling	10	27
7. Attitude of farmers negative towards the use of irrigation scheduling	8	22
8. Farmers confused because of divergent recommendations and messages received from irrigation advisors and consultants	8	22
9. Farmers do not appreciate the fact being prescribed and told what to do on the farm by an “outsider”	8	22
10. Farmers are hesitant to adopt irrigation scheduling due to bad experiences in the past with especially devices like tensiometers	8	22
11. Cash crop growers in general do not use real time irrigation scheduling but rather prefer general guidelines and irrigation calendars	7	19

Forty nine percent of consultants expressed their concern about the fact that many of the consultants operating in the irrigation fraternity lack the ability to interpret the data measured for purposes of decision-making (Table 19.5). Information like the soil water content of a specific field only becomes an economic valuable commodity in the context of decision-making once the raw data is interpreted. Forty three percent of the respondents are of the opinion that some farmers are still not aware of the potential benefits of the use of irrigation scheduling except for conserving water.

19.12 PROMOTING IRRIGATION SCHEDULING

Respondents were asked what aspects they perceive to be important to be included in a possible communication strategy to raise awareness amongst farmers and motivate them to become interested to implement objective irrigation scheduling on the farm.

Table 19.6 lists the aspects of irrigation scheduling taken into account by farmers before a decision is taken regarding the implementation of a specific irrigation scheduling method on the farm. It shows that the majority of respondents (64%) are of the opinion that the incentive for adopting irrigation scheduling should not only be the potential conservation of water, but rather the improvement of efficient water-use on the farm. The findings from the semi-structured interviews held indicate that the possible reasons why producers adopt the use of more sophisticated irrigation scheduling methods are usually combinations of the following:

- To ensure a high quality of crop.
- To save energy especially where water has to be pumped a considerable height or distance.
- To increase production yields of crops.
- To improve profitability through saving of especially nitrogen.
- To conserve water and to reduce pollution (saline conditions).

Table 19. 6: Aspects or essential elements regarding irrigation scheduling used by irrigation consultants to persuade farmers (N=37)

Aspects and potential benefits regarding irrigation scheduling	Number of respondents (n)	% Respondents
1. Irrigation scheduling must not be offered as saving of water but rather as the improvement of water use efficiency	24	64
2. Illustrate the possible saving of electricity and energy costs	18	48
3. The irrigation scheduling program or recommendations should be offered in terms of the whole farm management	16	43
4. Improvement of production yields and net profit	12	32
5. User friendly and easy to understand irrigation scheduling program or software	12	32
6. Possible saving and controlling of fertilisers – prevent leaching of fertilisers	9	24
7. Manipulation or management of the ratio between oxygen and water in the root zone	8	22
8. Improvement of quality of crops	7	19
9. Financial incentive for a farmer who implements irrigation scheduling like for instance differentiated water tariffs	6	16
11. Saving on maintenance of moveable irrigation systems (centre pivot)	5	14
12. Irrigation scheduling should serve as prerequisite for the access to production credits at cooperatives	5	14
13. Prevention of salinization/sodicity	2	5

Thirty two percent of the consultants regard the need for a user-friendly and understandable irrigation scheduling program as an important necessity for irrigation farmers to be willing to "buy into the implementation of an alternative irrigation scheduling approach".

The general feeling amongst 22 percent of the respondents is that a code of conduct should be developed, especially with regard to intellectual property and information management. Thirty three percent also indicate that a form of accreditation might be useful to guarantee the quality and standard of work of irrigation consultants and advisors operating in irrigation management.

19.13 SUMMARY

The semi-structured interviews with irrigation consultants and extensionists revealed the following:

- All the irrigation consultants indicated their competency in the use of computer programs and software to collect data from soil water measurements, but only 46 percent of them received formal agricultural training. The respondents expressed their concern about the fact that many of their fellow consultants operating in the irrigation fraternity, lack the ability to interpret the measured data for the purposes of decision-making.

- It is generally accepted that competence alone explains only part of the variation regarding the ultimate impact of irrigation consultation. Another major factor is the credibility of the person providing the service, which is often regarded as a combination of competence, trust and integrity. Consultants and farmers identified credibility to be very important in terms of changing the adoption behaviour of irrigation farmers.

- The need to uphold certain professional standards in consultancy and communication intervention with irrigation farmers was emphasised by many irrigation consultants as well as irrigation farmers. However, the problem is that no nationally accepted "code of conduct" exists in this respect.

CHAPTER 20
THE POTENTIAL ROLE OF INSTITUTIONS AS LEARNING SYSTEMS IN THE PROMOTION OF EFFICIENT WATER USE PRACTICES

There is little empirical evidence about the rate at which farmers become aware of new practices and innovations. Once a farmer becomes aware of or shows interest in an innovation or a new practice, he will collect all relevant information on that particular practice. Education and training were identified in Part Four (section 9.2) to play an important role in raising awareness among irrigation farmers regarding alternative scheduling practices and the potential of adopting such practices. Schön (1967) was one of the first wave of thinkers that argued that a 'learning system or network" is necessary to adapt to the continuous process of transformation that we experience.

In Part Three it was illustrated that the adoption of an innovation like irrigation scheduling is not only relating to an individual, but that it has a composite nature which includes technical and social practices at different domains and levels of farming, at different times. In order to meet these challenges, various actors like the Water Users Association (WUA) could play an important role as a "learning system" in the raising of general awareness amongst the irrigation farmers. It is expected of a WUA to plan and develop operational rules for a specific irrigation scheme in participation with the users, as implementers of Water Demand Management (WDM) through the development of a Water Management Plan (WMP). These aspects will also include irrigation water allocations to users and the administrative system to operate it. This collective planning of a WMP for an irrigation scheme was perceived by the research team to serve as an ideal opportunity to make irrigation farmers aware of certain principles of efficient water management on-farm. With these functions in mind the perception of respondents regarding the possible role that WUAs could play as a "learning system" was tested on a ten-point semantic scale (0= not important; 10= very important) and is illustrated in Figure 20.1.

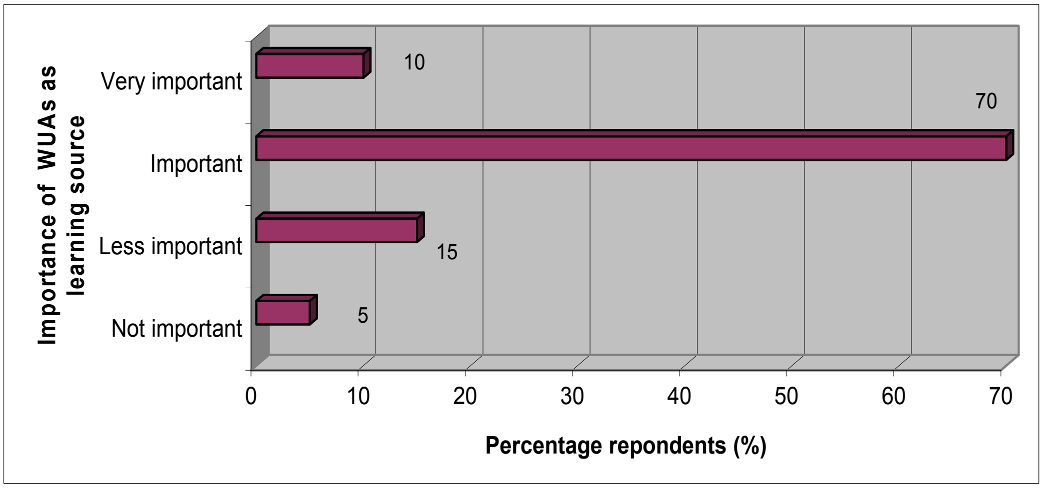
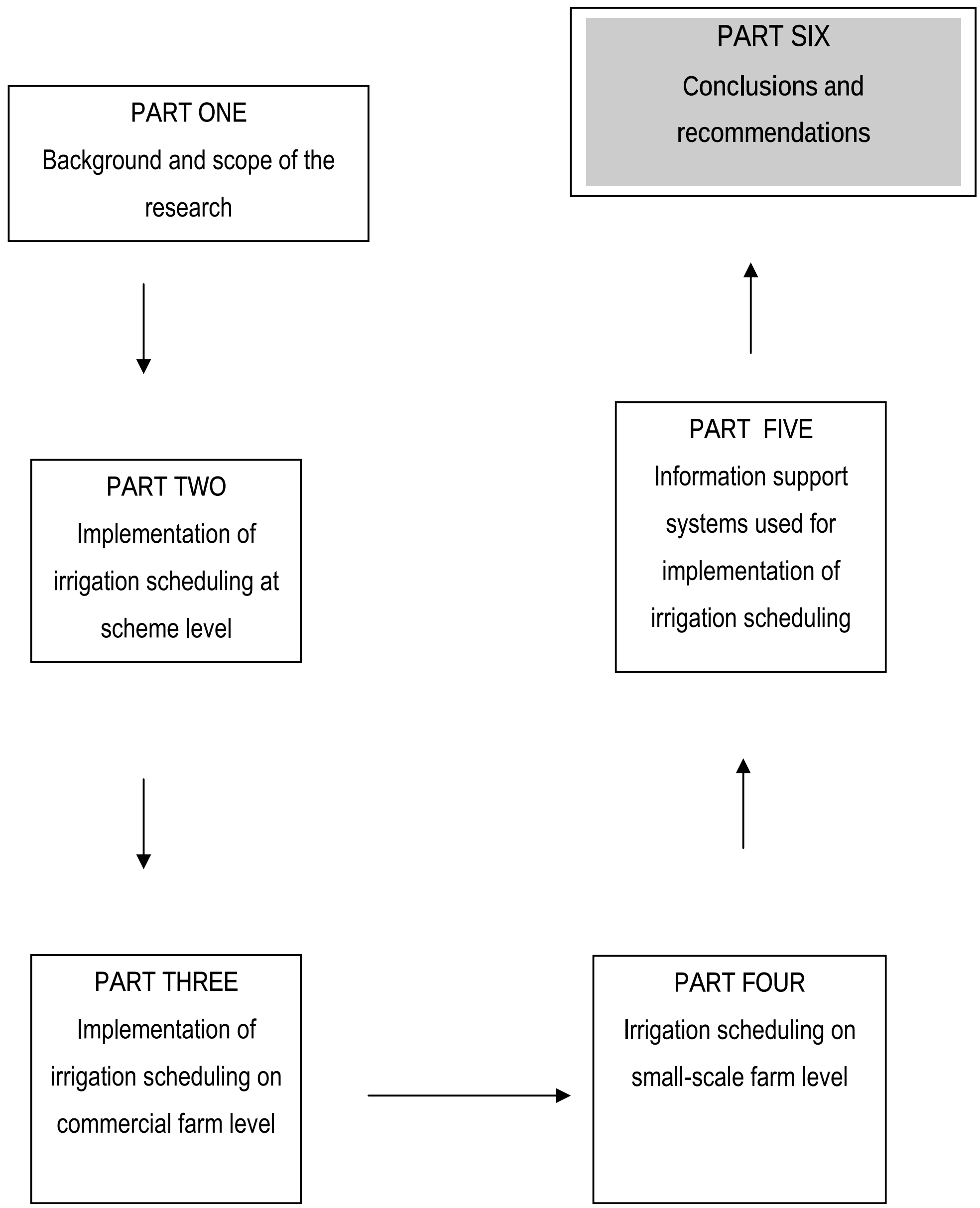


Figure 20. 1 Percentage distribution of respondents according to their assessment of the potential role of Water User Associations (WUAs) in promoting awareness of irrigation scheduling (N=137)

The majority of respondents (80%) were of the opinion that the WUA could and should play a more definite role in promoting awareness and the adoption of irrigation scheduling and efficient water use on the farm. WUAs should be evaluated in terms of the role it could play as part of an integrated knowledge network system in providing opportunities and an environment for social learning and building of "relationship capital" with farmers (van Woerkum, 2002).

PART SIX

CONCLUSIONS AND RECOMMENDATIONS



CHAPTER 21

CRITICAL FACTORS THAT INFLUENCE THE ADOPTION OF IRRICATION SHEDULING

Irrigation scheduling, which implies the provision of the required volume of irrigation water at the right time, is widely recognized by agricultural scientists as being a prerequisite for efficient water management on the farm. Although a great variety of irrigation scheduling methods and models are available to irrigation farmers in South Africa, only 18% appear to irrigate according to this fairly strict definition, using objective or scientific irrigation scheduling methods. The majority of farmers regard the use of subjective methods, which is based on intuition, local knowledge and experience as gained over many years in irrigation farming, to be adequate for decision-making.

One interpretation of this low rate of adoption is that irrigation farmers generally have a negative attitude towards objective irrigation scheduling methods, and consequently prefer relatively subjective decision-making strategies. More likely reasons are that the information provided to irrigators through objective assessments does not meet their managerial information needs, and therefore not all the irrigators found the net benefit of the implementation of objective scheduling very positive.

Objective irrigation scheduling represents an attempt by scientist to intervene and improve the irrigators' management on the farm. However, what is not appreciated is that the successful decision and accommodation of a singular innovation in the total management system is much more complex than an isolated adoption (McCown, 2002). Farmers go through a hierarchy of decisions or judgements prior to the seeking of extra precision in his decision on irrigation timing. This gap of discrepancy between what sciences has to offer as a solution and what farmers expect and need or what they regard as appropriate represented the focus of this investigation. It is clear from the results from this study that an innovation like irrigation scheduling is composed of a technical dimension (technical device or procedure) but also of an adapted human practice, including the condition that must prevail for such practice to happen (social dimension).

It was hypothesized that there is a significant difference among participant irrigation farmers in their irrigation scheduling techniques and practices use. Based on this assumption, several objectives were set. The objectives of this thesis are first to identify and classify the spectrum of soil-plant-atmosphere irrigation scheduling methods and techniques that are available for the use by irrigation farmers, researchers and extensionists in irrigation management, Secondly to determine the current adoption of irrigation scheduling methods and techniques by commercial and small-scale irrigation farmers on the irrigation schemes in South Africa, and to identify the human and socio-economic factors that influence the implementation of irrigation scheduling. The third objective was to identify the agricultural knowledge information systems that irrigation farmers use in their effort to learn more about irrigation scheduling to address these objectives. To address these objectives, the following assumptions were questioned that influence the adoption of irrigation scheduling practices.

- The implementation of irrigation scheduling practices on-farm is determined by independent and intervening variables. (Hypothesis 1)

- More precise irrigation scheduling offered by scientists is perceived to improve production efficiency. (Hypothesis 2)

- The technology level of farmers and the specific farm business characteristics determine irrigation farmers' approaches to problem solving and learning. (Hypothesis 3).

- Competent ground level support by research and extension professionals is conducive for the implementation of irrigation scheduling. (Hypothesis 4):

- Effective research-extension-farmer dialogue is necessary for the improvement of implementation status of on-farm irrigation scheduling practices. (Hypothesis 5):

Testing these five assumptions provided a framework for this thesis. This final chapter summarises how well the assumptions are supported by the empirical evidence found in this study. This study was embedded in a practical WRC research project (WRC Report TT 1137/1/05) and aims to contribute to the theory and practice of on-farm irrigation scheduling. Given this purpose, the study also concludes by posing some future research and extension challenges to improve on farm water use efficiency.

21.1 FACTORS THAT INFLUENCE THE ADOPTION OF IRRIGATION SCHEDULING

1. *Differential perceptions regarding the concept of "irrigation scheduling"*

As a concept, "irrigation scheduling" encompasses more than the restrictive definition recognized by agricultural scientists. Objective irrigation scheduling approaches represents a means for agricultural scientists to provide farmers and advisors with information for decision-making. The majority of irrigators perceive irrigation scheduling to include the use of intuition, local experience and observation in following "a schedule or time table for the application of irrigation." Irrigators thus tend to fall into one of the following categories:

- Some farmers have indicated a very strong belief in the use of more objective measuring of irrigation scheduling. Decisions are based on scientific indicators, and there is a general belief that technology provides an answer to their problems. For these farmers, objective measurement is ideal because data and measurements are repeatable and generally fit the paradigm of "scientific thinking".
- However, the majority of farmers use subjective irrigation scheduling, which is mainly based on intuition in adapting to fixed and semi-fixed

irrigation calendars. Little or no measured data is available, and therefore the decision taken by the farmer is hardly repeatable but rather based on the skills of a good manager and his specific mental model. Social researchers have shown that highly complex non-linear problems are often better solved by intuition than engineering. This is what a "good manager" means (Hayman, 2001).

It is clear from the findings that often the farmers' mental model and the scientists' scientific model of irrigation scheduling differs. Vanclay (2003) provides 12 reasons for non-adoption of scientific technology by farmers. Most of these reasons relate to the failure of scientists to understand the worldview of the farmer and the constraints under which they operate. The general tendency among agricultural scientists is to regard only empirical knowledge based on the biophysical system as being valid to deal with the complexities and variability of farming systems, and thereby often ignores decisions based on farmer experience and which is compatible with the specific social needs and situation of the farmer. This "technical-rationality" is often grounded as professional knowledge, but has often failed to resolve the dilemma of rigour versus relevance that farmers face in their daily decision-making.

These differences regarding the definition of irrigation scheduling were also evident within the discussions of the advisory committee members. Some members were convinced that irrigation scheduling referred only to the implementation of objective irrigation scheduling methods, while others also perceived the use of intuition as an alternative irrigation scheduling method, for which the concept, unless artificially delineated makes provision for.

It is clear that farmers and agricultural scientists have different perceptions regarding the definition of irrigation scheduling and this goes a long way in explaining the often-unsuccessful communication between scientists and farmers and the resulting low adoption rate. It is important that cognizance is taken of these differences and that more effective dialogue is pursued (between scientists and farmers) which is characterised by empathy and a willingness to listen and to engage in co-learning. Irrigation strategies can only be efficient when designers, irrigation suppliers, and agronomists and farmers communicate effectively and on a regular basis.

2. The effect of situational variation on decision making regarding irrigation scheduling

Farming enterprises involved in the growing of high value crops are more prepared to make use of objective irrigation scheduling because of the large scope of perceived improvement in crop quality. The current trends adopted within a high technology level farm must keep up with the traceability of product, changes in fertilization strategies from feeding the soil to feeding the plant, new soil management philosophies, integrated crop management, use of softer pesticides and herbicides, the world of ISO standards and Eurepgap and also produce to improve margins. The new paradigm in which high value crop farmers are competing also made farmers more aware of precise irrigation scheduling.

Precision scheduling provides more accurate information for tactical decision-making that could help the farmer to minimize the risk and to deal with change and variability. The decision of the farmer whether or not to use precise irrigation scheduling for tactical decisions, will depend on the position of the farmer on an input-response curve (Figure 21.1). For many tactical decisions the response curve is steep and then flat. When the farmer is still on the steep slope of the curve (A), the relative advantages will still be visible and relatively big (large response to the introduction of irrigation scheduling on the total irrigation requirement for a specific crop). Furthermore it will be cost-effective to spend additional time and resources on fine-tuning the irrigation scheduling. However, when a farmer is confronted with situations that are marginal and where risk and uncertainty prevail because of the flatness of response (beyond the optimum point B), there may be less to be gained from implementing precise irrigation scheduling. Even though water is the primary constraint to production, it represents a very small percentage of the total input costs (as indicated in Part Three). Because of the uncertainty of the location of point B and the fact that farmers in general are risk averse and fear of sliding down the steep response curve towards point A, a possible strategy is to apply more water than necessary ("insurance irrigation"). Therefore, operating on the flat part of the curve between points B and C as indicated in Figure 21.1 provides cheap insurance for a high value crop like horticulture. This study confirms the findings of Stirzaker (1999) that between points B and C, little financial incentive is perceived by farmers to reduce water application.

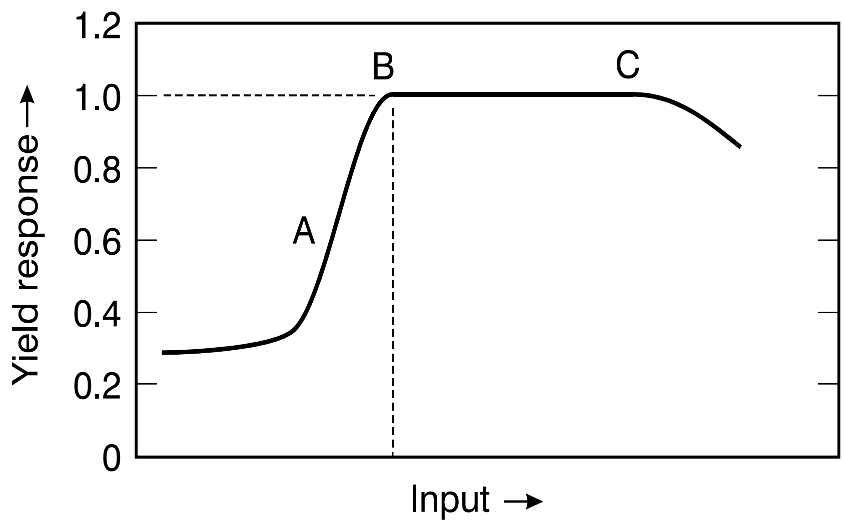


Figure 21. 1: Input -response curve for irrigation decisions

It is, therefore, imperative that agricultural scientists and extensionists should try to understand the difference between the real risk perceived by the farmer at farm level which are addressed with intuition most of the time, and the assumed risk by scientists in their modelling on a field level. Tactical decisions with regard to irrigation management refer to decisions taken everyday. These decisions are difficult for the farmer to take because of the uncertainty of their outcome. Furthermore, the farmer's position on the response curve should also be established through effective dialogue between the relevant stakeholders before recommendations regarding irrigation scheduling are offered. This dialogue implies effective two-way communication and continued, thoughtful exchange of ideas that matter most regarding irrigation management, and scheduling time.

3. Farmer's decision-making is limited by insufficient information

The irrigation farmer is in the first place a producer of crops. Therefore, according to Brookes (1948), the crop farmer is concerned with the integration of all the factors that determine plant growth and development, and it is the basic knowledge of this integration that is deficient. Rather than a shortage of information, many of the commercial farmers complain about "information dazzle" or information that cannot be readily integrated for use in decision-making regarding irrigation management.

For this to happen, it is essential that accurate, reliable, timely and appropriate information is developed, and effectively disseminated to extensionists, advisors and end users. However small-scale farmers experienced the opposite where appropriate and specifically adapted irrigation management information is often lacking. The majority of small-scale irrigation schemes are situated in extensive rural areas where modern communication technology like telephones, Internet and regular contact with professionals and the printed media is limited. This calls for creativity and special inputs in the development of appropriate training material to support small-scale farmers and extensionists.

This study indicated that the general technical knowledge and competence level of many of the men and women responsible for the support of the irrigation farmer are inadequate. Perhaps in the first instance it is the lack of regular self-reflection by scientists that had contributed to the adopting of a hard systems thinking as a common sense justification for their "scientific work" (Sebilotte, 1994). Unless scientists fully understand that irrigation farming systems are hierarchical systems, where what happens at one level is explained by what happens the level below, and is giving meaning by what happens at the level above, any research product will likely be trivial.

Furthermore, it is likely that the educational system responsible for the training and preparing of students to take up the relevant roles in water management is limited or inadequate. This shortcoming in training and competence of extensionists and advisors was confirmed by 49% of the irrigation consultants who referred to recommendations made by some of the consultants, which are often not compatible with the farmers' practical management needs. If farmers are unable to perform uniformly and precisely, according to the irrigation water application recommended, they tend to follow a general tendency of applying rather an excess of water over the whole field than too little water ("insurance irrigation").

The challenge exists for extension and irrigation consultants to gain the necessary skills and competence, not only to transfer general knowledge and information, but also to support farmers with the identification and conceptualization of problems in irrigation management. Extension involves more that just the transfer of information, but requires effective co-learning between the relevant parties by following learning based approach.

There is an urgent need for a study into the current status of training in irrigation management offered at all the tertiary institutions in the country. The curricula offered in irrigation management at tertiary institutions should be evaluated and shortcomings identified and addressed where possible.

4. Investment in irrigation scheduling

Experienced farmers in the use of objective irrigation scheduling methods indicated that it takes an enormous amount of work and time to get scheduling to be aligned as part of standard day-to-day irrigation management on the farm (Naude, 2002). Respondents perceive the implementation of objective irrigation scheduling methods as time consuming and costly and not practical enough for implementation on the farm. Therefore many irrigators do not perceive enough benefits (usefulness) for them to continue with the implementation of this scheduling approach and tend to revert back to subjective irrigation scheduling methods. Farmers are likely to continue with traditional irrigation scheduling technology until new irrigation scheduling technology is developed, which provides directly visible results or benefits with minimum cost or inputs time.

The benefits of the implementation of more precise irrigation scheduling methods tend to be more evident to producers of high value and intensive crops. The improvement of crop quality, saving on electricity costs, increased production yields and efficient use of fertilisers are perceived by this group of farmers as important motivational “driving forces” for the implementation of objective scheduling. However, for a large number of cash crop growers (cereals, cotton, etc), the possible financial advantages are not always evident and therefore these farmers generally are more willing to follow their meta-model based on intuition, experience and observation. This implies that the precision irrigation scheduling methods and procedures offered by research has limited value to offer to these farmers. This has not to say that in some years under certain conditions (for instance periods of drought), more precision will not make significant difference.

There is a great need that the risk that irrigators are prepared to take with the use of objective irrigation scheduling methods should be discounted against the possible benefits to gain from such implementation. Although this study identified certain trends, a more detailed analysis of the role of risk and uncertainty in the decision-making of irrigators is needed.

Seven percent of the respondents perceived absolutely no change in production efficiency since the introduction of irrigation scheduling on the farm. These include the number of irrigators that were newly introduced to the use of objective scheduling methods and some farmers involve in the production of pastures that raised certain concerns regarding the implementation of objective irrigation scheduling methods. A possible explanation for the relative low adoption rate of irrigation scheduling in the pasture industry is because of the requirements with regard to irrigation interval and amount as well as the large number of fields all at different crop growth stages. Therefore, for many in the pasture industry, it makes sense to follow a fixed or semi-fixed irrigation schedule in combination with the use of intuition. Although the use of conventional methods like the soil auger and shovel are still commonly use by these farmers, an urgent need exists to investigate the possible adaptation of real time irrigation scheduling models into irrigation calendars for pasture production. The possible use of a soil probe and the wetting front detector should also be further investigated and demonstrated to farmers.

5. Wrong extension packaging of irrigation scheduling?

In the past the benefits of possible water saving was perhaps overemphasized, while other relative benefits like saving on electricity operational costs, improvement of nitrogen and nutrient management, improvement of quality of crop and the increase in production yields were often neglected or not properly highlighted by extension in the dissemination of information. Farmers perceived the relative advantages attached to the practising of irrigation scheduling rather as a "multitude of possible benefits" offered to address the complexities of a specific farming system and not as a single advantage such as the saving of water.

Future initiatives by extension and research should therefore be directed to ensure that irrigation scheduling is offered to irrigators in an appropriate and sensible manner. Instead of focusing only on the conservation of irrigation water through more precise irrigation scheduling approaches, irrigation scheduling should rather be recommended for "trouble shooting" in irrigation management. The additional benefits mentioned above are invariably more visible to farmers and will also help to change perceptions, beliefs and attitudes of farmers towards the implementation of irrigation scheduling.

6. Uncertainty regarding future irrigation water allocations

Although farmers in general perceive the conservation of irrigation water to be very important, the implementation of irrigation scheduling to ensure more efficient water use on the farm is perceived as more important than saving water per se. Farmers' attitude towards the saving and efficient use of irrigation water is in general positive, however many farmers are apprehensive as to whether the practising of efficient irrigation practices on-farm may lead to a possible revisit of current allocations of irrigation water by

DWAF. The following statement by a very progressive irrigation farmer in Mpumalanga confirms that:

"Not many changes have taken place as far as an irrigation farmer in an irrigation scheme is concerned, except that if you do not keep on using the allocation of irrigation water, you will lose it. This makes farmers very much wary about the real value of irrigation scheduling"

It is therefore important that government (DWAF), as well as the relevant water management institutions, urgently address this concern or misperception of farmers appropriately to assure the necessary security of water allocations. If not properly addressed this misperception could act as a possible hindrance to the adoption of efficient irrigation management.

7. Potential role of WUA as a learning system in promoting efficient on–farm water use practices

The fact that 96% of the respondents also regard the implementation of irrigation scheduling by their fellow farmers as important, is a clear indication that farmers perceive irrigation water as a common property and therefore also support the use of sustainable irrigation practices not only at a farm-level, but also on scheme level. Often the assessment of water resources along with the planning and construction of the irrigation scheme is the responsibility of engineers. Usually the irrigation deliveries are set, and not specifically based or related to crop water requirements. Lack of cooperation and coordination between farmers and the administration staff on irrigation schemes contributes to the relatively poor water use efficiency experienced on some of the schemes.

The supportive role, which local water institutions should play with regard to the adoption and improvement of effective water management principles, emerged from the survey. Eighty percent of the respondents were of the opinion that the WUA could and should play a more definite role as a "learning system" for changing farmers' behaviour with regard to efficient water use. As

Water User Associations in South Africa will implement the Water Demand Strategy (WDM) as adopted by the Department of Water Affairs (1998), through the implementation of appropriate Water Management Plans (WMP), one of the new expected roles, which WUAs and irrigation agencies should take up, is the empowerment of farmers through facilitation of appropriate training programs. For the implementation of the WMP, it is expected of the WUAs to interact effectively and regularly with farmers, who are expected to have a prominent say in the design and management of an irrigation scheme. To accomplish this it is important that farmers should be prepared and motivated to organize themselves for the purpose of water user associations. This will also imply that an organisation like the WUA have to change their current way of thinking and adapt to the needs as expressed by the environment. In order to adapt, WUAs must become learning organisations- where within and between hierarchical levels of the organisation they share experiences and learn from it (Senge, 1993). Also the necessary support (technical and managerial) and general awareness should be offered through efficient dialogue between the WUAs and irrigation farmers.

A practical example is the role that the water authorities in Hermanus played during the early 90's as indicated in Box 21.1.

Box 21.1: Making Water Demand Management work!

The town of Hermanus in the Western Cape Province of South Africa faced a serious shortage of domestic water in the late 1990's. An option to alleviate the problem was to build a storage dam- but the high construction cost of it did not make this an attractive solution. The water authorities then decided that they would attempt to convince users to use less water. Subsequently an escalating block tariff structure for water was instituted but no significant changes in water use were experienced. When the authorities started to show the tariffs with user-friendly graphs on the accounts, users began to realize the cost saving in using less water. The outcome was that the total water use for the town decreased far beyond expectations and the building of the dam will not be necessary for several years to come.

The current initiatives and activities of some WUAs, which were visited were found to be remarkable and were perceived favourably by farmers. However, there are many water institution managers that still perceive their role only as that of delivering bulk water and the general management of the scheme.

8. The use of computer models for irrigation scheduling

Ownership of computers is with the exception of the small-scale farmers, no longer an issue amongst commercial farmers. In this study, all respondents indicated that they have access to computers, but computers were used rather for general farm management and record keeping (largely for tax and labour management purposes) and not for irrigation scheduling purposes.

The perceived usefulness of irrigation scheduling models is confined and the majority of irrigators still rely on intuition or paper and pen for key irrigation scheduling decisions. Apart from the requirement of certain levels of skills, computer literacy and access to weather data, regular interaction between professional advisors and irrigation farmers will always be needed before it can be implemented efficiently. These finings illustrate that irrigation scheduling models and programmes are predominately advisor-driven rather than farmer-driven, which bring about their distribution largely being geographically bounded. It is therefore clear from the response of irrigation farmers that although computer models and programmes provide useful information for discussion in a face-to face interaction, it cannot function in a *stand-alone mode*.

As already been emphasised earlier in the document, it must be kept in mind that models are built mostly by agricultural scientists and therefore reflect the decision-making style of the developer. Therefore it is important that scientists need to understand the farmers' management of risk and enter into a co-learning adventure through effective dialogue with farmers. Only through dialogue the real needs of farmers (felt and unfelt) will be identified to unlock the local knowledge and intuition of the farmer.

It is clear from the investigation among farmers that make use of scheduling models, that modifications to the majority of available computer irrigation scheduling packages are necessary to meet the requirements of the end-users. This includes the addition of online help and more clear and easy to understand graphical simulation of irrigation requirements, as well as the modification of the "scientific language" used in the models.

It is recommended that an alternative to the use of simulation models for real time irrigation scheduling should be developed like a site-specific irrigation calendar for irrigation farmers. This approach is currently being tested in Taung amongst the small-scale farmers involved with barley production. Initial results appear to be very promising and farmers are eager to apply the recommendations.

9. Flexibility in irrigation scheduling

The implementation of objective irrigation scheduling techniques, which are based on field soil water balance, requires that farmers take an appropriate amount of water from the supply system timeously. The inability of the bulk conveyance and delivery system to deliver water at the farm gates with the necessary reliability and flexibility will hamper the implementation of objective irrigation scheduling. This was found to be common in the older irrigation schemes where water is delivered to farmers in a predetermined schedule. With predetermined scheduled delivering followed water stress periods, which occur when, the time intervals between successive water applications are too large.

The building of on-farm storage facilities can provide the farmer with more flexibility in terms of the water he/she receives and the applied irrigation practices. Economic factors like additional capital and operating costs required compared with the potential yield reduction or increase because of the additional reliability of water supply will influence the final decision made by the farmer.

Lack of flexibility in water delivery was also attributed to the limitations of the canal system. In many of the older irrigation schemes the relatively poor state of canals and long distances that water has to travel with relative high spillage, caused serious problems in terms of the supply of water to farmers, especially during peak growing periods. Although the majority of irrigators are aware of the use of Ruraflex, not all of them can irrigate only during the nighttimes or low demand periods. Due to certain canal capacity limitations they also have to irrigate during peak and standard demand periods that are less cost effective. Therefore although a farmer can select a certain irrigation system designed to apply a certain volume of water in a 24-hour period, certain shortfalls could be created because of limitations in the delivery of water and, therefore, it is common to find farmers irrigating 24 hours per day, for seven days per week during peak growing periods.

With existing bulk water conveyance systems it is recommended that the designer (engineer of the scheme) should determine whether cost-effective alterations can be made to increase the manageability and effectiveness of the canal system. It is important for extensionists, designers and planners of irrigation systems, farmers and irrigation scheme managers to communicate regularly and effectively to address situation specific shortcomings regarding the delivery and reliability of irrigation water. Water management institutions like the WUA should also employ all reasonable effort to:

- Calculate the irrigation requirements for each crop grown in the WUA district
- Estimate as closely as possible, the area of each crop grown, preferably the average over more than one year in the WUA district, and
- Use the above to calculate the monthly and annual irrigation requirements for the WUA.

This information plus the use of a computer program like SAPWAT can assist irrigation scheme managers with the planning and management of an irrigation scheme. Appropriate training in the use of SAPWAT and to calculate the net irrigation requirements of an irrigation scheme, is essential.

10. Distribution uniformity of irrigation systems

The ability of an irrigation system to apply water uniformly and efficiently to an irrigated area is a major factor that influences the agronomic and economic viability of a production system. The awareness and regular evaluation of distribution uniformity and application rate of an irrigation system is an important managerial function required from an irrigator.

The distribution uniformity of an irrigation system depends both on the characteristics of an irrigation system and on the managerial decisions of farmers (Pereira, 1999). Surface irrigation is influenced primarily by the soil intake characteristics, while overhead irrigation is influenced by the condition of sprinkler packages and the pressure variation within a system (Reinders, 2003). These factors of an irrigation system need to be correctly managed to ensure that the distribution uniformity is at an acceptable level, which will ensure the optimal use of water resources.

It is a concern of many of the irrigation advisors and professionals that many farmers do not regularly evaluate the distribution of uniformity and application efficiency of on-farm irrigation systems. Although 64% of the respondents indicated that they measure distribution of uniformity of their irrigation systems on a regular basis, these practises were not validated on the farm. From discussions with extensionists and irrigation consultants it appears as if this figure is inflated. Eighteen percent of the respondents admit they do not pay attention to this aspect of irrigation management. If a farmer does not regularly measure the distribution uniformity of an irrigation system, he/she cannot calculate the mean application rate of irrigation, and is therefore not aware of the variability of application of irrigation. A critical factor often neglected by designers and planners of irrigation systems is the ease of management and operation of the irrigation system. The easier the system operation instructions are, the more likely the operators will carry them out.

Irrigation systems should be robust and easy to maintain by semi-skilled persons.

It is recommended that a comprehensive operation and maintenance manual always form part of any designed irrigation system. Extensionists, advisors and water institutions should play a more distinctive role in increasing the awareness of irrigators in this regard and also become more active in the evaluation of irrigation in the field. Currently, only the ARC ILI is offering this service countrywide with the help of a field laboratory unit. It is recommended that more extensionists and advisors responsible for the support of irrigation farmers should be equipped with a field laboratory that could be used for the field evaluation of irrigation systems and for regular on-farm demonstrations.

Although drip irrigation is generally efficient when it is well managed, flood irrigation should not be dismissed as a matter of principle. Properly designed, constructed and operated flood irrigation systems are very efficient in terms of water use, with the benefit of low running costs. Laser planning devices enable performance improvements in the infiltration system for level basins and level furrows found in the Lower Orange irrigation area. The impact of levelling accuracy on distribution uniformity and on yield was perceived to be highly significant. This was therefore adopted by the majority of farmers in the Lower Orange as a standard approach for new irrigation development. The need for appropriate maintenance and precision of land levelling is important as it facilitates irrigation scheduling and induces higher yields.

Incentives (like soft loans, rebates, etc) should be considered for those farmers who are prepared to use efficient irrigation management. Even on the farm these incentives could be introduced where the farmer awards his/her block manager for the efficient water utilization on the farm.

11. Irrigation water tariffs

On the majority of schemes the individual abstraction of irrigation water is not measured. Irrigators generally pay water tariffs that are based on irrigated area, and not on actual water volumes used. Consequently there is little financial and social incentive for the implementation of efficient water use.

It was generally found that farmers have a positive attitude towards the implementation of volumetric water tariffs, where a flow meter is installed to measure individual abstractions. The introduction of water tariffs based on volumetric allocations instead of on a flat rate based on area listed for irrigation is acknowledge by the majority of farmers (85%) as being an important condition for more efficient water use. This, however, requires proper water measurement at the intake of the bulk water conveyance system and at each outlet. The findings of a WRC research project (vd Stoep *et al.*, 2005) on the evaluation of different flow meters available for the irrigator indicated that commercially mechanical meters are available at relative low costs. These authors also identified the need for greater awareness by WUAs with regard to the availability and suitability of devices, especially as far as new technological development is concerned. However, from a farmers' point of view, it was identified that these measuring devices should be accurate and the users should trust the readings, which are generated.

The report by vd Stoep *et al.,* (2005) identified the need for the developing of a water measuring policy as a matter of urgency to guide WUAs in the selecting of appropriate devices and procedure for implementation. The use of volumetric measurement will mean that irrigators pay in proportion to their use of water services. Based on the findings of this research, the success of such a proposed policy will depend on the effectiveness of the communication between WUAs and farmers with regard to the process of measuring and interpretation of measured data. A visible and simple understandable way should be followed on a monthly basis to inform irrigators about their position regarding the water allocation. Financial incentives should be put in place for the farmer who is willing to schedule more accurately and prepared to use water more efficiently on the farm. Water trading is such an exciting mechanism to encourage the judicious use of water. The current tariff system does not provide incentives for farmers who use water wisely and should be revised.

12. Required attributes of extensionists and consultants for efficient knowledge support in irrigation management.

Several attributes of consultants and extensionists were identified in the study, which are critical for the building of trust and credibility between irrigators and the advisor or consultant. These are the following: technical competence; timely and focused support; integrity and credibility; understanding the context of the farmer and the industry; ability to interpret measured data and communicate effectively; availability, empathy and interpersonal sensitivity; and a preparedness to learn from each other.

Advisors and extensionists should be able and prepared to learn from each other, and from the farmer as well through effective dialogue between relevant stakeholders. This approach requires a paradigm shift from extensionists, as they should be prepared to take responsibility for their recommendations, but also be prepared to listen, observe and interpret what farmers are saying. It is important that advisors, consultants and extensionists involved in the dissemination of information regarding irrigation technology, should take cognizance of these attributes that were identified by the farmers for successful interaction with extension.

13. Knowledge support system

Irrigation consultants, cooperative extensionists and professionals from the industry are responsible for supporting commercial farmers with information regarding irrigation management. These professionals are usually used where farmers implement objective scheduling methods. The necessary skills and competence to interpret data and technology into useable information for the farmer is of paramount importance. Unfortunately many of the irrigation scheduling consultants and advisors operating as knowledge support system to commercial farmers are not properly trained in irrigation management and equipped to fulfil this responsibility. They also don't allow themselves enough time to spend and help farmers with the interpretation and possible recommendations concerning the measurements. Farmers perceived the regular visits of consultants (face–to-face interviews) as important in the dealing with feedback from irrigation farmers on the current trends of soil water balance in the field and the building of trust between parties.

It is recommended that a professional association like SABI could assist with the development of ethnic standards and competence requirements for accreditation and licensing of irrigation consultants and advisors. Although SABI is currently offering some short courses in irrigation management and design, the successful completion of such training is not stated as a prerequisite for the delivering of irrigation consultancy services.

14. Relationship between farmers, researchers and extensionists

A great obstacle to the adoption and use of objective irrigation scheduling is the lack of interactive communication between researchers, extensionists and farmers. Reviews of the World Bank and USAID experience in research have all identified research-extension linkages as constraint in realizing the full benefits of research (World Bank 2003, USAID, 2003). Although this relationship between research, extension and farmers seems ideal in theory, it has not been successful implemented in agriculture. As agriculture becomes more knowledge intensive, these linkages are found to become even more critical, demanding target and user-driven research and technology development.

Poor adoption rates of irrigation scheduling technologies demonstrate that linear, reductionist and positivist perspectives, or the 'Transfer of Technology' approach (TOT) familiar to scientists (Röling, 1994) do not work well for this particular problem. The TOT perspective does not easily accommodate the dialogue and negotiation among stakeholders necessary for working through a complex issue like irrigation management with many variables. It is important to harness the local knowledge and experience of farmers into the development and implementation of irrigation scheduling methods through participatory action research. This partnership between research-extension-farmer suggests a learning process of investigation, assimilation and of sharing as based on the experiential learning cycle of Kolb (1983). Essential to the partnership is ownership by all stakeholders of the learning and sharing paradigm. This approach entrenches the importance of mutual or co-learning between stakeholders. According to Cox *et al* (1995), the metaphor of a "*dance"* is used to describe the true participation where farmers and agricultural scientist engage in an effective dialogue and learning of each other's dance steps. This involves improvising, where dancers improvise as they go, testing each new step for its fit with other steps and with the whole dance pattern (Hayman, 2001). Essentially this demands for a paradigm shift from many researchers and extensionists, as new roles are required from these professionals.

15. Institution building

Farmers are keen to take up information and technology once they can perceive that it will improve their on-farm results, especially productivity levels. The overwhelming response in terms of the role that farmers themselves play as a recognised learning source in terms of irrigation scheduling, emphasises the important role that study groups (farmer directed groups) and agricultural institutions (WUAs, irrigation board, farmer unions) could play to deliver and provide the many features which make learning and training effective for adult learners. The "shared identity" to the learning network will establish tacit and explicit rules of coordination between individuals and different groups, which will generate social capital as an important step in the process of learning.

Therefore the following actions are important:

- Establishment of well-organised and well-facilitated farmer directed groups.

- Support of institutions in the creating of a network that will induce the building of a "shared identity" of network members, since this will increase the opportunity for learning to be shared.

- More emphasis on delivering irrigation management and irrigation scheduling training through agricultural institutions and organizations.

- Farmers should place more emphasis on the agricultural institutions to identify training needs to help improve participation

16. Learning cycle of irrigation farmers

As farmers proceed through the learning process of evaluation, trialling, and determining whether a specific irrigation scheduling method was appropriate for a specific farming system and their personal goals, some either adopted or rejected the scheduling method. Fifty nine percent of the respondents changed their perceptions regarding the most appropriate irrigation scheduling method since the inception of irrigation scheduling. The majority of respondents who changed their practices were not satisfied with the accuracy of the scheduling technique or with predictions offered by an irrigation scheduling model. Many expressed difficulties with the implementation and use of the tensiometer in the past, which also reflect the fact that certain irrigation scheduling approaches require a very steep learning curve to be achieved before it could be successfully implemented. From the findings it is clear that many farmers did meet these requirements but were disappointed with the results of implementing these methods of irrigation scheduling.

The majority (69%) of the respondents who discontinued objective irrigation scheduling took the decision because they were of the opinion that they had gained enough knowledge, confidence and experience to continue with the use of subjective scheduling methods. There is a clear tendency for farmers to initially prefer objective irrigation scheduling methods up to a stage where they feel that they have the situation under control, and will then move on to another phase of the production cycle which may include marketing, changing fertiliser management or labour management, etc. During this phase of production, farmers will implement subjective irrigation scheduling methods based on their local experience and knowledge gained.

The more experienced farmers often only use the objective irrigation scheduling methods as a monitoring system to re-assure them that they are still heading in the right direction. If necessary they will revisit the irrigation scheduling practice, which they have adopted. This “experiential learning cycle” which many farmers are following should be acknowledged. The extensionists and researcher should identify the position of a farmer on this learning cycle in order to render efficient support to the basic steps and translating that takes place during learning and by offering new learning opportunities. The understanding of the learning cycle that farmers are following also helps us to identify the different learning styles that farmers adopt. This will only be possible if efficient communication between the farmer and the professionals is developed.

Understanding the irrigator’s perceptions, needs and knowledge is critical for the successful implementation of efficient irrigation scheduling practises. The study has shed much light on these behaviour determinants, but follow-up investigations are necessary regarding the following:

- Establishing how perceptions and needs change over time and how they influence the pattern of implementation (approach of irrigation scheduling). This could be achieved through follow-up surveys involving, as far as possible, the same respondents or through more qualitative and case study approaches.

- Accurately quantify the various behaviour determinants in order to determine which individual determinant, in comparison to a cluster or multitude of them, explains variation in behaviour.

- A more detail assessment of the role of risk and its quantification as it pertains to probability of success as well as probability of failure and an evaluation as to whether and to what degree this encompassed in the valence perception of both advantages and disadvantages.

- Monitoring whether and to what degree needs (as reflected in problem perceptions) and their compatibility change as the adoption behaviour changes.

17. Learning and information sources used by irrigation farmers

A variation in styles, preferences and motivation for learning exists between the commercial and small-scale farmer, as well as between those farmers who are more progressive and those who are less business-oriented. Learning of the progressive commercial irrigation farmers was identified to be more self-directed, action-oriented and experiential in nature. Therefore, farmers in general indicated preference to informal learning opportunities as part of their farmer networks rather than the delivery of formal training. Networks with fellow farmers are particularly important for the commercial irrigator. Other learning sources, which include both social and expert sources, are the local cooperatives, private consultants and industry experts. Farmers involved in objective scheduling are more willing and prepared to seek additional "external" learning sources. The general expectation that the technological level of the farm determines the choice of irrigation scheduling method as well as the information sources used is supported.

Generally the small-scale irrigators also use farmer networks but rely very much on information from the departmental extensionists in regard to irrigation management. The isolation experienced by many of the small-scale irrigators due the remoteness of the areas where they are farming, often reduces the opportunity to build information and support networks conducive to sustainable irrigation management.

Access to different sources of technical knowledge and information is likely to improve the value of the initial trial period through the possible impact regarding the farmers' knowledge and will in turn influence the rate of adoption. Extensionists and irrigation advisors/planners responsible for the design and dissemination of irrigation scheduling information should recognise the adoption factors based on the age, farm size and level of farm management towards the methods of receiving information on irrigation scheduling. It is important to ensure that the necessary “information and learning networks” exist to ensure full participation of all the stakeholders. The role of informal farmer networks needs to be appreciated by irrigation extensionists and advisors in the dissemination of information.

Basic knowledge of the plant-soil-climate system is an essential requirement for the effective implementation of irrigation scheduling. Unfortunately many farmers (even experienced farmers) are lacking knowledge about the basic principles involved in irrigation management. Water-use efficiency on the farm does not only entail the implementation of irrigation scheduling but also requires a holistic view of the critical management aspects that will ensure optimal water use on the farm (i.e. cultivation, crop management and soil conservation practices). It is therefore not adequate that farmers are trained only in terms of irrigation management without upgrading the necessary knowledge and skills required on the basics of the soil and plant system.

The development and offering of basic courses in the introduction to irrigation principles and irrigation management similar to the “Waterwise on the farm” program offered in Australia should be considered and investigated. A training program, which includes activities like experiential learning, on-farm training, workshops, and field days, benchmarking of best management irrigation practices and studying of case studies in irrigation, could be considered. An attractive incentive scheme should be attached to this program, and the program should be planned and developed to incorporate both commercial and small-scale irrigators.

The possible extrapolation of the Water Care Training offered in the Limpopo Province under its revitalisation initiatives on small-scale irrigation schemes to the rest of the small-scale irrigation schemes in the country should be investigated.

In Chapter 2 (Part One) an overview and classification of the irrigation scheduling methods and computer programs available to irrigators in South

Africa was presented. This information could possibly be used in the development of information brochures and training material to serve the needs of commercial and small-scale irrigators. Especially new irrigators are not always aware of the possibilities (technologies and methods) available to them regarding irrigation scheduling, and currently no concise but also comprehensive manual is available.

21.2 FACTORS THAT INFLUENCE THE PROPAGATION OF IRRIGATION SCHEDULING AMONG SMALL-SCALE IRRIGATION FARMERS

There is no dispute that the extension efforts on the majority of the small-scale irrigation schemes have not achieved the desired results. Farmers often referred to the general lack of technical skills (particularly irrigation management) and the competence level of many of the extensionists.

The following recommendations and conclusion are proposed regarding the propagation of irrigation scheduling amongst small-scale farmers:

1. Ground level support for the implementation of sustainable irrigation practices

The majority of small-scale irrigation farmers perceive irrigation management as "new technology". The innovation processes of irrigation scheduling techniques with its three main components namely, creating a technique, dissemination of the idea and the adoption of it form a whole. The three components cannot therefore be allocated to different role players namely research who design the technique, extension services to disseminate technology and farmers to adopt it, without effective interaction between the relevant parties. Small-scale farmers, as illustrated in the case study at Bethlehem should also be included in the process of innovation and conditions should be created for them to participate. Therefore an interdependent partnership of researcher-extension-farmer should be developed. The success of the interface between farmers and extensionists will depend on the credibility of extensionists as illustrated through his technical competence in irrigation management.

The important role to be played by a mentor in the daily support of small-scale farmers was emphasized with the case studies of small-scale irrigation farming. According to the definition of de Beer (2005), a mentor is simply "someone who helps someone to learn something the learner would have learned less". Therefore, with this definition in mind, extensionists and selected farmers with the necessary experience in irrigation management can play an important role to help small-scale irrigation farmers with the improvement of on-farm water use efficiency.

2. *Sharing of irrigation equipment like the centre pivots at Taung is only possible with good cooperation between farmers*.

Small-scale farmers need to be well organized, and be able to manage and maintain their shared equipment. Local formal and informal farmer organisations are essential for proper cooperation and coordination of activities on an irrigation scheme. The positive interventions of farmer groups and organizations like the Farmer Support Units at Taung, local commodity farmer groups at Nkomazi and Tshiombo, block committees at Bethlehem as well as the role of management committees to steer the irrigation management on a scheme or project emphasize the necessity for the establishment of effective farmer organizations where the beneficiaries could take responsibility for their own development. Training and capacity building of farmers in this regard is needed, and should be the responsibility of extensionists and water institutions.

3. Strong institutional arrangements

A number of grants are available from DWAF (vd Merwe, 2004) to assist small-scale irrigation farmers, but two important conditions that have to be met before the applications can be made, is firstly that farmers have to form a legal entity (preferably a WUA) and secondly, that they must have applied for a water use license. The importance of the capacity building of farmers to enable them to form and effectively manage Water Use Associations as a legal entity on the irrigation schemes, is but one of the several challenges that faces extensionists and other key stakeholders in the development of small-scale irrigation.

4. External management of an irrigation scheme

Clarification of land tenure arrangements of irrigation farmers could increase the incentive to invest in their land and irrigation systems. This factor influences the general operation and attitude of farmers to maintain infrastructure and willingness to spend on inputs like fertilisers and irrigation scheduling equipment and practices. External management is not conducive to farmers‘taking responsibility for their farming enterprises. The farmers tend to neglect the maintenance of equipment if they do not see it as their responsibility.

5. Knowledge support system

Farmers need to understand the basic principles regarding the biological functioning of plants and gain the necessary insight into the complexity of the soil-plant-atmosphere systems before entering into a complex farming system like irrigation. For most of the small-scale farmers the expected learning curve to be achieved is too steep, and unachievable without proper and effective knowledge support. The ideal situation will be for small-scale farmers to start off with rain fed production on a limited scale, where the basic principles of crop production are learned, and then gradually move on to the more complex situation of crop production under irrigation. However, because the latter is not possible, an efficient and committed extension service is imperative for the successful development of small-scale irrigation farmers. Government should therefore ensure that such a service is put in place where required. The urgent need amongst small-scale irrigators regarding the necessary skills to manage irrigation systems should receive the required attention by all relevant role players.

6. *Introduction of objective irrigation scheduling methods to small-scale farmers*

It was observed that many of the small-scale irrigators are not at this point in time ready to be introduced to more sophisticated irrigation scheduling practices. This is mainly because many of them are still preoccupied with barriers like infrastructural problems emanating from inappropriate planning and design of irrigation systems, general lack of knowledge and skills in the maintenance and management of their irrigation systems. Therefore, the development of a site-specific irrigation calendar, as illustrated in the two case studies, namely, Taung and Bethlehem, seems like a possible approach to be followed in the development of small-scale irrigators.

7. Ageing and maintenance of infrastructure and irrigation systems

Ageing of infrastructure and irrigation equipment is inevitable. If no maintenance is done on the bulk water conveyance systems (canal systems) as observed in Tshiombo, Zanyokwe, Taung and Tugela Ferry small-scale irrigation schemes, it tends to break down completely and must be replaced at a very high cost. Regular monitoring and evaluation of the system for leaks, cracks, vegetation invasion and build–up of silt is important. The raising of awareness and support offer regarding the development of effective farmer organisations are essential roles to be played by extensionists and supportive role players.

8. Absence of stakeholders

In Nkomazi the general absence of stakeholders and inappropriate participation of farmers caused many problems regarding the role that extensionists and experts from the sugar industry can play in the training and support of farmers. The latter refers to the many landowners from Nkomazi who are staying in Johannesburg and Pretoria, and who rely on their families to manage and irrigate their lands. Stakeholders or their farm managers should be motivated to regularly attend meetings and training opportunities arranged by extension. Alternative communication channels for the dissemination of information should be identified and put into place where needed.

9. Breaking the "dependency syndrome"

Extensionists and irrigation professionals referred to the "dependency syndrome" that the majority of small-scale irrigators are suffering from. In an effort to break with this syndrome, farmers need to take responsibility and ownership for their own development. This can only be done through proper institutionalization and the establishment of farmer representative bodies, like, for instance, the Farmer Support Units found in Taung, commodity groups in Tshiombo and the irrigation block committees operating on the Bethlehem project. Farmers need to perceive the support from advisors and extensionists as being of a temporary nature and must accept the responsibility to develop the necessary urgency and motivation to be capacitated and empowered through the regular interaction with farmers and extensionists.

Communication networks, trust, commitment and shared values are some of the important elements of social capital that should be developed in order to foster a climate of co-learning. This study again confirmed that small-scale farmers do not operate in isolation, but rather in a social and business relationship situation in which the individual's position is progressively influenced as a result of others.

10. Enthusiastic and committed extension support - a prerequisite for sustainable small-scale irrigation development.

Small-scale irrigation farmers need intensive extension support to overcome their relatively low managerial capacity. Small-scale farmers in general are in desperate need of comprehensive extension support to inform them about new innovations and practices and to help them to become "aware" of the potential use of irrigation scheduling practices. However the needs and nature of the small-scale farmers are diverse and integrated with the broader society and economy. By assuming a linear, homogeneous approach of technology dissemination to research technology will downplay the boundaries of this diverse environment in which the small-scale farmer operates. Therefore a new strategy in technology development and transfer such as participatory action research will not only incorporate the collective knowledge of all the key role players, but will also increase the farmer ownership over the research and extension process. The science of irrigation is however complex and comprehensive, and therefore competent extensionist with a good working relationship with farmers and other irrigation professionals are needed.

The traditional approaches adopted to organize farmers and farming cooperatives, needs to be revised to meet the development challenges of the twenty first century. The main extension roles to help rural communities to become organized are as follows:

- Empowerment and ownership role - this can be a cornerstone of the new approach to extension. The extension staffs needs to help farmers and rural communities to organize themselves and take charge of their own growth and development.

- Community organizing role – extension officers must learn the principles of community–organizing and group management skills in order to help the community, especially the poor or weaker sections to organize itself for development.

- Human resource development role - the human resource development approach empowers people and gives new meaning to all other roles. Development of technical capabilities must be combined with the management capabilities.

- Mentorship role- the important role that mentors could play in helping farmers to overcome constraints in the steep learning curve many have to complete.

- Problem-solving and education role - problem solving is an important role, but is changing from prescribing technical solutions to empower farmer organizations to solve their own problems. This is achieved by helping them to identify the problems and seek the right solutions by incorporating their indigenous knowledge with improved knowledge and by using their resources properly.

11. Experiential learning or "learning by doing" approach

The importance of stimulating efficient interaction and dialogue between farmers, extensionists and researchers through experiential learning proved to be successful in the building of capacity amongst small-scale farmers. The opportunities for regular feedback from farmers to mentors and extensionists are numerous, and it also address the general problems that are often experienced regarding articulation of complex concepts like irrigation scheduling and other relevant issues applicabel to irrigation management. Extension officers should however be equipped with the necessary skills and knowledge to fulfil this facilitating role in starting a dialogue with farmers and must be prepared to listen sympathetically to what farmers have to say. This does not only expect a new approach to training of extension officers but also needs a change of attitude and perception by some extensionists.

The experiential learning approach followed in the projects, as indicated in the case studies of Bethlehem and Taung, reflects four main elements as proposed by Kolb (1995): concrete experience, observation and reflection, generalization and conceptualization and then active experimentation. Farmer Field Schools (FFS), which are based on these elements of experiential learning, can be used as a possible "extension vehicle" where the training and development is organized around a season-long series of weekly meetings focusing on agronomy, soil preparation, irrigation principles and irrigation and other farm management issues. With FFS the focus is on capacity building of the individual and the group of farmers. The experiential learning processes require people with the necessary skills and knowledge to help and support farmers, but also important facilitating skills to be able to ask the right questions at the right time.

The implementation of irrigation scheduling technology on the farm is important for the sustainable and efficient use of irrigation water. However, to enable farmers to implement recommended irrigation scheduling approaches and principles an environment conducive for "learning" should be developed. Learning assist farmers to receive decode and understand the information provided on irrigation scheduling, and hence help to make better-informed decisions regarding irrigation management. The change of irrigation practices is, however, a cumulative process, which builds on existing knowledge and practices through interactive learning in which effective dialogue between the farmer, extensionist and researcher plays a crucial role.

REFERENCES

ADAMS, D.A., NELSON, R.R. & TODD, P.A., 1992. Perceived Usefulness, Ease of Use, and Usage of Information Technology: A Replication. *MIS Quarterly* 16(2): 227-247.

ACKOF, R.L., 1978. *The art of problem solving.* John Wiley & Sons. New York.

AGROTOP, 2003. *Intermittent soil moisture measurement: Diviner 2000.* *http://www.agrotop.co.za/ismm.htm* (Downloaded 18/9/2003)

AJZEN, I. & FISCHBEIN, M., 1980. *Understanding Attitudes and Predicting Social Behaviour.* Englewood Cliffs, N.J. Prentice Hall.

ALAM, M., DUKE, H.R. & ORENDORFF, W., 1996. ET information use by Colorado farmers. In: Camp C.R., Sadler E.J. & Yoder R.E. (eds..) *Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling*, 3-6 November 1996, San Antonio, Texas, USA: 928-932.

ALLEN, G.R., PEREIRA, L., RAES, D. & SMITH, M., 1998. Crop evapotranspiration: guidelines for computing crop water requirements. *(FAO Irrigation and Drainage Paper No. 56)*. Rome: Food and Agriculture Organisation of the United Nations.

ALLEN, G.R., SMITH, M., PEREIRA, L.S. & PERRIER, A., 1994. An update for definition of reference evapotranspiration. *ICID Bulletin* 43(2): 1-34.

ALENE, A.D., POONYTH, D. & HASSAN, R.M., 2000. Determinants of adoption and intensity of use of improved maize varieties in the control highlands of Ethiopia: A total analysis. *Agrekon,* 39(4): 633-643.

ALENE, A.D. & HASSAN, R.M., 2003. The determents of farm-level technical efficiency among adoptions of improved maize production technology in western Ethiopia. *Agrekon*, 42(1): 1-14.

ALRøE, H. & KRISTENSEN, E.S., 2002. Towards a systematic research methodology in agriculture: Rethinking the role of value science. *Agriculture and Human values,* 19: 3-23.

ANDERSON, J., 1993. The economics of new technology adaptation and adoption. *Review of Marketing and Agric. Econ*. 61: 301-310.

ANGUNGA, R.A., 1997. *Developing the third world.* Nova Science Publishers, Inc. New York

ANNANDALE, J.G., VAN DER WESTHUIZEN, A.J. & OLIVIER, F.C., 1996. Die fasilitering van tegnologie oordrag deur verbeterde besproeiingsriglyne vir groente en meganistiese gewasmodeleringsbenadering. WNK Verslag No. 476/1/96

ANNANDALE, J.G., BENADÉ, N., JOVANOVIC, N.Z., STEYN, J.M. & DU SAUTOY, N., 1999. Facilitating irrigation scheduling by means of the Soil Water Balance Model. WRC Report No.753/1/99

ANNANDALE, J.G., JOVANOVIC, N.Z., STEYN, J.M., SOUNDY, P. & BACKEBERG, G.R., 2002. Technology Transfer of Soil Water Balance model for irrigation scheduling. FAO Workshop, Montreal, Canada.

ARABIYAT, T.S., SEGARRA, E. & JOHNSON, J.L., 2001. Technology adoption in agriculture: Implications for Groundwater conservation in the Texas High Plains. *Res. Cons. Rec*. 32: 147-156.

ARC, 1997. Irrigation systems. In: *Irrigation Design Manual*, ARC, Pretoria.

ARC, 1999. Water Conservation and Demand Strategy, ARC-Institute for Agriculture Engineers, Silverton, Pretoria.

ARGYRIS, M. & SCHöN, D., 1978. Organisational learning: a theory of action perspective. Reading Mass, Addison Wesley.

ATKINSON, R.L., ATKINSON, R.C., SMITH, E.E. & HILGARD, E.R., 1985. Introduction to Psychology, Ninth Edition, New York.

ATS RURAL DEVELOPMENT SERVICES, 2002. Rehabilitation of Zanyokwe Irrigation Scheme. Final Report.

BABBIE, E. & MOUTON, J., 2001. The practice of social research. Oxford University Press, Cape Town.

BACKEBERG, G.R., 1994. Die Politieke Ekonomie van Besproeiingsbeleid in Suid-Afrika. PhD thesis, University of Pretoria.

BACKEBERG, G.R., 1996. Constitutional change and natural resource policy reform in South Africa: conducive or obstructive to sustainable economic growth of agriculture? *Agrekon* 35(4): 160-169.

BACKEBERG, G.R., BEMBRIDGE, T.J., BENNIE, A.T.P., GROENEWALD, J.A., HAMMES, P.S., PULLEN, R.A. & THOMSON, H., 1996. Policy proposal for irrigated agriculture in South Africa. WRC Report KV 96/96.

BACKEBERG, G.R., SANEWE, A.J., 2005. The research and development strategy for water utilisation in agriculture-responding to diverse needs of farmers in South Africa. Special Session on "Driving Research for Change in Irrigation and Drainage Practices", 19th Congress of the ICID, Beijing, China, 12 September 2005.

BADENHORST, J.W., DE LANGE, M., MOKWENA, M.E. & RUTHERFORD, R.J., 2002. Water Conservation and Water Demand Management in

Agriculture: Development of Water Management Plans by Irrigation Water Suppliers in South Africa. ICID 18th Congress, Montreal, Canada.

BARR, N.F. & CARY, J.W., 2000. Influencing improved natural resource management on farms: A guide to understanding factors influencing the adoption of sustainable practices. Bureau of Rural Science, Canberra. *http://www.brs.gov.au/social-science/nat resource-mgt.pdf*

BARRET, PUCELL & ASSOCIATES, 1999. Determining a framework, terms, and definitions for water use efficiency in irrigation. Report to Land and Water Research and Development Corporation, Australia*, www.lwa.gov.au*

BASTIAANSEN, W.G.M., 2000. SEBAL based sensible and lantern heat fluxes in the irrigated Gediz basin, Turkey. *J of Hydro* 229: 87-100.

BASTIAANSEN, W.G.M. & BOS, M.G., 1999. Irrigation performance indicators based on remote sensed data: a review of literature. *Irrigation & Drainage System* 13 (4): 291-311.

BASTIAANSEN, W.G.M., MERENTE, M., FEDDES, R.A. & HOLTSLAG, A.A.M., 1998. A surface energy balance algorithm for land (SAL), Part 1: Formulation. *J of Hydro* 213: 98-212.

BATZ, F.J., PETERS, K.J. & JANSSEN, W., 1999. The influence of technology characteristics and the rate and speed of adoption. *Agr. Econ*. 21: 21-130.

BAWDEN, R., 1995. On the systems dimension in FSR. *Jnl of Farming Systems Research –Extension*, 5(2): 1-18.

BEMBRIDGE, T.J., 1991. The practice of agricultural extension: A training manual. Development Bank of Southern Africa, Halfway House.

BEMBRIDGE, T.J., 1996. Small-scale farmer irrigation schemes in South Africa. Appendix to Backeberg, G.R., Bembridge, T.J. & Bennie, A.T.P., 1996. *Policy proposal for irrigated agriculture in South Africa*, 1996. Water Research Commission.

BEMBRIDGE, T.J. & WILLIAMS, J.L.H., 1999. Factors affecting adoption of maize growing practices in small-scale farmer support programmes. *S. Afr. J.Agric.Ext:*28: 53-61

BEMBRIDGE, T.J., 2000. Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa. WRC Report No. 891/1/00.

BENNIE, A.T.P., COETZEE, M.J., VAN ANTWERPEN, L.D. & BURGER, R., 1988. 'n Waterbalans model vir besproeiing gebaseer op profielwatervoorsieningstempo en die gewaswaterbehoeftes. WRC Report No. 144/1/88.Pretoria, WRC.

BERGER, P.L. & LUKMANN, T., 1967. The social construction of reality. A treatise in sociology of knowledge. Anchor Books, Garden City, New York, USA.

BEUKES, O., 2002. Personal communication. Nietvoorbij, Stellenbosch, Western Cape

BICKMAN , L. & ROG, D., 1998. Why a handbook of applied social research methods? In: Bickman, L. & Rog, D. (eds.), Handbook of applied social research methods., Sage Publ., Thousand Oaks, California.

BIGGS, S.D., 1990. A multiple source of innovation model of agricultural research and technology promotion. *World Dev*., 18: 1481-1499

BIGGS, S.D. & SMITH, G., 1998. Beyond methodologies: coalition-building for participatory technology development. *World Dev., 26*: 239-248

BIOT, Y., BLAIKIE, P., JACKSON, C. & PALMER–JONES, R., 1995. Rethinking research and land degradation in developing countries. *World Bank Paper 289*, Washington DC, World Bank.

BLACKET, D.S., 1996. When adoption theory fails. *Proc. 8th Australian Agronomy Conference* Towoomba, Queensland: 104-107.

BLUM, A., 1996. Teaching and learning in agriculture: A guide to agricultural educators, FAO, Rome.

BOEKE, E., 2002. Personal communication. Natal Irrigation Consultants, Pietermaritzburg.

BOESCH, B.E., HUMPHREYS, A.S. & YOUNG, D., 1981. How scheduling fits in the irrigation program in Grand Valley of Colorado. In: *Irrigation Scheduling for Water and Energy Conservation in the 80's*, *Proc. of the American Society of Agric. Eng., Irrigation Scheduling Conference, ASAE*: 159 -165.

BOTHA, C.A.J., 1985. Die invloed van menskundige en fisiese faktore op besluitneming ten-opsigte van droogtebeplanning. M.Inst. Agrar., Univ. Pretoria.

BOTHA, C.A.J., 1986. The influence of different perceptions on the adoption practices related to drought resistance. *S. Afr. Jnl. for Agric. Ext*. 15:29.

BOTHA, C.A.J., 1997. Towards a measuring instrument to predict farmers' success. *S. Afr. Jnl. for Agric. Ext*. 26: 39-55.

BOTHA, C.A.J., & STEVENS, J.B., 1999. The need for changes in veld management technology generation and dissemination. *S. Afr. Jnl. for Agric. Ext*. 28: 108-126.

BOTHA, C.A.J., STEYN, G.J. & STEVENS, J.B., 2000. Factors which influence the acceptability of irrigation scheduling with specific reference to scheduling models. WRC Report K5/892/00.

BOTHA, F., 2003. Personal communication. SASRI, Malelane, Mpumalanga.

BRANKEN, P. & DE KOCK, C., 2001. Personal communication. Department Agriculture of Northwest, Potchefstroom.

BRUWER, J.J. & VAN HEERDEN, P.S., 1992. Spotlight on irrigation development in the RSA: the past, present and future. *SA Irrigation*, Dec 1992.

BUCHLEITER, G.W. & HEERMAN, D.F., 1986. Using computers to manage irrigation systems. *J Water Resource Planning & Management* 112(3):354-365.

BURMAN, R.D., CEUNCA, R.H. & WEIS, A., 1983. Techniques for estimating irrigation water requirements. In: *Advances in Irrigation. D. Hillel (ed) Academic Press, New York, 2:* 336-394.

BURT, C.M., 1996. Essential water delivery policies for modern on-farm irrigation management. In: Smith M., Pereira L.S., Berengena J., Itier B., Goussard J., Ragab R., Tollefson L. & Van Hofwegen P. (eds.) *Irrigation Scheduling: From Theory to Practice. Proceedings of the ICID/FAO Workshop on Irrigation Scheduling*, 12-13 September 1995, Rome, Italy, Water Reports No. 8.

CAMPBELL, R.R., 1966. A suggested paradigm of the individual adoption process. *Rural Sociology*, 31: 458-466.

CAMPBELL, G.S. & CAMPBELL, M.D., 1982. Irrigation scheduling using soil moisture measurements. In: Hillel, D. (ed.), *Advances in Irrigation*. 1, Academic Press Inc., New York: 25-42

CAMPBELL, G.S. & NORMAN, J.M., 1998. An introduction to environmental biophysics. Second Edition, Springer, 1998.

CAMPBELL SCIENTIFIC, 2003. Sentek soil probes available. *http://www. campbell.sci.com/updates/jan03.pdf*

CARY, J.W., 1992. Lessons from the past and present attempts to develop sustainable land use systems. *Rev. of Marketing &Agric. Econ.* 60(2): 57-64

CARY, J.W. & WEBB, T., 2000. Community land care, the national land care program and the land care movement. The social dimensions of land care. Bureau of Rural Science, Canberra. *http://www.affa.gov.au/corporate-docs/publications/pdf/rual science/social science/landcare.pdf*

CASWELL, M. & ZILBERMAN, D., 1985. The choices of irrigation technologies in California. *Amer. J. Agric. Econ*. May: 24-233.

CASWELL, M. & ZILBERMAN, D., 1990. The effects of pricing policies on water conservation and drainage. *Amer. J. Agric. Econ*. May: 883-890.

CHAMALA, 1987. Management Strategies to Promote Transfer of Irrigation Technology for the Improvement of the Murray Darling Basin's Land and Water Resources. Keynote address given to the Murray Darling Basin Ministerial Workshop on Transfer of Irrigation Technology, 28-30 July 1987, Yanco, New South Wales.

CHAMALA, S. & COUGHENOUR, M.C., 1987. Model for Innovation Development, Diffusion and Adoption. - A System for Agricultural Development. *J. Ext. Sys*.,3: 47-55.

CHAMALA, S. & MORTISS, P., 1990. Working together for Land Care: Group management skills and strategies. Brisbane, Academic Press

CHAMALA, S. & KEITH, K., 1995. Participative Approaches for Land care. Brisbane, Academic Press.

CHAMALA, S., 1996. Transfer of irrigation technology: Need for social and institutional strategies for its effective development and adoption. *Proc. Nat. Conf. Irrig. Assoc. Aust.* 14-16 May, Adelaide, 12-2 to 12-8.

CHAMBERS, R. & GHILDYAL, B., 1985. Agricultural research for resource poor farmers- the farmer first and last model. *Agricultural Administration*. 10:1-30.

CHANG, S. & LEE, Y., 2000. Conceptualising context and its relationship to the information behaviour in dissertation research process. *Jnl. of Library and Information Science*, *26(2):* 4-18.

CHECKLAND, P.B., 1981. Systems Thinking, Systems Practice. J Wiley & Sons, Chichester.

CHECKLAND, P.B. & SCHOLES, J., 1990. Soft systems methodology in action. John Wiley Publ., UK.

CHILDS, J.L., WALLENDER, W.W. & HOPMANS, J.W., 1993. Spatial and seasonal variation of furrow infiltration. *J. Irr. Drain. Eng*. 119(1): 74-90.

CHONE, X., VAN LEEUWEN, C., DUBOURDIEU, D. & GAUDILLERE, J.P., 2001. Stem water potential is a sensitive indicator of grapevine water status. *Ann Bot*. 87: 477-483.

CHURCHMAN, C.W., 1983. The systems approach. Dell Publishing Co., New York.

COX, P.G., SCHULMAN, A.D., RIDGE, P.E., FOALE, M.A. & GARSIDE, A.L., 1995. An interrogative approach to system diagnosis: An invitation to the dance. *Jnl. for Farming Systems Research Extension* 5: 67-83.

COX, P.G., 1996. Some issues of the design of agricultural decision support systems. *Agric Syst*., 52: 355-381.

COOL, C., 2001. The concept of situation in information science. *Annual Review of Information Science and Technology. 35:* 5 -42.

COUPAL, R.H. & WILSON, P.N., 1990. Adoption Water Conserving Technology: The case of surge Irrigation in Arizona. *Agr. Wat. Mgt.* 18: 5-28

CROSBY, C.T., 1996. SAPWAT 1.0 – A computer program for estimating irrigation requirements in South Africa. WRC Report No. 379/1/96. Pretoria, WRC.

CROSBY, C.T. & CROSBY, C.P., 1999. A computer programme for establishing irrigation and scheduling strategies in SA. WRC Report No. 624/1/99,Pretoria.

CROSBY, C.T., DE LANGE, M., STIMIE, C.M. & CROSBY, C.P., 2000. A review of planning and design procedures applicable to small-scale farmer irrigation projects. WRC Report No. 578/2/00.

CROSBY, C.T., 2004. The application of the SAPWAT website. *www.wca.watonet.org*

CSIRO, 2005. Off-and on-farm savings of irrigation water: Murrumbidgee valley water efficiency feasibility project, NSW Government, Australia.

CURTIS, A.L., McKAY, J., VAN NOUHUYS, M., LOCKWOOD, M., BYRON, I. & GRAHAM, M., 2000. Exploring landholder willingness and capacity to manage dryland salinity: The Goulburn Broken Catchment. Albury, Johnstone Centre, Charles Sturt University.

DANIELS, J. & CHAMALA, S., 1989. How farmers learn? Queensland Department of Primary Industries, Brisbane.

DAVIS, F.D., 1989. Perceived usefulness, perceived ease of use and user acceptance of information technology. *MIS Quarterly*, 13: 319-340.

DAVIS, F.D., ABGOZZI, R.P. & WARSHAW, P.R., 1989. "User acceptance of computer technology: A comparison of two theoretical models." *Management Science* 35: 982-1003.

DAVIS, F.D., 1993. User acceptance of information technology: system characteristics, user perceptions and behavioural impacts. *Int. Jnl. of Man-Machine Studies* 38: 475-487.

DE BEER, H., 2005. Mentoring skills. Course material, University of Pretoria: 29.

DE JAGER, J.M. & KING, 1974. Calculation for photosynthesis rate of a maize crop from environmental variable. *Canadian IBF Res. Report*: 321-338.

DE JAGER, J.M., 1979. PUTU a dynamic seasonal maize crop growth model. In: *Gulp Project Final Report*.

DE JAGER, J.M., 1992. The PUTU Decision Support System Monograph of the Department of Agro meteorology, University of the Free State, Bloemfontein.

DE JAGER, J.M., BOTHA, D.P. & VAN VUUREN, C.J.J., 1981. Effective rainfall and the assessment of potential wheat yield in a shallow soil. *Proc. Soc. Crop Prod*. 10: 51-56.

DE JAGER, J.M. & KENNEDY, J.A., 1996. Weather-based irrigation scheduling for various farms (commercial and small-scale). In: Smith M., Pereira L.S., Berengena J., Itier B., Goussard J., Ragab R., Tollefson L. &

Van Hofwegen P. (eds.) *Irrigation Scheduling: From Theory to Practice. Proceedings of the ICID/FAO Workshop on Irrigation Scheduling*, 12-13 September 1995, Rome, Italy, Water Reports No. 8: 33-38.

DE JAGER, J.M., SINGELS, A. & KENNEDY J.A., 2001. Research on a computer weather based irrigation water management system. WRC Report No. 581/01/01. Pretoria.

DE JAGER, J.M., VAN ZYL, W.H., KELBE, B.E. & SINGELS, A., 1987. Research on a weather service for scheduling the irrigation of winter wheat in the Orange Free State Region. WRC Report No. 117/1/87. Pretoria.

DE KLERK, C.H., 1979. Menskundige en omgewingsinvloede op praktykaanvaarding en reproduksiedoeltreffendheid in hoëpotensiaal beesboerderygebiede van Suidwes Afrika. D Agric (Inst. Agra.) Proefskrif, Univ. Pretoria.

DE KLERK, C.H. & DÜVEL, G.H., 1982. Human and environmental influences in practice adoption and reproduction efficiency in the high potential cattle farming areas of South West Africa. *S. Afr..Jnl. of Agric. Ext., 11*:1-15.

DE LANGE, M & MARITZ, P., 1998. Royal Society of South Africa –Working Conference implications of the New Water Policy: Problems and solutions. November 1998, DWAF, Pretoria.

DE LANGE, M., 2004. “Smallholder farmer training”: Need for the adaptation of training material for agriculture. WRC Workshop, May 2004, Pretoria.

DELPORT, F., 2001. Personal communication. Cape Irrigation Consultants Pty Ltd, Somerset Wes.

DENZIN, N.K., 1978. The research act. Second Edition, New York, McGraw Hill Book Co.

DENZIN, N.K. & LINCOLIN, Y.S. (eds.), 1994. Handbook of qualitative research. Thousand Oaks: Sage Publication.

DEPARTMENT OF AGRICULTURE, 2001. The strategic plan for South African Agriculture. Government Printer, Pretoria.

DEPARTMENT OF AGRICULTURE AND FORESTRY, REPUBLIC OF CISKEI, 1987. Zanyokwe Irrigation Scheme: Operation and Maintenance Practices. (Prepared by CISCARMEL Pty Ltd.)

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1986. Management of water resources of the Republic of South Africa, Pretoria

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2000. Implementation guidelines for water conservation and water demand strategy in the agricultural sector.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2003. Orange River Basin. *www.dwaf.pwv.gov.za.*

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 2004. The National Water Resource Strategy. *www.dwaf.gov.za.*

DEWEY, J., 1938. Experience and education. Kappa Delta, New York.

DINAR, A., CAMPBELL, M.B. & ZILBERMAN, D., 1992. Adoption of improved irrigation and drainage reduction technologies under limiting environmental conditions. *Env. Res. Econ*. 2: 360-373.

DINAR, A. & YARON, D., 1992. Adoption and abandonment of irrigation technologies. *Agr. Econ.* 6: 315-332.

DINAR, A. & ZILBERMAN, D., 1991. The economics of resource conservation, pollution-reduction technology selection: The case of irrigation water. *Res. Ener*. 13: 323-348.

DLULANE, W.T., 2004. Personal communication. Department of Agriculture Eastern Cape, Malenge Irrigation.

DOCKTER, D.T., 1996. AgriMet - The Pacific Northwest Cooperative Agricultural Weather Station Network. In: Camp C.R., Sadler E.J. & Yoder R.E. (eds.) *Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling*, 3-6 November 1996, San Antonio, Texas, USA: 870-873.

DOORENBOS, J. & PRUITT, W.O., 1977. Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage Paper 33, FAO, Rome.*

DOUTHWAITE, B., HAAN, N.C. MANYONG, V. & KEATINGE, D., 2001. Blending "hard" and "soft" science. The follow the technology approach to catalysing and evaluating technology change. *Cons. Ecol., 5 (2):* p13 *http:/www.consecol.org/vol 5/iss2/art13*

DROOGERS, P., KITE, G. & MURRAY-RUST, H., 2000. Use of simulation models to evaluate irrigation performance including water productivity, risk and system analyses. *Irr. Sci*. 19: 139-145.

DUNN, R. & DUNN, K., 1978. *Teaching students through their individual learning styles*. Reston Publ. Comp. Inc.

DU PLESSIS, F., 2002. Personal communication. MBB, Stellenbosch, Western Cape.

DU PLESSIS, T.J., 2000. Geoquip: *Irrigation scheduling with Waterman Neutron Probe. SA Bespr*. Apr/May 2000.

D'URSO, G. & MENENTI, M., 1995. Mapping crop coefficients in irrigated areas from Landsat TM images. *Proc. Europ. Symp. On Sat. Rem. Sensing II*, Europto, Paris, SPIE Vol. 2885

DU TOIT, J.G., 2002. Personal communication. MKTV Cooperative, Marble Hall.

DÜVEL, G.H., 1974. Die bemiddelende funksie van persepsie in innovasie-besluitneming. DInst Agrar, Univ Pretoria.

DÜVEL, G.H., 1975. The mediating functions of perception in innovation decision-making. *S. Afr. Jnl. of Agric., Ext 4*:25-36.

DÜVEL, G.H., 1982. Need creation and exploitation: The basis for change. *S. Afr..Jnl. of Agric. Ext., 11*:27-33.

DÜVEL, G.H., & SCHOLTZ, H.P.J., 1986. The non-acceptability of recommended veld management practices. *S. Afr. of Agric., Ext*.15:1-10.

DÜVEL, G.H., 1987. Situation determination: from theory to practical model. *S. Afr. J. Agric. Ext*., 16:1-10.

DÜVEL, G.H., 1990. Needs and their role in conservation farming. *Jnl. of Ext Systems 6(2*):21-41.

DÜVEL, G.H. & BOTHA, A.J., 1990. The conservation behaviour and perception of farmers in respect of the environment and recommended conservation. South African Institute for Agricultural Extension, Univ. Pretoria (Unpublished report).

DÜVEL, G.H., 1991. Towards a model for the promotion of complex innovations through programmed extension. *Jnl. of Ext Systems* 20:70.

DÜVEL, G.H., 1998. Monitoring extension: a cognition oriented approach towards evaluation. *S. Afr. J. Agric. Ext*., 27:30-45.

DÜVEL, G.H. & BOTHA, 1999. Human constraints to sustainable agriculture in the arid regions of South Africa. *Jnl. of Education and Extension,* 6(1):47-60.

EKSTEEN, J., 2002. Personal communication. Upington, Northern Cape.

ELIAS, N. & SCOTSON, J.L., 1965. The established and outsiders. Frank Cass & Co Ltd.

ELLIS, F, 1993. Peasant economics. Farm household and agrarian development. Second Edition, Cambridge University Press: 309.

ELLIS, F., 2000. Rural Livelihoods and Diversity in Developing Countries. Oxford University Press, Oxford.

ELLOF, C., 2001. Personal communication, DWAF Eastern Cape.

ELREDGE, E.P., SHOCK, C.C. & STIEBER, T.D., 1993. Calibration of granular matrix sensors for irrigation management. *Agron. J.,* 85(6):1228-1232.

ENGEL, P.G.H. & SOLOMON, M., 1997. Facilitating innovation for development. A RAAKS resource box. Royal Tropical Institute, Amsterdam.

ERASMUS, B., 2003. Personal communication. SA Malsters, Taung, Northwest Province.

FABER, B.A. & SNYDER, R.L., 1990. Extension activities needed to expand use of evapotranspiration data for irrigation. *Jnl. of Agron. Educ.*, 19(1):8-13.

FAO & WORLD BANK, 2000. Agricultural Knowledge and Information Systems for Rural Development (AKIS/RD). Strategic Vision and Guiding Principles. FAO, Rome and World Bank, Washington.

FARES, A. & ASHOK, K.A., 1998. Evaluation of capacitance probes for optimal irrigation of citrus through soil moisture monitoring in an entisol profile. *Irrig Sci (2000)1:*57-64.

FAIRWEATHER, H., AUSTIN, N. & HOPE, M., 2003. Water Use Efficiency: An Information Package. *Irrigation Insights No. 5.* Land and Water, Canberra, Australia.

FARRINGTON, J., CHRISTOPLOS, I. & KIDD, A., 2002. Extension, Poverty and Vulnerability. The Scope for Policy Reform. Final report of the study for the Neuchatel Initiative. ODI Working Paper 55, ODI, London.

FEATHER, P. & AMACHER, G, 1994. Role of information in the adoption of best management practices for water quality improvement. *Agric Econ.11:* 159-170.

FEDERER, G. & UMALI, D.L., 1993. The adoption of agricultural innovations: A review. *Tech. For. and Soc. Ch.* 43:215-239.

FERERES, E., 1996. Irrigation scheduling and its impact on the 21st century. In: Camp C.R., Sadler E.J. & Yoder R.E. (eds.) *Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling*, 3-6 November 1996, San Antonio, Texas, USA: 547-553.

FESTINGER, L., 1957. A theory of cognitive dissonance. Evanston Illinois: Row, Peterson.

FISCHBEIN, M. & AJZEN, I., 1975. Belief, Attitude, Intention and Behaviour: An introduction to Theory and Research. Reading, MA Addison-Wesley.

FISCHELON, G. & RYMON, D., 1989. Adoption of agricultural innovations: The case of drip irrigation of cotton in Israel. *Tech. For Soc. Ch*., 35:375-382.

FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS (FAO), 1986. Guidelines: land evaluation for irrigated agriculture. FAO: *Soils Bulletin No. 55, Rome.*

FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS (FAO), 1995. Water development for food security. *FAO: WFS/TECH/2*, Rome.

FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS (FAO), 2000. Affordable irrigation technologies for smallholders: opportunities for technology adaptation and capacity building. FAO, Rome.

FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS (FAO), 2001. Smallholder Irrigation Technology: Prospects for sub-Saharan Africa, FAO, Rome.

FOURIE, P., 2002. Personal communication. Bethlehem, Free State.

FRANK, B.R. & CHAMALA, S., 1992. Effectiveness of extension strategies. In: Lawrence , G., Vanclay, F. & Furse, B. (eds.) Agriculture, Environment and Society: Contemporary Issues for Australia, Melbourne. McMillan: 122-140.

FRÜHLING, P., 1996. 'A liquid more valuable than gold: on the crisis in Southern Africa, future risks and solutions', Sida, Stockholm, Sweden.

FUNTOWICZ, S.O. & RAVETZ, J.R., 1993. Science for the post-normal age. *Futures*, 25:739-755.

GARDNER, H.H., 1986. Water content. *Amer. Soc. Of Agronomy*, Madison, USA. In: *Methods of Soil Analyses, Part 1. Physical and Mineralogical Methods- Agronomy Monograph No 9 (2nd Edition*).

GAY, L.W. Bowen ratio measurements at sites C and L, Chapter A, USGS WRI 91(4):159.

GEAR, R.D., DANSFIELD, A.S. & CAMPBELL, M.D., 1977. Irrigation scheduling with neutron probe. *J Irrig. Drain. Div. (ASCE), 103(IR3*):291-298.

GEELS, F., 2002. Understanding the Dynamics of Technological Transitions. A Co-evolutionary and socio-technical analysis. Twente University Press, Enschede.

GEORGE, B.R.F., 1988. A simple method of scheduling irrigation. South Africa Sugar Association Experimental Station, Mt. Edgecomb.

GEOQUIP, 2001. *http://www.geoquip.co.za* (Downloaded:Jun 2001)

GHADIM, A. & PANNEL, D.J., 1999. A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics,* 21:145-154.

GIDDENS, A., 1984. The Constitution of Society: Outline of the Theory of Structuration. Policy Press, Cambridge.

GREEN, G.C., 1985a. Estimated Irrigation Requirements of Crops. Part 1 ARC, Pretoria.

GREEN, G.C., 1985b. Estimated Irrigation Requirements of Crops. Part 2 ARC, Pretoria

GREY, F., 2002. Personal communication. Vunisa Cotton, Makhatini, KwaZulu Natal.

GRILICHES, Z., 1957. Hybrid corn: An exploration in the economics of technological change. *Econometrica,* 25(4):501-522.

GUROVICH, L.A., 1997. Phytomonitoring Technology in Viticulture: A review of the state of the art. Office International Viticulture and Enology Congress. Dec. 1997, Buenos-Aires, Argentina.

HAARHOF, D., 2001. Personal communication. GWK, Kimberley

HAARHOF, D., 2004. Personal communication. GWK, Barkley West.

HAGMAN , J. & CHUMA, E., 2002. Enhancing the adaptive capacity of the resource users in natural resource management. *Agric Syst*., 73

HAMILTON, N.A., WOODRUFF, D.R. & JAMIESON, A.M., 1991. Role of computer based decision aids in farm decision-making and in agricultural extension. In: Muchow, R.C. & Bellamy, J.A., (eds*.) Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics*. CAB International, Bribane: 411-424.

HAMILTON, N.A., 1998. Co-learning tools: powerful instruments of change in Southern Queensland, Australia. In: Röling, N & Wagemeakers, M.A.E. (eds.) *Facilitating sustainable agriculture*. Cambridge University Press, Cambridge, UK.

HARDIE, 1985. Irrigation scheduling for optimum yield and fruit quality in southern Victoria: In: *Grapevine management in southern Victoria*., 11 July 1985. *Agdex:* 241.

HARGADON, A.B., 1998. Firms as knowledge brokers: Lessons in pursuing continuous innovation". *California Mgt. Rev*., 40(3):209.

HARRINGTON, G.F. & HEERMAN, D.F., 1981. State of art irrigation scheduling computer program. In: *Proc. of the ASAE Irr. Sched. Conference: Irrigation Scheduling for Water and Energy Conservation in the 80s*. *ASAE Publ., Am. Soc. Agron*: 171-178, St Joseph, MI.

HAVELOCK, R.G., 1986. Modelling the knowledge system. In Beal, G., Dissanayake M. & Konoshima, S. (eds.), Knowledge Generation, Exchange and Utilization. Westview Press, Boulder: 77-104.

HAYMAN, P.T., 2001. Decision support systems in Australian dry land farming: A promising past, a disappointing present and uncertain future. South Australian research and Development Institute, Waite Res. Precinct, Adelaide.

HEXEN, R.W. & HEADY, E.O., 1978. Water production functions and irrigated agriculture water no longer a plentiful resource, which should be sparingly used in agriculture. IOWA State University Press, Ames, Iowa.

HEYNS, P., 1995. Management of Water Resources in Southern Africa. Dept. of Water Affairs, Windhoek, Namibia.

HILL, R.W., 1991. Irrigation scheduling. In: Hanks J., & Ritchie J.R. (eds.), *Modelling Plant and Soil Systems . Agron. Mono No. 31. Am. Soc. Agron.,* Madison, WI: 491-509.

HILL, R.W. & ALLEN, R.G., 1995. Simple irrigation calendars: A foundation for water management. In: *Irrigation scheduling: from theory to practice, ICID, Rome.*

HILLEL, D., 1982. Introduction to Soil Physics. Academic Press. London.

HOCHMAN, Z., 1995. Action plan for decision support systems. NSW Agriculture, Orange.

HOLLAND, H. & ENGELFIELD, B., 2000. Water use efficiency. *http://www. probe for windows folder/probe article1.htm* (Downloaded: Dec 2001).

HOOGENBOOM, C., 2000. Future of CANERO in DDSAT suite of models. *Proc of Int CANEGRO Workshop*, Mt. Edgecombe, 2000:9-11.

HOLING, C.S., BERKES, F. & FOLKE, C., 1998. Science, sustainability and resource management. In: Berkes, F. & Folke, C. (eds.), Linking social and ecological systems: Management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge , UK.

HONEY, P. & MUMFORD, A., 1982. The manual of learning styles. Peter Honey, Berkshire.

HOWEL, T.A., 1996. Irrigation scheduling Research and its impact on water use. In: Cramp C.R., Sadler E.J., Yoder R.E. (eds.), *Evapotranspiration and irrigation scheduling*. *Proc of Int. Conference*. Nov 3-6, 1996. San Antonio, TX, ASASE, St. Joseph, MI: 21-23. *http://worldatlas.com/ webimage/countrys/af.htm* (Downloaded: July 2001)

HOWEL, T.A., 2001. Enhancing water use efficiency in irrigated agriculture. *Agron. J*., 93:281-289.

HUBONA, G.S. & GERTZ, S., 1997. External variables, beliefs, attitudes and information technology usage behaviour. *Proc of Annual Hawaii Int. Conf. on Systems Science*. IEEE Comp Soc. Press, California.

HUYGEN, J., VAN DEN BROEK, B.J. & KABAT, P., 1995. Hydra Model Trigger, a soil water balance and crop growth simulation system for irrigation water management purposes. In: Smith M., Pereira L.S., Berengena J., Itier B., Goussard J., Ragab R., Tollefson L. & Van Hofwegen P. (eds.) *Irrigation Scheduling: From Theory to Practice. Proceedings of the ICID/FAO Workshop on Irrigation Scheduling*, 12-13 September 1995, Rome, Italy, *Water Reports No. 8*.

INMAN–BAMBER, N.G., 1991. A growth model for sugarcane based on a simple carbon balance and the CERES Maize water balance. *S Afr J Plant Soil,* 8:93-99.

INMAN-BAMBER, N.G., 1995. Measured and simulated plant stress criteria for irrigation of sugarcane. *Proc S Afr. Irrigation Symposium*, 1991:144-148.

INMAN-BAMBER, N.G. & KIKER, G., 1997. Canegrow DSSAT Version 3.1. University of Hovac, Honolulu, USA.

INMAN-BAMBER, N.G., 2000. History of the CANEGRO model. *Proc. of Int CANEGRO Workshop*, Mt. Edgecombe, 2000:5-8.

IRROMETER CO., 1996. The use of the irrometer. *http://www.irrometer/watermark* (Downloaded: Jan 2001).

ISON, R.L., 1991. The search for system. In: Michalk D.L. & Pratley, J.E.(eds.), *Proc. of 9th Australian Agronomy Conference*, Charles Sturt University, Wagga Wagga.

ITIER, B., MARAUX, F., RUELLE, P. & DEUMIER, J.M., 1996. Applicability and limitations of irrigation scheduling methods and techniques. In: Smith M., Pereira L.S., Berengena J., Itier B., Goussard J., Ragab R., Tollefson L. & Van Hofwegen P. (eds.) *Irrigation Scheduling: From Theory to Practice. Proceedings of the ICID/FAO Workshop on Irrigation Scheduling*, 12-13 September 1995, Rome, Italy.

JACKSON, R.D., ISDO, S.B., REGINATO, R.J. & PINTER, P.J., 1981. Canopy temperature as a crop water stress indicator. *Water Resources Res.,* 17:1133-1138.

JACKSON, C., 1995. Environmental reproduction and gender in the Third World. In: Morse, S. & Stocking, M (eds.). *People and environment*. London, UCL Press: 109-130.

JARVIS, P., 1987. Adult Learning in Social Context. Billing & Sons, Worcester.

JENSEN, M.E., 1981. Summary and challenges. In: *Proc of ASAE Irrigation Scheduling Conference*: *Irrigation Scheduling for Water and Energy Conservation in the 80's.* ASAE, St Joseph, MI: 225-231.

JENSEN, R., 1982. Adoption and diffusion of innovation of uncertain profitability. *J Econ. Th*., 27:182-192.

JENSEN, M.E., BURMAN, R.D. & ALLEN, R.G., 1990. Evapotranspiration and irrigation water requirements. *ASCE Manuals and Reports on Engr. Practice No. 70*, *Am. Soc. Civil Engrs.,* New York.

JORDAAN, E., 2000. Continuous Soil Moisture Monitoring in Practice. SABI Conference, 1999.

JOVANOVIC, N.Z. & ANNANDALE, J.G., 1997. A laboratory evaluation of Watermark electrical resistance and Campbell Scientific 229 heat dissipation metric potential sensors. *Water SA,* 23(3):227- 232.

JOVANOVIC, N.Z. & ANNANDALE, J.G., 1999. A FAO type crop factor modification to SWB for inclusion of crops with limited data: Examples for vegetable crops. *Water SA,* 25(2).

KAINE, G., BEWSELL, D., BOLAND, A. & LINEHAN, C., 2005. Using market research to understand the adoption of irrigation management strategies in the stone and pome fruit industry. *Aust. Jnl. of Exp. Agric*., 45:1181-1187.

KARAR, E, 2003. Governance in water resource management: Progress in South Africa. Department of Water Affairs and Forestry, Pretoria.

KELLEHEAR, A., 1993. The unobtrusive researcher: A guide to methods. New South Wales, Australia. Allen & Unwin Publishers.

KELLY, G.A., 1955. The Psychology of Personal Constructs W.W. Norton, New York.

KELLY, K., SCHULTE, O. & JUHL, 1997. Learning Theory and the Philosophy of Science. *Phil of Science*, 64:245-267.

KELMAN, H.C., 1961. Compliance, identification and internalisation: Three processes of attitude change? *Jnl. of Conflict Resolution, 2:51-60.*

KENNEDY, A.J., VAN ANTWERPEN, R. & SINGELS, A., 2000. Experiences with neutron moisture meter re-calibration*. S.A. Irrigation,* 23-25

KHAN, S., 2004. Improving on-farm vs. regional water use efficiency –who pays and owns losses. CSIRO Land and Water: A Consultancy Report to the Pratt Water Group.

KILPATRICK, S., 1997. *Promoting learning networks for small business: how can group learning facilitate change*? Centre for Research and Learning in Regional Australia, University of Tasmania, Launceston

KLEPPER, B., BROWNING, V.D., TAYLOR, H.M., 1971. Stem diameter in relation to plant water status. *Plant Phys*., 48:683-685.

KLOCKE, N.L., SCHNEEDLOTH, J.P. & WATTS, D.G., 1996. Leaching from the best irrigation management in semi-arid climate. In: Camp C.R., E.J., Sadler, R.E., Yoder (eds.), *Evapotranspiration and Irrigation Scheduling*, *Proc. of Int. Conf*., ASAE, 769-774.

KLUTZE, A., 1986. Agronomy No 9: Methods of Soil Analysis. Part 1-Physical and Mineralogical Methods. Sec Edition. *Amer Soc of Agronomy*, Madison Publications, Wisconsin, USA.

KNOETZE, N., 2003. Personal communication, Oranje Riet Water User Association, Jacobsdal.

KNORR-CETINA, K.D., 1981. The manufacture of knowledge: An essay of constructivist and contextual nature of science. Pergamon Press, *Oxford*.

KOCH, B.H., 1985. The role of knowledge in the adoption of agricultural development practices. *S. Afr. Jnl. for Agric. Ext*., 14:11-15.

KOCH, B.H., 1986. Perception analysis as guideline in agricultural extension. *S. Afr. Jnl. for Agric. Ext*., 15:21.

KOCH, F., 1997. Weather stations make inroads into the rural areas of the Eastern Cape *http://www.ARCISCW//weatherstn.htm* (Downloaded: 14 Nov 2001).

KOCH, R., 1996. Computer controlled irrigation scheduling. *SA Bespr., Dec/Jan,* 1996.

KOEGELENBERG, F.H. & LATEGAN, M.T., 1996. Irrigation scheduling methods used in the Western Cape of South Africa. In: Camp C.R., Sadler E.J. and Yoder RE (eds.) *Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling, 3-6 November 1996, San Antonio, Texas, USA:* 905-909.

KOLB, D.A., 1984. Experiential learning. Experience as a source of learning and development. Prentice Hall, Englewood Cliffs, New Jersey, USA.

KOLB, D.A., 1995. Organisational behaviour: An experiential approach to human behaviour in organisations. Englewood Cliffs, NJ.Prentice Hall.

KOPYT, M., TON, Y., BENNER, Z. & BACHRACH, A., 2001. A trial of phytomonitoring technique for roses. *Acta Horticulture*, 547:205-212.

.

KRAMER, N.J.T.A., DE SMIT, J., 1977. Systems thinking: Concepts and notions. Marthinus Nijohf Social Sciences Division, Leiden.

KUBY, T., 1999. Innovation is asocial process. What does this mean for impact assessment in agricultural research? GTZ publication for strategic development.

KUHN, T., 1970. The Structure of Scientific Revolutions. Chicago, University of Chicago Press.

LAKER, G., 2001. Personal communication, University of Pretoria.

LANNON-KIM, C., 1994. The vocabulary of systems thinking: A Pocket Guide. In: Lannon-Kim, C (ed), A beginner's guide to system thinking. Pegasus Communications Inc., Cambridge, UK.

LATOUR, B., 1993. We have never been modern. Harvester Wheatsheaf, Hemel Hempstead, UK.

LAW, J., 1986. Power, action and belief: A new sociology of knowledge? Routledge, London.

LAW, J. & HASSARD, J., 1999. Actor network theory and after. Blackwell Publ., Oxford.

LEIB, B.G., HATTENDORF, M., ELLIOT, T. & MATTHEWS, G., 2002. Adoption and adaptation of scientific irrigation scheduling: trends from Washington. USA, *Agricultural Water Management,* 55.

LEEUWIS, C., LONG, N. & VILLARREAL, M., 1990. Equivocations on knowledge systems theory: An actor oriented critique. Knowledge in Society: *The Int. Jnl of Knowledge Transfer*, 3:19-27.

LEEUWIS, C. & PYBURN, R., 2002. Wheelbarrows Full of Frogs: Social learning in Rural Resource Management. Royal Van Gorcum, Assen.

LEEUWIS, C., 2004. Communication for Rural Innovation: Rethinking Agricultural Extension. Blackwell Science, United Kingdom.

LEWIN, K., 1951. Field theory in social science. Harper & Row, New York

LINDER, R.K., 1987. Adoption and diffusion of technology: an overview. In: Champ, BR, Highley, E. and Reemnyi JV (eds.). *Technological change in post harvest handling and transportation of grains in the humid tropics. ACIAR Proceedings 19:* 144-151.

LINEHAN, C & JOHNSON, F., 2002. Why current irrigation practices on irrigated dairy farms in Northern Victoria make sense. *Inst of Agric Eng*., Barton, Australia.

LINEHAN, C. KRISTIC, M.P. & KAINE, G., 2005. Combining Biophysical and Social Science to achieve change through targeted extension. *ACTA Horticulturae,* 672:211-216.

LITTLE, S., QUINTAS, P. & RAY, T., 2002. Managing Knowledge: An Essential Reader. Sage, London.

LORENTZ, S., 2003. Personal communication. SABI, Worcester, Western Cape.

LOXTON, VENN & ASSOCIATES, 1984. A final agricultural plan for Zanyokwe Irrigation Scheme. Volume 1, Consultancy Report.

LOUW, G. & DüVEL, G.H., 1978. Differential perception: A communication obstacle. *S. Afr. J. Agric. Ext., 7:*3-14.

LOUW, G. & DüVEL, G.H., 1993. The adoption of old man salt bush (*Atriplex nummularia*) as influenced by an extension program. *S. Afr. J. Agric. Ext., 15:*29-37.

LUNDVALL, B., 1992. *National systems of innovation*. Printer Publish, Londen

LYNCH, T., GREGOR, S. & MIDMORE, D., 2000. Intelligent support systems in agriculture: how can we do better? *Aust. Jnl. of Exp. Agric*., 40:609-620.

MACHULP, F., 1983. Semantic quirks in studies of information. In: Machulp, F. & Mansfield,U., (eds.), The study of information: Interdisciplinary messages. John Wiley & Sons, New York: 641-671.

MAHABILE, M., LYNE, M. & PANIN, A., 2002. Factors affecting the productivity of communal and private livestock farmers in southern Botswana: A descriptive analysis of sample survey results. Agrekon, 41(4):326-338.

MALAN, J., 2001. Personal communication. Malan Besproeiings Konsultante, Nelspruit.

MALANO, H.M. & VAN HOFWEGEN, P.J.M., 1999. Management of irrigation and drainage systems: a service approach. *JHE Nomograph 3*, Balkema, Rotterdam, The Netherlands: 149.

MALANO, H.M., 2000. Benchmarking irrigation and drainage performance:A case study in Australia. Report on Benchmarking Workshop. *http://www.wca.infonet.org/servlet.*

MALANO, H.M. & BURTON, M.A., 2001. Guidelines for benchmarking performance in irrigation and drainage sector. Food and Agriculture Organisation of the United Nations, Rome, IT.

MALTON, P., CANTRELL, R., KING, D., BENNET-CATTIN, M., 1984. Coming full circle: Participation in the development of technology. Ottowa, Canada. *Int. Dev. Res. Center.*

MANONA, Z, 2005. Personal communication. Department of Agriculture, Eastern Cape.

MANSFIELD, E., 1961. Technical change and rate of innovations. *Econometrica, 29*:284-315.

MARITZ, P.J., 2004. Irrigation Management Transfer: Sharing lessons from global experience: comments on overview paper. Department of Agriculture, Pretoria.

MARTIN, E.C., 2003. Methods of determining when to irrigate. Cooperative Extension college of Agriculture & Life Science, The University of Arizona.

MASLOW, A., 1968. Towards a philosophy of being. Von Nostrand, New York.

MATHIESON, K., 1991. Predicting user intentions: comparing the Technology Acceptance Model with Theory of Planned Behaviour. *Inf. Syst. Res*., 2(3):173-191.

MOLDEN, D.J., SAKTHIVADIVEL, R., PERRY, C.J., DE FRAITURE, C. & IBRAHIM, A.M., 1998. Indicators for comparing performance of irrigated agricultural systems. International Water Management Institute, Colombo, Sri Lanka.

MONTEITH, J.L., 1965. Evaporation and the environment. In: *The state and movement of water in living organisms*. XIX Symposium., *Soc. For Exp. Biol*., Swansea, Cambridge Univ. Press: 205-234.

MONTEITH, J.L. & UNSWORTH, M.H., 1990. Principle fundamental physics. Edward Arnold, London.

MORGAN, C.T. & KING, R.A., 1966. Introduction to Psychology. New York, McGraw-Hill.

MOUTON, J, 2001. How to succeed in your master's & doctoral studies. A South African Guide and Resource Book. Van Schaik Publishers.

MSMA, 1999. Marketing Surveys and Statistical Analysis: Agrimarket Survey, WRC, December 1999.

MUES, C., CHAPMAN, L. & VAN HILST, R., 1998. Land care: Promoting improved land management practices on Australian farms: A survey of land care and land management related programs. Canberra, Australia.

MYBURGH, P.A., 1998. Water consumption of South African vineyards: A modelling approach based on the quantified effects of selected viticulture, soil and meteorological parameters. D Sc Thesis - Univ Stellenbosch.

MYBURGH, P.A., 2002. Personal communication. ARC Nietvoorbij, Stellenbosch.

NAOR, A., 1999. Midday stem water potential as a plant water stress indicator for irrigation scheduling in fruit trees. *Acta Hort*., 537:447-454.

NAOR, A., HUPERT, H., GRRENBLAT, Y., PERES, M. & KLEIN, I., 2001. The response of nectarine fruit size and midday stem water potential to irrigation level in stage 3 and crop load. *J. Amer. Soc. Hort. Sci*., 126:140-143.

NAUDE, P. Personal communication. Hexriver, Western Cape.

NEW PARTNERSHIP FOR AFRICA'S DEVELOPMENT (NEPAD), 2003. Comprehensive Africa Agriculture Development Programme, Midrand, South Africa.

NETANGHENI, H., 2003. Personal communication. Limpopo Department of Agriculture.

NEUMAN, H.H. & THURTELL, G.W., 1972. A Peltier cooled thermocouple dew point hygrometer for *in situ* measurement of water potentials. In: *Methods of soil analysis: Part 1: Physical & Mineralogical Methods, 2nd Edition*, *Amer. Soc. for Agron.* , Madison, USA: 103-112.

NGUYEN, H.V., NIEBER, J.L. & MISRA, D., 1996. Modelling BMP impacts on ground water quality. In: Camp C.R., Sadler E.J., Yoder, R.E. (eds.), *Evapotranspiration and Irrigation Scheduling*, *Proc. of Int. Conf*., ASAE: 762-768.

NORTH CENTRAL RURAL COMMITTEE, 1955. How farm people accept new ideas. *NCR Publication No 1, Special Report No 15, Agric Ext Serv,* Iowa State, Ames, and Iowa*: 36.*

NYANGWA, M, 2004. Personal communication. Department of Agriculture Eastern Cape, Zanyokwe.

OLIVIER, F., 2002. Personal communication, SASRI, Komatipoort.

ORLOFF, S., HANSON, B. & PUTMAN, D., 2003. Utilizing soil moisture monitoring to improve Alfalfa and pasture irrigation. *Crop Mgt Network*, Oregon University.

PAIR, C.H., HINTZ, H.W., FROST, C.R., SNEED, R.E. & SCHULTZ, T.J., (eds.), 1983. Irrigation. *The Irrigation Ass*., Silver Spring, MD: 686.

PANNEL D.J., 1999. Social and economic challenges in the development of complex farming systems. *Agroforestry Syst*., 45:393-409.

PANNEL, D.J. & GLENN, N.A., 2000. A framework for the economic evaluation and selection of sustainability indicators in agriculture. *Ecological Economics, 33*:135-149.

PANNEL, D.J., MARSHALL, G.R., BARR, N., CURTIS, N., VANCLAY, F & WILKONSON, R., 2005. Understanding and promoting adoption conservation technologies by rural landholders. Unpublished manuscript, submitted to *Australian Jnl. of Exp. Agric.* http://www.general.uwa.edu.au/u/dpannel/dp0502.htm. (Downloaded: December 2005)

PATTON, M.Q., 1990. Qualitative evaluation and research methods. Sage Publ., Newbury Park, California, USA.

PEARCE, W.B., 1989. Communication and the Human Condition. Carbondale, Illinois. Southern Illinois University Press.

PENMAN, H.L., 1948. Natural evaporation from open water, bare soil and grass*. Proc. Roy. Soc., London,* a193:120-145.

PEREIRA, L.S., 1996. Surface irrigation systems. In: Pereira, L.S., Feldes, R.A. Gilley, J.R. & Lesaffre,B. (eds.). *Sustainability of Irrigated Agriculture*. NATO ASI Series, Kluwer Academic Publishers, Dordrecht: 269-289.

PEREIRA, L.S., 1999. Higher performance through combined improvement in irrigation methods and scheduling: A discussion. *Agric. Water Manag*., 40(2):153-169.

PERET, S., 2001. New Water Policy , IMT and smallholding irrigation schemes in South Africa: institutional challenges. FAO International E-mail Conference on Irrigation Management Transfer.

PHENE, C.J, REGINADO, R.J., ITIER, B. & TANNER, B.R., 1990. Sensing irrigation needs. In: Hoffman G.J., Howell T.A. & Solomons K.H. (eds.): *Management of Farm Irrigation Systems*, *Am. Soc. Agric. Engr*., St Joseph, MI: 207-261.

PHILIP, JR., 1969. Theory of infiltration. *Advances in Hydroscience*. 5: 215-296.

POTGIETER, J., 2002. Personal communication. Gauteng Department of Agriculture, Johannesburg, Gauteng.

PRETORIUS, H., 2003. Personal communication. DWAF, Hartbeespoortdam, Northwest.

PRETTY, J.N., 1994. Alternative systems of inquiry for sustainable agriculture. University of Sussex, IDS. *IDS Bulletin*, 25 920: 37-48.

PRETTY, J.N. & SHAH, P., 1994. Soil and Water Conservation in the Twentieth Century: A history of coercion and control. *Research Series No 1:* Rural History Centre, University of Reading.

PROBE FOR WINDOWS, 2000. Probe for Windows: Water Use Efficiency *http://www.rsne.com.au/articles/wu*

PRUIT, W.O. & ANGUS, D.E., 1961. Comparisons of evapotranspiration with solar and net radiation and evaporation from water sources. Chapter VI: First Annual Report, Univ. of California: 74-107.

PURCELL, J. & CURREY, A., 2003. Gaining acceptance of water use efficiency framework, terms and definitions. AQC1 Final Extended Report-Stage II. *http://www.wa.gov.au/final_report*

RAES, D., SMITH, M., DE NYS, E., HOLVOET, K. & MAKARAU, A., 2002. Charts with indicative irrigation intervals for various weather conditions. In: *Irr. Adv. Services and Participatory Ext. in Irr. Management, Workshop FAO-ICID*, Montreal, Canada.

RAINE, S.R., Mc CLAYMONT, D.J. & SMITH, R.J., 1998. The effect of variable infiltration on design and management guidelines for surface irrigation. *Proc. Nat. Conf. Irrig. Assoc.* Aust. 14-16 May, Adelaide.

REASON, P. (1988) Human Inquiry in Action. Sage, London: 34-48.

REINDERS, F., 2003. Personal communication. ARC, Silverton, Pretoria.

RICHARD, P. & DIEMER, G., 1996. Agrarian technologies as socio-technical hybrids. Food crop improvement and management of land and water in sub-Saharan Africa. *APAD Bulletin*, 11, Germany: 39-41.

RITCHIE, J.T., 1972. Model for predicting evaporation from a row crop with incomplete cover. *Water Resource. Res., 8*:1204-1213.

ROGERS, E.M., 1983. Diffusions of innovations. Third edition, McMillan, London: 93.

ROGERS, E.M., 1995. Diffusions of innovations. Fourth edition, New York, Free Press.

RöLING, N.G, 1988. Extension Science: Information Systems in Agricultural development. Cambridge University Press, Cambridge.

RÖLING, N.G, 1989. The Agricultural Research-Technology Transfer Interface: A Knowledge Systems Perspective. International Service for National Agricultural Research (ISNAR), The Hague.

RÖLING, N.G. & ENGEL, P.G.H., 1990. IT from a knowledge system perspective: Concepts and issues. *Knowledge in Society: The Int. Jnl. of Knowledge Transfer*, 3:6-18.

RÖLING, N.G., 1992. The emergence of knowledge systems thinking: A changing perception of relationships among innovation, knowledge process and configuration. *Knowledge & Policy: The Int. Jnl. of Knowledge Transfer and Utilisation,* 5:42-64.

RÖLING, N.G., 1994. Platforms for decision making about ecosystems. In: Fresco, L. (ed.) *The future of the land*. John Wiley & Sons.

RÖLING, N.G., 1996. Towards and interactive agricultural science. *European Jnl of Agric. Educ. and Ext.,* 2(4):35-48.

RÖLING, N.G., 2002. Beyond the aggregation of individual preferences. Moving from multiple to distributed cognition in resource dilemmas. In: Leeuwis, C., & Pyburn, R. (eds.), Wheelbarrows Full of Frogs. Social learning in Resource Management. Royal van Gorchum, Assen: 25-47.

ROSSOUW, J.G., 1989. The impact of imposed technology on a traditional rural society in Transkei: An evaluation of the Ncora Irrigation Scheme. DSc thesis, University of Fort Hare.

ROTHERT, S., 2000. Water conservation and demand management potential in southern Africa: an untapped river*. Int. J. Water*, 1(1):118-144.

ROWAN, R., 1986. The intuitive manager. Wilwood House Ltd., England

RURAL URBAN CONSULTANTS, 2001. Zanyokwe irrigation Scheme: Final Report. Prov. Land Reform Office (LDA)

RUTTAN, V.W., 1996. What happened to technology adoption-diffusion research? *1*: 51-73.

SAAIMAN, B., 2003. Personal communication, Elsenburg, Stellenbosch.

SAHA, A., LOVE, A.H. & SCHWART, R., 1994. Adoption of emerging technologies under output uncertainty. *Am. J. Agr. Econ*.,76:386-864.

SAKURATINI, T., 1981. A heat balance method for measuring water flux in the stem of intact plants. *J Agric. Met.,* 37:9-17.

SALJO, R., 1979. Learning in the learner's perspective: Some common-sense conceptions. Report from the Institute of Education, University of Gothenberg, No.76

SANTOS, F.L., 1996. Evaluation and adoption of irrigation technologies: Management design curves for furrow and level basin systems. *Agr.Syst., 52*: 317-329.

SALMON, P., 1985. Living in Time: A New Look at Personal Development. Dent and Sons, Aldine House, London.

SAVAGE, M.J., McINNES, K.J. & HEILMAN, J.L., 1996. The “footprints” of eddy correlation sensible heat flux density, and other micrometeorological measurements. *S Afr. Jnl of Sci.,* 92:137-142.

SCARBOROUGH, V., KILLOUGH, S., JOHNSON, D.A & FARRINGTON, J. (eds.), 1977. Farmer-led Extension: Concepts and Practices. Intermediate Technology Publications, London.

SCHACKEL, K.A., LAMPINEN, B., SOUTHWICK, S., OLSON, W., SIBETT, S. KRUGER, W., JAGER, J. & GOLDHAMER, D., 2000. Deficit irrigation: Maintaining productivity with less water. *Hort Science,* 35:1063-1066.

SCHER, E.M., 1995. Economic factors in farmer adoption of agroforestry: Patterns observed in Western Kenya. *World Development*, 23:787-804.

SCHÖN, D.A., 1967. Technology and change: The new Heraclites. Oxford: Peragamon

SCHÖN, D.A., 1983. The reflective practitioner: How professionals think in action. New York, Basic Books.

SEBILLOTTE, M., 1994. System research and action. Proc. of system-orientated research and rural development. CIRAD-SAR, Montpellier, France.

SENGE, P., 1993. *The fifth discipline: The art and practice of the learning organization*. Century Press, London.

SENGE, P.M., KLEINER, A., ROBERTS, C., ROSS, R.B. & SMITH, B.J., 1996. The fifth discipline field book: Strategies and tools for building a learning organisation. Nicholas Brealy Publication, London.

SERAGELDIN, I., 1995. Water Resource Management: A new policy for a sustainable future. *Water International,* 20:15-21.

SEETAL, A.R., 2002. "Thukela-a world in one Catchment": Balancing the scale (The Policy Perspective). Towards integrated Catchment: Increasing the dialogue between scientists, policymakers and stakeholders". Symposium, Kalmar (Sweden), 18-22 August 2002.

SHAND, M.J. & BASSON, M.S., 2003. South African water resources, availability, demands and strategic issues. *Proc. of Joint RSA – Australian Workshop on water resource management.* Lancemore Hill, Kilmore, Australia.WRC Report No. TT 236/04.

SHANNON, E.L., HOLDEN, J.R. & RAINE, S.R., 1996. Adoption of improved irrigation practices by Burdekin cane growers. In: Camp C.R., Sadler E.J. & Yoder R.E. (eds.) *Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling, 3-6 November 1996, San Antonio, Texas, USA*: 214-212.

SHEARER, M.N., 1987. Developing effective extension Irrigation programs in the Third World countries. In: *13th International Congress on Irrigation and Drainage*, Casablanca, Morocco: 1-8.

SHEARER, M.N. & VOMOCIL, J., 1981. Twenty-five years of modern irrigation scheduling promotional efforts. In: *Irrigation Scheduling for Water and Energy Conservation in the 80's. Proceeding of ASAE Irrigation Scheduling Conference, 14-15 December 1981, Chicago, Illinois, VSA*.

SHOCK, C.C., 2000. Granular matrix sensors: instrumentation for soil moisture determination. *http://www.irrometer/granular.htm* (Downloaded: Jan 2001).

SHOCK, C.C., FEIBERT, E.B.G. & SAUNDERS, L.D., 1996. Precision irrigation scheduling with granular matrix sensors. *ASAE Proc. of Int. Conf. On Evapotranspiration and Irrigation Sched,* San Antonio: 1105-1108.

SHUTTLEWORTH, W.J., 1993. Evaporation. In: Maidment, D.R. (ed.) Handbook of Hydrology McGraw Hill.

SILVA, W.L.C. & MAROUELLI, W.A., 1996. Evaluation of irrigation scheduling techniques for processing tomatoes in Brazil. In: Camp C.R., Sadler, E.J., Yoder, R.E. (eds.), *Evapotranspiration and Irrigation Scheduling*, *Proc. of Int. Conf*., ASAE: 522-526.

SIMON, H.A., 1976. Administrative behaviour: A study of decision-making processes in administrative organisation. Third Edition, Free Press, New York.

SINGH, B., BOIVIN, J., KILPATRICK, G. & HUM, B., 1995. Automatic irrigation scheduling systems (AISSUM): principles and applications. *J. Irr. Drainage Engr., 121(1*):43-56.

SMITH, M., 1992. CROPWAT, a computer program for irrigation and management. *FAO Irrigation and Drainage Paper No 46. United Nations Food and Agricultural Organisation. Rome, Italy.*

SOLOMON, P., 2002. Discovering information in context. *Annual Review of Information Science and Technology,* 36:29-64.

SPANNER, D.C., 1951. The Pettier effect and its use in the measurement of suction pressure. *J. Exp. Bot*., 11:145-168.

SQUIRES, V.R., 1991. A system approach to agriculture: In: Squires V.R. & Tow, P.G. (eds.). Dry land farming – a system approach. Sydney University Press, Sydney.

STANDER, C., 2004. Personal communication. Capespan, Cape Town.

STEWART SCOTT INC., 1998. Planning and implementation of irrigation schemes: Situation analysis and evaluation report. Limpopo Province Department of Agriculture, Pietersburg.

STEYN, J., 2002. Personal communication, Makhatini, KwaZulu Natal.

STIMIE, C., 2003. Personal communication. Rural Integrated Engineering, Pretoria.

STIMIE, C., 2004. Personal communication. Rural Integrated Engineering, Pretoria.

STIRZAKER, R.J., HUTCHINSON, P.A. & MOSENA, M.L., 2000. A new way for small farm irrigators to save water. CSIRO, Canberra, Australia.

STIRZAKER, R.J., 2001. Personal communication. CSIRO, Canberra, Australia.

STIRZAKER, R.J., 2003. Personal communication, CSIRO, Canberra, Australia.

STIRZAKER, R.J., 2005. Personal communication, South Africa.

STRIZAKER, R.J., STEVENS, J.B., ANNANDALE, J.G., MAEKO, T., STEYN, J.M., MAROBANE, W., NKGAPELE, J. & JOVANOVIC, N., 2004. Building capacity in irrigation management with wetting front detectors. WRC Report No. TT230/04, 2004.

STONE, J.F. & NOFZIGER, D.L., 1995. Calibration of neutron moisture probes by transfer through laboratory media. *Principles Soil Sci*., 160:155-163.

SUMBERG, J. & OKALI, C., 1997. Farmers' Experiments Creating Local Knowledge. Boulder, London.

SWANEPOEL, J., 2004. Personal communication. Department of Northwest Agriculture, Potchefstroom, Northwest Province.

SWART, B., 2003. Personal communication. SASRI, Komatipoort, Mpumalanga.

SWART, B., 2004. Personal communication. SASRI, Komatipoort, Mpumalanga.

SWART, B., KHOSI, M. & MTEMBU, P., 2003. Personal communication. Extension meeting. Walda, Mpumalanga.

SWANSON, B.E. & CLAAR, J.B., 1984. The history and development of agricultural extension. In: BE Swanson (ed.), *Agricultural Extension: A Reference Manual*. FAO, Rome: 1-9.

TACKER, P., ASHLOCK, L., VORIES, E., EARNEST, L., CINGOLANI, R., BEATY, D. & HAYDEN, C., 1996. Field demonstration of Arkansas irrigation scheduling program. In: In: Camp C.R., Sadler, E.J., Yoder, R.E. (eds.) *Evapotranspiration and Irrigation Scheduling*, *Proc. of Int. Conf*., ASAE: 974-979.

TAYLOR, S. & TODD, P.A., 1995. Understanding Information Technology Usage: A test of competing models. *Information Systems Research,* 6(2):144-176.

TERBLANCHE, L., 2003. Personal communication. Department of Agriculture, Upington.

THOMSON, S.J. & ARMSTRONG, C.F., 1987. Calibration of the Watermark model 200-soil moisture sensor. *Appl. Eng. In Agric*., 3(2):186-189.

TOLMAN, E.C., 1967. A psychological model. In: Parsons & Shils (eds.). *Toward a general theory of action.* Cambridge: Harvard University Press.

TON, Y. & NILOV, N., 1996. Phytomonitoring Technology in Control of Crop Growth. In: International Symposium on Plant Production in Closed Ecosystems, *Book of Abstracts*. Narita, Japan: 77.

TON, Y., NILOV, N. & KOPYT, M., 2001. Phytomonitoring: The new information technology for improving crop production. *Acta Horticulture*, 562:257-262.

TRAVERS, M.W., 1977. Essentials of learning. Fourth Edition, McMillan Publisher, New York.

TRIMMER, W. & HANSEN, H., 1994. Irrigation scheduling. Oregon State University, USA.

TYLER , S.W., KRANZ, S., PARLANGE, M.B., ALBERTSON, G., KATUL, G., COCHRAN, G.F., LYLES, B.A & HOLDER, G., 1997. Estimation of groundwater evaporation and salt flux from Owens Lake, California, USA. *J. Hydrology,* 200:110-135.

UNITED STATES BEAREAU OF RECLAMATION, 1997. Water Measurement Manual. United States Department of the Interior. Denver, Colorado. *http://www.usbr.gov/pmts/hydraulics lab/pubs/wmm.html.*

USAID, 2003. Linking producers to markets: A renewed commitment to agriculture. A USAID Draft Strategy for Agricultural Development. In Eicher, C., (ed.) *Flashback: Fifty years of donor aid to African Agriculture. Successes in African Agriculture:* Conference Paper No 16. Michigan State University.

USHER, R. & BRYANT, I., 1989. Adult education as theory, practice and research. Routledge, London.

VALEV, I. ,DUMTROV, P. & POPOVA, Z., 1996. Irrigation scheduling for conjunctive use of rainfall and irrigation based on yield-water relationship. In: Smith M., Pereira L.S., Berengena J., Itier B., Goussard J., Ragab R., Tollefson L. & Van Hofwegen P. (eds.) *Irrigation Scheduling: From Theory to Practice. Proceedings of the ICID/FAO Workshop on Irrigation Scheduling*, 12-13 September 1995, Rome, Italy.

VAN ANTWERPEN, R., 2000. Simulating water use of stressed sugarcane. *Proc of Int Canegro Workshop*, Mt. Edgecombe, 2000: 22-23.

VAN AVERBEKE, W., MIMARETE, C.K., IGODAN, C.O. & BELETE, A., 1998. An investigation into food plot production at irrigation schemes in Central Eastern Cape. WRC Report No. 719/1/98.

VANCLAY, F., 2003. Social principles to inform agriculture. In: Wilson B.P. & Cur, A. (eds.) *Proc. of the 2002 Australian Academy of Science Fenner Conference on the Environment:* 9-24.

VANCLAY, F. & LAWRENCE, G., 1994. Farmer rationality and the adoption of environmentally sound practices: a critique of the assumptions of traditional agricultural extension. *European Jnl. of Agric. Educ. and Ext*., 1:59-90.

VANCLAY, F., 1997. The social context of environmental management in agriculture: a background for understanding land care. In: Pratley, J. & Robertson, A. (eds.) Agriculture and the Environmental Imperative, *CSIRO Publ*., Collingwood

VANCLAY, F & LAWRENCE, G., 2001. *Farmer rationality and the adoption of environmental sound practices: A critique of the assumptions of traditional agricultural extension.* http://www.bib.wau.nl/ejaehttp//

VAN DEN BAN, A.W. & HAWKINS, H.S., 1996. Agricultural Extension. Second Edition, Blackwell Science, Oxford.

VAN DER MERWE, F., 2001. Personal communication. Department of Water Affairs and Forestry, Pretoria.

VAN DER MERWE, P., 2004. Personal communication. Department of Water Affairs and Forestry, Pretoria.

VAN DER MERWE, P., 2002. Personal communication. BOKKEVELD BESPROEIING BK., Vredendal.

VAN DER STOEP, I., 2004. Personal communication. University of Pretoria, Pretoria.

VAN DER STOEP, I., BENADE, N., SMAL, H.S. & REINDERS, F.B., 2005. Guidelines for irrigation water measurement in practice. WRC Report TT248/05

VAN DER WESTHUIZEN, A.J., 2003. Personal communication. Van der Kloof, Northern Cape.

VAN HEERDEN, P.S., 2000. Personal communication. Bloemfontein.

VAN HEERDEN, P.S., CROSBY, C.T. & CROSBY, C.P., 2001. Using SAPWAT to estimate water requirements of crops in selected irrigation areas managed by the Orange Vaal and Orange Riet Water Users Association. WRC Report TT163/01.

VAN STRIJP, 2002. Personal communication. Loskop Irrigation Board, Groblersdal.

VAN VELSEN, J., 1967. The extended-case method and situational analysis. In: A.L. EPSTEIN (ed), *The craft of social anthropology*. Travistock Publ., Social Sc. Paperbacks, London. p 129-149.

VAN WOERKUM, C.M.J., 2002. Orality in environmental planning. *European Environment*, 12:160-172.

VAN ZYL, W.H., DE JAGER, J.M. & MAREE, C.J., 1989. Correction factors for evaporimeter coefficients used for scheduling irrigation of wheat. WRC Report No 151/1/89.

VERSFELD, D., 2000. Sharing South Africa's water: uncovering challenges for development through Strategic Environmental Assessment. International Symposium on Contested Resources: Challenges to Governance of natural Resources in South Africa, Cape Town, 18-20 October 2000.

VUSANI, W., 2004. Personal communication. Tsolo , Eastern Cape.

WALLACE, J.S. & BATCHELOR, C.H., 1997. Managing water resources for crop production. *Philosophical Transactions of the Royal Society of London,* 352:937-947.

WATERMARK ELECTRONIC MODULE, 2001. The Watermark sensor. http://www.irrometer.com/agcat.htm//.

WEBSTER, F., 1995. Theories of the information society. New York: Routledge

WILLIAMS, J.H., 2004. Personal communication. Fort Hare, Eastern Cape.

WILSON, T.D., 1999. Models in information behaviour research. *Jnl. of Documentation*, 55(3):249-270.

WHINLESEY, N., McNEAL, B. & OBERSINNER, V.,1986. Concepts affecting irrigation management, in energy and water management in western irrigated agriculture. Boulder, Westview Press

WOODHILL, J., 2002. Sustainability, social learning and the democratic imperative. Lessons from the Australian Land care movement. In: Leeuwis, C., & Pyburn, R. (eds.), Wheelbarrows Full of Frogs: Social learning in Resource Management. Royal van Gorchum, Assen.

WORLD BANK, 2003. International assessment of Agricultural Science and Technology for Development. Regional Consultation, Nairobi, Kenya. January, 2003.

YIN, R.K., 1994. Case Study Research: Design and Methods. Second Edition, Sage, Thousand Oaks.

YOUNGER, V.B., MARSH, A.W., STROHMAN, R.A., GIBEAULT, V.A. & SPAULDING, S., 1981. Water use and turn quality of warm season and cool season turfgrasses. *Calif. Turfgrass,* 31(3):1-4.

ZEREN, A., 1999. Survey on irrigation and fertilising practices in Israel. *http://www.netafim/1.4.5.2.1.5.htm//*

APPENDIX 1: QUESTIONNAIRE ON IRRIGATION SCHEDULING AMONGST FARMERS

A. Information regarding respondent

Name of respondent: …………………………………………………...

Consultant	Departmental officer	Cooperative official	Irrigation Board	Other

Name of Company/Department/Institution/Cooperative::………………………………

Phone number: ………………………………Fax number: ………………………………

E-mail address:………………………………

B. Information regarding the irrigation scheme:

1.

Production area (Irrigation scheme)	Area under irrigation (ha)	Number of farmers that irrigate	% Farmers that schedule irrigation	Which irrigation system are used the most (order of appearance)	Tariff of water for the farmer (R/ha/pa or R/cub m/pa)

2. Please specify the main crop(s) that are cultivated as for each specific irrigation scheme as well as the occurrence (%) of the type of farming concern on the specific irrigation scheme:

Company concern: 1

One man concern: 2

Irrigation Scheme	**Main crop (s)**	**1**	**2**
		%	%
		%	%
		%	%

B. Implementation of Irrigation scheduling methods

Please specify the irrigation scheduling method that is used as for each specific irrigation scheme, *as well as the percentage of farmers that use the specific irrigation scheduling method*

Name of irrigation scheme	Shovel method	Measuring of soil moisture content (name specific soil measurement method)	Use of computer irrigation models (name specific model)	Gut feeling or intuition	Who helps the farmer with irrigation scheduling (consultant/fellow farmer/self/agric. cooperation)?
	% Farmers	% Farmers Method:	% Farmers Model:	% Farmers	
	% Farmers	% Farmers Method:	% Farmers Model:	% Farmers	
	% Farmers	% Farmers Method:	% Farmers Model:	% Farmers	

C. Please specify the names as well as contact numbers of irrigation services in your area

Name of Institution	Contact person	Tel no/ Fax no/Cell no

APPENDIX 2: QUESTIONNAIRE TO COMMERCIAL IRRIGATORS – TESTING INTERVENING VARIABLES RESPONSIBLE FOR THE IMPLEMENTATION OF IRRIGATION SCHEDULING PRACTICES

Note: Original questionnaire was designed for computer analysis

Enumerator:………………….. Date of interview:………………….

A. Independent variables

1. Name of farmer (Person interviewed).
2. Respondent number (Code).
3. Name of farm.
4. Province and /or district.
5. Farm size (ha):
    a. Total farm size (ha).
    b. Area under irrigation (ha).
6. Age.
7. Education level of respondent.
8. Attitude towards training:
   Have you attended any training in irrigation? (Yes/No)
9. Farming experience: No of years.
10. Non-farming experience: No of years.
11. Crop production:
    a. Crops cultivate by area (ha) and yield (t/ha).
12. Do you apply crop rotation? (Yes/No).
13. Indicate the crop rotation applied on the farm.
14. Indicate the most important crop(s) in terms of **INCOME**?
15. Indicate the most important crop in terms of **AREA UNDER IRRIGATION**?
16. Indicate the source for irrigation water used on the farm?
17. Indicate the irrigation method (s) used as per specific crop planted under irrigation?
18. Indicate the allocation of irrigation water registered for the farm (m^3 or ha listed)?
19. What is the current tariff (R/ha) that is charged for irrigation water rights?

B. Intervening variables regarding irrigation scheduling

20 Do you regard the current irrigation tariffs to be expensive in relation to the other operational input costs (Yes/No)?

21 Indicate the operational cost of irrigation (percentage) in comparison to the other input cost items like seed, fertilizer, pest control, weed control, labour, marketing, fuel/electricity and mechanization.

22 When and where did you for the first time hear about irrigation scheduling?

23 Describe in your own words what do you think is meant with the concept “irrigation scheduling”?

24 Adoption:

24.1 Do you apply irrigation scheduling on the farm (Yes/No)?

24.2 When did you start with the practicing of irrigation scheduling on the farm?

24.3 Provide possible reasons why you have started with the implementation of irrigation scheduling practices on-farm?

24.4 Using a ten-point scale, rate *how important* do you regard the implementation of irrigation scheduling on the farm?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

24.5 Indicate the current irrigation scheduling method implemented on the farm (Soil auger/Measurement of soil water content/Computer simulation models/Irrigation calendar /Intuition).

24.6 List the possible reasons in order of priority for using the specific irrigation scheduling method on-farm as indicated in 24.5.

24.7 When did you start to use this specific scheduling method on-farm as indicated in 24.5?

24.8 *How easy* do you find the implementation of irrigation scheduling on-farm (rate on a ten-point scale)?

1	2	3	4	5	6	7	8	9	10

▲ Not easy ▲ Very easy

24.9 Indicate the percentage increase in production efficiency since the introduction of irrigation scheduling on the farm

24.10 How *satisfied* are you with the implementation of irrigation scheduling on-farm (rate on a ten-point scale)?

1	2	3	4	5	6	7	8	9	10

▲ Not easy ▲ Very easy

24.11 List in order of priority the problems that you encounter with the implementation of the specific irrigation scheduling method mentioned in 24.5.

24.12 If you have made use of alternative irrigation scheduling method(s) in the past than mentioned in 24.5, please indicate the specific method (s) used.

24.13 Please list the possible reasons in order of priority that influenced you to change from irrigation scheduling method, if applicable.

24.14 If you **have never before** implemented irrigation scheduling on the farm, list the possible constraints in order of priority that prevent you from implementing irrigation scheduling practices on-farm?

24.15 If you **had implemented irrigation scheduling on the farm**, but discontinued the practice. Please list in order of priority the possible reasons for discontinuing this practice.

24.16 Indicate the basic knowledge requirements needed for the efficient implementation of irrigation scheduling on a farm in priority order.

24.17 How important (using a ten-point scale) is it for you personally that your *fellow irrigators* of the district also implement irrigation scheduling on-farm?

1	2	3	4	5	6	7	8	9	10

▲ not important ▲ Very important

24.18 Motivate your rating provided in 24.17.

24.19 Rate on a ten-point scale the general awareness of fellow irrigators regarding the implementation of irrigation scheduling?

1	2	3	4	5	6	7	8	9	10

▲ Not aware at all ▲ Very much aware

24.20 How efficient do you rate the use of irrigation water in your district? (Use the ten-point scale)

1	2	3	4	5	6	7	8	9	10

▲ Inefficiently ▲ Very efficient

24.21 Please indicate the level of accuracy (on a ten-point scale) with which irrigation scheduling is implemented on the farm?

1	2	3	4	5	6	7	8	9	10

▲ Not accurately ▲ Very accurately

24.22 Rate your personal satisfaction (on a ten- point scale) with the current level of accuracy of irrigation scheduling practised on the farm?

1	2	3	4	5	6	7	8	9	10

▲ Not satisfied ▲ Very satisfied

24.23 List possible constraints in order of priority that prevent you from practising more accurate irrigation scheduling on-farm.

25. Perceptions regarding the use of computer models for irrigation scheduling:

25.1 In the case where an irrigator is not using computer models for irrigation scheduling on-farm. Are you aware of any computer irrigation model that is used for irrigation scheduling in your district? (Yes/No)

25.2 If so, mention any specific model you are aware of.

25.3 Using the following ten-point scale, indicate to what extent you regard the use of computer irrigation scheduling models as important for efficient and accurate irrigation scheduling decisions on the farm?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

25.4 If you lack aspiration for the implementation of computer irrigation scheduling models on-farm. Mention the main reasons for that in order of priority.

26 Perceptions regarding the use of soil water measurement on the farm:

26.1 How frequently do you measure soil water content on the farm? (Weekly/Every fortnight/Monthly/Sporadic/Any other frequency)

26.2 How would you rate your satisfaction with the current frequency of soil water monitoring on-farm, using the following ten-point scale?

1	2	3	4	5	6	7	8	9	10

▲ Unsatisfied ▲ Very satisfied

26.3 List in order of priority the most important characteristics taken into account with the selection of an irrigation scheduling device to be used on the farm.

26.4 Rate the how important the visibility of the wetting front after an application of irrigation for irrigation management decisions, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

27. Perceptions regarding the monitoring and evaluation of irrigation *distribution uniformity* and *application rate* on pressurized irrigation systems

27.1 Indicate the frequency of testing the distribution uniformity of the irrigation system (More frequently than once per season/Once per season/Once per annum/Once in a five year cycle/Not at all).

27.2 Indicate the frequency of testing the application rate of the irrigation system (Once per season /Sporadic as needed/Not at all).

27.3 To what extent are you satisfied with the current maintenance program of the irrigation systems on the farm?

1	2	3	4	5	6	7	8	9	10

▲ Not satisfied ▲ Very satisfied

28 Knowledge support for the implementation of irrigation scheduling

28.1 Please list the institutions or persons in order of priority that support you with the implementation and decisions on irrigation scheduling on-farm.

28.2 How important would you rate the support of an irrigation consultant or professional expert for the implementation of irrigation scheduling on farm, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

28.3 How important would you rate the support of your fellow farmer for the implementation of irrigation scheduling on farm, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

28.4 If you currently make use of the service of an irrigation consultant, please indicate on the following ten-point scale your satisfaction with the service delivered.

1	2	3	4	5	6	7	8	9	10

▲ Not satisfied ▲ Very satisfied

28.5 List the attributes of consultants or advisors as perceived important for the deliverance of an efficient irrigation scheduling service.

28.6 How important would you rate the supportive role of the newly established WUA to help make farmers aware of the use of irrigation scheduling on farm, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not important ▲ Very important

28.7 To what extent will a possible increase of irrigation water tariffs contribute to make farmers more aware of the use of irrigation scheduling on farm, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not at all ▲ Definite awareness raising

28.8 To what extent will the implementation of volumetric water tariffs help to increase the awareness of farmers to use irrigation scheduling on farm, using the following ten point scale?

1	2	3	4	5	6	7	8	9	10

▲ Not at all ▲ Definite awareness raising

C. DEPENDANT VARIABLES

Perception of irrigation scheduling technology

29. Relative advantages perceived using the following Likert ten-point scale subsequent to the implementation of irrigation scheduling on the farm

1	2	3	4	5	6	7	8	9	10
▲ Not important									▲ Very important

29.1 Saving of water

29.2 Increase of production or yield

29.3 Improving of quality of crops

29.4 Saving of electricity or energy operational costs

29.5 Efficient use of nitrogen

29.6 Increase of profit

30 If you are making use of the services of an irrigation consultant,

APPENDIX 3: SEMI - STRUCTURED INTERVIEWS

1. Name .

2. Geographical area.

3. Education level.

4. Experience as irrigation consultant.

5. What irrigation scheduling model or program are used for the service rendered? Why the specific program or method?

6. Profile of irrigation consultancy service:

   a. Number of clients that form your clientele to be serviced.
   b. Total area scheduled (ha).
   c. Crops scheduled.
   d. Ideal size of clientele group.
   e. Frequency of measurement of soil water content.
   f. Frequency of consultation with client to discuss recommendations.
   g. Consultation tariff (charge pr ha, point of measurement, etc).

7. Profile of the potential client that regularly make use of the service.

8. Key attributes and competencies needed for effective irrigation consultancy service to be rendered (service and irrigation consultant)?

9. What are the perceived reasons why you think farmers are not interested in irrigation scheduling services and /or objective irrigation scheduling practices?

10. What advantages of objective irrigation scheduling are you highlighting during your communication with farmers or potential clients?
11. Do you think the average irrigation farmers has the necessary capacity to implement objective irrigation scheduling without the support of the irrigation consultant?

12. Are irrigation farmers in general guilty of practices where they are over-irrigating their crops?

13. To what extent will an increase in irrigation water tariffs serve as an incentive to persuade farmers to use objective irrigation scheduling methods?

14. To what extent will the implementation of volumetric water tariffs help to increase the awareness of farmers to use irrigation scheduling on farm, using the following ten point scale?

15. Mention some incentives that you can think of that will motivate an irrigation farmer to implement objective irrigation scheduling.

16. Have we used in the past the correct strategies and action plans to try and "sell" the concept of irrigation scheduling to farmers? What are the general mistakes that were made?

17. The role of the farmer group in the communication network? Identify other role players in the farmer communication network.

18. How important are the following aspects to you?
    a. Regular maintenance of irrigation systems.
    b. Regular measurement of distribution uniformity and application rate?

19. To what extent have you witnessed that farmers will use your service for a couple of seasons and then rely on their own experience and intuition?

20. Farmers who are not making use of your irrigation scheduling services, what are the most common methods that they rely on?

21. General feeling about the registration with an accredited institution e.g.instance SABI.