THE RANGE, DISTRIBUTION AND IMPLEMENTATION OF IRRIGATION SCHEDULING MODELS AND METHODS IN SOUTH AFRICA

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LIST OF ACRONYMS

AED	Atmospheric Evaporative Demand
ARC	Agricultural Research Council
ARC-ILI	Agricultural Research Council Instituut vir Landbou Ingenieurswese
BBP 17	Beste Besproeiings Praktyke
BEWAB	Besproeiingswater Bestuursprogram
BMP	Best Management Practices
CMA	Catchment Management Agency
CROPWAT	Crop Water Requirements Program
DBSA	Development Bank of South Africa
DOA Northwest	Northwest Provincial Department of Agriculture
DSSA	Decision Support System for Agro Technology Transfer
DWAF	Department of Water Affairs and Forestry
E	Soil water evaporation
Eo	Pan evaporation
ECATU	Eastern Cape Appropriate Technology Unit
ET	Evapotranspiration
ETref	Reference evaporation (Penman-Monteith Method)
ET0	Evapotranspiration as calculated from evaporation pan
FAO	Food and Agriculture Organisation of the United Nations
FSDA	Free State Provincial Department of Agriculture
FFS	Farmer Field School
FSU	Farmer Support Unit
GIS	Geographical Information System
GWK	Griekwalandwes Cooperative
KDA	KwaZulu Provincial Department of Agriculture
LAI	Leaf Area Index
LANOK	Landbou Ontwikkelings Korporasie
LPDA	Limpopo Provincial Department of Agriculture
LWP	Leaf Water Potential
MPDA	Mpumalanga Provincial Department of Agriculture
MSSA	Marketing Surveys and Statistical Analysis
NCDA	Northern Cape Provincial Department of Agriculture
DOA	National Department of Agriculture
NEWSB	New Soil Water Balance
NIEP	Nkomazi Irrigation Expansion Programme
NWA	National Water Act (Act No. 36 of 1998)
ORWUA	Orange Riet Water User Association
PCA	Plant Canopy Analyser
PRWIN	Probe for Windows
RAW	Readily Available Water
RDP	Rural Development Program
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
TDR	Time Domain Reflectometry
TOT	Transfer of Technology
TSB	Transvaal Suiker Beperk
VINET	Vineyard Evaporation for Irrigation System Design and Scheduling
WC/DM	Water conservation/Demand Management
WFD	Wetting Front Detector
WMP	Water Management Plan
WUA	Water User Association

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EXECUTIVE SUMMARY

INTRODUCTION

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

This project was introduced with the purpose of identifying social, cultural, economic and technological factors, which inhibit the adoption of irrigation scheduling practices on the farm. Understanding and gaining insight into some of the human factors that determine individual irrigation farmers' decisions to either adopt or reject the implementation of irrigation scheduling will help to plan and design effective propagation strategies for the implementation of irrigation scheduling amongst irrigators. A large number of irrigation scheduling methods and models are available in South Africa as discussed in Chapter 2. They include various soil, atmospheric and plant monitoring techniques as well as a range of scheduling methods based on soil-water balance and computer simulation models. To appreciate the variety of irrigation scheduling methods and models currently available to farmers, advisors, consultants and extensionists it was necessary to categorize the scheduling method according to their application.

Secondly, the adoption of irrigation scheduling amongst commercial and small-scale farmers was investigated with the purpose of identifying the possible human and socio-economic factors that may influence the adoption thereof. This investigation was done on macro (scheme) level as well as micro (on-farm) level. Important human and socio-economic factors were identified that influence the adoption of irrigation scheduling practices. An overview of the service currently rendered by irrigation consultants is provided and the important information and learning sources that irrigators generally use were investigated.

PROJECT OBJECTIVES

Five objectives were set out in the original proposal.

1. Investigate and describe the variety, range and scope of models and methods of irrigation scheduling in South Africa.
2. Investigate, analyse and describe the levels of application by a cross section of subsistence and commercial farmers, institutions and advisors of a selection of irrigation scheduling models and methods.
3. Investigate, analyse and describe the reasons from a cross section of subsistence and commercial farmers, institutions and advisors, for using the different irrigation scheduling methods and models.
4. Investigate, analyse and describe why irrigators discontinue with the implementation of irrigation scheduling.
5. Make recommendations concerning the propagation and institutionalising of the proper sustained implementation of irrigation scheduling methods and models.

METHODOLOGY

The overall approach for meeting the objectives is summarized in Figure 1.

Step 1
There are a vast number of irrigation scheduling methods and models available to help the farmer with decisions regarding when the crops require water and how much irrigation needs to be applied. These include the various soil, plant and atmospheric monitoring techniques as well as a range of scheduling methods based on soil-water balance and simulation models. *Step 1* was to identify the irrigation scheduling methods and models that are available for the South African irrigation farmer, and to categorize these methods and computer models according to their possible use. Irrigation farmers in their irrigation management decisions often use intuition, which was acknowledged in the framework used for categorization.

Step 2
A quantitative assessment was conducted on a national basis amongst 332 irrigation schemes, which provides an overview of the implementation and distribution of irrigation scheduling methods, and models amongst commercial and small-scale farmers on a scheme level (macro level) in the nine provinces of South Africa. It served to identify the different institutions and agencies that provide support to farmers with the implementation of irrigation scheduling *(Step 2)*.

Step 3
Objectives three to five of the project focused on the intervening variables that operate as direct determinants of adoption or rejection of irrigation scheduling practices. Perceptions, attitudes and needs of irrigation professionals (consultants, advisors, industry experts and irrigation specialists) and irrigators regarded as opinion leaders in their respective areas, formed the basis for the 70 semi-structured interviews that were conducted *(Step 3)*. Each of these interviews were recorded on tape and transcribed afterwards.

Step 4
By combining the findings of the macro-level study and the insights gained from the semi-structured interviews conducted with key individuals in the irrigation fraternity, a more focused approach was followed in the identification of human factors and constraints that impact on the adoption of irrigation scheduling practices of commercial and small-scale farmers. The quantitative survey amongst a random sample of 134 commercial farmers from eight different provinces (Northwest, Eastern Cape, KwaZulu Natal, Western Cape, Limpopo, Northern Cape, Free State and Mpumalanga) represented the micro level of the study *(Step 4)*. Step 4 also comprised the investigation and description of the irrigation practices and scheduling methods used by small-scale farmers as well as their perceptions and possible reasons (human, social, and economic) for adopting or rejecting the use of irrigation scheduling methods. Interviewing key informants on several of the small-scale irrigation schemes formed the second phase of this investigation. Four small-scale irrigation projects were selected for more detail investigations and assessments, to illustrate the different approaches followed in the training and development of small-scale irrigation farmers in the use of irrigation scheduling practices.

Step 5
The data, insights and findings gained from the different interviews and surveys amongst commercial and small-scale irrigation farmers were incorporated in the conclusions and recommendations *(Step 5)*.

STEP 1
Identify irrigation scheduling methods and models available for the South African irrigator

STEP 2
Quantitative assessment of the implementation and distribution of irrigation scheduling methods (macro level)

STEP 3
Semi-structured interviews with irrigation consultants and extensionists rendering an irrigation scheduling service

STEP 4
Quantitative survey to determine the human factors that influence adoption of irrigation practises on farm (micro level)

STEP 5
Conclusions and recommendations

Figure 1 A framework to illustrate the overall approach for meeting the objectives of this study. Steps 2 and 3 were carried out concurrently with iteration between the project team, farmers and respondents from the irrigation industry.

RESULTS

The report comprises seven chapters. Chapter 1 describes the rationale behind the introduction of irrigation scheduling to the farmer, as one of the elements of efficient water use on the farm. The three main focus areas of the project, namely the identification and classification of irrigation scheduling methods and models commonly used in South Africa, national survey of the implementation and distribution of irrigation scheduling methods and models on an irrigation scheme level, and the micro level assessment of the human factors and constraints that influence the adoption or rejection of irrigation scheduling are discussed in Chapter 2, 3, 4, and 5. Chapter 6 deals with the different approaches which farmers follow to solve problems and the different information sources that farmers use to learn about irrigation practices.

The timing and depth criteria used in irrigation scheduling can be established by using several approaches to scheduling based on soil water measurements, use of soil water balance estimates, atmospheric measurements and plant stress indicators in combination with simple rules, observations or very sophisticated models. The various irrigation scheduling methods and approaches available in South Africa were classified according to a framework based on the mode of operation and the possible users of the specific method or technique (Chapter 2). Irrigation scheduling techniques and methods were classified into the following categories: intuition, atmospheric based quantification of evapotranspiration (ET), soil water measurement, plant based monitoring and integrated soil water balance approach which includes pre-programmed irrigation methods as well as real time scheduling approaches. Some of these methods and techniques were found to be "transferable" to farmers, while others will only be considered as research tools.

The survey amongst 332 irrigation schemes (which included 51 small-scale irrigation schemes) showed that 18% of the farmers are applying objective scheduling practices, while the majority of irrigators rely on the use of intuition or subjective irrigation scheduling (Chapter 3). Subjective irrigation scheduling is based on instinct, knowledge, experience and confidence gained over many years of farming. The great variation in irrigation figures reported (0-100%) suggests that farmers perceived irrigation scheduling as either one of the following approaches:

- The implementation of scientific or objective scheduling methods like soil water measurement sensors and the use of crop evapotranspiration (ET) data to determine when, and how much to irrigate
- A combination of both scientific or objective scheduling methods and intuition or subjective irrigation scheduling methods
- The use of intuition or subjective scheduling methods.

The findings of the survey reveal several important relationships regarding the implementation of irrigation scheduling:

- The irrigation method used on the farm determines the choice of irrigation scheduling methods implemented by the farmers. Positive interrelationships were found between the use of mechanized irrigation systems (centre pivots), drip, micro and the implementation of objective scheduling, while slightly negative relationship exist between flood irrigation and the implementation of objective scheduling methods.
- The technology level of the farming operation, size of the farming operation and the type of crops produced on the farm determine the choice of irrigation scheduling methods selected. Corporate farming concerns and farms with high value crops were more likely to adopt and invest in sophisticated irrigation scheduling methods.
- Although computer usage on the farm is currently common, the use of computer scheduling models are still limited to the high technology level farms and need efficient support form irrigation advisors and consultants.
- The application of a flat rate tariff for the use of irrigation water on the majority of irrigation schemes do not provide the necessary financial incentives to farmers to adopt very sophisticated irrigation scheduling methods.
- Irrigation scheduling at farm level depends on the regular and effective supply of water. The majority of farmers (75%) experience an effective on-demand system, while 25% indicated that they could hardly apply crop-based scheduling methods because of a fixed proportional delivering system or the use of surface irrigation methods on the farm. A significant negative correlation was found between the implementation of objective irrigation scheduling and the flexibility in terms of water delivery and irrigation management options, implying that this inhibits the practice of precise irrigation scheduling.
- In spite of general expectations that farmers with bigger allocations are more reluctant to use objective irrigation scheduling methods, no significant relationship was found.

The acceptability of the implementation of irrigation scheduling on-farm was evaluated through a quantitative survey conducted among 134 commercial irrigation farmers (Chapter 4). It is evident from the study that socio-economic factors like the age of the farmer, experience of irrigation, and the level of education play an important role in the general willingness of a farmer to trial and perhaps on a later stage adopts or rejects irrigation scheduling methods. Farmers with relatively more experience in irrigation management tend to be more willing to rely on their own experience, knowledge, observations and intuition than on the use of objective scheduling methods.

Farmers generally perceived the efficient use of irrigation water on the farm as being the major reason for the adoption of irrigation scheduling practices on the farm, and not just the conservation of irrigation water *per se*. Perceived indicators of efficient use of irrigation water on the farm include the improvement of the quality of high value crops, increasing of production yields, decreasing of energy (diesel and electricity) operational costs and improvement of the management efficiency of nitrogen and other nutrients. Accuracy, reliability, ease of implementation and affordability are some of the important technological characteristics of scheduling methods and devices that were identified by the farmers.

As farmers advance through a learning process of evaluation, trialing and experimenting with specific irrigation scheduling methods, some will change practices and discontinue some irrigation methods, while others will change the implementation of irrigation scheduling methods from the one to the other. 57% of the respondents changed their irrigation scheduling methods since they started scheduling, while 12% of the respondents indicated the discontinuance of objective irrigation scheduling.

Significant differences in the general awareness of computer models exist between irrigators that belong to the objective irrigation-scheduling group and those from the subjective irrigation-scheduling group. Twenty nine percent of respondents that belong to the group of objective scheduling were aware of computer models, while only 5% of the respondents involved in subjective scheduling could name an irrigation scheduling model. Respondents who do not use computer-scheduling models either perceive it as being too difficult to apply on the farm (37%) or are not practically adapted for their specific circumstances (35%). Twenty five percent of the respondents indicated the lack of the necessary computer skills, which prevent them from the use of this technology on farm.

Although the majority (64%) of respondents indicated the regular evaluation of distribution uniformity of irrigation systems on the farm, many farmers are still reluctant to allocate the necessary time for this management activity. Farmers in general are positive towards the implementation of volumetric charges, however the practical implementation of such an approach raised concerns.

The majority of small-scale farmers do not perceive irrigation scheduling as an important production constraint (Chapter 5). They are preoccupied with the persisting barriers to progress, which include lack of credit, infrastructure, and access to markets, land tenure, vandalism and theft and extension support. Many of the extensionists involved in the survey admitted that they lack the necessary knowledge and skills in irrigation management, and are consequently not in a position to render an effective service to farmers.

Extensionists and irrigation professionals often referred to the "dependency syndrome" that the majority of small-scale irrigators are suffering from. In an effort to break away from this syndrome, farmers need to take the responsibility for and ownership of their own development. This can only be done through proper institutionalization and establishment of farmer representative bodies, such as, the Farmer Support Units found in Taung, commodity groups in Tshiombo and the block committees operating on the Bethlehem apple project. Farmers need to perceive the support from advisors and extensionists as being of temporary nature, and to develop the necessary urgency and motivation to be capacitated and empowered through the regular interaction and dialogue between farmers and extensionists.

Irrigation farmers access a variety of sources of information and belong to various information networks (Chapter 6). This study reiterated the fact that farmers do not operate in isolation but rather in a social and business situation in which the individual's position is progressively influenced as a result of others. Different information sources were identified which irrigation farmers access and that fit the different farming styles as well as the lifecycle-stage of the farmer:

- Some farmers indicated that they seek information and advice mainly from local experts like the local co-operative extensionists, fellow farmers or water institutions like the irrigation board, and do not regularly make use of "outside information".
- The more progressive farmers and relatively bigger farm businesses were more likely to use irrigation consultants and experts of industries for advice and their perceptions. 35% of the respondents use consultants as a major source of information regarding irrigation scheduling. Members of this group also base their information on "opinion leaders" in the farming community.
- The third group is more outwardly focused and consult widely whenever information is needed. Furthermore, this group is likely to be participating already in other learning activities like training, study groups, and external networking.

The study reveals that commercial irrigation farmers rely mainly on information from the local co-operative, private consultants, industry experts and fellow farmers, while the majority of the small-scale irrigators depend more on information from the departmental extensionists. A significant relationship exists between the number of information sources used and the implementation of the type of irrigation scheduling methods which, implies that farmers involved in the use of objective scheduling methods are more willing and prepared to seek additional information sources outside the irrigation area than the farmers involved in subjective scheduling methods.

The irrigation farmers identified desirable attributes of extensionists, consultants and advisors that play a crucial role in the uptake of information about new irrigation. Some of the attributes which were identified include the following: their credibility, integrity, technical competence, vision and focus of the farmer within the bigger picture furthermore aspects such as the understanding of the context of the farmer and his specific farming style, effective communication with the farmer, skills and knowledge to effectively interpret irrigation data into a format that is understandable to the farmer to be significant.

CONCLUSION AND RECOMMENDATIONS

This project helped to quantify the scale of implementation of irrigation scheduling amongst commercial and small-scale farmers. Based on the data, it is clear that perceptions, attitudes and beliefs influence the adoption behaviour of farmers regarding the use of irrigation scheduling methods and techniques.

One of the most valuable insights derived from this project was the identification of the vast difference in perception regarding irrigation scheduling and what it involves. Some of the farmers perceive irrigation scheduling as a means of finding solutions to their problems, and will therefore make use of the most scientific and sophisticated methods that are available, while the majority of irrigation farmers are more interested in the use of irrigation scheduling to identify "troubles or problems" (trouble shooting) experienced with irrigation. These farmers are therefore not always interested in absolute accuracy and sophisticated equipment, because no relative advantages could be perceived from the use of it. Therefore, it is inevitable that farmers will differ in their selection of the most appropriate scheduling method and technique, as their needs will be based on the relative technology level of operation required on the farm.

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The Steering Committee responsible for this project was made up of the following persons:

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CHAPTER ONE: Irrigation scheduling as part of Water Use Efficiency

INTRODUCTION

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. Agriculture in southern Africa is a very important activity in terms of economic development but is also identified as one of the major water users in the region. Here in South Africa the total area under irrigation for commercial and subsistence 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

WATER USE EFFICIENCY AND THE IMPLEMENTATION OF IRRIGATION SCHEDULING

The efficiency of water use in agriculture is relatively low, with poor management and inadequate designs being the main causes of high water losses resulting in low yields, reduced irrigated areas and environmental problems. Fruhling (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 water (ARC, 1999).

Water use efficiency (WUE) is a generic label for any performance indicators used to describe the relationship between water (input) and agricultural product (output) on a scheme, farm and field level. Agronomy and engineering are the predominate means for enhancing WUE. WUE usually encompasses indices like crop water use and irrigation water use (Barret Purcell & Associates, 1999). Efficiency is a term that creates a mental picture of a system in which we can twist dials, tweak components, and ultimately influence the efficiency of the system. Unfortunately, the agricultural irrigation system we deal with is much more complex than a factory analogue.

The main pathways for enhancing WUE in irrigated agriculture is to increase the output per unit water (engineering and agronomic management aspects), reduce losses of water to unusable sinks and reduce water degradation (environmental aspects). To improve water use efficiency, a co-ordinated approach at different levels of the irrigation system is required: starting at the bulk water source system, followed by the bulk water conveyance system up to the farm and field level. Any definition of water use efficiency will depend to a large degree on the outlook of the person producing the definition. Those managing the 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. Irrigators are more interested in how much product, or perhaps how much profit, they can produce with a given amount of water. Finally, those involved in resource management are more interested in reducing wastage of the resource, especially where such wastage has negative off-site impacts on the environment. All these factors are important in the larger picture; no one definition of efficiency is completely appropriate.

This study focused on the irrigation performance on-farm, and there are wide ranges of practices, which may potentially improve on-farm water use efficiencies:

- *On farm water storage and distribution:* storage and distribution of on-farm water may represent a considerable component within the whole farm water management system in areas where secured water supply is a problem. Storage failures are commonly attributed to inadequate site investigation, poor construction and seepage losses.
- *Performance of in-field application system:* the ability of the system to apply water uniformly and efficiently to the irrigated area is a major factor influencing agronomic and economic viability of the production system.
- *Agronomic aspects of water use efficiency:* the main objective with irrigation management is to supply a desired amount of water to the crop at a specific time. Effective irrigation management requires some knowledge about how much (irrigation volume) and when to apply (the irrigation schedule), also referred to as *irrigation scheduling*. Adequate prediction by the farmer or irrigation manager of the irrigation volume and schedule requires having some knowledge of water availability within the crop root zone and the rate of crop water use.

Irrigation scheduling has been defined as 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 purpose of irrigation scheduling is to inform the farmer about when to apply water and how much water to apply to obtain a desired objective (Hill, 1991). This 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).

The application of irrigation scheduling must be seen as one of several activities of the total water management on the farm to ensure the efficient use of water. The interest shown in improving the water use efficiency in South Africa is increasing, 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 a big role in improving water use efficiency on a farm level and reducing the production cost (Annandale *et al*., 2002). Efficient water use can only be realized when the commodity price of the crop produced is higher than the full cost of water and its application.

The objective of irrigation scheduling normally involves maximising profit or crop productivity and may involve taking advantage of irrigation opportunities, minimising deep percolation and leaching, or soil and salinity management. Irrigation scheduling can reduce water use only by reducing runoff from either irrigation or rainfall, by decreasing percolation of water beneath the root zone in excess of any required leaching for salinity management, by reducing soil water evaporation after an irrigation, or by controlling soil water depletion in a manner that reduces ET during known non-sensitive crop growth stages (Howell, 1996). However, in some case irrigation scheduling may lead to the increase of water use, while concurrently increasing crop yield.

Irrigation scheduling requires a good workable knowledge of the crops' water requirements and of the different soils' water 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.

The implementation of irrigation scheduling technologies was not always very successful and Shearer and Vomocil (1981) indicated that behavioural patterns and attitudes of farmers, as well as the need for continuous technical support of the farmers, who dedicate time to other higher priority activities, are some of the major constraints that prevent farmers from applying irrigation scheduling. An important issue is also that the irrigation scheduling method is mainly judged in economic terms. On the other hand, Shannon *et al*. (1996) carried out a participatory learning program amongst cane growers in the Burdekin (Australia). The growers were encouraged to collect crop growth and water use data, which helped in understanding processes and problems and improved their credibility of the result.

Very often, the complexity of computerized systems is an obstacle to the implementation. 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) also recommended checking the soil water balance program (Donkerhoek data) with field measurements of soil water in the Western Cape (South Africa).

Jensen (1981) summarized the Proceedings of the American Society of Agricultural Engineers Irrigation Scheduling Conference (Chicago, Illinois, 1981). He indicated that the challenges are to develop complete and reliable technologies to be applied to farmers' requirements as well as training of extension personnel. The research needs for the implementation of irrigation scheduling technologies were indicated by Itier *et al*. (1996), who summarized a number of papers delivered at the ICID/FAO Workshop on Irrigation

Scheduling (Rome, Italy, 1995). Itier *et al.* (1996) also indicated needs for technology transfer oriented towards simplicity of methods and training of farmers and extensionists.

Despite the apparent importance of irrigation scheduling and the large amount of research resources devoted to it, the adoption of objective irrigation methods and models by farmers have been well below expectations. This study reveals that adoption of an innovation like the practicing of objective irrigation scheduling is a dynamic process of decision-making where the impact of learning by doing on personal perceptions is illustrated.

CHAPTER TWO: Classification of irrigation scheduling methods and models used in South Africa

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, till 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.

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.

1. Intuition or subjective scheduling methods
2. Atmospheric based quantification of evapotranspiration (ET)
2.1 Measurement of ET
2.2 Estimation of ET
3 Soil water measurement:
3.1 Soil water potential
3.2 Soil water content
3.3 Wetting Front Detector
4 Plant based monitoring
4.1 Visual observation of plant appearance
4.2 Trunk and branch diameter measurement
4.3 Leaf water potential (LWP)
4.4 Sap flow
4.5 Canopy measurements (temperature and radiation)
4.6 Phytomonitoring
4.7 Remote sensing methods
5 Integrated soil water balance methods:
5.1 Pre programmed irrigation scheduling methods
5.2 Real-time irrigation scheduling methods
6 Irrigation control or automation

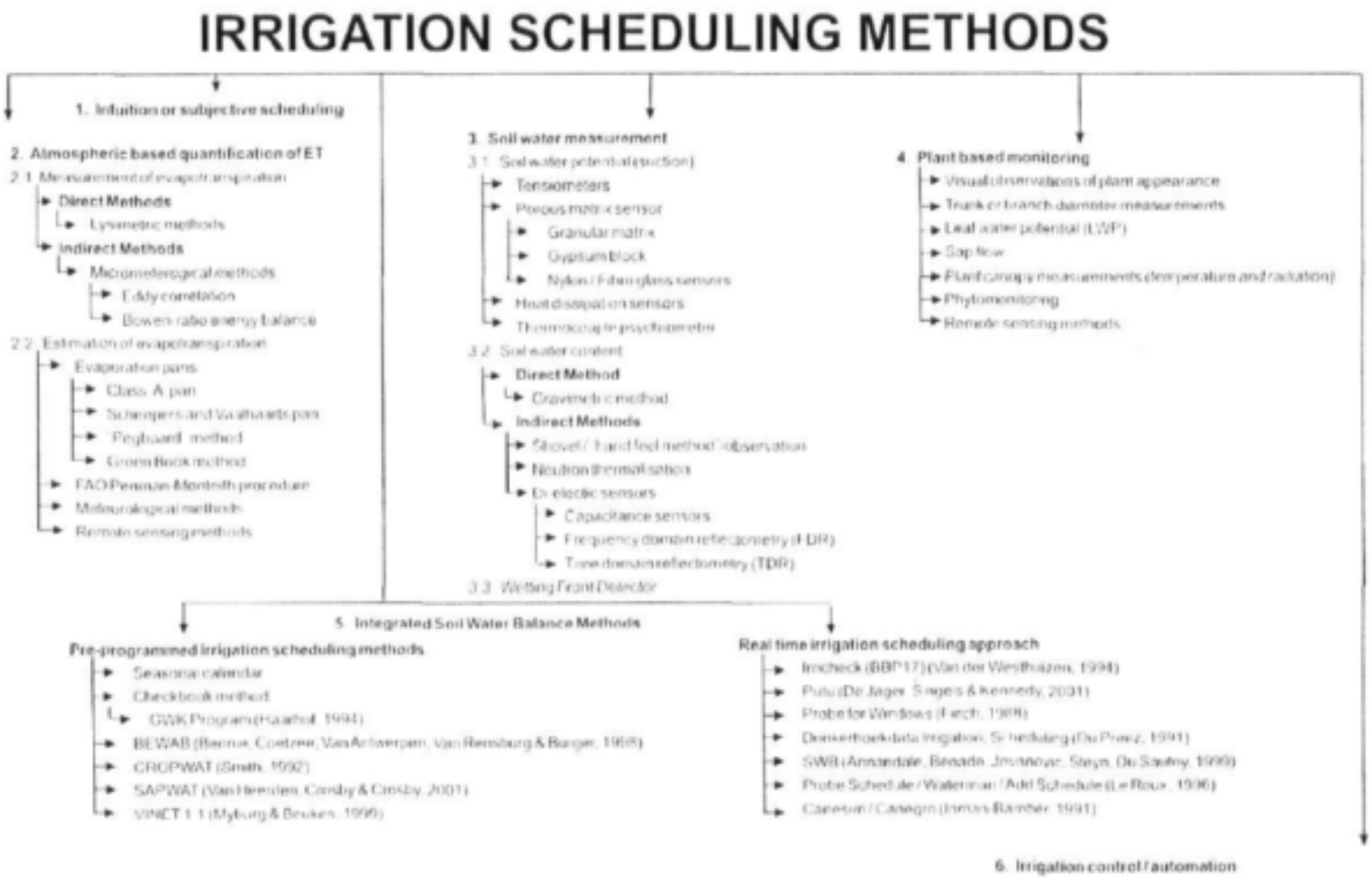


Figure 2.1 Classification of irrigation scheduling models and methods used in South Africa

DESCRIPTION OF IRRIGATION SCHEDULING MODELS AND METHODS USED BY IRRIGATORS

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". Irrigation applied when one's neighbour irrigates. 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	Intuition
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. ATMOSPHERIC BASED QUANTIFICATION OF EVAPOTRANSPIRATION

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 either 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.

2.1 Measurements of evapotranspiration

A. Direct method
2.1.1 Lysimetric methods
B. Indirect methods
2.1.2 Micrometeorological methods:
- Bowen-ratio
- Eddy correlation

A. Direct method

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. 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.	
Mode of operation	Weighing lysimetric method
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.	
Shortcomings: ❑ It is an expensive method. ❑ Time consuming.	
Users: Mainly used by researchers to determine real time ET, and for irrigation scheduling purposes.	

B. Indirect methods

2.1.2 Micrometeorological methods:

- **Eddy correlation**

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 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).	
Mode of operation	Measurement of eddies
Advantages: ❑ The most direct measurement of sensible and latent heat fluxes is possible with micrometeorological methods (Shuttleworth, 1993). ❑ No assumptions are made 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. ❑ The off-shelf eddy correlation systems are 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.	

- **Bowen-ratio energy-balance**

Description	
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.

2.2 Estimation of evapotranspiration

2.2.1 Meteorogical methods
2.2.2 Evaporation pans
- ❑ Class A pan
- ❑ Scheepers and Vaalharts pan

2.2.2.1 Pegboard method
2.2.2.2 Green Book method
2.2.3 FAO Penman-Monteith procedure
2.2.4 Remote sensing methods

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. Data from the automatic weather station are processed into a user-friendly format 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, 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.	

2.2.2 Evaporation pans

Crop ET is estimated using evaporation pans and crop coefficients, which relate crop ET to the evaporation measured in the pan (Pruitt, 1996; Doorenbos & Pruitt, 1977). While the standard Class A-evaporationpan 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.

1. 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 is 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%.

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.
- Very good and 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.

2. Scheepers and Vaalharts pan	
Description Widely used as on-farm evaporation pan for making evaporation measurements. A farmer himself could manufacture this evaporation pan by using a standard 200 l oil barrel. This evaporation pan is not made from stainless steel or special low carbon steel as in the case of the commercially available evaporation pans. This pan is 250 mm deep and 570 mm in diameter with the measuring scale prepared from Perspex.	
Mode of operation	Pan evaporation measurement
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).	
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.	
Users: Commercial farmers, advisors and researchers.	

2.2.2.1 Pegboard method

Description	
This type of scheduling monitors the accumulation of evaporation until predetermined levels, indicating the need for irrigation. 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. ❑ Total accumulated irrigation per crop (George, 1988). The amount of freely available moisture 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 is worked in terms of 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 record is kept.	
Users: Sugarcane farmers (small-scale and commercial farmers) in KwaZulu Natal and Mpumalanga	

2.2.2.2 Green Book method

<table>
<tr><td colspan="2">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</td></tr>
<tr><td>Mode of operation</td><td>Evaporation and crop factors</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td colspan="2">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.</td></tr>
<tr><td colspan="2">Users:
Used by some farmers involved in pasture production and advisors in the field.</td></tr>
</table>

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 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 (Doorebos & 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.

2.2.4 Remote sensing methods

Description

In, remote sensing methods, evaporation are evaluated (usually in conjunction with meteorological methods) by determining certain radiative or reflective 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 and
- Estimation of the parameters of the soil-vegetation-atmosphere continuum, such as soil water, crop evapotranspiration and crop biomass production.

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 images. Evapotranspiration can be retrieved directly without the use of crop coefficients. 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, constitutes 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.
- 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 Orange Riet) and irrigation consultants.

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).

3.1 Soil water potential (suction)

Soil water potential is measured through the use of:

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

3.1.1 Tensiometers (Irrometer / Jetfill / Adcon's electrotensiometer / 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. 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 gives point measurements and representative sites or stations should be identified before installation in the field. Information is localised and is site specific and therefore many observations are needed for accurate characterisation of a field. ❑ High labour requirement if not automatically logged. High degree of maintenance required. Regular service needed after installation – each tensiometer should be inspected for air accumulation often. ❑ Usually only operate between saturation and about –70kPa. They are thus not much use for measurements in the dry end of the spectrum. Air bubbles may enter at this point (termed the air entry potential). ❑ To prevent regular refill of tensiometers that have sucked air, most farmers are tempted to keep all tensiometer readings at low suctions, often resulting in over irrigation. ❑ The relatively long response time (particularly at suctions above 30kPa) makes them less suitable as a portable measurement device (Mullens *et al.*, 1986). ❑ Temperature-sensitive. ❑ Needs a retention curve to convert measured data into volumetric water content.	
Users: Farmers, consultants, researchers and extensionists	

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.

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, allowing many replicates, accurate and can be left in the field 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. The disintegration is dependant on the pH of the soil water. It needs 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, 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. It 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 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.	
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 not very suitable for localised irrigation because it gives point measurements. ❑ It is susceptible to inaccuracies caused by soil disturbance during installation. It needs individual calibration (calibration dependent) - 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	

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: ❑ An advantage of this sensor is that it returns information on both soil water and the temperature of the soil at the probe site. ❑ Accurate and continuous monitoring. ❑ 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, but the optimal range of measurement is from 0 to 100 kPa.
Shortcomings: ❑ Fairly large power requirements if measurements are taken 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 good, while the sensitivity in heavier clays is less than that for lighter soils. ❑ Tedious calibration is needed to ensure accuracy.
Users: Researchers.

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 in making this measurements 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.	
Shortcomings: ❑ It is calibrated empirically, with solutions of known water potential connected to the psychrometer chamber. ❑ 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. ❑ Expensive.	
Users: Mainly researchers use this method.	

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

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

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 used where 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 is usually poor unless the operator is very experienced. 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.

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 without disturbing 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 once access tubes are installed and conveniently distributed in the field.
- ❑ The main limitations relate to safety rules, which have to be followed to operate, transport and store the radioactive probe. It requires an operating licence because it contains radioactive material.
- ❑ Calibration is delicate, time and labour consuming. Using the neutron probe with a single calibration equation for all soils provides only limited accuracy.
- ❑ 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.

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. **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.	
Mode of operation	Di-electric measurement
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 soils.	

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.

Users:

More suited for use by a group of farmers because of the cost of the instrument, researchers, extensionists and consultants.

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 every 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 were experienced under irrigation systems like centre pivot and furrow irrigation. ❑ Buried depth is crucial.
Users: Farmers (commercial and small-scale), researchers, extensionists and consultants.

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.

The following plant monitoring methods will be discussed:

- 4.1 Visual observation of plant appearance
- 4.2 Trunk or branch diameter measurements
- 4.3 Leaf water potential (LWP)
- 4.4 Sap flow
- 4.5 Canopy measurements
- 4.6 Phytomonitoring
- 4.7 Remote sensing methods

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.

4.2 Trunk or branch diameter measurements

Description A sensor (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.	
Mode of operation	Measurement of diameter
Advantages: ❑ It is fairly easy to install and must be connected to a logging system.	
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.	

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.

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. Both techniques require tree sampling and lead to necrosis of the trunk- this is why it is necessary to change sampling site frequently.	
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.	
Users:	
Researchers, progressive commercial fruit growers and wine producers in the Western Cape with the help of consultants.	

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:

- The problems experienced are that the index threshold values need to be adjusted to each crop. The index does not work accurately when little rainfall occurs during the dry cycle.
- 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).

Users:

Relatively expensive and seems to be limited to advisors and researchers.

4.6 Phytomonitoring

Description

It 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. It incorporates plant-sensing techniques, sampling rules, measurements protocols, data interpretation and crop-specific application techniques. 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 is about 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. ❑ Very short time is required for delivering information on plant status to user.	
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	

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 2.2.6 Remote sensing).

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. Models can be used either for strategic planning or tactical purposes. 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.

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.

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 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.

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:

(i) 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.

(ii) 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, 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

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. 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.

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 by the irrigator whenever soil water instruments have been installed or irrigation is anticipated.
- ❑ 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

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
5.1.3 **BEWAB** **(Besproelingswater 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
5.1.4 CROPWAT (Crop Water Requirements)	Smith , 1992	❑ An 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
5.1.5 SAPWAT (South African Procedure For Estimating Irrigation Water Requirements)	Crosby & Crosby, 1999 Van Heerden, Crosby & Crosby, 2001	❑ It is 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.

Models	Developed	Principles of the model	Application
5.1.6 VINET 1.1 (Estimating Vineyard Evaporation for Irrigation System Design and Scheduling)	PA Myburgh and C Beukes (ARC Infruitec Nietvoorbij) 1999	❑ 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.	❑ Commercial wine and table grape growers, consultants, engineers and small-scale table grape farmers. ❑ Areas: ➢ Summer rainfall region: ○ Northern Cape ○ Limpopo ○ Mpumalanga ○ Northwest Province ○ Gauteng ○ Northern Cape: Eksteenskuil ➢ Winter rainfall region: ○ Western Cape

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
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, sweetcorn, 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
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 ❑ *Shortcomwigs:* ➢ 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
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.	❑ Users are irrigation consultants, commercial farmers and researchers. ❑ 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.

Models	Developed	Principles of the model	Application
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. ❑ 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 E0 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
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 ❑ The 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.	❑ Users are irrigation consultants, commercial farmers and researchers in the RSA. ❑ Deficit irrigation strategies where water supply is limited can be accurately described.

Models	Developed	Principles of the model	Application
5.2.6 **Probe schedule** (Neutron probe) **Add schedule** (Diviner) **Waterman** (Neutron probe)	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. ❑ Commercial farmers, consultants are needed for the initial stages. ❑ Western Cape commercial fruit growers.

Models	Developed	Principles of the model	Application
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, 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. ❑ 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.

5.3 Irrigation Control or Automation

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.	
Mode of operation	Automation through soil-plant-atmosphere measurements
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.	
Shortcomings: ❑ Irrigation control systems that use either soil or plant water sensors, in general, are affected by sensor location and field placement.	
Users: Farmers and irrigation consultants.	

CONCLUSION

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.

Models	Developed	Principles of the model	Application
5.1.3 **BEWAB** **(Besproelingswater 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
5.1.4 CROPWAT (Crop Water Requirements)	Smith , 1992	❑ An 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
5.1.5 SAPWAT (South African Procedure For Estimating Irrigation Water Requirements)	Crosby & Crosby, 1999 Van Heerden, Crosby & Crosby, 2001	❑ It is 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.

Models	Developed	Principles of the model	Application
5.1.6 VINET 1.1 (Estimating Vineyard Evaporation for Irrigation System Design and Scheduling)	PA Myburgh and C Beukes (ARC Infruitec Nietvoorbij) 1999	❑ 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.	❑ 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

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
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, sweetcorn, 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
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
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.	❑ Users are irrigation consultants, commercial farmers and researchers. ❑ 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.

Models	Developed	Principles of the model	Application
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. ❑ 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 E0 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
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 ❑ The 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.	❑ Users are irrigation consultants, commercial farmers and researchers in the RSA. ❑ Deficit irrigation strategies where water supply is limited can be accurately described.

Models	Developed	Principles of the model	Application
5.2.6 **Probe schedule** (Neutron probe) **Add schedule** (Diviner) **Waterman** (Neutron probe)	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 ET_o 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. ❑ Commercial farmers, consultants are needed for the initial stages. ❑ Western Cape commercial fruit growers.

Models	Developed	Principles of the model	Application
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, 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. ❑ 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.

5.3 Irrigation Control or Automation

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.	
Mode of operation	Automation through soil-plant-atmosphere measurements
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.	
Shortcomings: ❑ Irrigation control systems that use either soil or plant water sensors, in general, are affected by sensor location and field placement.	
Users: Farmers and irrigation consultants.	

CONCLUSION

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.

CHAPTER THREE: Implementation of irrigation scheduling methods

INTRODUCTION

Despite the importance of irrigation scheduling and the large amount of research resources devoted to it, the adoption of irrigation scheduling techniques by farmers has been below expectations. This gap between science and practice of irrigation scheduling has traditionally been seen as the failure of adoption that should be addressed by extension (Stirzaker *et al.*, 2004). This view is based on the assumption that the cause of the problem is the lack of awareness of solutions by the target audience, but it ignores the possibility that research and extension programs have been based on the worldviews of the problem solvers, rather than those of their clients (Blacket, 1996).

Irrigation scheduling was introduced to farmers thirty years ago according to Shearer & Vomocil (1981) and Fereres (1996). These efforts have been efficient in conserving water/energy (Shearer *et al.*, 1981; Dockter, 1996; and Alam, 1996), improving crop yield and quality (Silva & Marouielli, 1996; Tacker *et al.* 1996), and reducing non-point pollution (Boesch *et al.*, 1981; Klock *et al.*, 1996 and Nguyen *et al.*, 1996). However, worldwide the adoption of more objective irrigation scheduling methods (also referred to as SIS or scientific irrigation scheduling by Leib *et al.*, (2001)) has been below expectations.

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. Koeglenberg & Lategan (1996) believe that only consultants have the technical expertise necessary to implement irrigation scheduling correctly, while Itier (1996) contends that scheduling methods and techniques must be simplified to match time constraints, training level, and income potential of producers.

Behavioural patterns and attitudes of people, as well as the need for continuous technical support to the farmers, who generally dedicate time to other higher-priority activities, are the major obstacles according to Shearer *et al.* (1981) in the implementation of irrigation scheduling. 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.

Chapter Three of this report presents the results of a quantitative assessment of the application and distribution of irrigation scheduling methods and models in the nine provinces amongst irrigation farmers. It also gives an overview of perception of irrigation consultants and extensionists involved in rendering irrigation-scheduling services to farmers. This provided the research team with an overview of the application and distribution of different irrigation practices and methods of scheduling applied amongst commercial and small-scale farmers on a scheme level (macro level). It also reflects the different institutions and agencies that provide support to farmers with the application of irrigation scheduling.

Apart from a few studies that have referred to the relative low adoption of irrigation scheduling methods by farmers (Annandale *et al.*, 1996) and human factors that determine the adoption of computer irrigation scheduling models (Botha *et al.*, 2000), this is the first comprehensive study to determine the implementation and distribution of irrigation scheduling methods in South Africa.

PROFILE OF THE RESPONDENTS, DATA COLLECTION AND ANALYSIS

Chapter Three refers to the findings derived from a national survey that was conducted in the nine provinces amongst approximately 332 irrigation boards and government schemes in operation. Surveys and interviews were the main tools for gathering information and assessing the implementation of irrigation scheduling amongst 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 of the specific irrigation scheme or the opinion irrigators in the area ("reported figures"). This is therefore a fairly true 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.

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 exploited. Methods used for collecting data included telephonic interviews, face-to-face interviews and questionnaires (with instruction letters) faxed or e-mailed to clients. 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 key issue guiding this part of the investigation was essentially to obtain a broad picture of the application and distribution of irrigation and scheduling methods in the nine provinces amongst 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 of irrigation practised 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 which the major crops grown in the irrigation area (an estimation of the proportions of each crop) and the type of farm business concerns (either a one-man concern or a company or an estate farming concern) 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.

Ultimately a relatively high response (74%) was obtained in the survey due to special efforts made by the project team to contact respondents again where necessary. The co-operation from 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 of 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, 40 irrigation scheme boards and 11 community food gardens were included in the survey. The data regarding small-scale farmers was collected by personal interviews, as well as from discussions held with local extension officers and advisors involved with the support of these farmers.

The total population of registered irrigation board schemes, government schemes and Water User Associations were considered, to ensure accuracy and reflectivity of the current irrigation situation. The analysis of the data involved the use of statistical package for social science (SPSS version 10). Before analysis, data was put into a computer readable format, which involved coding, editing, data cleansing. Where necessary modifications were made regarding the collapse or creation of new variables.

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 opinions of 15 789 (60%) of the commercial irrigators 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 irrigators per province (N=297)

Province	Area under irrigation (ha)	Number of irrigation farmers accounted per province (n)
GP	1 586	100
FS	44 925	1 710
KZN	74 431	886
MP	70 196	1 081
NC	155 193	2 894
EC	44 049	929
WC	116 271	3 833
Limp	49 779	1 107
NW	93 241	3 349
Small-scale	109 347	18 639
Total	**759 019**	**34 528**

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

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). The 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 some by project participants perform some functions.
    - Community schemes, usually small in size, operated by water users themselves.
    - State or corporation financed schemes, such as sugar cane, 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 3.3.

Table 3.3 Frequency distribution according to the types of irrigation schemes included in the survey (2003) (N=297)

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

In 1998 (National Water Act 36, 1998) the establishment of WUAs was started and some of the irrigation board schemes and government schemes have already been transformed into WUAs. At a Water User Association (WUA) level, the commitment and sustained involvement is a function of the services or benefits derived from being part of the association.

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 Orange Riet Water Users Association, the irrigation schemes of Scholtzburg, Modderrivier, Rietriver, and Orange Riet River are calculated as four different WUAs for statistical reasons while they are incorporated into one WUA.

IMPLEMENTATION OF IRRIGATION SCHEDULING BY IRRIGATION FARMERS

Respondent were requested to indicate the implementation of irrigation scheduling as per respective irrigation scheme with the necessary precautions taken to avoid social desirability of the question and the possible answers. 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 3.1).

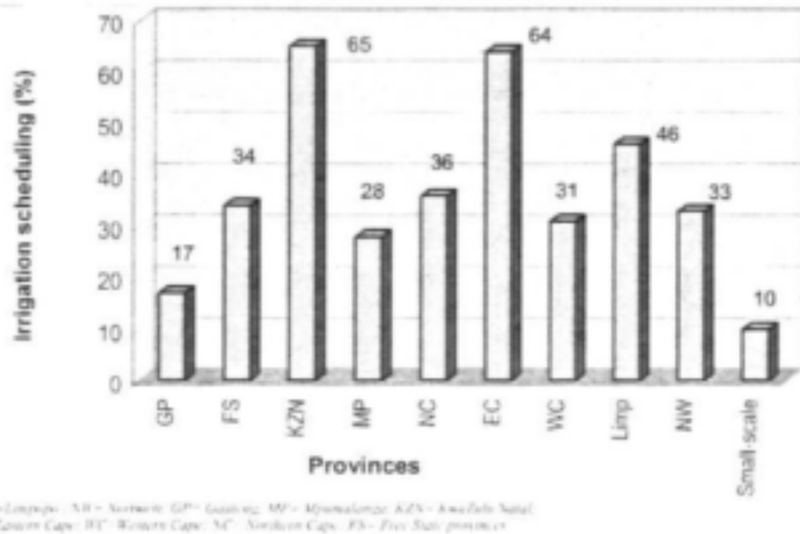


Figure 3.1 The perceived percentage implementation of irrigation scheduling as indicated per province (N=297)

The highest implementation of irrigation scheduling was reported for KwaZulu Natal (65%) and the Eastern Cape (64%), which also reflects the difference in perception about the implementation of intuition. This however, is not a true reflection of the implementation of objective irrigation scheduling for these provinces as 68 percent of the respondents of KwaZulu Natal and 57percent the respondents in the Eastern Cape, also perceive intuition as a form of irrigation scheduling method practiced by irrigators and consequently these figures are inflated. Intuition did not feature to the same extent in other provinces.

The relatively low irrigation figure reported for the small-scale farmers (10%) is due the fact that only eight percent of the respondents included in the survey were small-scale farmers. The figure reported for the implementation of irrigation scheduling by small-scale irrigators therefore represents mainly the perceptions of officials and extensionists responsible for providing support in these irrigation areas. It does not include the use of subjective scheduling methods as an alternative scheduling method and only reflects the implementation of objective scheduling methods. This finding illustrates the differential perceptions regarding the definition of irrigation scheduling and attached perceptions by farmers and advisors or extensionists.

The reported figures of irrigation scheduling reflected in Figure 3.1 clearly indicate 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 or subjective irrigation scheduling and was therefore appropriately 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 however regard irrigation scheduling mainly as the implementation of objective scheduling methods like soil water content measurement, use of crop evapotranspiration figures (long term and real time) and computer models instead of intuition. This group of respondents therefore recorded implementation

figures of irrigation scheduling that reflects solely the use of objective irrigation scheduling methods on a scheme level. These recorded figures were 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 scheduling methods and intuition or 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.

A highly significant relationship was found between the reported implementation of irrigation scheduling and the perception of respondents regarding the use of intuition ($r = 0.985$, $p<0.01$). This implies that the higher the reported percentage of irrigation scheduling is the more intuition is regarded as a form of scheduling.

DIFFERENCE IN PERCEPTION REGARDING THE IMPLEMENTATION OF IRRIGATION SCHEDULING

The irrigation scheduling methods commonly used by irrigators as reflected in the survey were clustered into six groups:

- Use of long term ET 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 monitoring like sap flow, leaf water potential, and phytomonitoring.
- Measurement of soil water content and potential with soil moisture sensors: use of tensiometers, neutron probes, capacitance measurements (Diviner, Enviroscan, etc), and dielectric conductivity (gypsum blocks).
- The use of computer models, both based on soil water balance and mechanistic models.
- Feel and appearance method: where the tile probe, soil auger or spade is used to determine the status of the soil water content. This method also helps farmers to reveal where the soil water is located.

Figure 3.2 summarizes the percentage implementation of different irrigation scheduling methods as perceived 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 indicated that the reported and recorded figures do not differ substantially on the implementation of the different scheduling methods. The reported implementation figures of objective scheduling methods vary between 2% and 18%, as indicated in Figure 3.2. The recorded percentage varies slightly more.

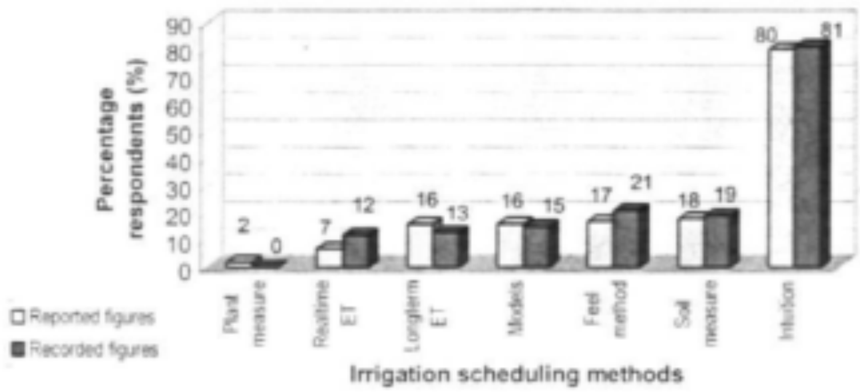


Figure 3.2 Implementation of different irrigation scheduling methods by irrigation farmers according to figures recorded and figures reported by representative respondents from the different irrigation schemes (N=297).

The majority of respondents (80%) reflect the use of intuition as an irrigation scheduling method, while the reported implementation figures of objective irrigation scheduling methods vary between 2% and 18% as indicated in Figure 3.2. The recorded percentages vary slightly more. Only a few commercial fruit and wine grape growers in the Western Cape indicate the use of plant measurements (2%) like the measurement of leaf water potential, sap flow and phytomonitoring.

The use of intuition as an irrigation scheduling method by irrigation farmers entails the incorporation of a fixed or semi-fixed irrigation calendars based on experience, knowledge, observation and feeling. 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).

According to the irrigation scheduling figures reported it was clear that different perceptions exist regarding the definition "irrigation scheduling". Perception, according to Atkinson *et al.*, (1985), is the process by which human beings organize, integrate and recognize patterns of stimuli. But perception is not merely a passive reception and automatic interpretation of stimuli, but rather an active process in which the incoming data are selectively related to the existing cognitive structure. "Perception refers to the world of immediate experience - the world as seen, heard, felt, smelled and tasted" (Morgan & King, 1966).

IRRIGATION SCHEDULING GROUPS

Based on the response by respondents on the implementation figure of irrigation scheduling by irrigation farmers 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 3.3.

Scheduling group 1: 0-20% reported implementation of irrigation scheduling
Scheduling group 2: 21-40% reported implementation of irrigation scheduling
Scheduling group 3: 41-60% reported implementation of irrigation scheduling
Scheduling group 4: 61-80% reported implementation of irrigation scheduling
Scheduling group 5: 81-100% reported implementation of irrigation scheduling

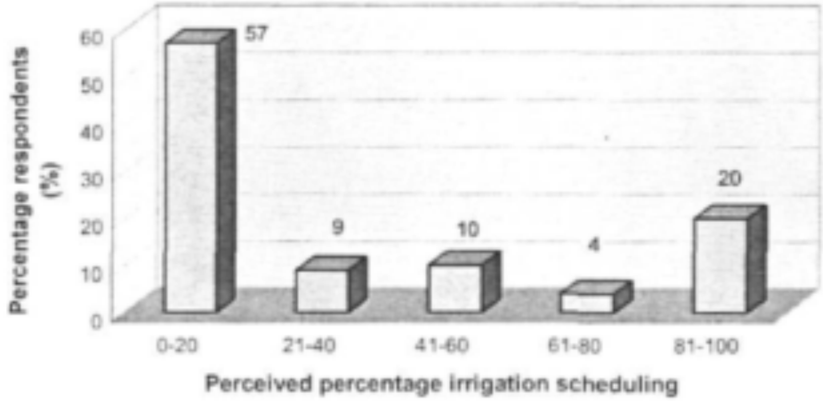


Figure 3.3 Percentage distribution of irrigation groups (schemes) according to the reported percentage implementation of irrigation scheduling (N=297)

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 perception amongst many respondents that intuition is a form of scheduling.

The degree to which intuition is perceived to be part of scheduling is further investigated and Figure 3.4 reveals the percentage of respondents who use intuition and those who use objective scheduling methods which include various soil monitoring methods, plant monitoring methods, integrated soil water balance estimations and use of crop evapotranspiration figures to determine when, and how much to irrigate within each category of reported percentage scheduling.

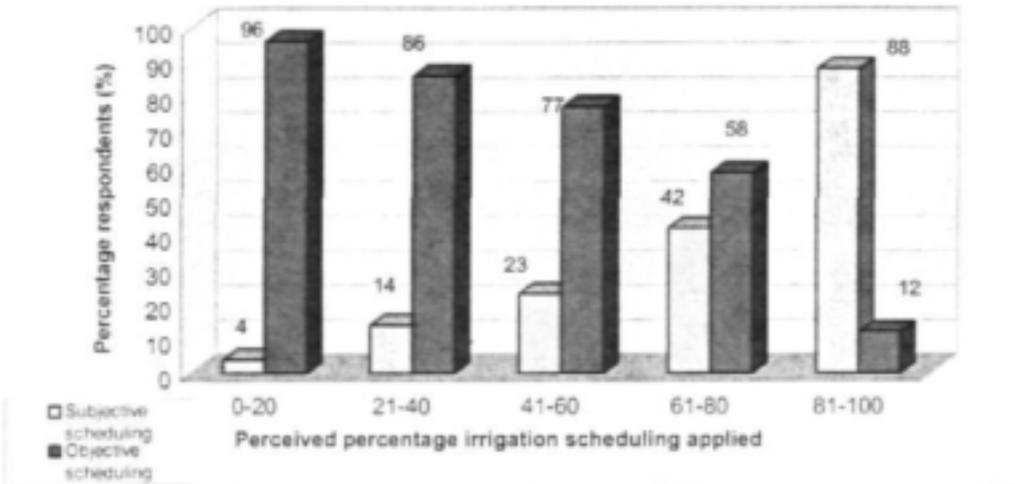


Figure 3.4 Distribution of respondents according to their perception regarding intuition as an irrigation scheduling method as per irrigation scheduling group (N=297).

The fact that the percentage of respondents who regard 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 irrigators' perception of irrigation scheduling. According to Louw & Düvel (1993), the intervening variables (mostly defined as covert) that appear to be immediate and a direct precursor of decision-making of irrigation scheduling behaviour, are needs, perceptions and knowledge.

These findings are important, especially for irrigation consultants and the extensionists regarding the planning and implementation of appropriate communication strategies to promote awareness and adoption of the practising of objective irrigation scheduling amongst farmers. Farmers from the group where intuition is perceived as the main practice of irrigation scheduling have different felt needs to be addressed in terms of information required for irrigation management decisions, than farmers from the group where objective irrigation scheduling is regularly used in decision making. The characteristics of the five different irrigation-scheduling groups will clearly be different and therefore needs to be taken into account by irrigation advisors and extensionists in future support strategies.

INTERRELATIONSHIP BETWEEN IRRIGATION SCHEDULING METHODS AND THE IMPLEMENTATION OF IRRIGATION SCHEDULING

Figure 3.5 shows the correlation between the different irrigation scheduling methods with the implementation of irrigation scheduling by irrigators.

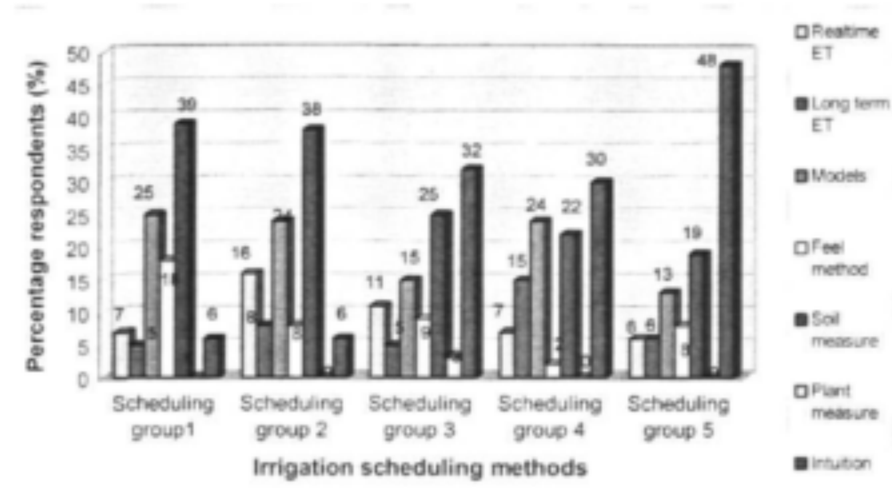


Figure 3.5 Application of different irrigation scheduling methods by scheduling groups 1-5 (N=165)

Scheduling group 1: 0-20% reported implementation of irrigation scheduling
Scheduling group 2: 21-40% reported implementation of irrigation scheduling
Scheduling group 3: 41-60% reported implementation of irrigation scheduling
Scheduling group 4: 61-80% reported implementation of irrigation scheduling
Scheduling group 5: 81-100% reported implementation of irrigation scheduling

This figure illustrates 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. soil measurement and the use of computer models or programs to schedule irrigation on the farm than the use of intuition. The use of intuition was found to be less than 15% amongst these irrigators. Figure 3.5 also indicated that as the respondents reported relatively higher figures of implementation of irrigation scheduling, the contribution of intuition also clearly increased (scheduling groups 3-5). These findings also illustrate the differential perception regarding the implementation of "irrigation scheduling".

COMPUTER MODELS AND THE INTERRELATIONSHIP WITH 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 in terms of everyday management decisions. However the use of computer models amongst irrigation farmers is still limited and the majority of irrigators that reported engagement in models also referred to the help and support provided by consultants and extensionists in this regard. Figure 3.2 indicated that sixteen percent of the irrigation schemes referred to the use of computer irrigation scheduling models by farmers.

As indicated in Chapter 2, 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 models were developed to help the farmer with better-informed decisions in water management. The real time irrigation scheduling models and programmes are based on actual daily conditions, usually soil water content and atmospheric demand, and therefore needs regular measurements and monitoring of the soil-water-atmosphere conditions prevailing. Figure 3.6 illustrates the implementation of the different irrigation models as reported by the respondents.

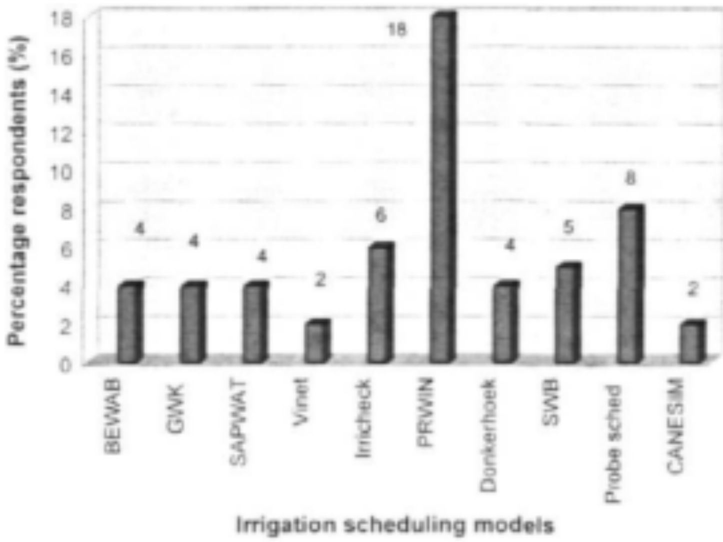


Figure 3.6 The implementation of irrigation scheduling models by farmers (N=297)

PRWIN was found to be popular amongst the irrigators, 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.

As discussed in Chapter Two, numerous irrigation models and computer 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. However, from the responses received from respondents it is clear that these models and programmes are without the necessary support of extensionists and irrigation consultants, found to be too complex or difficult to be used by the majority of farmers. These results in irrigation scheduling models and programmes being predominately advisor-driven rather than farmer-driven, and therefore the distribution largely appear to be advisor specific and thus geographically bounded. This tendency is evident in Table 3.4, where the use of a computer programme like PRWIN was reported in eight of the nine provinces.

Table 3.4 Distribution of irrigation models amongst the nine provinces as indicated by respondents (N=297)

Models	Provinces
BEWAB	Free State, Northern Cape, Northwest
Irricheck	Free State, KwaZulu Natal, Mpumalanga, Northern Cape, Limpopo, Northwest
SAPWAT	Free State, KwaZulu Natal, Mpumalanga, Northern Cape, Eastern Cape, Northwest
SWB	KwaZulu Natal, Mpumalanga, Limpopo
PRWIN	Free State, KwaZulu Natal, Mpumalanga, Northern Cape, Eastern Cape, Western Cape, Limpopo, Northwest
CANESIM	KwaZulu Natal, Mpumalanga
Probesched	Mpumalanga, Northern Cape, Eastern Cape, Western Cape
Donkerhoek	Western Cape
GWK	Northern Cape
Vinet	Western Cape, Northern Cape, Small-scale

INTERRELATIONSHIP BETWEEN IRRIGATION TARIFFS AND IRRIGATION SCHEDULING METHODS

The National Water Act (1998, No 36) determines that any person that is registered in terms of a regulation or holding a license to use water, must pay all imposed charges. Since 1996/97 new water tariffs were 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 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. This 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 system, and is based on the costs associated with that particular scheme (Van der Merwe, 2004).

The water tariffs as indicated in Table 3.5 reflect the water resource management charges levied for users of irrigation board schemes and WUAs as per province, while the tariff applicable to irrigators on government irrigation schemes include the water resource development as well as the operation and maintenance (O&M) charge. On a current irrigation scheme like Pongola, for instance, the tariff that irrigators 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.

Table 3.5 The distribution of respondents according to the irrigation tariffs reported as per province (N=297)

Province	Irrigation tariffs (R/ha/annum)				Total number respondents
	0-250	251-520	521-1043	1044-3900	
Gauteng	5	0	0	0	5
Free State	6	2	7	0	15
KwaZulu Natal	19	3	1	2	25
Mpumalanga	19	12	3	0	34
Northern Cape	8	12	10	2	32
Eastern Cape	6	4	1	2	13
Western Cape	35	12	9	10	66
Limpopo	11	7	2	0	20
Northwest	18	5	10	0	33
Small-scale	19	17	9	1	46
No figure reported					7
Total	**146**	**74**	**52**	**17**	**297**

The small-scale irrigation farmers 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 3.7 compares the different types of irrigation schemes regarding the irrigation tariffs reported for the respective irrigation schemes.

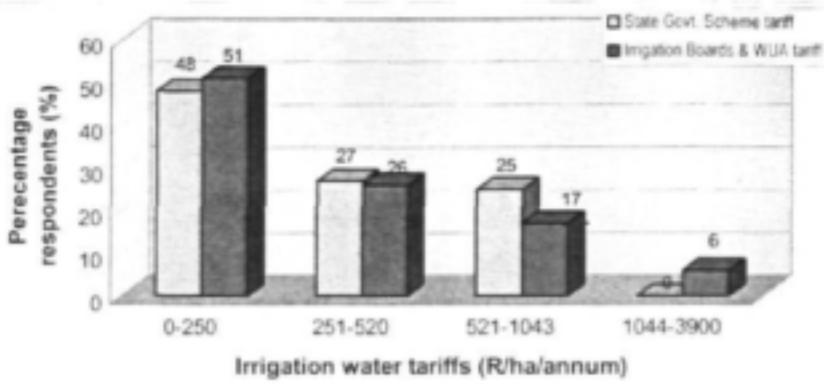


Figure 3.7 Frequency distribution of the irrigation tariffs applicable for the different irrigation schemes included in the survey (N= 297)

Figure 3.7 indicates that 48% of irrigators on government schemes and 51% irrigators respectively on irrigation board schemes are paying water tariffs of R250 per hectare per annum or less for their irrigation water allocation. The mean tariff for irrigation water that irrigation farmers pay is R397.97 per hectare per annum, with the highest tariff R3 900 per hectare per annum. 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).

Caswell & Zilberman (1985) and Caswell & Zilberman (1990) argue that higher water tariffs would induce the adoption of water saving technologies like objective irrigation scheduling. Table 3.6 shows the correlations that were found between the implementation of irrigation scheduling methods and the applicable water tariffs for irrigation schemes.

Table 3.6 Relationship between the implementation of irrigation scheduling methods and irrigation tariffs (N=297)

Irrigation scheduling methods	R	p
Plant measurement	1.0	<0.05
Real time ET	0.331	<0.05
Long term ET	0.203	>0.05
Computer irrigation scheduling models	0.085	>0.05
Soil moisture measurement	0.063	>0.05
Feel method	-0.227	<0.05
Intuition	*-0.177*	*<0.01*

Table 3.6 indicates that significant negative correlations exist between the perceived application of intuition as well as the feel method and the applicable irrigation water tariff for irrigators. This implies that there is a tendency that irrigators are more prepared to use intuition and the hand-feel irrigation scheduling method rather than objective irrigation scheduling when tariffs are relatively low. Except for significant correlations that exist between objective irrigation scheduling methods like the application of real time ET methods ($r=0.331$; $p<0.05$) and the use of plant monitoring ($r=1.0$; $p<0.05$), no statistical significant correlation could be found 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.

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 irrigators guarantee of receiving his entitled water allotment). These factors have to be taken into account 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 there response to price signals by more efficient water use strategies is perhaps smaller.

INTERACTION BETWEEN FLEXIBILITY OF DECISION-MAKING AND IRRIGATION SCHEDULING

Irrigation scheduling at farm level results in a delivery schedule, i.e. a real time decision as to when and how long and at which flow rate to irrigate, expressed in absolute values. This however, depends on the regular and effective supply of water.

Three approaches to the management of irrigation water conveyance systems are generally found:

- *"Continuous flow" approach*
  In this system the manager aims to maintain the supply in the system so that any user can abstract water at any time. In a canal and river system, 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. 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.

- *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. This system is often found on the government and the majority of irrigation board schemes. Farmers request the water they will need, specifying the time of the week they will be abstracting and the period of time needed. 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 a schedule applicable (e.g. every 7 days or fortnight). The flexibility of irrigators' decision making on 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 (Eksteen, 2002).

The majority of farmers (75%) experience effective bulk water delivering system and field irrigation methods conducive for the implementation of appropriate irrigation scheduling methods. Twenty five percent of the farmers perceived that they could hardly implement crop-based scheduling methods due to fixed proportional bulk water delivering system, or the application of surface irrigation or the lack of canal capacity, especially during peak 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:

- Decentralization of decisions and responsibilities of the delivering system (e.g. main canal level and secondary canal levels).
- 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, the technique usually results in excessive water depths being applied when the water is available, and water stress periods often 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.

Long canals where water takes a considerable time to travel the length of the canal and spillage as well as lack of canal capacity, especially during peak periods of the growing season, are very common occurrences and could be problematic to many farmers for the practising of sophisticated, objective irrigation scheduling methods.

Reliability as recalled by Burt (1996) is a prerequisite for the implementation of efficient 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 was also found to be an essential condition for the establishment of trust and confidence between water management institutions and the irrigators. Figure 3.8 indicates the difference in flexibility of water delivery experienced by farmers in the five different irrigation-scheduling groups.

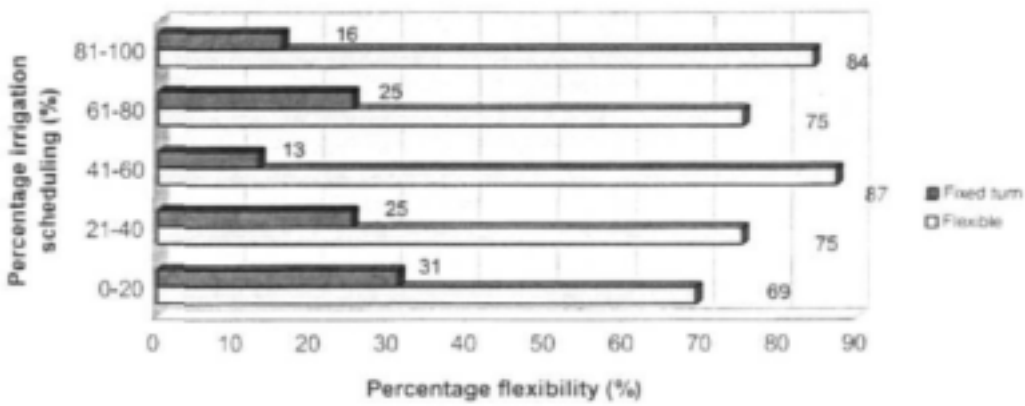


Figure 3.8 The relationship between perceived flexibility of bulk water delivery and the implementation of irrigation scheduling (N=297)

The relationship between flexibility of bulk water delivery and the implementation of objective irrigation scheduling is significantly negative ($r=-0.316$, $p<0.01$) implying that increased flexibility is associated with a higher reported implementation of objective irrigation scheduling. This also means that higher levels of fixed turn water delivery are associated with lower levels of 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 or flexibility to irrigate. The majority of respondents in this province uses surface irrigation and indicated that crop-based irrigation scheduling is very difficult to implement due the management of delivery or due to the practicing of surface irrigation methods. This irrigation technique's performance is still considered to be low, and the irrigation efficiency must be evaluated in terms of uniformity of water application and losses and also in terms of the ease of scheduling and timing irrigations (Eksteen, 2002).

Photo 3.1 Table grape production under surface irrigation in the Upington area (DWAF, 2003)

According to Terblanche (2003) the adoption of laser leveling by farmers lead to a significant improvement in accuracy of distribution uniformity. It facilitates irrigation scheduling and reduces water wastage and leads to increased yields. The majority of farmers in the Lower Orange River scheme have adopted this practice, and laser planning is done on all new irrigation development. However, the older fields still under surface irrigation are facing variability in terms of time, space of infiltration and farmers in general experience problems in controlling the field intake and discharges that influence their irrigation efficiency. Farmers often experience surface runoff water due to delays in the cutting of the supply that result in water damming up at the lower end of the bed, and often over-flows.

IRRIGATION ALLOCATION AND THE INTERRELATIONSHIP WITH IRRIGATION SCHEDULING

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 Box1:Orange Riet WUA area).

Box 3.1: Orange Riet Water Users Association

"The Orange 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 Orange 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 3.2 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 irrigators, 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 higher evaporation figures. The majority of irrigation farmers (57%) received an allocation for irrigation between 6 201-11 000 m^3/ha/annum (Figure 3.9).

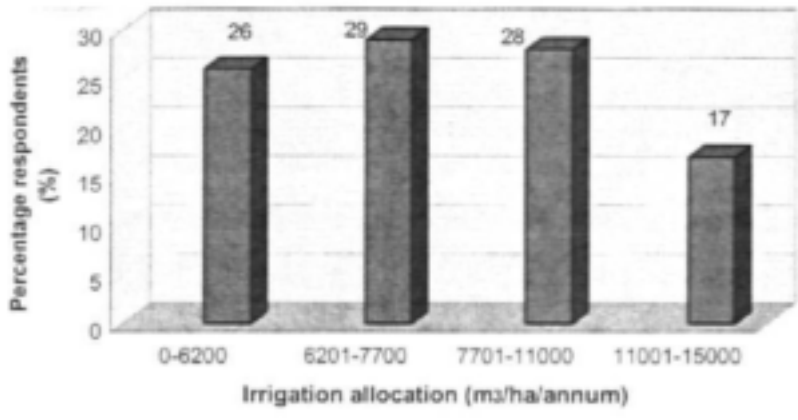


Figure 3.9 Distribution of respondents regarding irrigation water allocation in South Africa (N=297)

The general expectation that farmers with bigger allocations are more reluctant to implement precise irrigation scheduling was supported. The findings are shown in Table 3.7 and reveal that a significant correlation exists between the use of intuition as well as the feel method and higher allocations of irrigation water. However, it needs to be emphasized that many of the respondents with bigger irrigation water allocations also made use of surface irrigation or received water on fixed turns, viz. farmers from the Lower Orange and are not in a position to apply precise irrigation scheduling methods.

Table 3.7 Relationship between the implementation of irrigation scheduling methods and irrigation water allocations based on the actual figures collected (N=297)

Irrigation scheduling methods	r	P
Real time ET	- 0.229	0.297
Long term ET	-0.063	0.725
Computer irrigation scheduling models	-0.009	0.931
Soil moisture measurement	-0.114	0.415
Feel method	0. 477	0.045
Intuition	0.242	0.004

Table 3.7 indicates that no significant correlations exist between the application of objective irrigation scheduling methods and the allocation of relative smaller volumes of irrigation water.

INTERRELATIONSHIP BETWEEN TYPE OF FARMING OWNERSHIP AND THE IMPLEMENTATION OF IRRIGATION SCHEDULING

Respondents were asked to give an indication of the occurrence of different types of farming concerns in their irrigation schemes. The major types of farm business enterprises are:

- One-man concern: where the individual farmer, usually the owner, is responsible for all the management activities on the farm.
- Corporate concern: the latter is usually of a much bigger scale with the irrigation management usually assigned to a specific person(s) or consultant (s) and not 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 hypothesized that the more sophisticated and objective irrigation scheduling methods are the more likely it to be used by the big corporate or estate concerns, while the one-man concerns tend to use the more subjective irrigation methods. Table 3.8 provides an overview of the distribution of respondents according to the percentage occurrence of corporate farming concerns in the different irrigation areas.

Table 3.8 Distribution of respondents according to occurrence of corporate concerns (N=297)

% Corporate concern	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	3
Total	**297**	**100**

The percentage of corporate farming concerns 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 one-man 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 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 3.9 illustrates the distribution of the application of different irrigation scheduling methods as it occurs between the two types of farming concerns generally found amongst irrigation farmers.

Table 3.9 Distribution of respondents according to the types of farming operations and the implementation of irrigation scheduling methods (N=291)

Irrigation scheduling methods	Corporate concern (n=101)		One man concern (n=190)		Total (N)
	(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

The findings illustrate a tendency that objective scheduling methods are more often use by irrigators involved in corporate or estate concerns (Table 3.9). No significant correlations were found, except for the fact that a significant negative correlation ($r=-0.499$; $p< 0.01$) exist between the application of intuition as an irrigation scheduling method within corporate concerns, meaning that the latter group of irrigators were in general more prepared to make use of objective irrigation scheduling with the necessary support of the irrigation extensionists and consultants.

RELATIONSHIP BETWEEN THE CROPS SELECTED UNDER IRRIGATION AND IMPLEMENTATION OF IRRIGATION SCHEDULING

The assumption is that objective irrigation scheduling practices becomes more important under conditions where water intensive and high valued crops are produced. These crops are usually very sensitive to periods of subnormal irrigation, which will influence the production of high quality premium produce. With irrigated pastures on the other hand the expectation is that farmers are more inclined to use fixed or semi-fixed irrigation scheduling programs. The following figures (Figure 3.10 - 3.11) provide an overview of the crops grown under irrigation as reported by respondents on the different irrigation scheme

Cash crop types

The most important cash crop types currently grown under irrigation and based on the area planted are shown in Figure 3.10.

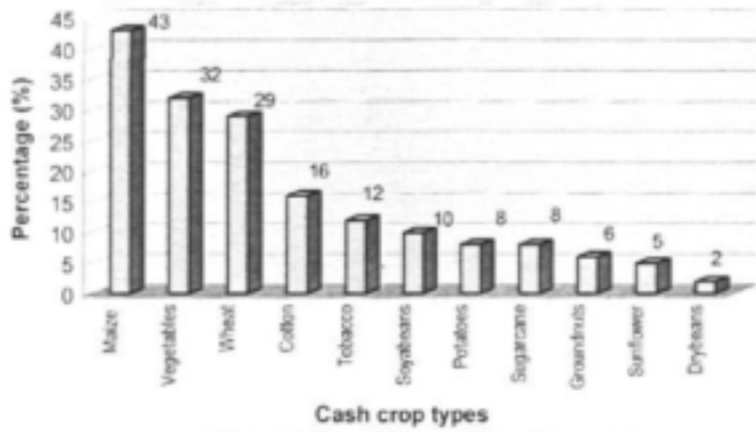


Figure 3.10 Percentage irrigation schemes on which various cash crops are produced (N=297)

Maize, vegetables and wheat are the most important cash crops planted under irrigation. Crops like paprika, sugar beans; barley, peas and rice are grown on less than 2% of the respondents.

Intensive horticultural crops

The most popular horticultural crops grown under irrigation are indicated in Figure 3.11, which reflects the estimated percentage areas.

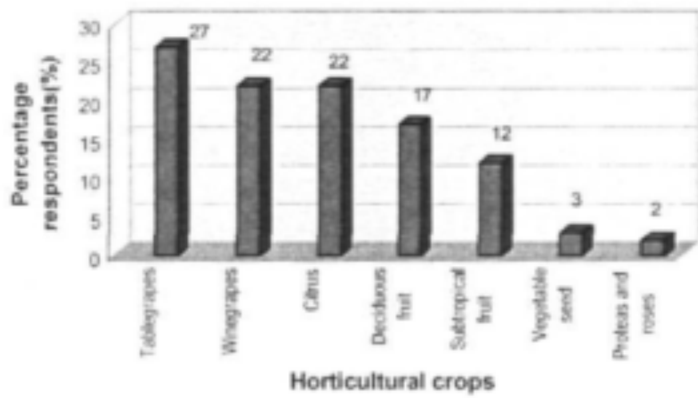


Figure 3.11 Percentage irrigation schemes on which the different intensive horticulture crops are grown (N=297)

Table grapes, wine 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.

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

Table 3.10 indicates the number and percentage of irrigation schemes on which the different crop types and combination of crop types are grown. Cash crop types alone or in combination with intensive, high value crop types are planted on the majority of irrigation schemes.

Table 3.10 Frequency of the number and percentage of irrigation schemes under different crops and combination of crop (N=297)

Crop types	n	%
Intensive crops	47	15
Cash crops	86	29
Pastures	8	3
Intensive + Cash crops	86	29
Intensive crops + pasture	21	7
Pasture + cash crops	38	12
Intensive + cash crops+ pasture	15	5
Total	**297**	**100**

Intensive crop = high value irrigation intensive crop types; Cash crop types like maize, wheat, cotton, sugar cane, etc.; Pasture = lucerne, kikuyu, ryegrass, etc.

A positive correlation ($r=0.271$; $p<0.01$) exists between the crop type selected by the farmer and the percentage objective irrigation scheduling that farmers apply. According to these findings farmers involved in the growing of relatively intensive horticultural crops like citrus, table grapes, subtropical fruit, wine grapes, etc are more inclined to schedule irrigation precisely with the support of sophisticated irrigation scheduling methods like neutron probes, computer models, etc.

Table 3.11 indicates the application of the different irrigation scheduling methods as reported for the different crops and combination of crops grown.

Table 3.11 Distribution of respondents according to the types of crops and irrigation scheduling methods (N=297)

Irrigation scheduling method	Intensive or high value crop types		Cash crop types		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
Computer 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**

A significant correlation ($r=-0.581$; $p<0.01$) exists between the implementation of subjective irrigation scheduling and the production of cash crops like wheat, maize, cotton, and sugar cane. This can be attributed to the possibility that a relatively high percentage of cash crop types reported by respondents are grown under sprinkler irrigation systems. The interrelationship between the on-farm irrigation system used and the implementation of irrigation scheduling is important and will be discussed in more detail with the next section.

The adoption of precise or objective irrigation scheduling methods was reported to be relatively lower amongst cash crop farmers as indicated in Table 3.11. The majority of these irrigation farmers have the perception that they have a very good workable knowledge of the crop water requirements of most of the cash crop grown on the farm. The additional time and effort required for precise irrigation scheduling was not perceived to be cost effective for many of these farmers. Many of the respondents indicated that their subjective beliefs about the irrigation scheduling approach followed are based on either information generated from own experience and trialing or scheduling programs provided by "credible information sources".

RELATIONSHIP BETWEEN ON-FARM IRRIGATION SYSTEMS AND IRRIGATION SCHEDULING

The irrigation systems used on the farm are critical as they determine how much water can be applied to the crop. 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 irrigation management. The method selected should be capable of applying water efficiently and uniformly. The choice of irrigation methods usually depends on many factors including capital and the operation costs, water use efficiency, labour requirements, ease of management and local soil and field topography.

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 3.12 indicates that the majority of irrigation farmers (53%) are using quick coupling or hand move sprinkler irrigation systems.

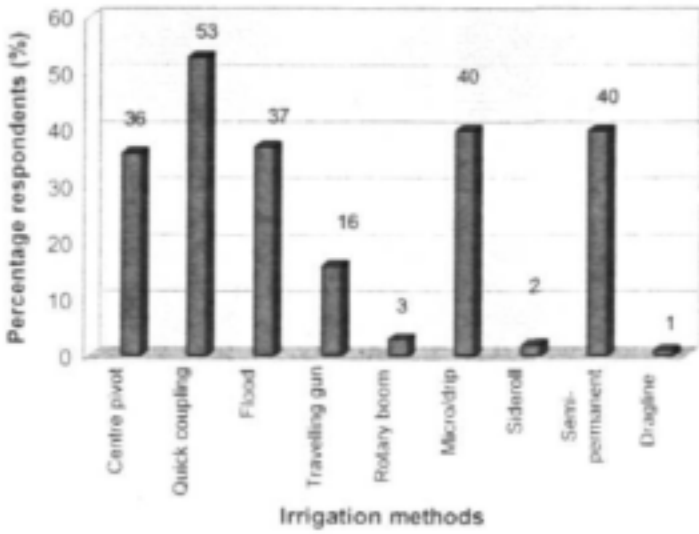


Figure 3.12 Percentage distribution of respondents according to the implementation of different irrigation methods (N=297)

The classification of irrigation systems used in Figure 3.12 is based on a categorization developed by the ARC (1997). Figure 3.12 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 (1999). There is however a tendency that 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 furrow and basin irrigation) is still a dominant method of water application to pasture and a wide range of field crops. Especially the short furrow is very popular amongst the small- scale farmers and used in the Lower Orange irrigation scheme for growing of grapes and lucerne. The majority of farmers are making use of traditional systems where the water control is carried out manually, according to the ability of the irrigator. Many farmers (commercial and small-scale) indicated that it is very difficult to control "how much" water to apply.

Photo 3.3 Short furrow irrigation often used by commercial farmers in the Northern Cape and small-scale farmers. (Courtesy of Stimie, 2003)

B) *Mechanized irrigation systems* can be classified according to whether they are stationary, move periodically or move continuously.

- Stationary 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 for the moveable systems because of operational constraints.

Photo 3.4 Floppy irrigation 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.

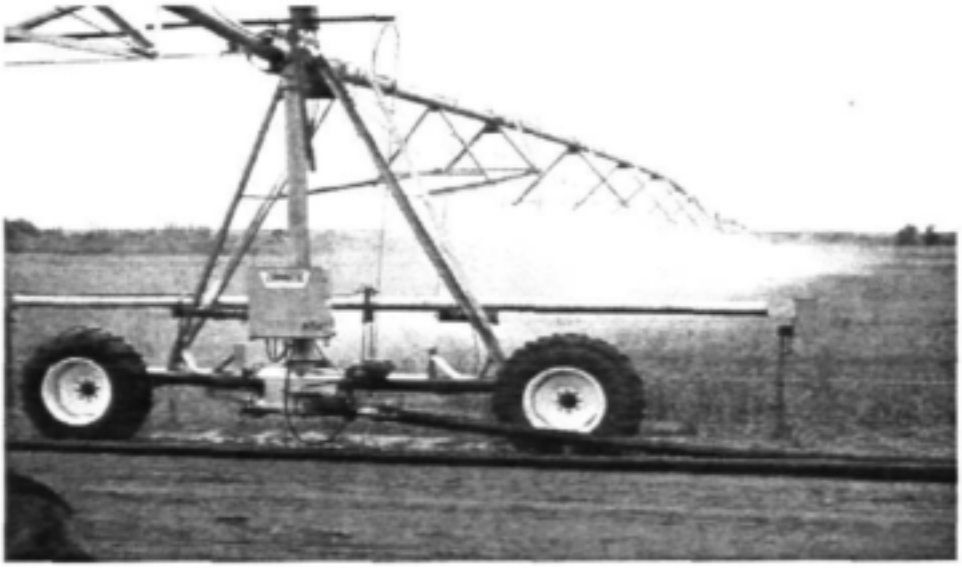


Photo 3.5 A linear irrigation system in operation on the Riet River irrigation scheme (2003)

- Portable irrigation systems include dragline; semi-dragline, 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.

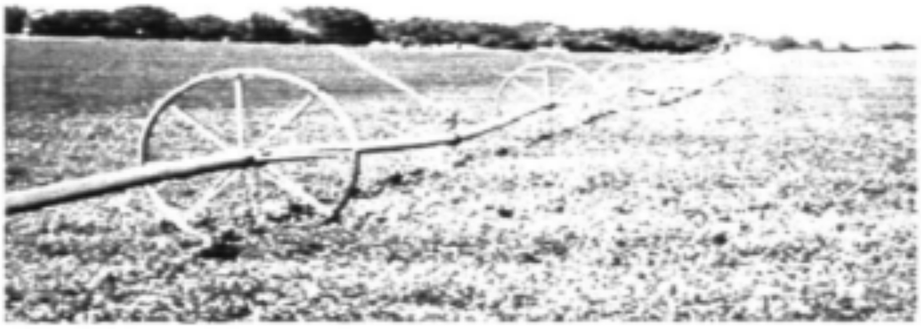


Photo 3.6 Lucerne production under a side roll irrigation system in the Sand/Vet irrigation scheme

Photo 3.7 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).

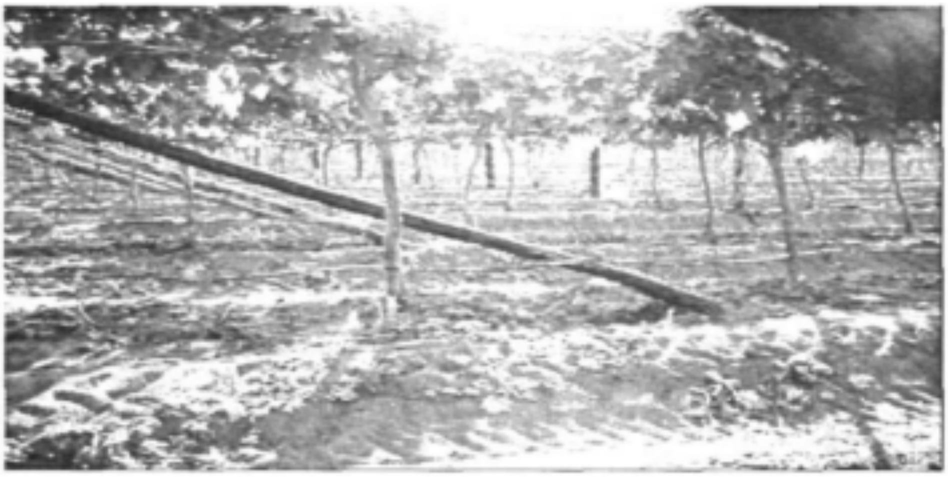


Photo 3.8 Table grape production under drip irrigation in Mpumalanga

C) *Interrelationship between irrigation method use on-farm and irrigation scheduling method selected*

- Figure 3.13 illustrates the differences regarding the use of irrigation methods between the different irrigation scheduling groups. Positive correlations were found between the implementation of objective irrigation scheduling methods and the uses of centre pivots ($r=0.230$, $p<0.05$), drip/micro irrigation ($r=0.194$, $p<0.05$), while negative correlations were found between the uses of sprinkler irrigation systems ($r=-0.206$, $p<0.01$), side-roll irrigation systems ($r=-0.774$, $p<0.05$), dragline and semi-dragline ($r=-1.0$, $p<0.05$).

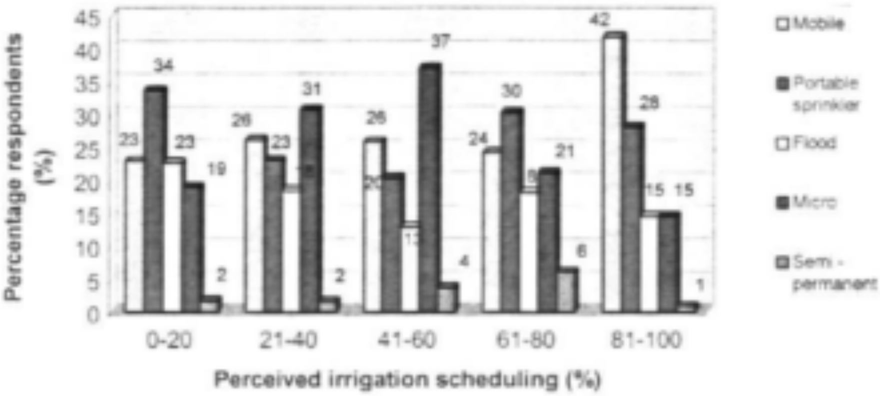


Figure 3.13 Frequency of distribution of the use of different irrigation methods as relevant for the five irrigation-scheduling groups (N=297)

Many of the current centre pivots used by farmers are multipurpose machines where fertilizers are applied with the water (fertigation) and attachments for the application of pesticides and herbicides prevail. Farmers usually apply large applications of irrigation with extended intervals (14 days) with flood and hand move sprinkler irrigation. The assumption is that the determining factor is the depth of the soil and the water holding capacity of the soil. Although these factors still remain important with the use of short cycle systems like drip, micro and centre pivot, the previously assumption has become impossible. The cost of pumping large quantities of irrigation water has become increasingly important for the farmer and therefore irrigation strategies were developed that favour irrigating during of-peak hours (Ruraflex or green hours), which can have a significant impact on the farm profit. This however necessitates more precise irrigation scheduling with the help of objective scheduling methods.

THE ROLE AND GENERAL PERCEPTIONS OF IRRIGATION CONSULTANTS

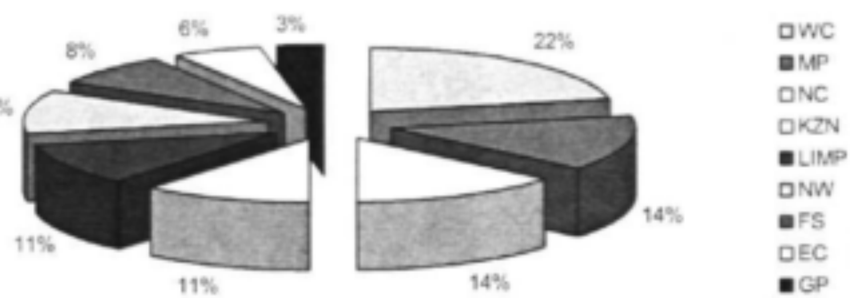
The complexity of irrigation technology, especially the use of real time irrigation scheduling methods, makes it difficult for many farmers to apply this technology on a day-by-day basis. It often necessitates refinement and the implementation of relative sophisticated irrigation technology has generally been through support rendered in this regard by industrial representatives, private irrigation consultants and extensionists from agricultural cooperatives.

In an environment seeking to improve client focus (farmer focus), it is easy to place less emphasis on the other partner in the development of irrigation farming, the irrigation consultant or irrigation extension practitioner. The selection and evaluation of an irrigation consultant often poses a challenge for many farmers. Presented here are some of the general perceptions and attitudes of irrigation consultants and important facts concerning their training, competencies and experience that deserve consideration.

Approximately 70 semi-structured interviews were conducted with key individuals and opinion leaders within the irrigation-farming sector. This specific format of 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. Each of these interviews was recorded on tape and transcribed afterwards. Potential respondents were identified from a number of sources. To be considered for this survey, respondents needed to be currently working as a consultant or advisor involved in the rendering of irrigation scheduling support services.

Geographical distribution

The geographical distribution of respondents in this survey (Figure 3.14) indicated 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 3.14 Distribution of irrigation consultants as per province (N=37)

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. The formal qualifications of the consultants ranged considerably as indicated in Table 3.12, and all but one respondent have received tertiary qualifications.

Table 3.12 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 consultants (51%) have a non-agricultural post-matric qualification (technical or engineering). This means that the majority of consultants are technically qualified, but does not place them in an agricultural professional category. Appropriate agricultural knowledge is often perceived as a precondition for effective irrigation scheduling support.

Experience
The experience of the irrigation consultants varies considerably, with 19% of the consultants having been involved in irrigation management for more than sixteen years. 60 percent of the consultants are rendering a consultancy service for less than ten years. Since the mid 90's, many new irrigation consultancies were initiated.

Table 3.13 Experience level of respondents in irrigation management (N=37)

Experience in irrigation scheduling (years)	Number of respondents	% Respondents
0-5	10	27
6-10	12	32
11-15	8	22
16+	7	19
Total	**37**	**100**

Experience in irrigation management is usually associated with the acquisition of confidence and skills in observing, listening and analysing a specific situation required to offer appropriate 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 management decisions. This was due to the fact that in the past I always wanted to tell farmers what to do and even tried to withhold certain information from them to ensure them depending on my consultancy service. Subsequently I have realised that the more one can stimulate farmers to think and act on the irrigation information provided, the bigger the demand for the specialised services from irrigation consultants become."*

All of the irrigation consultants indicated their competency in the use of computers and the ability to use appropriate software.

Irrigation consultation services 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 also are also responsible for recommendations regarding fertilisers, insect control, financial management and general irrigation management (operating pressure, uniformity of deliverance, etc). Forty eight 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 prominent when farmers experience relative low rainfall years (drought). Farmers who in the past have discontinued the services of professional irrigation consultants for whatever reason, are more prepared to employ them and spend additional resources for more clarity on the exact status of the soil moisture level during periods of relative low rainfall.

Profile of the potential clientele
Consultants and extensionists seldom have contact with all potential clients, but usually reach out to or are approached by specific types of clients depending their perceived

credibility and acceptability. The attributes and characteristics of the clientele that usually engage in irrigation scheduling consultancy have been examined (Table 3.14).

Table 3.14 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

33 percent respondents indicated that their clientele usually consist of the relative more business-oriented farmers, while twenty-two 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. It is clear from Table 3.14 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 with irrigation farming and/or are involved in the production of high valued, intensive crops.

The finding also illustrate that a relative low percentage of corporative or estate farming concerns do make use of an irrigation consultant. This could be due to the fact that many of the corporate farming concerns often appoint their own irrigation expert to address this need.

Ideal number of clients

Interviewees were asked to indicate the current number of clients they are servicing and these findings are reflected in Figure 3.15.

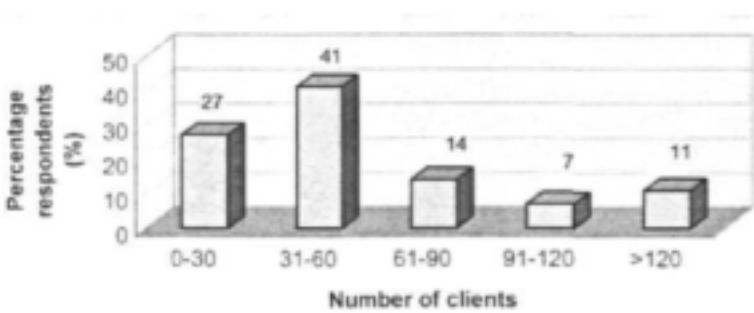


Figure 3.15 Distribution of respondents according to the number of clients served (N=36)

The majority of consultants (68%) have a clientele group of 60 farmers or less (Figure 3.15). 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 numbers 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 consultant himself.

Profile of service delivery by irrigation consultants

Important for effective delivering of irrigation scheduling services is the regularity that the soil water content status is monitored and the relative time span between collecting 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, and then 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 however, indicate that they also 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. indicate 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.

Requirements of an effective irrigation scheduling consultancy

The irrigation consultants identified key attributes and competencies imperative for the rendering of effective irrigation scheduling consultant services. This ranges from personal attributes like interpersonal communication skills to technical knowledge, expertise and ethnical competence and is indicated in Table 3.15.

Table 3.15 Ethnical competencies and personal attributes perceived by respondents necessary for delivery of a successful irrigation consultancy (N=37)

Attributes and characteristics for effective irrigation consultancy	Number of respondents	% 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 deliverance of effective irrigation scheduling services. 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.

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 any to successfully engagement with irrigation farmers and managers.

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.*

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 perceptions of consultants in this regard are reflected in Table 3.16.

Table 3.16 Reasons as perceived by consultants why farmers do not engage in the use of objective irrigation scheduling (N=37)

Reasons for farmers not scheduling as perceived by consultants	Number of respondents	% 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 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 form irrigation advisors and consultants	8	22
9. Farmers do not appreciate the fact to be prescribed and told what to do on the farm by an "outsider"	8	22
10. Farmers are hesitant to enter into 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 are rather prepared to use 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. 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 apart from conserving water.

Promoting irrigation scheduling

Interviewees 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. The following aspects were identified (Table 3.17).

Table 3.17 Aspects and 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 on farm	24	64
2. Illustrate the possible saving of electricity and energy costs	18	48
3. Improvement of production yields and net profit	12	32
4. User friendly and easy to understand irrigation scheduling program or software	12	32
5. Possible saving and controlling of fertilisers – prevent leaching of fertilisers	9	24
6. Manipulation or management of the ratio between oxygen and water in the root zone	8	22
7. Improvement of quality of crops	7	19
8. Financial incentive for a farmer who implements irrigation scheduling like for instance differentiated water tariffs	6	16
9. Saving on maintenance of moveable irrigation systems (centre pivot)	5	14
10. Irrigation scheduling should serve as prerequisite for the access to production credits at cooperatives	5	14
11. Prevention of salinization	2	5

Table 3.17 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 more efficient use of water on the farm. The findings from these semi-structured interviews 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 yields
- To improve profits through saving of especially nitrogen.
- To conserve water and to reduce pollution (saline conditions).

32 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 many of the interviewees (22%) is that a code of conduct should be 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 standards of work of irrigation consultants and advisors operating in irrigation management.

CONCLUSION

The survey shows clearly that differential perception exists regarding the definition of "irrigation scheduling" by farmers and its application on the farm. Some farmers perceive irrigation scheduling solely as the implementation of objective irrigation scheduling methods, also referred to as scientific irrigation scheduling (SIS). However the majority of farmers in this study perceive irrigation scheduling also to include the use of intuition and experience together with objective irrigation scheduling when making decisions regarding how much and when to apply irrigation water. 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 ($r=-0.531$, $p<0.01$) was found to exist between the use of intuition as an irrigation scheduling method and the irrigation scheduling figures reported by respondents.

Although a large number of irrigation scheduling tools and methods have been developed and used in South Africa, the implementation of objective irrigation scheduling methods are below expectation. Only 18% of the respondents confirmed the use of objective irrigation scheduling methods and thereby "schedule" according to the strict definition offered by scientists. For the majority, scheduling is about the use of intuition, observation, experience and the monitoring of management decisions to ensure efficient irrigation management.

The implementation of irrigation scheduling models, especially real time models, has proved to be restricted. User-friendly and understandable models like BEWAB, which can be used for the development of irrigation calendars, seem to be more easily adopted. The use of computer models as an irrigation scheduling method amongst farmers is restricted to 16% of the irrigation schemes, mainly where private consultants or advisors support their implementation.

A negative interrelationship between bulk water delivery and the application of objective irrigation scheduling exist. The general problems experienced by irrigators are 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. This hampers the implementation and practising of more precise and objective scheduling methods.

The irrigation method used on the farm determines the choice of irrigation scheduling methods to be implemented by the farmer. Generally the use of a centre pivot and drip/micro are associated with the use of objective irrigation scheduling. 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. Corporate farming concerns and farms with high value irrigated crops are more likely to adopt and invest in sophisticated scheduling methods. Evidence indicates that those farmers with bigger irrigation water allocations tend to make more use of intuition and are more reluctant to implement precise irrigation scheduling.

Information collected from irrigation consultants reveals the following:

- Only 46 percent of the irrigation consultants and extensionists rendering a consultancy service to farmers received official agricultural training and technical qualifications.
- Irrigation consultants in general perceived the competency in the use of computer programs and appropriate software to collect and analyse data from soil water measurements as being of utmost importance. However the computer must be seen as a tool that can aid a properly trained irrigation consultant but will not make computer operators experts in irrigation management.
- 32 percent of the irrigation consultants prefer to offer a package of services to clients instead of only monitoring irrigation management.
- Farmers who are relatively more business-oriented form the major clientele group of irrigation consultants. The ideal size of a clientele group is perceived as being not more than 60 farmers per irrigation consultant. Although a certain threshold number

of clients are needed to be able to offer a cost-effective service, personal attention is perceived as very important for providing efficient consultancy services.

- Appropriate, accurate and understandable software programs for both farmers and consultants are perceived by the majority of irrigation consultants as being a prerequisite for the rendering of efficient irrigation scheduling services.
- Many irrigation consultants are of the opinion that farmers often lose interest to continue with the implementation of objective irrigation scheduling on farm because they lose trust in the technology. This is often because of inadequate skills of some of the consultants to effectively interpret data for use by farmers' in making daily management decisions.
- Some irrigation consultants have a need for a code of ethics while others also expressed an urgent need for some form of accreditation.

CHAPTER FOUR: Perceptions, attitudes and behaviour of irrigation farmers

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). Griliches (1957) and Mansfield (1961), who conducted contemporaneous empirical studies of adoption rates of a number of industrial innovations, concluded that economic variables were the major determinants of technological change or adoption of innovations.

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). The small-scale farmers interviewed in this study, did not even mention irrigation scheduling as one of the major production constraints, but were preoccupied by persistent barriers to progress which included factors such as lack of credit, infrastructure, access to land, access to markets and extension support.

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. This is because most human behaviour occurs in environments where humans interact and respond – by actively changing environment instead of simply reacting to it. We are part of a world that we seek to understand, and our imperfect understanding plays an active role in the shaping of events in which we participate.

Behaviour in its simplest form can be regarded as a movement brought about by forces resulting from a system being in tension (Düvel, 1990). The above implies that for any adoption to occur, the farmer must experience a need or tension. In other words the farmer must have a sense of dissatisfaction with the current method of irrigating and believe that it is within his or her capability to improve.

According to the model of Tolman (1967), behaviour is intentional (there is a motive for a specific action) and behaviour is guided by past experience and expectations concerning the new technology. Tolman (1967) differentiates two sets of variables in his model, namely independent variables (e.g. personal and environmental factors), dependent variables (e.g. behavioural change or adoption and consequences of adoption) while Düvel (1990) included needs, beliefs, perceptions and knowledge as intervening variables to the model. The extension worker cannot do much about the independent variables (the way it is) nor can he directly change the way people behave. Therefore the focus should be on the intervening variables that are changeable and the direct precursors to successful adoption.

Table 4.1 The relationship between behaviour determining variables in agricultural development (Düvel, 1991 as cited by Stevens, 2003)

Human (psychological)		**Economic–Technical**	
Independent variables	**Intervening variables**	**Dependent variables**	
		Behaviour	**Consequences of behaviour**
Personal and environmental factors (age, education, experience, etc)	Needs Perception Knowledge	Adoption of practices	Efficiency: Yield and Profit (saving of water)

Non-adoption of any innovation or practice can be traced back to two basic causes: the individual is either incapable or unwilling to adopt. A farmer may be incapable of adopting the technology either because it is too complex or too expensive.

Willingness to adopt depends on the farmer's perception of the technology in relation to their current needs and knowledge. The farmer must experience a "needs tension" before he/she will set him/herself the goal of using an irrigation scheduling device. A need incompatibility occurs when the farmer decides that the new technology does not fit his/her aspirations, goals or problems (Düvel, 1990).

Chapter four deals with the human factors and constraints that impact on adoption of irrigation scheduling practices. The aim of this part of the project was to determine the perceptions of farmers on the selection and use of irrigation scheduling tools. The quantitative survey amongst a random sample of 134 farmers from eight of the provinces (Northwest, Free State, Northern Cape, Eastern Cape, KwaZulu Natal, Western Cape, Limpopo and Mpumalanga) formed the micro level of study.

RESEARCH METHODOLOGY

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

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 was 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 southeastern part of South Africa, within the Eastern Cape Province (Figure 4.1). This area is characterized by natural poor quality of 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).

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.

Figure 4.1 Base map of the Fish to Tsitsikama water management area (DWAF, 2004)

- *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 4.2).

Figure 4.2 Location map of the Upper Orange water management area (DWAF, 2004)

The Riet River Irrigation Scheme (Figure 4.3) was selected after discussions with members of Griekwaland Wes Agricultural Cooperative and various opinion leaders in the Free State and Northern Cape. There was a general consensus 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. 37 farmers from Riet River, Van der Kloof and Lower Orange River irrigation schemes were interviewed.

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, a random sample of 10 respondents was selected from the list of clients serviced by a private irrigation consultant in that area, after consultation with him. 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.

Figure 4.3 Location map of the Orange Riet River catchment area (DWAF, 2003)

❑ *Mpumalanga: Nelspruit/Malelane and Onderberg*

The study area is situated in the Inkomati water management area (Figure 4.4), 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 centers on irrigation with related industries and commerce.

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.

Figure 4.4 Base map of the Inkomati water management area (DWAF, 2004)

- *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 (Figure 4.5). The Mzimvubu River, which also reflects in the name of the water management area, is the largest undeveloped river in South Africa (DWAF, 2004).

Figure 4.5 Base map of the Mzimvubu to Keiskamma water management area (DWAF, 2004)

Seventeen respondents from this water management area (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.

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

The Crocodile west and Marico water management areas borders on Botswana to the northwest (Figure 4.6). 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 4.6 Base map of the Crocodile and Marico water management area (DWAF, 2004)

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

The Middle Vaal water management area is situated in the Free State and Nortwest 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 4.7). 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.

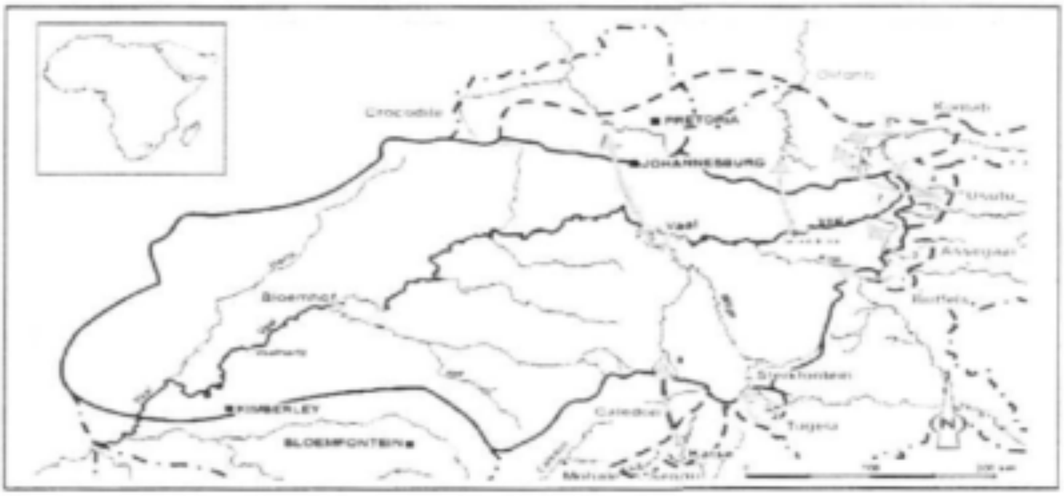


Figure 4.7 Location map of the Middle Vaal water management area (DWAF, 2004)

- *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 is the Riviersonderend River as indicated in Figure 4.8 drain most of the water management area. The economy of the region is mainly agricultural based, and vineyards and fruit orchards are grown under irrigation.

Figure 4.8 Base map of the Breede water management area (DWAF, 2004)

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.

- *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 4.9).

Figure 4.9 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.

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 the research procedures and questionnaire used in the study were discussed with respective government officials, irrigation scheme managers, members of the local farmers' association, private consultants and commodity institutions active in the different areas.

Table 4.2 provides a summary of the distribution of location and respondents that participated in the collection of information for this part of the study.

Table 4.2 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**

The main objectives of the questionnaire for irrigation farmers were:

- To assess the demographics of the respondent 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 relative advantages of economic returns 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.

Most of the questions were open-ended which minimizes external influences and allows the respondents to motivate their replies. 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. Frequency distributions, bivariate and univariate analyses, correlation coefficients and qualitative analysis techniques were used.

Chapter Three of this study reveals that only 18 percent of the irrigation farmers make use of objective or more scientific irrigation tools like the use of soil water measurement and computer models, while 80 percent rely on the use of intuition and local knowledge based on personal, first-hand experience. The percentage of respondent regarding intuition as part of irrigation scheduling increases dramatically from 4 to 88% with the increased percentages reported irrigation scheduling. These findings imply that farmers differ in their perception of what irrigation scheduling is and this will determine farmers' willingness and "need tension" regarding their adoption behaviour. Farmer's decisions to adopt new irrigation scheduling methods in preference to the old technologies depends on complex factors, of which farmers' perceptions provide a key in identifying and understanding the role of possible factors operating as behaviour determinants in regard to irrigation scheduling technology.

The adoption of innovations in agriculture has been studied intensively since Griliches (1957) pioneering work on the adoption of hybrid corn in the USA. Despite the numerous studies, the results in this field have in general been disappointing. The missing link is usually the dynamic nature of adoption decisions involving changes in farmers' perceptions and attitudes as information is progressively collected.

SOCIO-ECONOMIC FACTORS ASSOCIATED WITH THE ADOPTION OF IRRIGATION SCHEDULING

In this section factors (independent variables) that influence adoption decision through the possible influence on the farmer's subjective perceptions, attitudes and uncertainty are described.

1. Age

It was hypothesized that younger farmers tend to be more inclined to adopt objective irrigation scheduling to increase the overall water use efficiency on the farm. The relative age of decision-makers is a key factor in determining the life cycle "disposition" (Vanclay, 2003). The age distribution of the respondents is indicated in Figure 4.10.

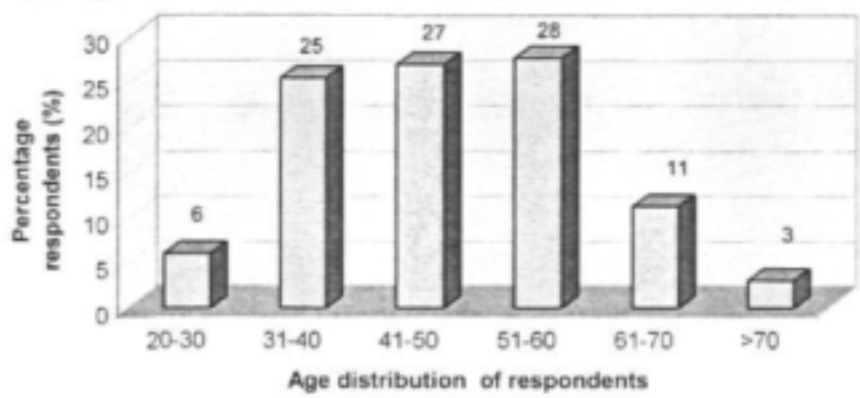


Figure 4.10 Distribution of respondents according to age (N=134)

Figure 4.10 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 interrelationship between age and the irrigation method that irrigators use was tested and is illustrated in Figure 4.11.

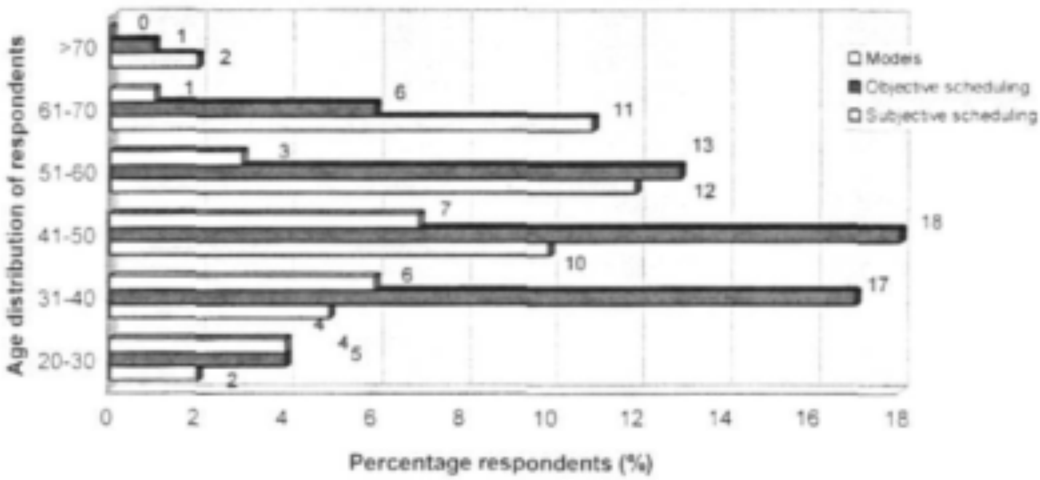


Figure 4.11 Distribution of respondents according to age and the implementation of irrigation scheduling (N=134)

The increase in age and experience suggests a reduction in the willingness to invest in new practices like objective irrigation scheduling (risk aversion) and an increase in the use of intuition and a fixed program as a method of scheduling (Figure 4.11). However, this relationship is non-significant linear correlation ($r=0.058$, $p>0.05$).

The adoption of objective scheduling is highest in the 30-50 year age group. A similar tendency is found in the case of the adoption of computer models, although the application of a linear test shows no statistical significance. These findings suggest that age is associated with a number of other factors, which, due to the effect of multi-co linearity allow no simple conclusion regarding its effect. However it was found that younger farmers were more willing to use irrigation scheduling models because of their computer literacy levels, and were more prepared to use computer programs for farm management plans and budgets in which irrigation management is often reflected. This relationship was found to be significant and is supported by the Pearson correlation coefficient of ($r= 0.206$, $p < 0.05$).

2. Education

The interrelationship between the education level of the respondents and the adoption of objective irrigation scheduling methods is presented in Figure 4.12.

Sixty–one percent of the respondents that implement objective irrigation scheduling had obtained a post matric and technical qualification while 66% of respondents using subjective irrigation scheduling obtained a post matric and technical qualification.

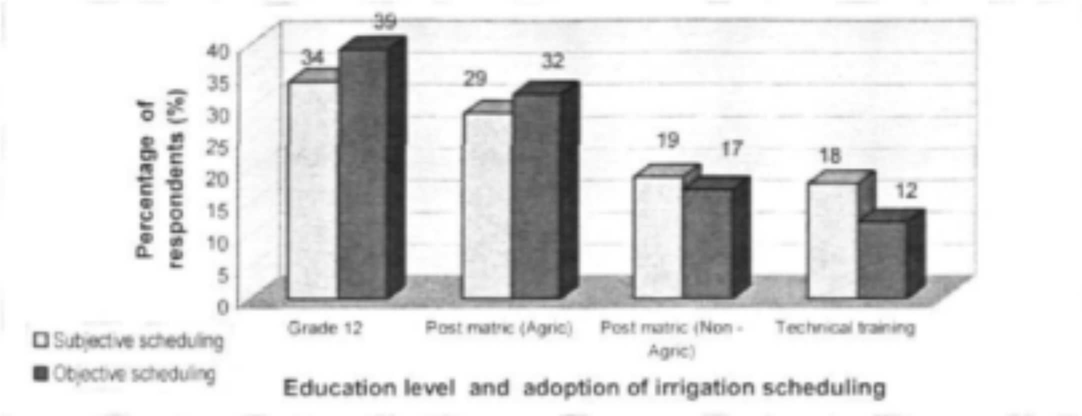


Figure 4.12 Education levels and the adoption of objective scheduling methods by respondents (N=134)

Mixed evidence regarding the relationship between farmers' education levels and the adoption of agricultural practices exists. Several studies Alene *et al*, 2000, Alene & Hassan, (2003) found that education is positively related to adoption behaviour of farmers. The interrelationship between farmers' formal education level and the adoption of objective irrigation scheduling methods shows statistic significant relationships (X^2=4.768; df=5; $p<0.05$) as farmers with post-matric qualifications generally were more prepared to use objective scheduling methods. Higher levels of education in general make irrigators more aware and willing of the use of different information and learning sources in decision-making.

3. Property size and irrigation scheduling

Many farmers and irrigation consultants are of the opinion that property size (irrigation area) is a major factor, which will influence the practice of irrigation scheduling. The general assumption is that bigger farm sizes with corresponding bigger area to irrigate will necessitate the use of more objective irrigation scheduling technologies. This assumption was tested and the following interrelationship was found (Figure 4.13).

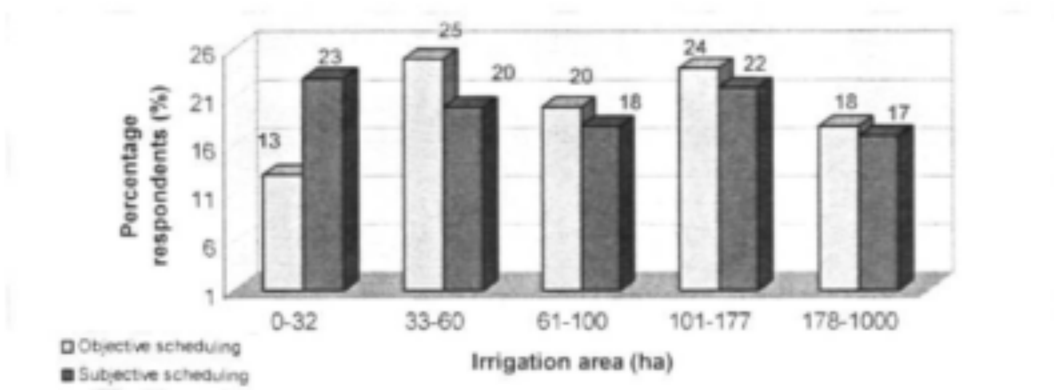


Figure 4.13 Interrelationship between irrigation area and application of irrigation scheduling (N=134)

Figure 4.13 indicates that there is a slight tendency for the implementation of objective irrigation scheduling to increase with the increased irrigation area and for the implementation of subjective irrigation methods to decrease, but as the correlation coefficient suggests ($r=0.137, p>0.05$) this is not statistically significant. This suggests that there are other factors involved in influencing the irrigation scheduling behaviour of farmers like the general aversion of risk by farmers.

4. Experience and irrigation scheduling

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 experience farmers are building confidence and knowledge over time, which in addition to the experience gained from other farmers, becomes a powerful factor in addressing the best irrigation management practice.

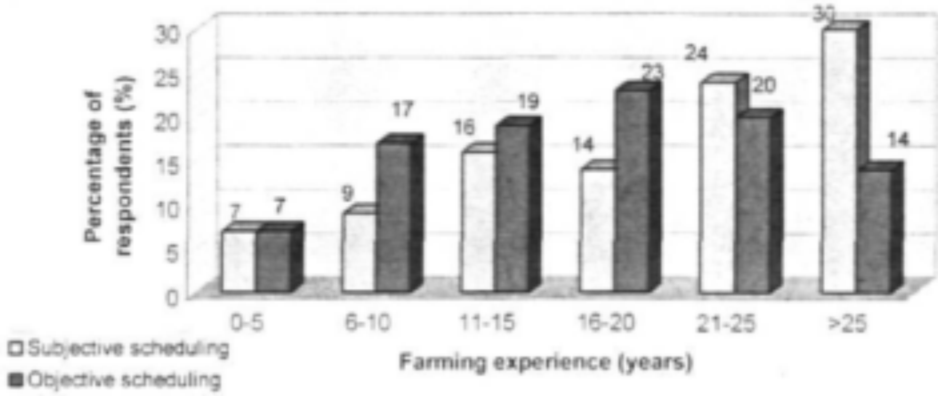


Figure 4.14 Farming experience and irrigation scheduling of respondents (N=134)

From the findings in Figure 4.14 it is evident that the respondents are not lacking experience. These findings also illustrate that farmers with relatively more irrigation farming experience also were more prepared to rely rather on their experience, observation and intuition instead of making use of objective irrigation scheduling, but no statistical significant correlation could be found ($X^2=3.64.768; df=5; p=0.601$).

Non-farming experience

It is noteworthy that 61% of the respondents' experience was limited to that of farming, while the rest of the respondents have a wide range of experience, which includes education, commerce, industry, business and the technical field. It does appear that farmers who had experienced other careers before farming were more open to innovation and more likely to seek objective advice as part of the decision-making process, but no statistical significant correlation could be found ($r=0.018, p>0.05$).

PERCEIVED ACCEPTABILITY OF IRRIGATION SCHEDULING

The classical five-stage adoption process (NSRC, 1955) assumes that adoption of new practices is not an instantaneous act, but rather a process that extends over a period of time and implies a sequence of phases. The acceptability of a specific irrigation scheduling practice or the change from one irrigation scheduling practice to another, usually evolve over the following stages of adoption:

1. Awareness: where the individual is exposed to a new practice or innovation.
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. Trial: making full use of the innovation within his or her current situation.
5. Adoption: individual decides to continue or reject the full use of the innovation.

1. Awareness of irrigation scheduling

In this context, "awareness" means not just awareness of the existing of an innovation, but the awareness that it's potential of practical value to the farmer. According to Ghadim & Pannell (1999), when a farmer reaches this point of awareness it serves as a trigger which prompts the farmer to be willing to "open his ears and eyes" - and to begin noting and collecting information about the specific innovation in order to decide whether to proceed or not to the next step of adoption, namely trialing of the specific innovation.

All but one of the farmers indicated that they had heard about irrigation scheduling before. Respondents were asked to indicate the source that introduced them to irrigation scheduling. Twenty eight percent of the respondents indicated that the local agriculture cooperatives (grain, citrus and cellars) played a major role in raising awareness about irrigation scheduling.

Table 4.3 Information sources used to raise farmer's awareness of irrigation scheduling (N=134)

Sources of introduction to irrigation scheduling	Number of respondents	%
Cooperatives	37	28
Private consultants/advisors	28	21
Fellow farmers	27	20
Universities	18	13
Government extensionist	11	8
ARC Institutes	8	6
Representatives	4	3
Missing	1	
Total	**134**	**100**

From Table 4.3 it is evident that private irrigation consultants and advisors from wine cellars and commodity institutions like the sugar, citrus, subtropical fruit and deciduous fruit industries as well as fellow farmers play a significant role in raising awareness amongst farmers. Many fruit growers referred to the important role that research institutes of the ARC have played in the past or are still playing in advocating irrigation scheduling amongst farmers.

Perception about what irrigation scheduling entails

Respondents were asked to define irrigation scheduling and the following were found:

- two respondents (2%) did not answer,
- while 6 (4%) did not know,
- 11 (8%) were unsure ,
- 85 (64%) had an idea
- and 30 (22%) knew what it was.

Farmers were in general aware of the terminology irrigation scheduling, but it was apparent that 14% of the respondents were still unsure regarding an appropriate definition of the concept. This emphasizes the important role that extensionsists and irrigation institutions have to play in the training and informing irrigators in this regard.

Perceived importance of irrigation scheduling
Figure 4.15 indicates the perception of respondents regarding the importance of irrigation scheduling on the farm.

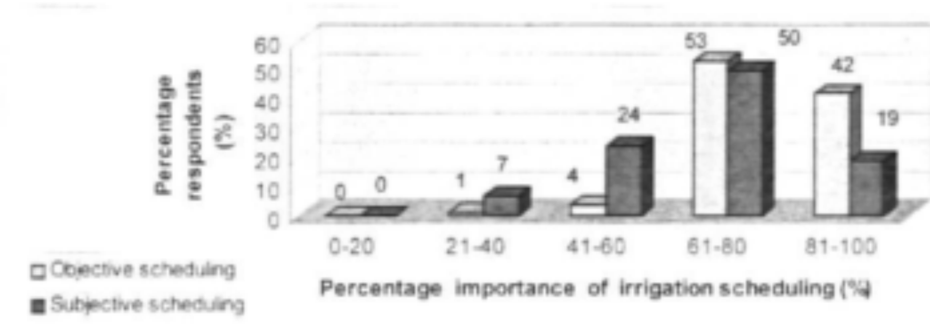


Figure 4.15 Respondents perception regarding the importance of irrigation scheduling and the interrelationship with the application of different irrigation scheduling methods (N=134)

Figure 4.15 reveals that nearly all respondents (93%) regarded irrigation scheduling as important practice on the farm, and this perception indicates a positive relationship with objective irrigation scheduling (X^2=21.45; df=7; p=0.003; Gamma=0.509; p<0.01). This implies that farmers implementing objective irrigation scheduling methods perceive irrigation scheduling as relatively more important than farmers involved in subjective irrigation scheduling.

Perceived importance of the application of irrigation scheduling by fellow farmers
Farmers were asked to rate the importance of the practising of irrigation scheduling by their fellow irrigation farmers in the area. Approximately 96% of the respondents regarded the implementation of irrigation scheduling by fellow farmers to be important. 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.

2. Interest
Reasons provided by farmers for their initial interest shown in the implementation of irrigation scheduling revealed tremendous variation (Table 4.4).

Table 4.4 Respondents' 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	47	62	34	59	81	60
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
"Can't farm without it"	2	3	4	7	6	4
Popular and socially acceptable	2	3	0	0	2	1

The majority of respondents (62%) 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 4.4). 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. Nine percent of this category of irrigators emphasized the importance of precise irrigation scheduling practices 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 4.4 it is interesting that 14 percent of the respondents using subjective scheduling methods indicated that they were 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.

3. Evaluation and trialing as prerequisites for the adoption of objective irrigation scheduling

For irrigation farmers to adopt certain irrigation scheduling practices requires an understanding of their current situation, what improvements are possible, and how these improvements will meet their needs. 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 process (Rogers, 1983, Bembridge, 1991). Therefore, trial and evaluation of a new irrigation scheduling practice can provide valuable information to the irrigator, which can reduce uncertainty and promote skill development. 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.

Box 4.1: Technologies are not yet practices

A technique or a technology is a way to produce or organize, out of any context (invention), whereas a practice is technique borrowed by a social and economic context (innovation) (Ellis, 1993).

Techniques can be formulated independent of farmers and relates to theory. Practices concern the ways in which farmers work and are heavily influenced by the actual conditions in which technical operations are carried out. Practices are assumed to be the result of direct intention, which in turn depends on objectives set by the farmer in a context of constraints and effectiveness. Lastly, farming practices underlie the concepts of a specific cropping and livestock system.

Researchers and extension agents must acknowledge that adoption implies adaptation technologies to fit a specific situation. Technologies are seldom adopted and implemented as such. Farmers tend to adapt them to their needs, constraints and limitations they face. Through such adaptation an innovation (new technology) becomes a practice. It should also be acknowledge that a practice is often indigenous and involves a combination of experience and local knowledge. Agriculture has evolved this way for millenniums, with little or no external intervention whatsoever.

The final 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).

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, trialibility and the observability.

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. In Table 4.5 the perceived characteristics or attributes of the ideal irrigation scheduling technology are reflected in terms of:

- Risk characteristics: some technology has risk reducing effects in a high-risk environment, where others have no effect on risk or even increase it.
- Initial capital costs: the initial capital costs to be spent before the device could 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.
- Relative management complexity: management complexity is defined as the number of activities that have to be performed to adopt or use the new irrigation scheduling device or technology.

Table 4.5 Distribution of respondent's perception regarding the technological characteristics of irrigation scheduling devices and methods (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				
Practical 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 that farmers' decisions to adopt or reject the use of a specific irrigation scheduling technology are strongly determined by the accuracy and reliability of information produced for decision-making (72%). This illustrates that irrigation farmers are generally "risk averse" and therefore perceive quality information as an important prerequisite for the adoption of appropriate irrigation technology.

Very close to the risk characteristics of irrigation scheduling technology, respondents rated characteristics regarding the adaptiveness or easiness of technology to interact with other technology in the relevant farming system. To benefit from the irrigation scheduling technology, these technologies have to be adapted to the local conditions before finally adopted by farmers. When a farmer needs to carry out many activities to implement a certain irrigation scheduling technology before it could be used for decision-making, it will negatively influence the adoption of such a technology. In general farmers found it difficult to implement computer models and some of the sophisticated soil water measurement devices like tensiometers. 37% of the respondents expect appropriate irrigation scheduling technology to be simple for implementation and easy to understand.

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 generate an "option" for some farmers to delay the implementation of such an investment as like in the case of some of the more sophisticated scheduling methods. Farmers therefore have to decide whether the longterm investment will pay off and if the necessary incentives are evitable to adopt such a technology.

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.

4. Innovation characteristics that determine adoption or rejection of irrigation scheduling

4.1 Perceived relative advantages

The relative advantage means the degree to which a new technology or practice is perceived as better than the one it supersedes (Rogers, 1983). Relative advantage is normally interpreted in terms of financial advantages to the farm business or as perceived by the farmer. Agricultural practices that are believed to be profitable are usually readily adopted.

Relative advantages regarding the specific irrigation method and device selected
Farmers were asked why they have selected the specific irrigation scheduling method chosen. The perceptions of respondents for choosing the specific device or irrigation scheduling method are reflected in Table 4.6.

Table 4.6 Distribution of respondents according to the reasons provided for selecting specific irrigation scheduling method (N= 134)

Reasons for the selection of a specific irrigation scheduling method	Number of respondents (N)	Percentage respondents (%)
Relative easy and practical to implement	105	78
Reliability	88	65
High accuracy	67	50
Timely information provided for efficient decision making	50	37
Affordable	38	28
Could be used in own time with relative good results	15	11
User friendly and easy to interpret	10	8
To much water applied in the past	10	8
Popular amongst fellow farmers	3	2
No response	3	2

78 percent of the respondents emphasized the importance of the relative easiness and practicability of implementation of a scheduling method or tool. The second most important reason mentioned by 65% of the respondents is the reliability of the scheduling tool.

Improvement of production efficiency
An impression of respondents' perception regarding the improvement of production efficiency subsequent to the implementation of irrigation scheduling was obtained. Fifty nine percent of the respondents were in a position to indicate response in terms of production efficiency subsequent to the introduction of objective irrigation scheduling on the farm. Within this group of respondents, the majority (63%) indicated an improvement in terms of production efficiency of between 0-10 percent (Figure 4.16). Respondents, who did not respond on the question, were either too shortly involved with objective irrigation scheduling to have recorded any changes or perceived attributing changes in production efficiency to the introduction of improved irrigation systems (changing from flood irrigation to sprinkler or centre pivot irrigation).

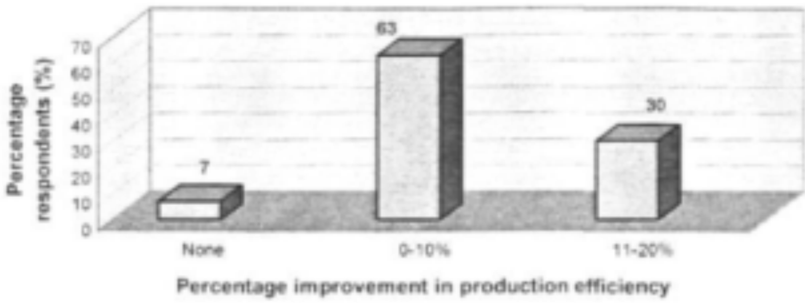


Figure 4.16 Perception of respondents regarding the improvement in production efficiency since irrigation scheduling (N=84)

The main aspects of production improvement perceived in the production of cash crops (maize, wheat, cotton, sugar cane, etc.) are in order of importance: an increase in production yield, saving on nitrogen input costs and saving on the relative operational cost of irrigation. One of the farmers referred to an average improvement of 1ton/ha between the 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 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.

Fruit growers and producers of high value/high input crops perceived mainly the improvement of quality and shelve life of the crop, increase of production yields, improved efficiency of the management of nutrients and irrigation in the orchards as main advantages subsequent to the introduction of irrigation scheduling on the farm. Opinion leaders and advisors in the fruit industry often 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 was 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).

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 tensiometer and was still willing and capable of using it for his daily irrigation management decisions.

Seven percent of respondents, perceived no change in production efficiency subsequent to the adoption of the use of 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 or the use of evaporation pans to help them with decision-making.

The interrelationship between the perceived improvement of production efficiency and the irrigation method used on the farm was tested and is indicated in Figure 4.17.

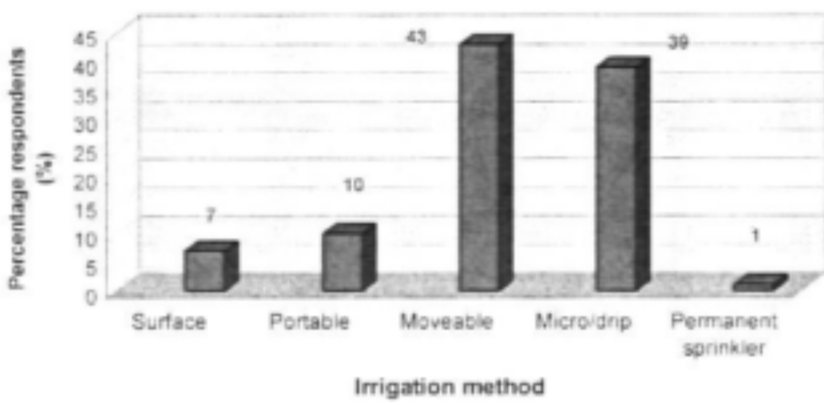


Figure 4.17 Respondents perception regarding the improvement of production efficiency and the irrigation method used on the farm (N=84)

It is clear from the findings in Figure 4.17, that it was mainly respondents irrigating with centre pivots, traveling guns, dragline systems and micro or drip irrigation systems 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. These systems however could easily lead to inefficient irrigation, if a farmer does not take into account factors like soil depth and water holding capacity of a specific field. Therefore soil as well as irrigation system constraints are important factors to include in any irrigation management strategy to cope with peak water demands of a specific crop.

Irrigation 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. Farmers were asked to indicate the operational cost of irrigation in relation to the other cost items applicable to various crops. Seventy percent of the respondents perceived the actual cost of irrigation water to be expensive. Table 4.7 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. A very positive finding was that the majority of farmers interviewed were either able to refer to their crop budgets or directly responded to it.

Table 4.7 Distribution of perceived irrigation operational costs applicable regarding the production of cash and high value/high input crop types. (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**

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 were 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 between 0-10% of the total production costs per hectare. However, 65% of the cash crop farmers indicate the operational cost of irrigation to be between 11-30% of the total production cost. These findings illustrate that the operational cost of irrigation for producers of high value crops is relatively low proportionate to the other production cost, although the major advantages by the implementation of precise irrigation scheduling will be demonstrated in terms of the quality of the crop produced and the quantity of nutrients applied.

It was found in the study that the operational cost of irrigation could vary considerably depending on whether a farmer was receiving water from a canal distribution system within an irrigation scheme, or whether the farmer was pumping water directly from a river. 76 percent of the respondents indicated that they receive water from a canal delivering system, while 15 % respondents pump water directly from a river. Ten percent of the respondents use boreholes as an applicable 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 4.8 reveals that farmers experience different operational costs for irrigation where different water sources and irrigation systems were used. The unit operational cost of irrigation as calculated in Table 4.8 reflects only the actual water cost, electricity and an average labour costs of R275/ha as assumed for this exercise.

Table 4.8 Irrigation water application costs as reported 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, Northwest Province (2003).

Source of irrigation water	Irrigation system	Tariff of irrigation water (R/ha/annum)	Electricity 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 4.8 illustrates that a substantial difference (R243/ha) regarding the total irrigation cost/season/ha exists between the uses of low *versus* high-pressure centre pivots due to the difference in electricity consumption between these two irrigation systems. 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.). Also a clear difference 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 an irrigation scheme. This is mainly because of the higher operational electricity costs.

Although farmers are generally aware of the operational costs of irrigation, they did not rank it as the most important production cost. An indication of irrigators' viewpoints in this regard was obtained from their importance rank order of the production costs for the production of cash crops like maize, wheat, etc. and high value, intensive crops like fruit and wine grapes. These viewpoints are summarized in Table 4.9.

Table 4.9 The perceived importance rank order of operational irrigation costs relative to the other production cost factors in terms of cash and high value/high input crops

Production factor	Cash crops (n=92)		High value/high input crops (n=76)	
	Weighted Percentage	Rank order position	Weighted Percentage	Rank order position
Fertilizers	89.7	1	26.4	2
Seed	41.1	2		
Labour	38.2	3	61.4	1
Pest and weed control	13.2	4	14.1	4
Mechanization	5.8	6		
Marketing	8	5	22.8	3
Packaging			5.2	5
Irrigation	4.4	7	2	6

Amongst the cash crop farmers the operational cost of irrigation was ranked position seven while producers of high value, intensive crops ranked it position six on average.

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 4.18 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 since the implementation of objective irrigation scheduling on the farm (χ^2=21.71; df=7; $p<0.05$).

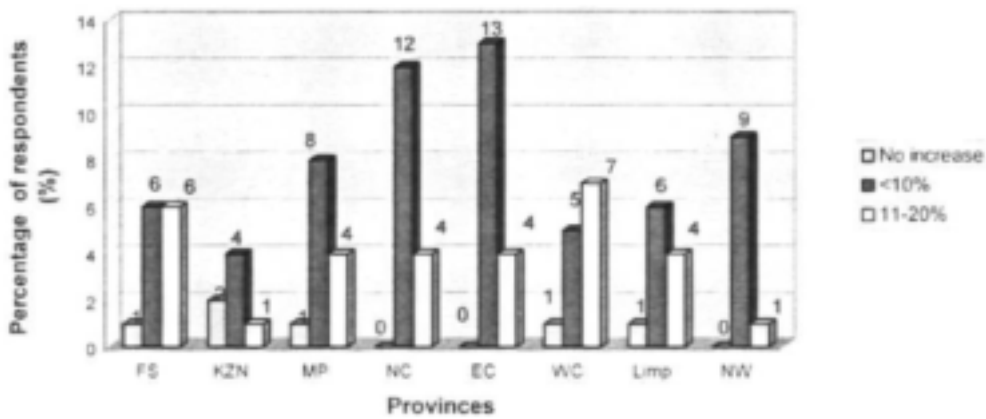


Figure 4.18 Percentage distribution of respondents in different provinces according to their perceived relative increase in production efficiency due to the implementation of objective irrigation scheduling methods (N=84)

It was found that 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 perceived substantial improvement in production efficiency (between 11-20%) subsequent to the introduction of objective irrigation scheduling.

4.2 Risk and uncertainty

Trialing and evaluation of new irrigation scheduling technology helps a farmer to collect some information regarding the possible advantages (improvement of production efficiency, financial incentives) as well as to reduce uncertainty to allow for better decision-making. Risk assessment is one of the important factors considered during the appraisal or evaluation phase of an alternative practice recommended, as farmers tend to be strongly "risk averse". Given the fact that high uncertainty is a normal attribute of innovations before they have been trialed on the farm, risk aversion was found to have a negative influence on the adoption of sophisticated, objective scheduling methods.

Many of the farmers interviewed preferred a minimum risk (as indicated in Table 4.5) and were in favour of a balance between the need for profit and security regarding a comfortable life.

4.3 Complexity

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? 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).

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 4.10.

Table 4.10 The perceptions of respondents related to the easiness of the implementation of irrigation scheduling (N=134)

Perception of the relative easiness of implementation of irrigation scheduling	Number of respondents				Total number of respondents (N=134)	
	Objective scheduling (n=76)		Subjective scheduling (n=58)			
	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 4.10 reveals that the majority of farmers (70%) perceived irrigation scheduling as relatively easy to implement, while 27% perceived it to be difficult to implement. Although the majority of respondents (82%) perceived the implementation of objective irrigation scheduling methods on the farm to be relatively easy, no significant relationship could be found between the implementation of objective irrigation scheduling and the perception of easiness of irrigation scheduling ($r= 0.046$, $P>0.05$).

Knowledge level needed for the application of irrigation scheduling
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 4.11 Respondents' perception regarding the required level of knowledge needed for effective irrigation scheduling (N=134)

Knowledge level of irrigation scheduling	Objective scheduling (n=76)		Subjective scheduling (n=58)		Total (N=134)	
	Number of respondents	% Respondents	Number of respondents	% Respondents	Number of respondents	% Respondents
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
	76	**100**	**58**	**100**	**134**	**100**

The findings reflected in Table 4.11 reveal that farmers perceived different prerequisite levels of knowledge to be successful in the implementation of irrigation scheduling. It is noteworthy that the adopters of objective irrigation scheduling methods regard the knowledge demands to be significantly higher (χ^2=12.62, df=7, p=0.082; Gamma=0.288, p=0.044) than those who practise subjective irrigation scheduling.

4.4 Compatibility

Another critical aspect of the farmers' perception is whether the technology is perceived to be compatible with their farm and 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 compatibility will be judged: the current system of farming and the social system embracing the farming community or broader cultural beliefs and values. An apparent example of irrigation scheduling practices not adopted 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 that they experience with the implementation and adoption of current irrigation scheduling methods selected for the farm. Table 4.12 provides an overview of the compatibility of the practising of irrigation scheduling by farmers.

Table 4.12 Perceived problems experienced by respondents with the use of irrigation scheduling methods (N=134)

Problems	Number of respondents	% Respondents
No problem	76	57
Not sure about the accuracy of measurement	38	28
Not easy to understand and apply on the farm	21	16
Variability in climate and soil types on the farm complicate the efficient use and interpretation of data	12	9
Very expensive	8	6
Uncertainty - novelist to irrigation scheduling	2	2
Not enough time available	3	2
Lack of flexibility (irrigation system, management)	2	2
No support or help available from irrigation consultants	1	1
New extensionist (personality, communication skills)	1	1
Health risk (i.e. neutron probe)	1	1

The majority of respondents (57%) 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. Twenty eight percent of the respondents doubt the accuracy of measurement of the soil water content. 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.

4.5 Observability

As farmers interact with technology, so their knowledge increases through experimentation and trialing on the farm. This affects the overall perceptions of the attractiveness of the innovation and also reduces the uncertainty about its potential benefits. The advantages of using objective and more sophisticated irrigation scheduling practices should be observable, before farmers will adopt the new practice. Farmers were asked to rate the perceived relative advantages of using irrigation-scheduling methods on a ten-point 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.

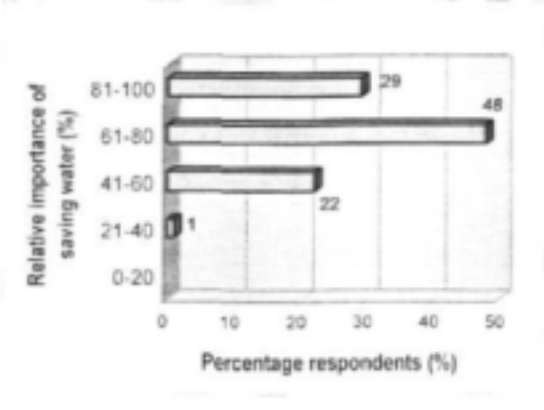


Figure 4.19a Respondents perception regarding the saving of water since introduction of irrigation scheduling (N=134)

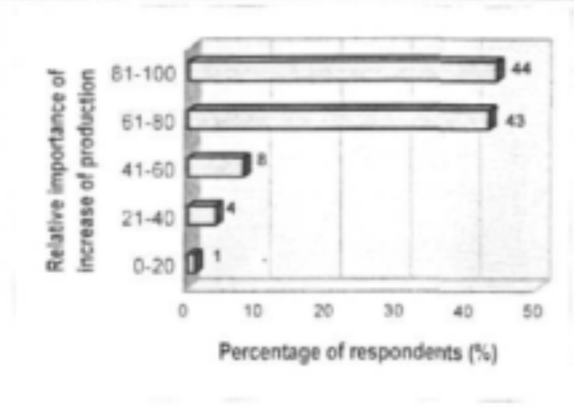


Figure 4.19b Respondents perception regarding the increasing of increasing production yields since introduction of irrigation scheduling (N=134)

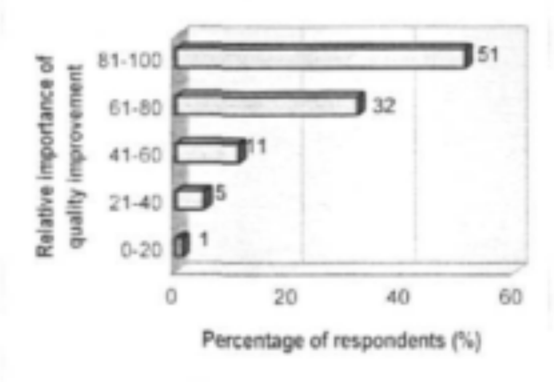


Figure 4.19c Respondents perception regarding the improving of quality of crops since introduction of irrigation scheduling (N=134)

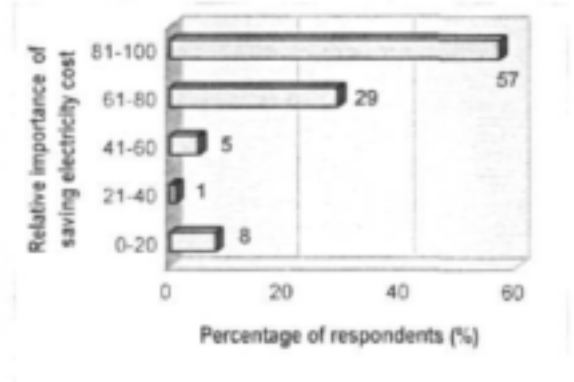


Figure 4.19d Respondents perception regarding the saving on electricity or energy operational costs since introduction of irrigation scheduling (N=134)

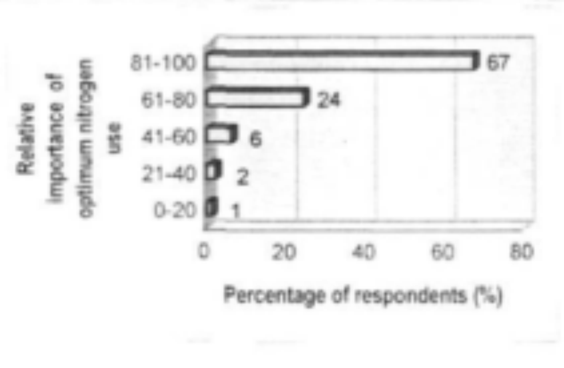


Figure 4.19e Respondents perception regarding the efficient use of nitrogen since introduction of irrigation scheduling (N=134)

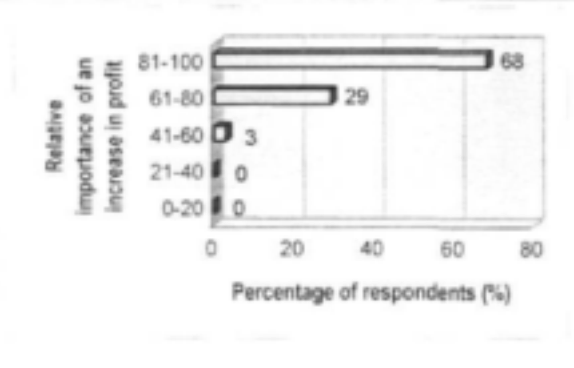


Figure 4.19f Respondents perception regarding the increase of profit since introduction of irrigation scheduling (N=134)

Farmers were asked to rate the importance of the relative advantages subsequent to the introduction of irrigation scheduling and the findings are illustrated in Figures 4.19 (a-f) on a ten-point semantic scale. The expressed scale assessments of the benefits or advantages that farmers perceive with the implementation of irrigation scheduling indicate that the optimization of profits on the farm, the optimum use of nitrogen to prevent nitrogen leaching, improvement of production yields, energy operational cost saving, and the ensuring of quality crops were considered as the primary benefits. It was however obvious those respondents involved in the production of high value crops with a definite quality component, perceived the latter as the predominant reason for the application of objective scheduling methods.

Although the conservation of water is perceived to be important to farmers, they do not perceive the relative advantages of the implementation of irrigation scheduling as the saving of water *per se*, but rather to ensure the wise use of irrigation water on the farm. For most of the irrigators in South Africa irrigation water is limited, and the water saved by reducing irrigation applications per hectare may be used to irrigate additional land and thereby possibly resulting in an increase in total net income. Many farmers indicated that they were able to irrigate additional land since they introduced objective irrigation scheduling on the farm. Also the practices of double cropping found often amongst irrigation farmers were perceived as an observable advantage since the application of irrigation scheduling.

For many small-scale farmers, however as indicated in Appendix A, the application of irrigation scheduling necessitates the application of bigger volumes of irrigation water, more regularly. This also involves 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 many small-scale farmers, and many of them are often guilty of under-watering their crops.

It is important to refer to Figure 4.19d, where the perception of respondents on the possible saving of electricity or energy was tested as a consequence of improved irrigation scheduling. 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.

Electricity is usually charged at prices that vary for peak, standard and low demand (Ruraflex) periods. The Ruraflex rates apply during the late hours of the night and over the weekend so that some degree of automated control is usually desirable. The exploitation of Ruraflex rates was found to be more exploited by the farmers involved in the growing of crops like wheat, maize, etc where electricity and water operational costs form a significant percentage of the total production costs.

The questionnaire used in the survey also allowed respondents the opportunity to list and rate additional advantages as perceived with the application of irrigation scheduling. Fourteen percent of the respondents indicated "peace of mind" since they are sure that the right amount of irrigation water at the right time of the crop growth is applied with the practicing of irrigation scheduling.

Visibility of the wetting front

The irrigation-wetting front is often not visible for many of the irrigation farmers, unless they use a soil auger or spade to monitor it. 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 visibility regarding the wetting front after irrigation for decision-making on a ten-point scale. Figure 4.20

indicates that 98% of the respondents perceived it to be important for efficient irrigation management.

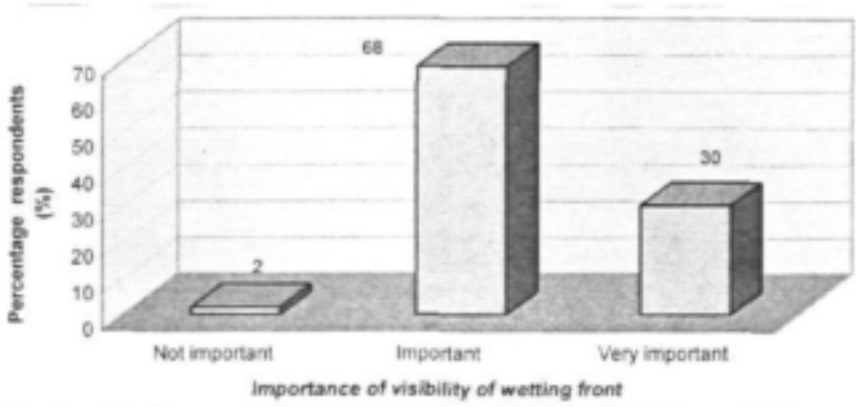


Figure 4.20 Respondents perception regarding the importance of the visibility of the wetting front after irrigation. (N=134)

Farmers traditionally make use of a spade to monitor how deep the wetting front moved since the last application of irrigation, and many farmers indicated their return from the implementation of sophisticated scheduling methods to the use of this simple but very 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.

ADOPTION AND/OR DISCONTINUING OF IRRIGATION SCHEDULING

Farmer's decision to adopt new agricultural technology depends on complex factors after analyzing and trialing and is indeed a social process. Adoption according to Vanclay (2003) is not only unthinking response to new information; rather it is a deliberate decision by an individual farmer in response to a wide range of issues. Adoption, however, not always needs to follow the sequence of stages as indicated in this discussion, but it may be that a farmer gathers additional information about a certain innovation after he has already adopted the specific innovation, as confirmation for his decision.

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 could be effectively implemented. In this instance therefore we are not dealing with the adoption of one innovation only, but rather a package of innovations offered to the farmer. This package usually includes the effective management of the irrigation system and proper cultivation practices to name a few. It is important that innovations recommended must be adapted for the specific situations in which they will be used *before farmers will adopt it.*

Farmers were asked to rate the accuracy of their current irrigation scheduling on the farm, using a ten-point semantic scale.

Table 4.13 Respondents' perception of the accuracy of 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**

According to Table 4.13, the majority respondents (66%) rate the accuracy of their irrigation scheduling relatively high (between 70-80%). There is a clear tendency for respondents implementing objective irrigation scheduling to be more convinced of the accuracy of their method than was the case with those using subjective scheduling. For example, 71 percent of the objective irrigation scheduling group rated their accuracy of irrigation scheduling between 70-80%, while only 59% of the subjective scheduling group provide the same assessment.

Satisfaction with current level of irrigation scheduling

In response to a question as to how satisfied respondents were with the current accuracy of implementation of irrigation scheduling, it does appear as if the farmer group using subjective methods is relatively more satisfied than farmers using objective irrigation scheduling methods. According to Figure 4.21 thirty five percent of the group that use objective irrigation scheduling methods, rate their satisfaction with the accuracy of their irrigation scheduling more than 70%. This percentage satisfaction is 52 percent in the group of respondents using subjective methods.

This is an important finding for the extensionists and irrigation consultants to take cognizance of, as it illustrates the difference of the "felt needs" (needs that are perceived by irrigation farmers that will motivate them to act upon) between the two groups, namely the objective and subjective irrigation-scheduling group.

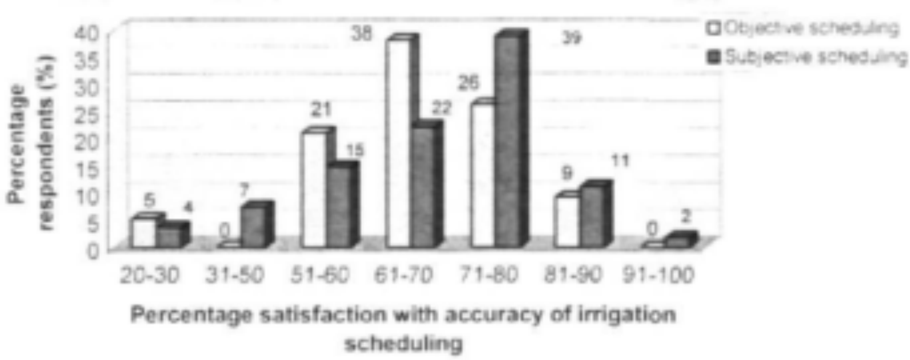


Figure 4.21 Percentage distribution of respondents who perceived satisfaction regarding their current accuracy of irrigation scheduling (N=134)

It is only because of an existing need that a person can have a goal or a goal appears to be attractive (Düvel (1990). This should be incorporated into any communication strategy planned for irrigation farmers.

Changing and discontinuing of irrigation scheduling methods
As farmers go through the learning process of evaluation, trialing and appraising whether a specific irrigation scheduling method is fit for the specific farming system and whether it would help them to reach their personal goals, some are likely to adopt and others to reject the scheduling method. 59 percent of the respondents indicate that their perceptions had changed since they started with irrigation scheduling, while 57% of the respondents indicated a change of irrigation scheduling practices over a period of time. 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 4.22 shows the time lapse since respondents started to implement irrigation-scheduling practices and also indicate the change in implementation of objective and subjective irrigation scheduling approaches over different periods of time.

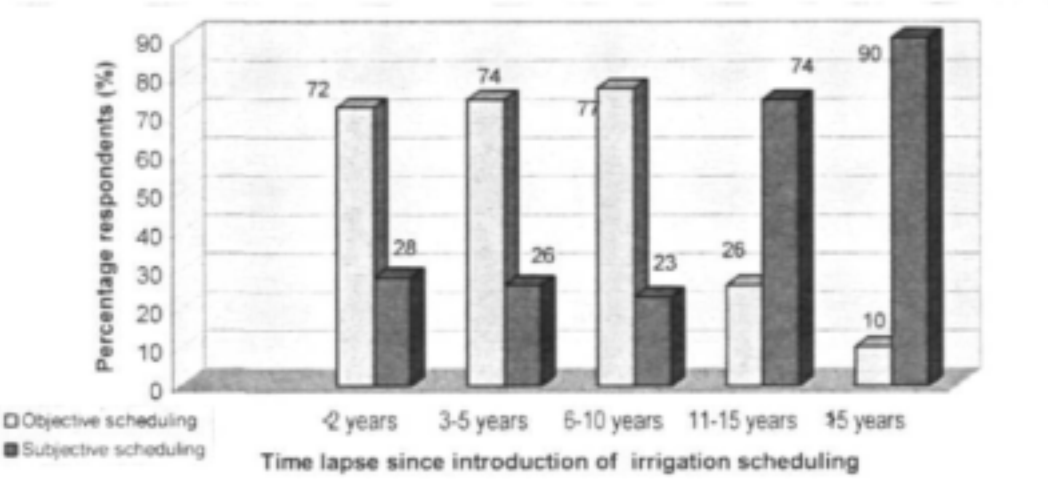


Figure 4.22 Percentage distribution of respondents according to the time lapse since the inception of irrigation scheduling (N=90)

It is clear from Figure 4.22 that farmers 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. 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. Respondents also appreciated the important role of irrigation consultants and extensionists during the initial stages of irrigation development on a farm.

The tendency reflected in Figure 4.22 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 4.14.

Table 4.14 Perceived reasons as identified from respondents for the need to change irrigation scheduling practices (N=134)

Reasons perceived for changing irrigation scheduling	% Respondents
Measurement and/or predictions were not accurate (tensiometers and certain computer irrigation models)	49
Too much irrigation was recommended with some computer programs as specific situations and daily atmospheric fluctuations were not taken into account	33
Time consuming	22
Capital and operational cost of irrigation scheduling too high	19
Irrigation scheduling method too complicated for application on farm	15
Did not perceive any advantages from practicing the specific irrigation scheduling method	11
Method did not provide information about the wetting front after the irrigation application	11
Gained enough experience and knowledge	11
Size of property increased and necessitated change	4
Lost interest in specific method and returned to "traditional method"	3
Change of irrigation systems on the farm	2
Too much of a health risk associated with specific method (neutron probe)	1

According to Table 4.14 the majority of respondents (49%) changed practices because they were unsatisfied with the accuracy of measurement of certain devices or with the predictions provided by computer models. Several respondents referred to their rather negative 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. Some computer models and programs were perceived to have "misled" farmers in the past with recommendations not adapted to a specific farming system and for a specific area. Some models underestimate evaporation grossly for warmer areas and crops like certain fruit tree cultivars had higher water requirements than predicted by the model. Often recommendations on irrigation were made without taking into account a specific irrigation systems' capacity as well as the management capacity of farmers.

Twenty two percent of the respondents also emphasized that sophisticated irrigation scheduling practices were very time consuming. If farmers are unable to perceive any visible relative advantages (as been reflected in Figure 4.19 (a-f)) attached to the effort and time put into this exercise, they are likely to opt for an alternative that is more compatible with their personal needs. Farmers must perceive a need regarding certain outputs, before they are likely to engage in spending more time and money on this exercise.

Discontinuing irrigation scheduling

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 following reasons as indicated in Table 4.15.

Table 4.15 Perceived reasons regarded by respondents for the 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

The majority of respondents discontinued the application of objective irrigation scheduling to follow a fixed program and/or intuition. 69 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. 63 percent respondents indicated that they found the practical implementation of objective irrigation scheduling troublesome, while 50% indicated time as the major constraint to be able to follow more objective scheduling practices. Thirty one percent of respondents stopped with 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 are in general expected for the simplifying of research information and offering of the information in an effective and understandably way to the farmers. 19 percent of the respondents claimed that consultants were not available in certain 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.

Adoption 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 types this is a major problem farmers 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.

Farmers however indicated that they have difficulty using models *per se* for real time decision-making, and therefore the majority of them need professional support to be able to apply models on a farm-level. Farmers in general clearly indicated that the use of irrigation scheduling models are dependent upon capable and willing irrigation advisors and extensionists to help and support the farmer with the application 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.

According to the findings 26% of the farmers use models to schedule irrigation. Nearly all the farmers interviewed have access to a computer. However, significant differences in the general awareness about models, which are available for irrigation scheduling, exist between farmers involved with objective irrigation scheduling and those involved in subjective irrigation scheduling. 29 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 used for irrigation scheduling. The findings also illustrate the difference in needs that exist between irrigators that use objective versus subjective irrigation scheduling methods.

The following computer models and programs were found to be in use or known to respondents as indicated in Table 4.16.

Table 4.16 Awareness and use of computer models and programs for irrigation scheduling (N= 34)

Irrigation Models	% Respondents
PRWIN	30
Irricheck	17
SAPWAT	15
SWB	16
Donkerhoek	8
Probe Sched/Add Sched/Waterman Sched	8
BEWAB	2
Vinet	2
Canesim	2
Total	**100**

PRWIN as indicated in Table 4.16 was predominantly used by 30% of the respondents. Fifteen percent of the respondents were aware of the SAPWAT model. This was probably because of the implementation of the model on an irrigation scheme or WUA level in South Africa to calculate the water requirements. Although SAPWAT was not developed as a real time irrigation-scheduling program, it was found that many farmers were interested in the use of it for irrigation scheduling purposes on the farm. The irrigation calendars offered in the program, which are backed by the application of the model on the irrigation scheme and WUAs, help farmers to build trust in the use thereof.

Perceptions regarding the effectiveness and accuracy of computer models and programs for use in irrigation scheduling

Farmer's perception regarding the effectiveness and accuracy of models in terms of irrigation scheduling were assessed (Figure 4.23).

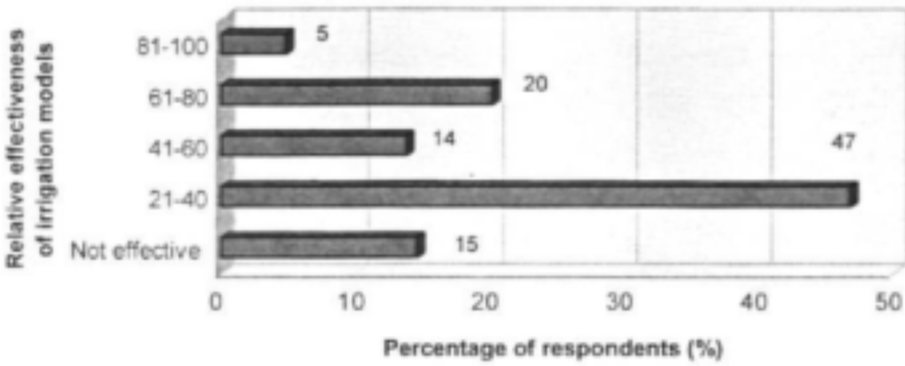


Figure 4.23 Distribution of the perception of respondents regarding the relative effectiveness of irrigation models (N =124)

The findings in Figure 4.23 illustrate that 47% respondents regarded the effectiveness of models to be between 21-40 %. There was a clear tendency from the collected data for higher assessments being made by farmers engaged in objective irrigation scheduling. Fifteen percent of the respondents perceive the use of models and computer program as being inappropriate for implementation on the farm. These respondents were generally of the opinion that models and computer programs could only provide generic guidelines to the potential user. They are also of the opinion that models and programs are generally not adapted for specific situations and conditions on the farm and needs to be attuned according to the farming system, local situation and management capacity of the farmer. This group of respondents also indicated that they lacked the necessary trust and confidence in irrigation consultants and extensionists for their interpretation of the data for making daily irrigation management decisions.

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 4.17 reflects some of the perceptions of the respondents in this regard.

Table 4.17 Respondents' reasons for the lack of aspiration to use computer models for irrigation scheduling on-farm (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 a 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 - satisfy with current information sources	6
Unit of farming to small to implement models	3
Too expensive for farmers	3
Lack of flexibility (irrigation system)	2

It is apparent from Table 4.17 that respondents who have no aspiration to use irrigation scheduling models, either perceive them as being too difficult to use and to implement on the farm (37%) or because it is not practically adapted to their specific farm circumstances (35%). 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 belongs to the age group of fifty one and older and referred to the fact that the computer models and programs available for irrigation scheduling are based on estimates which are not always accurate to be used in decision-making on the farm. In general amongst these farmers a perception was found that the time and financial cost involved in purchasing computers and to gain the necessary skills was not cost-effective. Also included in this group of farmers are those who favour more to work 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 agriculture cooperatives (or private companies currently), fellow farmers and private consultants to inform them on new irrigation technology.

PERFORMANCE OF IN-FIELD APPLICATION SYSTEMS

Managing irrigation systems efficiently 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). Irrigation systems with poor distribution uniformity experienced reduced yields due to water stress and/or water logging. Nutrients can be leached out of the soil due to excess water being applied to overcome poor irrigation uniformity. Poor maintenance of irrigation systems in general will increase the operational costs of irrigation and also influence the efficiency of fertilizer use.

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' awareness and inclusion of regular monitoring and evaluation of irrigation distribution uniformity and the application rate on pressurized irrigation systems were tested. The results of the general perception of respondents in this regard are shown in Table. 4.18.

Table 4.18 Percentage distribution of respondents according to their frequency of testing for distribution uniformity (N=122)

Intervals between measuring distribution uniformity (C_u)	% Respondents
More frequently than once per season	20
Once per season	38
Once per year	6
Once per 3 years	3
Once per 5 years	15
Not at all	18
Total	**100**

Thirty eight percent of the respondents indicated that distribution uniformity is evaluated only once a season, while 20 % of respondents, mainly those farmers using micro and drip irrigation, indicated more regular frequency of evaluation. Eighteen percent of the respondents reported no evaluation of distribution uniformity. 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. 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.

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).

PERCEPTIONS ABOUT THE IMPLEMENTATION OF VOLUMETRIC WATER TARIFFS

Water Demand Management (WDM) is an innovative strategy that was identified to help with the management of water resources in southern Africa. On the majority of schemes the individual abstraction of irrigation water is not measured, and 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 water demand management and it does not encourage the efficient use of water by irrigators.

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 (Figure 4.24). Many farmers however indicated that the necessary financial incentives for the implementation of irrigation scheduling and efficient use of water on the farm in general lack with the current water allocation and flat tariff system in use by water organisations.

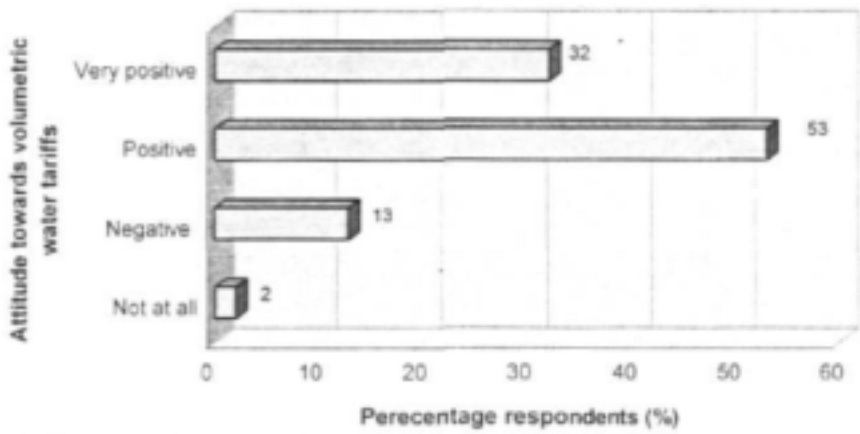


Figure 4.24 Attitudes of respondents towards the application of volumetric water tariffs (N=134)

Although the majority of farmers (85%) showed a relatively positive attitude towards the application of volumetric water tariffs with the placement of a measurement device at each individual abstraction point, 13% of the farmers indicated concern about the accuracy and the practical application of this approach. Unfortunately, the limited number of flow measurement devices currently installed in the field is not perceived to be successful by farmers, and therefore several questions regarding the practical implementation of the concept were raised.

CONCLUSION

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 some cases from farmers, but more importantly they must be prepared to enter continuous, lifelong learning.

The findings of this part of the study reveal certain general perceptions and attitudes of irrigators regarding the application or discontinuing of irrigation scheduling:

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

- The relationship between the size of irrigated area and the adoption of objective irrigation scheduling reveals no significant correlation although a slight tendency was found for the implementation of objective scheduling to increase with and increase in the size of the irrigated area.
- 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.
- Fellow farmers, private irrigation consultants and extensionists from the local cooperatives and cellars were perceived by respondents to play an important role in the raising of awareness amongst farmers regarding the potential use of objective irrigation scheduling.
- 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 and the effective management of nutrients were also perceived as being important motivational "drivers" for the implementation of objective irrigation scheduling.
- Farmers perceived predominantly the optimization of profits and the optimum use of fertilizers (nitrogen) as important relative advantages since the introduction of objective irrigation scheduling. The saving on energy costs, improvement of production yields, and ensuring of quality crops were perceived as being secondary benefits.
- 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.
- The majority of respondents (98%) perceived information regarding the position of the wetting front after the application of irrigation as important information for irrigation management decision-making. It was therefore found that many of the respondents either use the shovel or soil auger or tile probe to monitor this aspect of irrigation management on a regular basis.
- 59 percent of the respondents perceive a substantial improvement of production efficiency since the introduction of objective irrigation scheduling practices. Cash crop growers and producers of high value/high input crops however indicate differential perceptions in this regard.
- It is often assumed that the perceptions of the possible relative advantage of the introduction of an agricultural practice like irrigation scheduling are of the same order irrespective of locality or community. This was not as farmers from different localities perceived different improvement of substantial production efficiency subsequent to the implementation of objective irrigation scheduling on the farm.
- Farmers' response regarding the minimum required "knowledge level" for the efficient implementation of irrigation scheduling revealed four different levels of knowledge. Generally adopters of objective irrigation scheduling perceived their knowledge demands to be significantly higher than those who practise subjective irrigation scheduling.

- This study clearly illustrates that 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 models available to irrigators however need the support and guidance of a professional before it can be implemented efficiently.
- Although the majority of respondents were aware of the necessity of regular evaluation and maintenance of the irrigation systems to ensure uniform distribution and application of irrigation, only 64% of the respondents indicated their attendance to it on a regular basis.
- 84 percent farmers positively perceived the implementation of volumetric charges of irrigation water, but many raised their concerns about the practical implementation of such an approach. Currently a WRC project is registered which will evaluate the efficiency of flow measurement devices available to farmers as well as the general problems farmers experience with the implementation of devices. This research will identify possible strategies for the future to overcome the hindrances in this regard.

CHAPTER FIVE: Acceptability of irrigation scheduling for small-scale irrigation farmers

INTRODUCTION

Irrigation has long been seen as an option to improve and sustain rural livelihoods by increasing crop production. 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 form 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 5.1:

Table 5.1 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 these 202 small-scale irritation schemes, 79% are in the Eastern Cape, KwaZulu Natal and the Limpopo Province. As a whole, such schemes account for 4% of the irrigated areas of SA and from a rural and socio-economic point of view such schemes are of cardinal importance.

According to a World Bank study the performance of small-scale farmer irrigation systems has generally been below expectations and eventually led to producing low economic and financial returns (Serageldin, 1995). In Africa the performance has been disappointingly low (FAO, 1995).

RESEARCH METHODOLOGY

The aim with this part of the study was to investigate and describe the irrigation practices and irrigation scheduling methods which small-scale farmers are using as well as their perceptions and possible reasons (human, social and economic) 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. After consultation with the steering committee and several key informants, four small-scale irrigation schemes were selected for more intensive surveying namely:

- Tshiombo in Limpopo Province.
- Taung in the Northwest Province
- Nkomazi east (Walda, Boschfontein, Low's Creek, Figtree) in Mpumalanga Province
- Bethlehem Apple project in the Free State.

Three food plot irrigation schemes were selected in the Limpopo Province to identify the constraints and challenges that these irrigators face in terms of the adoption of efficient water management. *(Appendix 1)*

- Arethusaneng, Driekop, Limpopo Province
- Maroke, Driekop, Limpopo Province
- Maputlesebope, Driekop, Limpopo Province

ADOPTION OF IRRIGATION SCHEDULING ON SMALL-SCALE IRRIGATION SCHEMES

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. These different dimensions mean the development programs and policies need to include many disciplines and different levels of intervention. This presents a challenge for professionals trained in the more conventional reductionistic scientific paradigm. Farmer participation is important in the decision making in order for farmers to feel a sense of ownership. A review of the literature done by Bembridge (1996) indicates that, with a few exceptions, the economic success of small-scale farmer irrigation schemes in South Africa falls far short of the expectations of planners, politicians, development agencies and the farmers themselves.

Existing 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 practically all-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 function 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 outgrowers 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 in South Africa, 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 are very popular because of the easiness to manage and maintain (Stimie, 2003). On the community food gardens many of the farmers are making use of short furrow irrigation in their vegetable crop production.

i) Eastern Cape

According to Bembridge (2000) there are fifty small-scale irrigation schemes in the Eastern Cape comprising 9 527 ha with 6 349 participants. Table 5.2 indicates the information as collected by Bembridge (2000) as well as additional information collected by Eloff (2001) and Williams (2004).

Table 5.2 Eastern Cape Irrigation Schemes (Bembridge, 2000; Eloff, 2001 and Williams, 2004)

Scheme	Area irrigated	Paticipants		Total	Major crops	Water source	Irrigation method	Energy source	Management 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
Izikolelho	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
Mjkweni	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	1546	1678	Veg, maize	River	Sprinkler/ Dragline		Comm farmers
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
Mhombe	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
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
Ngqeni	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; CP= 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, and the changing scenario in government financed irrigation schemes in the last couple of years due to shortage of funding, has resulted in the deterioration of the physical structures, and in some cases, theft and vandalism of the irrigation equipment.

In a short report on the current situation and activities of the irrigation schemes as provided by Williams (2004), it was indicated that many of the schemes are only producing on a very limited scale (Photo 5.1). The major reason submitted for this situation was the fact that many farmers have to seek for their own credit sources and need to prepare appropriate business plans. The majority of these farmers are not in a position to draw up a business plan themselves and the necessary support in this regard is also lacking. The Kat River Valley was one of the former Ciskei irrigation schemes that were transferred to newly settled farmers. These citrus farmers are members of the Kat River Cooperative, which is responsible for production inputs, and the marketing of the citrus. A full time extensionist is employed by the cooperative to support these farmers with their day-to-day decisions on management and production. These farmers at present use no objective scheduling, although tensiometers were used in the past. Farmers are making use of a fixed irrigation schedule provided by the local citrus cooperative, as it was found to be easier for farmers to understand and implement.

Photo 5.1 Keiskammahoek irrigation scheme *(Courtesy of vd Stoep, 2004)*

The majority of schemes (75%) in the Eastern Cape use either sprinkler systems or draglines. Although this pressurized irrigation technology is highly efficient and most frequently used on schemes in the Eastern Cape, the maintenance is often neglected. The consequences of poor maintenance of irrigation equipment led to yield losses and increased pumping costs.

Photo 5.2 Sprinkler irrigation system used at Keiskammahoek irrigation scheme *(Courtesy of vd Stoep, 2004)*

According to Stewart Scott Inc. (1998), the irrigation systems are not used efficiently due to under-designed pipelines, lack of know-how of extension officers and farmers, leaks in the irrigation system and incorrect nozzle sizes and low pump efficiencies. This contributes to the general inefficient water management practised by many of the small-scale farmers. The majority of farmers irrigate according to a fixed schedule, operating in two equal shifts of ten hours with the pipes being moved in the morning and once again during the afternoon. These farmers do not measure the irrigation applied. The departmental extension officers are responsible for the delivery of technical support and help with the preparation of business plans but in general are lacking the necessary competency and technical skills (Bembridge, 2000; Williams, 2004).

Farmers' major problems experienced on the irrigation schemes in the Eastern Cape, as cited by Bembridge (2000), and again confirmed by extension officers in the Eastern Cape during 2004, are indicated in Table 5.3.

Table 5.3 Rank order of the major problems that farmers experience on the Eastern Cape irrigation schemes (Bembridge, 2000, Vusani, 2004)

Scheme problems	Rank position
Poor maintenance of infrastructure and equipment	1
Lack of farmer training	2
Local and political conflict	3
High pumping costs	4
Lack of credit	5
Poor market opportunities	6

In the majority of schemes as indicated in Table 5.2, 54% of the farmers are pumping irrigation water using mainly diesel as source of energy. According to Bembridge (2000) and

Williams (2004) many of the crop losses are experienced due to engine breakdowns. It is evident from the rank order of problems, as experienced by farmers on the relative bigger irrigation plots (>50ha), that irrigation costs in terms of the actual pumping costs, is ranked in the fourth position. On the smaller units (less than 50 ha) pumping costs are not perceived to be a major problem for farmers. Farmers are mostly occupied with aspects like political conflict, theft and lack of access to appropriate credit.

ii) Limpopo

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.

114 schemes with a total irrigable area of 18 629 ha are included in the Revitalising Program 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 were 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 enables 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. Extensionists should be properly trained to assist farmers in the day-to-day irrigation management issues. This support program will also entail the support of farmers with training in sound irrigation scheduling principles.

Table 5.4 Frequency of crop types found on the 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**

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 Department of Agriculture through the local extension agents. Fees are collected for the pumping of water on a plot basis.

Case study 1: Fixed irrigation table as a barrier to the practice of irrigation scheduling - Tshiombo irrigation scheme

The first case study deals with a small-scale irrigation scheme Tshiombo Irrigation Scheme, 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 morgens (1.3-1.7 ha) (Perret, 2001).

Background

The Tshiombo Irrigation Scheme is situated at the northern side of Thoyandou, 40 km from Louis Trichardt in the Limpopo Province (Figure 5.1). 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. Nine hundred and thirty 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 are planned to play an important role to ensure the effective distribution of irrigation water to the four irrigation blocks of the irrigation scheme.

Figure 5.1 Base map of Levuvhu/Mutale water management area to indicate the situation of Tshiombo irrigation scheme near Thoyandou (DWAF, 2004)

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 have been grown on the scheme, including maize, cabbage, Swiss chard, chilies, 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 are receiving a pension as an off-farm income. Farmers receive the water free of charge, while they pay R1 per month per plot, irrespective of the size of the plot.

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 house rules and conventions on a block level, and if a farmer fails to obey the house 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 is followed on the scheme for irrigation scheduling according to the filling of the seven storage dams:

Table 5.5 Timetable followed for irrigation on Tshiombo (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

Interviews with farmers from blocks 1 and 2 revealed that they did not experience problems with water supply, as they were nearest to the weir. However farmers from block 3 and 4 indicated some water shortages at critical periods of the crop production, which had negative effects on their management possibilities and potential income.

It is however the responsibility of farmers to maintain the supply furrows of the different irrigation blocks. If a farmer is busy with the cleaning of his furrow from weeds on a particular day when water is received, his neighbour would be allowed to use water during the time. This approach worked well as farmers were 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 used different irrigation schedules than those farmers from blocks 3 and 4. Farmers from block one (nearest to the weir) did not irrigate on Mondays, so that a chance was provided for farmers in block 2, 3 and 4 to irrigate, more especially for the farmers of blocks 3 and 4 where water is stored in a dam before irrigation takes place.

Farmers in block 1 and 2 usually irrigate from 6h00 till 12h00 and only two farmers could irrigate simultaneously. The first two farmers nearest to the canal are the first to irrigate, and then followed at 12h00 by the other two farmers. The following day the order of irrigation will change, although this schedule of irrigation is not fixed. It 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 from 6h00 till 10h00, to provide some opportunity for the rest of the farmers. Farmers irrigating in blocks 3 and 4, usually make use of water that is stored in storage dams. Farmers from these blocks irrigate daily, and depending on the volume of water stored, they are allowed to irrigate either one seedbed (0.107ha) or two seedbeds per irrigation cycle. 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 only regular field inspection to monitor their irrigation efficiency. The extensionists also indicated that his knowledge level on irrigation scheduling *per se*, and the use of methods like the "feel method" and other more sophisticated devices was inadequate to support farmers if and when required.

Extensionists were asked what they perceived as the major barriers to optimal crop production in Tshiombo, and the following production constraints were identified (Table 5.6).

Table 5.6 The importance rank order of perceived problems representing constraints in crop production (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, because of damaged fences	3
Transport problems experienced with delivering of produce to markets (expensive) and inadequate market strategy	4
Lack of easily available credit	5
Established local cooperative not addressing the needs of farmers	6

The major constraint perceived by the extensionists was the availability of water from April till July, especially for irrigators from blocks 3 and 4. The lack of maintenance of canals and vandalism causing severe problems in the distribution of irrigation water and therefore influence the production of winter crops (cabbage). However, it was also admitted that some of the secondary canals in blocks 3 and 4 were dirty, and over grown with weeds and invaders.

Photo 5. 3 Poor maintenance of secondary irrigation canals and excessive vegetative growth on the canal banks at Tshiombo irrigation scheme (irrigation blocks 3 & 4) often cause inefficient water distribution efficiency.

Photo 5.4 Vandalism of irrigation delivery structures like a canal sluice gate at Tshiombo irrigation scheme prevent effective water distribution on the scheme (2003)

It was found that 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 about the operational execution of the scheduled timetable of delivery and the required maintenance activities of the canals.

Lessons learned
The irrigation community at Tshiombo has operational and institutional arrangements that appear to work relatively well and have stood the test of time, and much can be learnt from this. 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 obligations that govern individuals and groups in a community. Crosby *et al* (2000) found that farmers' success and acceptability of irrigation schemes are closely related to the management system of the scheme.

Individual irrigation farmers on this scheme have very little opportunity to apply their own adapted irrigation scheduling methods based on farmer and specific crop needs, as the availability of irrigation water is dictated by a fixed schedule (time-table) of bulk water deliverance. At present farmers tend to irrigate their fields in accordance with this fixed irrigation timetable. However, instances of transgression of the water-sharing rules by some plot holders indicate that the current water–sharing timetable is inadequate at times. Some farmers were clearly more successful than others and made better use of the available irrigation water. 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). The practices that should be adopted by all the farmers to optimize available water include 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 5.3).

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. However, many small-scale farmers, as well as extension officers, are in general unaware of the correct implementation of short furrow irrigation like the correct cut time of water input, shortening of the length of some furrows and the filling of alternative furrows for better wetting of the field.

From the field visits it appears that many farmers apply full irrigation (meaning the filling of furrows as a standard practice) on the whole plot, instead of identifying the more sensitive crops like Swiss chard, etc. and then practise full irrigation only on these crops. A deficit irrigation approach could be applied on the rest of the crops that are perhaps less sensitive.

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 delivering and availability of bulk water on Tshiombo is based on the cooperation and collaboration of all the water users of the scheme, it necessitates that all farmers should adhere and obey the rules and regulations of water sharing as agreed upon. There are, however, some farmers, who are guilty of transgressions of the irrigation timetable, and, together with a lack of commitment to regular maintenance of secondary canals, are contributing to this problem.

iii) Mpumalanga

Irrigation development on schemes in the Mpumalanga has been based mainly on establishing commercial farmers, most of who are involved in sugarcane, maize, tobacco, vegetable and wheat production. 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.

Table 5.7 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
Elandsdoorn	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
Mapochsgronde	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 probe Wetting 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

Case study 2: Partnership between industry and government for sustainable agriculture development: Nkomazi Irrigation Project (Low's Creek, Walda, Figtree, Boschfontein)

The second case study reveals the experience of small-scale sugarcane growers in Nkomazi-east that, are served by extension officers of the Mpumalanga Provincial Department of Agriculture (MPDA) and extensionists of the sugar industry (TSB and SASRI) on irrigation management and other production aspects.

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, and support small-scale sugar growers with technical information. SASRI extensionists are responsible for the appropriate training of field staff, and for the expertise needed in this regard. Both parties are to gain from such an agreement. The sugar industry needs sugarcane for their mills in Komatipoort and Malelane, and TSB has allocated a quota of 4 500 ha to the Nkomazi small-scale farmers. Furthermore, government is lacking expertise and resources to service small-scale sugarcane growers properly, and saw this as an opportunity to add value to their existing extension services in these areas.

The development activities of Nkomazi Irrigation started in 1985 with the focus on the production of crops like cotton, maize, vegetables, sisal, leather fern and some sugarcane. Large losses were suffered and farmers accumulated relatively large outstanding production loans. Since 1990 when the Nkomazi Irrigation Expansion Programme (NIEP) was implemented, the development approach was revised with more focus on the production of sugarcane. 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.

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 from this division, who were situated in the Nkomazi area, were responsible for the weekly soil water measurements that were taken with a neutron probe. The data was submitted on a daily basis to an agricultural engineer based in Nelspruit, who was also responsible for the interpretation of the data and made appropriate recommendations. These recommendations were prepared in consultation with extensionists from SASRI and involved the period of irrigation that was needed to fulfill the crop water requirements as determined for the next week. 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 during 2002, due to a lack of operational funds experienced by the Department of Agriculture. The majority of small-scale sugarcane growers in the Nkomazi subsequently follow SASRI irrigation guidelines available in a fixed irrigation schedule without any objective monitoring of the soil water content.

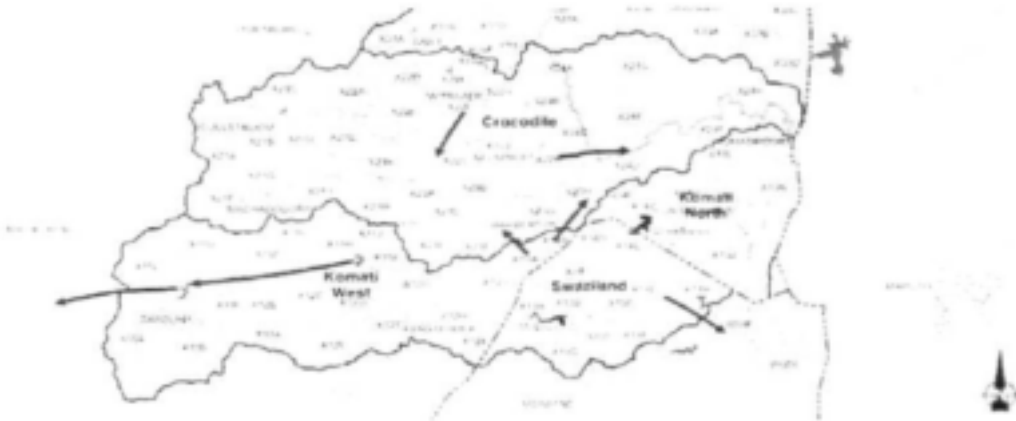


Figure 5.2 Base map of the Nkomazi irrigation scheme within the Inkomati water management area (DWAF, 2004)

On the majority of irrigation schemes in Nkomazi "energy centres" or field offices have been established. These "energy centres" are buildings on the irrigation site where general administrative duties are taken care of like, for instance, the settlement of electricity bills, record keeping and networking where needed. It also serves as a venue for the meeting of farmer groups with the executive committee of the project and it is also used for appropriate training offered by the local extensionists.

Photo 5.5 Discussions between the local extension officer, the irrigation engineer and a local farmer at the Walda energy centre.

Walda

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 irrigated in blocks and follow a three to four hour irrigation cycle. The general recommendation to farmers is not to exceed 16 mm application per irrigation cycle, because of the specific soil type that occurs. 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, that prevents the development of the root systems of sugarcane beyond that layer and also impedes penetration of water after an irrigation application. The soils at Walda are also relatively high in clay content (approximately 40%), and for that reason extensionists recommend that farmers should not apply more than 16 mm per irrigation cycle. However, farmers usually start to irrigate at 6h00 in the morning till 18h00 when the water is shut, and farmers leave for their homes in villages nearby. This practice often leads to over irrigation as indicated in Photo 5.6.

Photo 5.6 Small-scale sugarcane growers often use sprinkler irrigation. Inefficient irrigation practises often lead to relative high percentage of run-off during irrigation (2003).

Low's Creek Irrigation Scheme

This scheme is found in the Tikhontele village, Mpumalanga and it consists of 35 farmers with the average plot size of 7 ha under sugarcane. A canal extracts water from the dam to the field. Each farmer is responsible for pumping water from the canal to his specific plot. The crops that are planted in Low's Creek Irrigation Scheme are indicated in Table 5.8:

Table 5.8 Crops grown in the Low's Creek Irrigation Scheme.

Crops	Area (ha)
Sugarcane	218
Litchis & bananas	62
Roads, etc	2
Total	**282**

Farmers use mainly sprinkler, floppy and dragline irrigation system on the sugarcane, while a couple of farmers have changed to the use of drip irrigation. Only one farmer from Low's Creek uses flood irrigation.

These growers generally follow a pre-scheduled program of daily irrigation as provided by SASRI especially for the improvement of the sucrose content (quality) and irrigated daily. 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.

Problems that are regularly encountered by these farmers are the lack of maintenance of sprinklers, which end up in leaking sprinklers, and nutrients that are leached. 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 therefore some of the farmers hesitate to accept information from the younger extension officers responsible for extension services in the area. Some farmers at the top end of the scheme, furthest away from the water source experience water shortages due to lack of pressure because of the over pumping by farmers at the bottom end of the scheme.

Figtree, Boschfontein (1&2)

Figtree and Boschfontein irrigation projects are two irrigation projects in the Magudu Irrigation Development, 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 irrigated in 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 night time 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 what they regard as their biggest constraint that prevent them from success with their farming ventures? Apart from the lack of appropriate credit and general problems which farmers mentioned, relative high electricity costs per month was perceived to be their biggest constraint, which prevent them from making a profit from 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 decision however contributed to injudicious use of electricity, for instance, the unnecessary starting and stopping of pumps when farmers are shifting irrigation pipelines in between irrigation cycles.

The following is an income statement of one of the relative successful sugarcane farmers at Walda for the production season 2003/2004 as supplied by SASRI (Swart, 2004).

Table 5.9 A statement of income and expenses of a small-scale sugarcane grower at Walda for the 2003/2004 season (SASRI, 2004)

Farm size (ha)		4.2
Revenue		
Tons		343
Tons/ha		82
RV%		13.4
Tons RV		45.93
RV price		1 429
Gross Income		65 617
Fat rate (14%)		5 189
Interest on retention		0
Gross income		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**

It is important to emphasize the proportional high operational costs of electricity and irrigation water (24.8%) in comparison with other production costs of sugarcane. This particular farmer however produced 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). The average production for many of the small-scale cane growers in the Nkomazi irrigation scheme is approximately 60t/ha, which clearly indicates why the less successful farmers, in general find it difficult to make a profit. These figures support the perception by 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.

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.

Lessons learned

- It was found that many farmers were over-irrigating and free water was 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 of irrigation per irrigation cycle, many farmers were found to still practise a 10-12 hours irrigation cycle, which, 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.
- Another problem, which extensionists and advisors often experience, is that many of the farmers (owners) on these irrigation projects are part time-farmers, who work in Gauteng or elsewhere and therefore never attend the regular farmer meetings held at the energy centres. The workers on the fields of these farmers, also not regular attend monthly meetings, and therefore are not well informed about important decisions taken.
- The majority of farmers involved in the production of sugarcane were found to be relatively old and many of them were receiving a pension. Some of the younger extension officers complained about the resistance showed by some of the elder farmers regarding irrigation and production recommendations offered, due to fact that their credibility was questioned.
- Many of the extension officers rendering support to farmers lacked appropriate training in irrigation management and therefore could not help farmers in this regard.
- Apart from a 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 general SASRI guidelines on the production of sugarcane. Much over-irrigation was evident amongst farmers due to the lack of appropriate knowledge about 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.
- The average production yield for sugarcane by small-scale farmers in the Nkomazi area, according to Botha & Swart (2003), varies between 65-70t/ha. This was found to be substantially lower than the average production of 100-110t/ha for commercial growers in the same area. Some of the constraints that prevent optimal production by small-scale growers are poor soil preparation, poor crop and irrigation management skills (Swart, Khosi and Mtembu, 2003).
- The established energy centres offer excellent infrastructure for appropriate training programs on-site to be offered to farmers. However, it appears that these facilities and resources are not optimally used to improve the irrigation efficiency of farmers.

(iv) Western Cape

Small-scale farmer irrigation in the Western Cape is confined to a few schemes. The figures as presented in Table 5.10, 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 5.10 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, 85 percent of the small-scale farmers are involved in food plot production and earn less than R20 000 per annum. The more commercial oriented small-scale farmers (earning more than R20 000/annum) are involved in the production of crops like flowers, lucerne, deciduous fruit, and grapes.

The majority of small-scale farmers does not make use of objective irrigation scheduling, but rely on intuition or a fixed irrigation schedule (Beukes, 2002). According to Beukes (2002), the average small-scale fruit grower in the Western Cape lacks the basic knowledge regarding soil preparation, cultivation of fruit and sound irrigation management. Only a small percentage of the new small-scale fruit growers are properly trained in irrigation management and have the confidence to apply irrigation scheduling methods like the use of evaporation pans, feel method and the soil auger to monitor irrigation applications. The majority of small-scale fruit growers however rely on themselves or their fellow farmers for irrigation scheduling decisions.

Du Plessis (2002) is of the opinion that small-scale farmers' decisions regarding the irrigation frequency and length of an irrigation cycle to follow are mainly determined by availability and reliability of irrigation water. Since water availability and reliability are often lacking in some irrigation areas, many of the small-scale farmers are rather guilty of under-irrigation than over-irrigation.

(v) KwaZulu Natal

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 5.11). 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), the irrigation farming activities at Makhatini had been limited to 50 ha under irrigation. At that stage, 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 access to credit, and the fact that many of the farmers still struggle with debt accumulated from previous production seasons. During the last couple of years, rain fed cotton production out-produced irrigated cotton production, and therefore many farmers subsequently changed to rain fed cotton production. Vunisa Cotton supports the farmers involved in cotton production with access to credit, establishment of appropriate marketing opportunities and supply of technical support on cotton production. No objective scheduling methods is implemented by farmers who rely on a fixed schedule as provided by the industry.

Apart from the debts that farmers are struggling with, the extensionist from Vunisa Cotton at Makhatini irrigation scheme observed the following constraints that prevent farmers from optimal crop production:

- Lack of adequate maintenance of their irrigation systems - many nozzles and sprinkler packages were in a very poor condition, and need to be replaced.
- 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.
- Skills and technical knowledge of departmental extensionist was inadequate.
- Vandalism and theft.

Apart from cotton and sugarcane produced on the Makhatini irrigation scheme, the other irrigation schemes mainly produce sugarcane for which a ready market exists. 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 basis. These four extension officers supervised the extension activities of forty technicians from the Department of Agriculture. These extension officers and technicians provide technical assistance on 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.

Table 5.11 Small- scale irrigation schemes in KwaZulu Natal (2003)

Scheme	Area irrigated (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 Experimental Station

(vi) Northern Cape and Free State

In the Northern Cape and Free State, the irrigation schemes indicated in Table 5.12 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 5.12 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 Appleproject	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*

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, there is no specific training program 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 farmers identified the need for the development of appropriate training programmes and efficient training of farmers in basic irrigation management principles.

The "mentorship program" that has been adopted by the Department of Land Affairs, was also initiated at schemes like Opperman. In this program, commercial farmers act as "mentors" to the 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 rôle in the future training of farmers regarding irrigation scheduling.

Case study 3: Apple project in Bethlehem

This case study illustrates how small-scale apple growers with the intensive support of an experienced "mentor" on a project basis have developed adapted irrigation scheduling methods appropriate for their specific needs.

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 closed 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 delivered by the municipality from the Gerald dam. The availability of 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 5.3 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. Each participant received one-hectare land where five different apple cultivars were planted. This strategic decision was taken to ensure that all the farmers have the same opportunities to gain experience for the different marketing and management requirements as applicable for the different cultivars. The 106 ha apple orchard was divided in 8 different irrigation blocks, according to different slopes, soil potential, and topography of the farm to ensure more effective management. A block manager per block was elected, and served on the executive committee as representative of a specific block, which meets every week. During these weekly meetings, planning and operational management for the next week are discussed as well as relevant training sessions for block managers and farmers are 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 (Mr. H Peko).

Photo 5.7 Pieter Fourie (mentor of the AFGRI Apple Project) and Hendrik Peko (chairperson of the management committee)

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.

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 was perceived to lend itself to allow for the practising of fertigation, and therefore, more precise fertilizer management as needed for the five different cultivars.

These farmers use a fully automatic Motorola computer system, which controls the irrigation on the 8 irrigation blocks. The irrigation management strategy selected for the farm is based on the SAPWAT model for irrigation planning and the prediction of crop water requirements. 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.

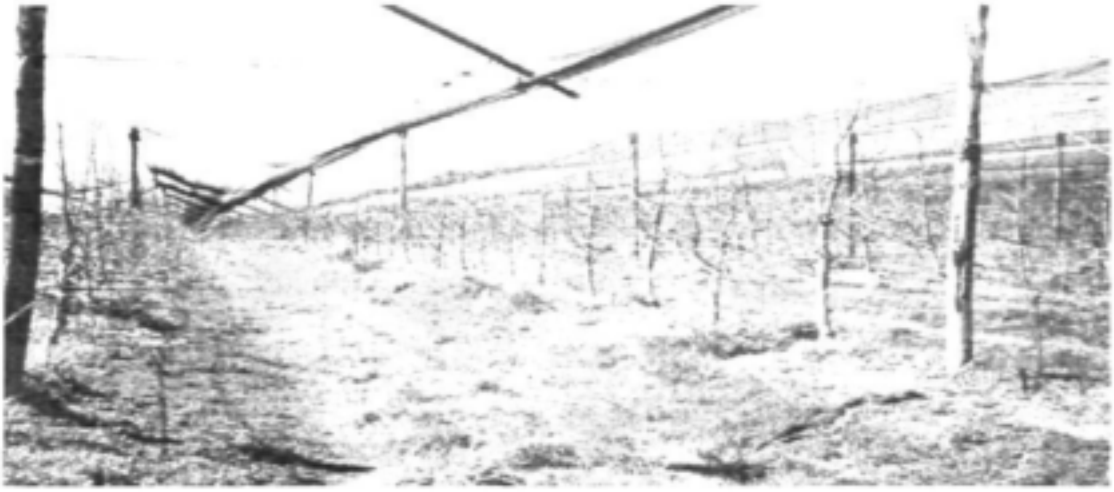


Photo 5.8 Apple orchards under drip irrigation in the AFGRI project for small-scale farmers outside Bethlehem (2003).

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 by the mentor 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. The mentor is of the opinion that 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. This opportunity is also used for the training of block managers and farmers of a particular block in the use of different irrigation scheduling tools (e.g. feel method) and to illustrate general production aspects in the orchard. This approach of continuous training and experiential learning of farmers, as well as the provision of ample feedback opportunities to the management system, proved to be appropriate to ensure that the necessary adaptation of existing irrigation technology like computer models (SAPWAT) and soil water measurement devices to the specific conditions of a farm. According to Fourie (2002), when SAPWAT was used for the first time in this project, it was found to over-predict the crop water requirements during certain growth stages. However, through intensive monitoring with soil augers and regular observations by farmers it was successfully attuned.

Farmers are expected to attend the training sessions regularly as arranged for a specific block. Block managers also help the participating farmers with general dissemination of information on irrigation management. Irrigation specialists from Stellenbosch also assist this project with the evaluation of the applied irrigation management on a two yearly basis. Although this was recognized as perhaps an expensive exercise, both block managers as well as the mentor are convinced that it is a cost-effective exercise in terms of the value added to this project.

Lesson learned

- The learning based approach used on this farm relies on training of trainers (block managers), and recognizes the importance of the farmers' role in the dissemination of information to other farmers. This strategy was found to be very successful. 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.
- This project illustrates the importance of the development of proper institutional structures, where farmers take ownership and are trained in many aspects of irrigation management and leadership.
- This project also demonstrated the route that has to be followed to develop an appropriate scheduling method adapted for a specific farm. The important role to be played by a mentor or extensionist in the support of new farmers (small-scale) on a daily basis cannot be over emphasized. Without this important support, the application of sustainable irrigation management practices by small-scale farmers is very unlikely.

(vii) Gauteng

In Gauteng, apart from the many community gardens (approximately 1 200 ha) (Potgieter, 2002) that were established or still in the process to be established, Rust de Winter 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. Limited time period tenure contracts are also restricting people's investment in the property they occupy and also limiting the level of land utilization. These issues are inhibiting the normal development and functioning of the irrigation scheme. Irrigation scheduling as part of water management enjoys a very low priority among farmers taken into account the socio-political constraints that farmers are faced with according to Botha *et al*, (2000). This situation is currently still experienced in this area.

Table 5.13 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.

(viii) Northwest

In Northwest, the discussion is restricted to the larger irrigation schemes that occur in the province, namely Taung and Disaneng irrigation schemes. Except for the Taung and Disaneng irrigation schemes, which are commercially orientated, most of the 20 schemes in Northwest Province are based on vegetable growing both for food security and income (Branken & de Kock, 2001). Apart from these two larger irrigation schemes, many community gardens are to be found in the province where farmers produce vegetables by making use of hosepipe, flood and dragline irrigation methods.

Table 5.14 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			

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.

Case study 4: Partnership agreement between farmers and the private industry: Taung irrigation scheme, Northwest

This scheme was established in the former Boputhatswana 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 participating in the irrigation practices on the scheme. Each farmer has an average plot size of 7.5 ha. The scheme receives water from the Vaal River via Bloemhofdam and 14 streams and 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 5.4 Base map of the Taung irrigation scheme within the Lower Vaal water management area (DWAF, 2004)

Three to four farmers usually share a centre pivot, and this implies that they must plant crops 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).

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 on this irrigation scheme use 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 summer crop production seasons, while South African Malsters (SAM) provide support to 211 farmers with the production of barley. The irrigation scheduling methods that farmers follow in the production of the different crops varies as indicated in Table 5.15.

Table 5.15 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

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.

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 both SAM and the extension officer became concerned about the over-irrigation that generally took place during the initial stages of the production season, and the under-irrigation 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.

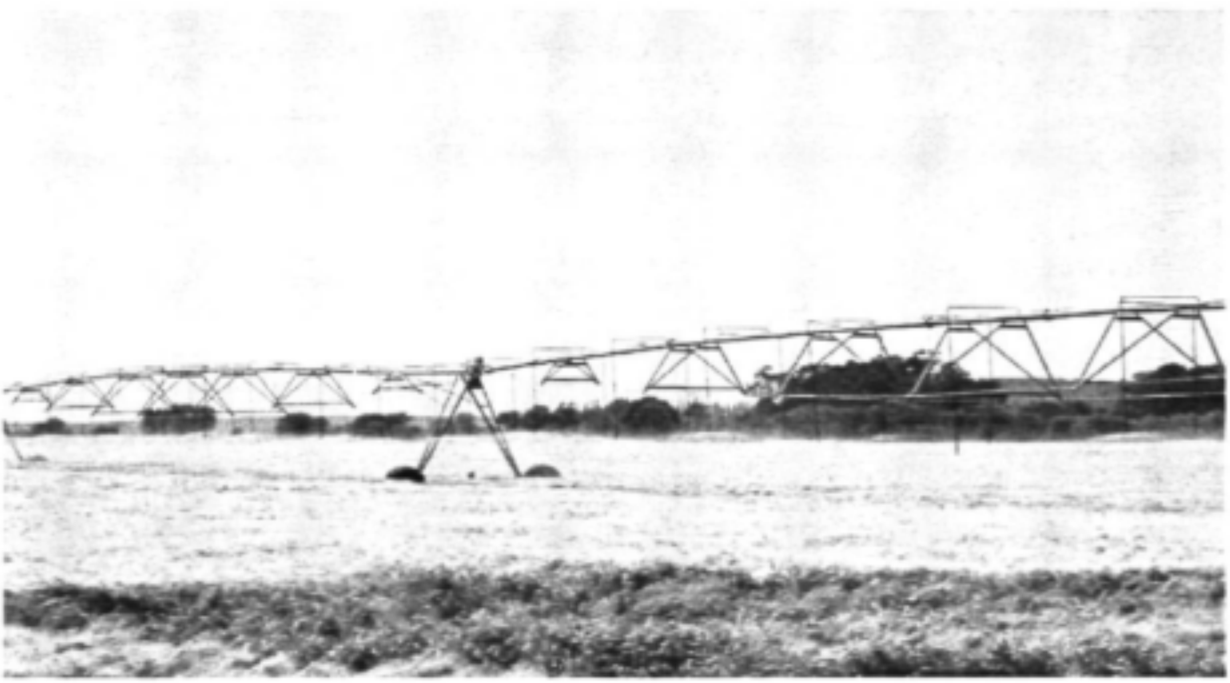


Photo 5.9 Relative old and often under-designed centre pivot irrigation systems used for crop production at Taung irrigation scheme. (2004).

Apart from the on-going research, an irrigation consultant was also appointed since 2003 to measure the soil water content on a weekly basis with a neutron probe at the cost of the farmers. The computer program, which the consultant is using, is the same as the one that

Griekwaland Wes Cooperative uses. This service is compulsive to growers who are participating under this production program. The information derived from 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.

Photo 5.10 Regular training of farmers at Taung is scheduled with the local extensionists and researchers in irrigation management

Lesson learned

- It is clear from this specific case study that the use of relative high irrigation technology like centre pivots very often require the support of appropriate trained professionals to ensure efficient use of this equipment. Without this 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.

- Cognizance should be taken of the original capacity and design of an irrigation system before farmers are allowed to extend the irrigation systems to satisfy the need of additional farmers. This aspect was clearly illustrated at Taung where this decision has 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.

CONCLUSION

Certain 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, appropriateness of technical design of irrigation systems and the general commitment of irrigation farmers. The following were some of the major conclusions and recommendations reached by the project team:

- Small-scale farmers should participate in all phases of the irrigation scheme. Farmers 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. 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.
- It is also clear from the included case studies, that irrigation schemes where farmers are responsible for the management of the project, a tendency occurs that farmers embark on high value crops like apples and barley, while the traditional government schemes like Tshiombo, mainly concentrate on the production of cereal crops and vegetables which are relative easy to market locally.
- Consultants and extensionist without appropriate technical training and understanding of the situation of smallholder irrigation development should rather not participate unless they receive appropriate training beforehand. Ground level support for the implementation of sustainable irrigation practices is imperative.
- Sharing of irrigation equipment like the 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.
- Sprinkler irrigation is attractive to many of the small-scale farmers – but it was also found that it leads to excessive water use like in the Nkomazi. Short-furrow is extensively applied by the majority of food gardens and homestead gardens. 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 increased realization amongst scientists that one should rather support farmers with their current irrigation systems and try to improve the general irrigation management efficiency through appropriate training and efficient dialogue between farmers, research and extension. Scientist will gain a better understanding of the situation and explore with the farmers what can be achieved on the farm.
- Many small-scale farmers indicated that they experience a serious lack of competent advisors and extensionists with specialized training in irrigation. Appropriate training material and courses for the big number of illiterate small-scale farmers lacks and should be addressed by researchers, extensionist and rural developers.

- Clarification of land tenure arrangements of irrigation farmers could increase farmers' incentive to invest in their land and irrigation systems.
- It was observed that many of the small-scale irrigators are at this point in time not ready to be introduced to more sophisticated irrigation scheduling practices. 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 of 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 is probably the approach to be followed in the development of small-scale irrigators.

  It was found that farmers, who have been irrigating for an extended period, have a better understanding of irrigation and its limitations, and was generally more willing and prepared for the trialing and evaluation of new irrigation technology like the implementation of irrigation scheduling. New farmers to irrigation development should first be helped to become accustomed to the "new farming system" before they could be introduced to irrigation scheduling principles. Many of the small-scale farmers often lack the necessary knowledge and experience related to the basic principles of cultivation and production of crops. Farmers need to understand the basic functioning of a plant and the important dynamics between climate,soil and plant systems.
- In Nkomazi the general absence of stakeholders and inappropriate participation by farmers caused many problems regarding the role that extensionists and experts from the sugar industry can play in the training of and support to farmers. The latter especially refers to the many landowners found at Nkomazi who are staying in Johannesburg and Pretoria, and who rely on their family to manage and irrigate their lands.
- 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 institutionalizing and establishing of farmer representative bodies, like for instance the Farmer Support Units found in Taung, commodity groups in Tshiombo and the block committees operating on the Bethlehem project. Farmers need to perceive the support from advisors and extensionists as temporarily, and to develop the necessary urgency and motivation to be capacitated and empowered through the regular interaction between farmers and extensionists. This study again confirmed that small-scale farmers do not operate in isolation, but rather in a social and business relationship situation in which individual's position is progressively influenced as a result of others.
- Effective extension support by enthusiastic and committed extensionists is a prerequisite for sustainable small-scale irrigation development. Small-scale farmers need intensive extension support to overcome their relatively lower managerial capacity. Small-scale farmers in general need extension support to inform them about new innovations and practices and assist them to become "aware" of the potential use thereof.
- 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 require people with the necessary skills and knowledge to help and support farmers. Extension officers should

be equipped with the necessary skills and knowledge to play an efficient facilitators' role in starting of a dialogue with farmers and to listen sympathetically to what farmers have to say.

- 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 curriculums and training manuals be developed to support extensionists and advisors with the training of farmers. The innovation processes of new irrigation scheduling techniques with its three main components (creating a technique, disseminate 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 distribute them and farmers to adopt them. 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.

CHAPTER SIX: How farmers learn about irrigation scheduling practices

INTRODUCTION

Today, more than ever, a wide range of information sources on new innovative irrigation practices is available to farmers. The science of irrigation scheduling has a long, illustrious pedigree and a large number of methods and models have been developed to determine when crop requires water, and how much irrigation needs to be applied as indicated in Chapter Two. Studies however, have indicated that farmers do not make use of scientific tools as expected. 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).

Information sharing and dissemination through agricultural extension has been inadequate in the past because irrigation departments have not been effective extension units (Shearer, 1987). Furthermore, information left sitting idle in research centers because of inappropriate information dissemination strategies (Malton *et.al*, 1984). The obstacle has often been the communication gap between researchers and extension personnel on the one hand and farmers on the other. The contention is that the existing communication gap emanates not so much from the language or cultural differences but rather from the methods employed for dissemination of agricultural information.

Irrigation farmers access various sources of information and belong to various information networks, which include both formal and informal information networks. The quality of information networks between stakeholders (researcher, extensionist and farmers as part of the agricultural knowledge triangle), and their means of accessing outside information are important adoption factors. Farmers generally use three categories of information sources namely: interpersonal sources, mass media and interactive electronic information systems like computers, videos, etc. Rogers (1983) 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", was recognized since the early 1980 (Rogers, 1983). The need to determine how different irrigation farmers are learning and how they perceive the present information sources at their disposal is imperative for the planning and implementation of future communication strategies as well as to understand the process of change.

DECISION AND SUPPORT SYSTEMS TO IMPROVE THE IMPLEMENTATION OF IRRIGATION SCHEDULING PRACTICES

The findings of this study reveal that individuals will approach problem solving and learning in different ways, depending on what is effective for them. The process of introducing an irrigation scheduling method into the farmers' psychological field or life space requires an appropriate support and communication structure between researchers, irrigation system managers, extensionists, consultants, advisors and farmers.

To assist farmers with the decision making and implementation of irrigation scheduling, the following support and information sources have been identified (Figure 6.1):

1. Private irrigation consultants
2. Cooperative extension officials
3. Representatives of seed, fertilizer and pharmaceutical companies
4. Fellow farmers or the farmer himself.
5. Extension officers from the Department of Agriculture and officials from Department of Water Affairs
6. Farmer study groups and growers' societies like the avocado, banana, and table grape grower's societies.
7. Representatives and advisors from irrigation companies.
8. Commodity institutions or industry specialists like for instance Vinpro (KWV), Cape span (citrus and deciduous fruit), SASRI (South African Sugar Research Institute), etc.
9. Irrigation board scheme or Water Users Association officials.

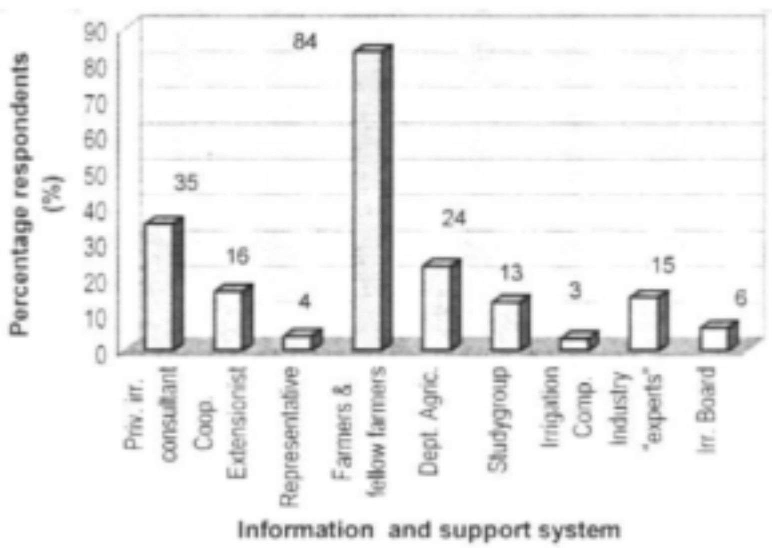


Figure 6.1 Distribution of respondents according to their use of various information and support system regarding irrigation scheduling (N=297).

Figure 6.1 shows that the majority of farmers (84%) depend on their fellow farmers, themselves or the study groups that they belong to, for support regarding irrigation 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 knowledge of their own farming situations through close observations of the changes on the farm over many years. 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. This is an important step underlying the process of technology adoption decisions.

Farmers also seek advice from fellow farmers, perceived as "opinion leaders" by their fellow farmers. The respondents perceive these "opinion leaders", usually experienced and relatively progressive irrigation farmers as important sources of information and learning. Many young farmers also referred to the potential "mentor role" that some of the experienced fellow farmers play regarding irrigation scheduling, decision-making and management. This acknowledgement of the value of "farmer knowledge and experience" and the interaction between farmers of a community, contribute to the building of social capital of a community which plays an important role in the dissemination of information, learning outcomes and interaction that takes place. The distance between "opinion leaders" and potential adopters as well as the frequency of contact maintained between the different parties is likely to influence the potential rate of adoption. The higher the frequency of contact between the opinion leader and the potential adopters, the more likely it was found that the potential adopter will benefit from the information, improve his/her skills and also reduce uncertainty about the new technology.

Respondents were asked to rate the importance of fellow farmers' knowledge and opinions for decision-making in irrigation scheduling on a ten- point scale. The majority of respondents (90%) regarded information shared and collected from fellow farmers to be very important, and this information source (Figure 6.2) was awarded a mean rating of 7.2 on a semantic scale.

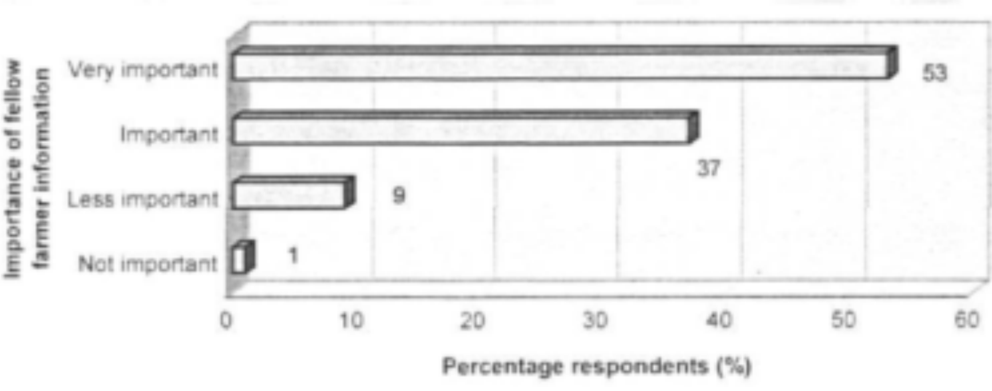


Figure 6.2 Perception by respondents of fellow farmers as an important information source for irrigation scheduling (N=134)

The services of private irrigation consultants and/or other professionals from the cooperatives and industry operating in the area are often use in cases where farmers apply computer models and/or highly sophisticated scheduling devices like the neutron probe, etc. Many farmers identified the important roles that study groups and commodity institutions like Cape span, Vinpro, and SASRI play in the learning and support rendered to farmers with irrigation scheduling. A general tendency that occurs is that "new farmers" in irrigation are more prepared to rely on the support and advice of industrial experts and/or consultants than on opinions shared by fellow farmers. The valuable input received from irrigation consultants and industrial experts was acknowledged especially during the initial phases of irrigation farming. In this study, "industrial experts" refers to professionals that belong to a specific commodity or industry i.e. deciduous fruit, sugar, wine cellars or citrus.

Farmers draw from a range of sources in their learning about irrigation management and scheduling, and possible changes in irrigation management is likely to be influenced by a number of information sources. Informal interaction and networking in study groups, farmer groups and between farmers was found to be very important in farmer learning. These interactions usually provide farmers with an opportunity to compare views on how information could be applied to their own situations and to tests each other's opinions and attitudes before making decisions. The differences in the use of the various information and learning sources by the five different irrigation-scheduling groups are expressed in Table 6.1.

Table 6.1 Distribution of respondents according to the use of different support and information systems and percentage use of irrigation (N=297)

	% Implementation of irrigation scheduling					**Total**
	0- 20% **(n=165)**	**21- 40%** **(n=28)**	**41- 60%** **(n=30)**	**61- 80%** **(n=12)**	**81-100%** **(n=57)**	
Information/support system	%	%	%	%	%	%
Irrigation company	0.6	4	17	0	4	3
Study group	7	2	47	25	9	13
Farmers & fellow farmers	93	82	53	92	79	84
Cooperative extensionist	10	1	27	50	23	16
Private consultant/advisor	26	57	70	58	32	35
Representatives (seed, fertilizers, agrochemical companies)	5	0	3	8	4	4
Irrigation board/WUA	5	4	7	33	5	6
Department of Agriculture extensionists and DWAF officials	31	18	23	0	12	24
Industry extensionist (Vinpro, Capespan, SASRI, ARC Nietvoorbij)	13	32	40	8	5	15

Private consultants and cooperative extensionists are the main sources of information used by commercial irrigation farmers. Amongst the small-scale farmers, government or departmental extension officers are the most frequently used sources. Of the 51 small-scale farming projects involved in the survey, a relatively small percentage (14%) referred to alternative interactions, which included contact with private industry experts, while the majority of the small-scale irrigation schemes depended upon support rendered by governmental extension officers. A significantly negative relationship was found between the scheduling figure reported and the use of departmental extensionist ($r=-0.254$, $p<0.05$). This implies that the majority of small-scale irrigation schemes included in the survey revealed a very low percentage of scheduling implementation. The reason for this was that in the majority of cases, the reported figure of scheduling reflects the opinion of an official responsible for extension or development of the particular scheme rather than that of the small-scale farmers.

During the interviews, farmers identified the unavailability of appropriate technical support from research institutions in certain commodities like subtropical fruit and citrus as being problematic. In these industries, farmers overcame the constraints through the establishment of respective growers' societies and study groups *viz* avocado, banana, mango and citrus. Some of these "interest specific groups" also appointed their own advisors to support farmers with different production aspects, which also includes irrigation management and scheduling.

In some irrigation areas where local cooperative and private consultants are not rendering irrigation scheduling services and support, farmers rely on the support and consultation from representatives of fertilizer, agrochemical and seed companies. 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 linkages with the "outside world". For many farmers this is their only link with what is happening on the neighbouring farms. Usually a "recipe" or fixed irrigation calendar based on crop growth stage and the number of days after sowing or planting is offered to farmers rather than an irrigation calendar that takes the phenological stage of the crop into consideration.

Farmers approach problem solving and learning in different ways, according to the different styles of farming (Vanclay, 2003). Some farmers prefer listening, others reading, others observing while others learn by doing *(experiential learning)*. Based on the different information and learning sources that irrigation farmers have at their disposal (Figure 6.1), farmers can be categorized into four different groups regarding the use of learning sources:

- *Localized information source:* This group of farmers makes use of fellow farmers, study groups, departmental extension officers, irrigation board scheme officials, water user association officials, local cooperative officials, local field days and representatives of seed, representatives from agrochemical and fertilizer companies to acquire relevant information.
- *Specialist or expert advice information source:* This group of farmers' uses private irrigation consultants, specialists from the ARC, industry related expertise like SASRI, Cape span, Vinpro, professionals from universities or tertiary institutions, and representatives 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 differ in their preference either for formal or informal training opportunities. The majority of irrigation farmers interviewed prefer informal sources of learning mainly because they are familiar with them, and they can choose learning sources, which fits their specific needs and situation. 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 is an important source of informal learning:* The most important 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. Printed media as a source for increased awareness relating to a practice like irrigation scheduling is often used and acts as a stimulus for further discussion and debate between farmers.

It is of the utmost importance that clear and concise information on the costs and benefits of alternative irrigation scheduling methods are available. During the interviews farmers indicated irrigation scheduling to be time consuming and costly. "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 Table 6.1. Farmers often differ in the learning sources they access for learning.

Informal interaction with other irrigation farmers and social networks played a very important role in farmer learning. Such interactions provide opportunities for farmers to compare views on how information could be implemented within their own situation and to test each other's values and attitudes towards making changes based on the information. Knowledge gained from other farmers is very valuable because it is local and comes from direct experience and observation over time. Therefore, fellow farmers were cited as an important source of support and information for both learning for change and continuous learning. It was found that family members (i.e. father) often play an important role in decisions to be taken on the farm, which also includes decisions regarding irrigation scheduling.

Understanding the cognitive styles of individual irrigation farmers or the individual groups of irrigators can assist the extensionist or advisor to focus on the most appropriate means of offering the irrigation-scheduling package to farmers. Based on the response of respondents about the information or learning sources they accessed regarding irrigation scheduling, four learning pattern groups of farmers could be identified:

- Farmers who do not rely on additional information regarding irrigation scheduling on the farm.
- Farmers that regularly use at least another learning source before decisions are taken on irrigation scheduling.
- Farmers that consult at least two additional information sources regarding irrigation scheduling, before changing or making decisions regarding irrigation scheduling.
- Farm businesses that use three or more additional learning sources before decisions are taken regarding irrigation scheduling.

Figure 6.3 reflects the degree to which farmers use a multitude of sources in the application of irrigation scheduling.

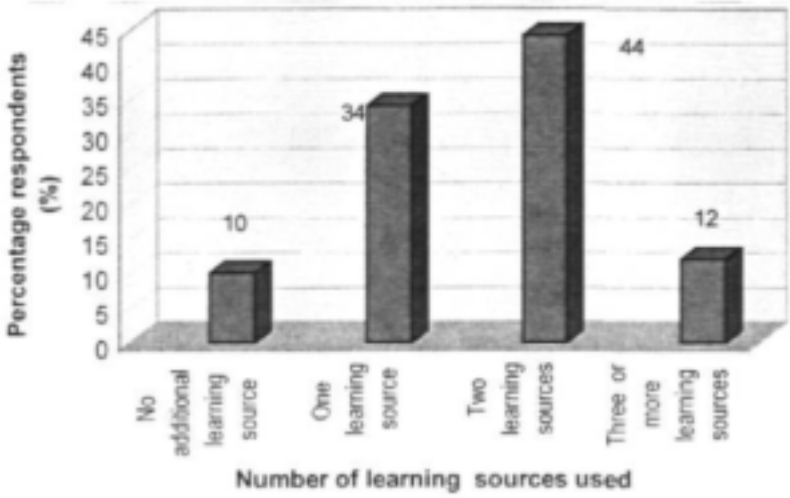


Figure 6.3 Distribution of farmers according to their use of multitudes of learning sources (N=134)

It is clear from Figure 6.3 that the majority of farmers (90%) are making use of one or more additional learning sources, while 10% indicated that they rely only upon themselves for decision-making regarding the application of 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 ($r=-0.17$, $p>0.05$). It was also found that as the size of irrigation area increase farmers are generally more prepared to use additional learning sources ($r=0.23$, $p<0.05$). The level of education of farmers also played a role regarding preparedness to their use of additional learning sources for decision-making regarding irrigation management. Farmers with college and university training, in general were more prepared to make use of additional learning sources, while farmers with a matric qualification often rely on their own experience and knowledge gained over the years.

Figure 6.4 highlights the interrelationship between the number of learning sources used by farmers and the implementation of objective and subjective irrigation scheduling methods.

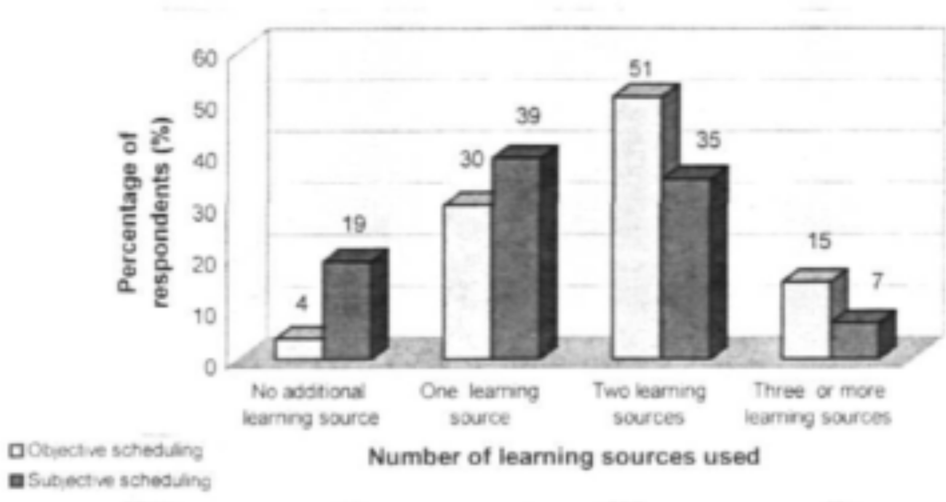


Figure 6.4 The frequency of learning sources regularly used by irrigation farmers and the interrelationship with the application of irrigation scheduling (N=134)

A statistically significant correlation was found between the number of information sources used and the implementation of the type of irrigation scheduling methods (X^2=8.90,df=2,p=0.012; Gamma = 0.445, p=0.004). This implies that farmers, who apply objective irrigation scheduling methods, are more inclined to use more than one information or learning source. Irrigators involved in the application of subjective scheduling methods are more willing to rely on personal experience and perhaps one additional source of information, usually within the boundaries of a specific irrigation area ("localized knowledge"). These findings also proves that it will be incorrect to believe that "science" does have automatic credibility, and legitimacy, but rather that farmers create their own knowledge through external information networks, trialing and experimentation. Farmers will only use scientific knowledge when it is consistent with their own understanding.

These findings also support the general expectation that the technology level of the farmers and their approach to management determines their choice of the irrigation scheduling method selected and eventually the number of learning sources that need to be used. Farmers that make use of objective irrigation scheduling methods are more willing to rely on the support from professionals like irrigation consultants and advisors invariably high technology information sources and/or weather data for decision-making. Furthermore, these farmers are more prepared to make contact with a multitude of learning sources as indicated in Figure 6.4. However, farmers that are not involved in the production of high value/high input crops will most probably use fixed pre-scheduled irrigation programs based on experience or supplied by some institution or fellow farmer, with little or no objective monitoring of soil moisture or soil water balance. Therefore, this category of farmers is often satisfied with limited outside contact, and rather prefers to rely on local expert knowledge.

From interviews held with farmers it is clear that different farmers require a greater or lesser number of observations of success by other farmers, before they are prepared to test an innovation or new technology like objective scheduling. Factors like the availability of information, the perception of the possible monetary value of the new technology and the fact that farmers put different social status values on being seen as innovative, play an important role in the adoption process.

THE RELATIVE ROLE OF PRIVATE IRRIGATION CONSULTANTS AS A SOURCE OF LEARNING

Thirty-five percent respondents identified experts of industries and private irrigation consultants to play an important role during the start-up of an irrigation enterprise and during the initial learning stages. The level of farm management and technology needed on the farm dictated the need for expert irrigation advice and the support needed from private irrigation consultants. In cases of relatively higher levels of irrigation and farmer management, the advice of the consultant and experts were commonly perceived as complimentary or additional to the farmers' viewpoint in decision-making regarding irrigation scheduling. Farmers with a relatively low level of irrigation management on the other hand tend to rely mainly on their own intuition and experience as gained in the field. This tendency is supported with findings from a study amongst some of the small-scale farmers where the wetting front detector was introduced as an irrigation-scheduling tool. These small-scale irrigation farmers were depending on "outside" information for irrigation management due to the lack of knowledge and experience existing amongst the local extension personnel (Stirzaker, *et al.*, 2004).

The role and importance of irrigation consultants for decision-making was tested in the survey, and Figure 6.5 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 especially during the initial stage of irrigation farming or when changing to another enterprise.

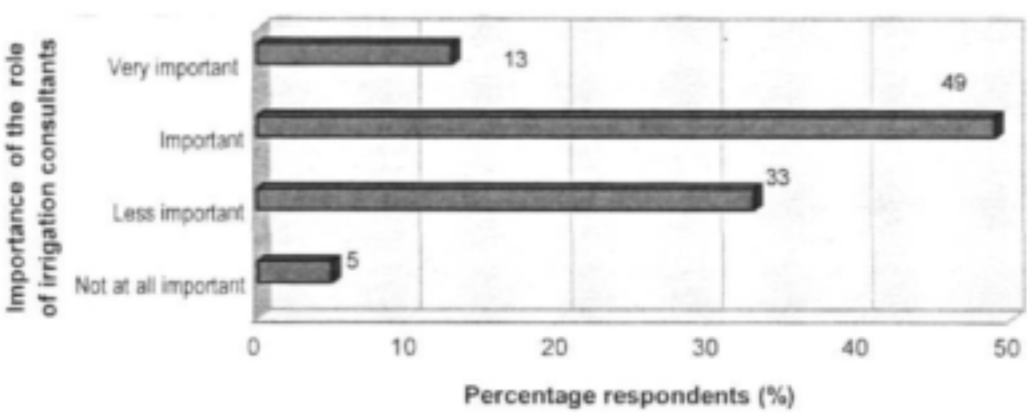


Figure 6.5 Percentage distributions of respondents according to their assessment of the importance of irrigation consultants as information source for irrigation scheduling (N=134)

To work successfully with irrigation farmers, extensionists and advisors should respect the skills and knowledge of farmers. They must be prepared to acknowledge the skill, knowledge and experience of farmers instead of expecting farmers only to be reactive. The credibility and competency of the extensionists and advisors as perceived by respondents are very important for the successful application of a new irrigation scheduling practice or method. Many farmers were only in a position to refer to a person, extensionists A or consultant B's programs, without even knowing what specific program the person was using and what the program entails. The importance of trust and credibility of the person responsible for support ("jockey") with irrigation scheduling was emphasized more than once.

The following attributes of an irrigation consultant and advisor are according to respondents very important in the building of trust, credibility and the delivering of an effective irrigation scheduling service (Table 6.2).

Table 6.2 Respondents' perception of the critical attributes expected of the irrigation consultant and/or advisor (N=134).

Attributes of irrigation consultants	Number of respondents	% 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

The following attributes of advisors and extensionists as identified are critical for the building of trust and credibility between the two parties:

- The first qualification farmers expect of irrigation consultants is *experience and competency in the irrigation area (42%)*. The consultant must have both educational and practical knowledge of the irrigation system operation and management, which includes irrigation scheduling. Farmers perceive this attribute in general as an important basis for the building of long-term 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 consultants. However, 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. In conjunction with integrity, farmers perceived this as an important basis for the building of trust.
- *Timely, focused information (35%):* In general, there is an expectation that the consultant/advisor should be able to understand the bigger picture. An advisor /consultant should be able to see what innovations or practices are on the horizon, keep the farmer informed of these as they emerge and as they are appropriate to the farming system of the farmers, and be sensitive to timing. Many farmers acknowledged this attribute as the biggest advantage of irrigation consultant or extension services.

- *Integrity and credibility (28%):* Advisors are expected to be unbiased, trustworthy, maintain confidentiality, and be reliable. Integrity of a person was identified to be of utmost importance for the building of a sound relationship.
- *Understanding the context (18%):* It is important that the irrigation consultant /advisor must be well informed about 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 style of a specific farmer. The consultant/advisor must also understand the social norms and values as applicable for the specific farmer, and recommend practices that are feasible in terms of the specific farmers' economic, social and environmental context.
- *Ability to communicate effectively and interpret measured data (13%):* Firstly 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 interpret the data they have measured because of their formal training (either insufficient or inappropriate). Because irrigation scheduling is about providing information concerning a living, dynamic ecosystem, knowledge and experience in agronomy, soil physics, climate and the interaction of these elements are required. In the second place, 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.
- *Availability, empathy and interpersonal sensitivity (11%):* T he ability and availability of advisors 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 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 should be able and prepared to learn from each other and from the farmer as well. Advisors 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 force the technology down upon farmers, without adopting a participatory approach in this regard.

PERCEPTION OF THE POTENTIAL ROLE THAT WATER USER ASSOCIATIONS COULD PLAY REGARDING 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 play an important role to raise awareness amongst farmers regarding alternative practices and enabling them to adopt such practices.

The WUAs should be organized to play an important role in the raising of general awareness amongst the irrigators for the possible benefits (relative advantages) as well as the risks associated with the implementation of certain irrigation practices. The perception of respondents regarding the possible role that WUAs could play in this regard was tested on a ten-point semantic scale (0= not important; 10= very important) and is illustrated in Figure 6.6.

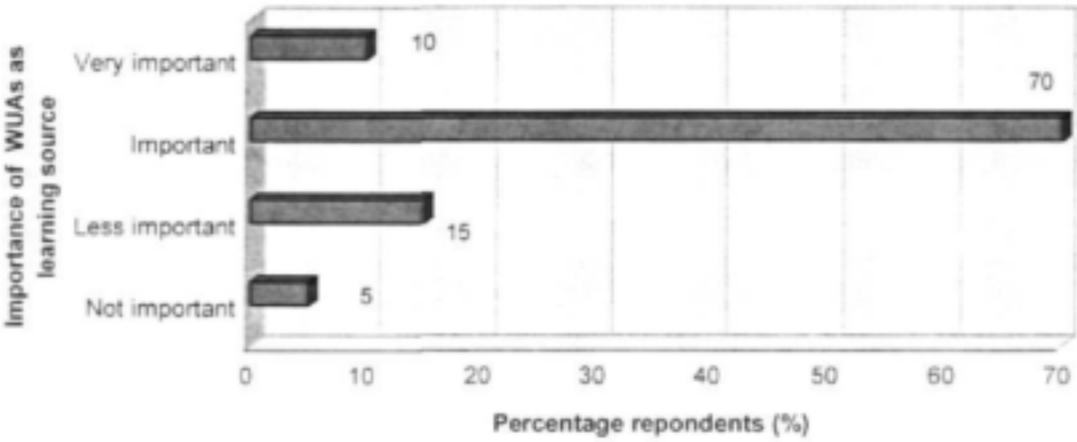


Figure 6.6 Percentage distribution of respondents according to their assessment of WUAs potential role in the awareness promotion of irrigation scheduling practices (N=137)

The majority of respondents (80%) were of the opinion that the WUA could and should play a more definite role in the adoption process of irrigation scheduling and efficient water use on the farm.

CONCLUSION

In conclusion, it was found that farmers use different learning sources 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.
- 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 number of information sources used and the application of the type of irrigation scheduling methods ($X^2=8.90$, $p<0.05$). This implies that 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 technology level and approach to management by the farmer determines the choice of irrigation scheduling method selected and eventually the information sources used.

The irrigation farmers identified desirable attributes of extensionists, consultants and advisors like credibility, integrity, technical competence and effective communication to mention a few to play a crucial role in the uptake of information concerning new irrigation practices and technology. The majority of respondents (80%) are of the opinion that institutions like the WUA can play an important role in raising awareness amongst farmers for the application of efficient irrigation management practices, as well as irrigation scheduling.

CHAPTER SEVEN: Conclusions and Recommendations

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 the irrigation farmer 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 intuition, which is based on own 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 superficial 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). This gap of discrepancy between what science has to offer as a solution and what farmers expect and need or what they regard as appropriate represented the focus of this investigation. This study indicated that the perceived inappropriateness is related to the risk and management complexity associated with.

The following conclusions and recommendations based on the outcome of the study should serve as general guidelines for the improved diffusion and implementation of irrigation scheduling among irrigators.

CRITICAL FACTORS THAT INFLUENCE THE ADOPTION OF THE IMPLEMENTATION 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, experience and observation in following "a programme 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.

The general tendency among agricultural scientists is to regard only empirically knowledge or based on "science" as being valid, and thereby often ignores knowledge based on farmer experience and which is compatible with the specific needs and situation of the farmer. These differences regarding the definition of irrigation scheduling was 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 production of high value crops are more prepared to make use of objective irrigation scheduling because of the large scope of perceive 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. 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. For many tactical decisions the response curve is steep and then flat. When the farmer is still on the steep slope of the curve, 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, there may be less to be gained from implementing precise accurate irrigation scheduling with detailed simulation models. Farmers in general are risk averse, and will therefore opt for insurance irrigation whenever possible.

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, which refer to decisions taken everyday, 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 referred to imply 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 decisions to be taken 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.

However, 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. It is likely that the educational system responsible for the training and preparing of students to take up these 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.*

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 curriculum offered in irrigation management at these tertiary institutions should be evaluated and shortcomings identified and addressed where possible.

4. Cost of irrigation scheduling

Irrigators perceive the implementation of objective irrigation scheduling methods as time consuming (50%) and costly and not practical enough for implementation on the farm (65%).

Therefore many irrigators do not perceive enough benefits 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 sophisticated irrigation scheduling methods tend to be more evident to producers of high value and intensive crops. The improvement of crop quality and efficiency of nitrogen and nutrient management 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 (maize, wheat, cotton, etc), the possible financial advantages are not always evident and therefore these farmers generally are more willing to follow a fixed or semi-fixed schedule for irrigation.

There is a great need that the risk that irrigators are prepared to take with the use of sophisticated 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 farmers involve in the production of pastures that raised certain concerns regarding the implementation of objective irrigation scheduling methods. Pasture farmers are concerned about the fact that there is a general lack of simple, practical way of keeping track with the soil water content changes that are taking place in the shallow root zone of pastures. Therefore, for many of the pasture producers in the country 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 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" 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 "sold" 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 application 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 make 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. Role of WUA regarding the adoption of irrigation scheduling
The fact that 96% of the respondents also regard the implementation of irrigation scheduling by there 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 needs. 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 in the adoption process of irrigation scheduling and 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. Also the necessary support (technical and managerial) and general awareness should be offered through efficient communication between the WUAs and irrigators.*

A practical example is the role that the water authorities in Hermanus played during the early 90's as indicated in Box 7.1.

Box 7.1: 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 of the 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 majority of irrigators still rely on intuition or paper and pen for making irrigation scheduling decisions.

From the responses received it is clear that computer irrigation scheduling models and programmes are too complex or difficult to be used by the majority of farmers without the necessary support of extensionists and irrigation consultants. This results in irrigation scheduling models and programmes being predominately advisor-driven rather than farmer-driven, and result in their distribution largely being geographically bounded. The majority of irrigation scheduling models available to farmers require certain levels of skills, access to computers, computer literacy and easy access to weather data.

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.

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. Only through effective dialogue between farmers and the professionals responsible for the support, will it be possible to identify the real needs of farmers (felt and unfelt) and unlock the local knowledge and intuition of the farmer.

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 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 measure the distribution of uniformity. 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.18% 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 irrigation management.

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. *Reliable and accurate flow meters should be identified and put into operation as soon as possible. The findings of a WRC research project on the evaluation of different flow meters available for the irrigator will soon be available. Important in this regard is that this device should be accurate and the users should trust the readings, which are generated.*

The use of volumetric measurement will mean that irrigators pay in proportion to their use of water services. A visible and simply 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 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 communicate effectively and interpret measured data; 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. 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 representatives from supplier companies are responsible for supporting commercial farmers with information regarding irrigation management. 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 as very important in the building of trust between parties, as well as to be assured of the current trends of soil water balance in the field.

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 agricultural technologies have and continue to derive great benefits for the private sector, public sector research and technology transfer institutions have failed to provide small-scale farmers with appropriate technology to meet their needs. Although this relationship between research, extension and farmers seems ideal in theory, it has not been successful in many parts of the world. 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 research organizations (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. Essential to the partnership is ownership by all stakeholders of the learning and sharing paradigm. Important is that each of the partners must be committed to the learning and the sharing paradigm. This partnership entrenches the importance of mutual or co-learning that exist between stakeholders. 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 education and training effective for adult learners. These networks and interaction between individuals and between individuals and groups build social capital, which is important for the process of learning.

Therefore the following actions are important:

- *Establishment of well-organised and well-facilitated farmer directed groups.*
- *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 proceeded through the learning process of evaluation, trialing, 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 seven 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 a computer 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. 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 experience, and knowledge gained. The more experienced farmers often only use the objective irrigation scheduling methods as a monitoring system to re-assure themselves that they are still heading in the right direction. If necessary they will revisit the irrigation scheduling practice, which they have adopted. *This "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. 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.*
- *Quantifying more accurately the various behaviour determinants in order to the degree to which individual critical advantages, in comparison to a cluster or multitude of them, explain 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, this group of farmers give 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. *Extensionist 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 Two 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.

SERVING THE SMALL-SCALE IRRIGATION FARMERS

There is no disputing 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*

Extension is responsible for the simplifying of research information and delivering it to the farmer in an effective and easily understandable manner. Also extensionists should be able to play an important role in giving feedback to researchers on the problems generally faced by small-scale farmers. Therefore an interdependent partnership of researcher-extension-farmer should be developed.

2. *Sharing of irrigation equipment like the 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. 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. External management of an irrigation scheme
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.

4. 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.*

5. 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.*

6. Ageing and maintenance of infrastructure
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 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.*

7. 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.*

8. 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.

9. Effective extension support by enthusiastic and committed extensionists is 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 to organizing 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.*

- *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.*

10. Experiential learning or "learning by doing" approach

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.

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CAPACITY BUILDING

Capacity building forms an integral part of this project, and the number of contacts made and interviews conducted since the start of the project inevitably brings about changes in people's behaviour and perception. Numerous interviews and discussions amongst the irrigators, advisors, extensionists and consultants and the project team members took place in various irrigation areas of the country and served as a basis for communicative learning and dialogue.

The capacity building that took place during the project period was mainly done at three different levels:

- The first level was the general attitude towards the application of irrigation scheduling. Through the numerous interviews, discussions, and dialogues with people at various levels within the project, awareness was raised of the importance of irrigation scheduling and efficient use of water on the farm. Members of the project team and students of the University of Pretoria, farmers and many professionals in the irrigation industry have acquired knowledge, and understanding of the social, cultural, economical and technological constraints of farmers, which may determine the adoption, or rejection of irrigation scheduling practices.

  The close and intensive interaction and involvement with small- scale irrigators on the irrigation projects namely Driekop (Maputlesebope, Arethuhareng & Moroke), Louw's Creek, Boschfontein, Figtree, Tshiombo, Taung, Bethlehem Apple Project and Elandskraal provided the opportunity for stakeholders to benefit directly through their participation in the project. Small-scale farmers and food plot growers benefit by the increase in awareness of alternative irrigation scheduling approaches, learning of irrigation scheduling and even receive technical irrigation advice as they participated in the project.

  As a result of the number of interviews conducted with commercial farmers of the various selected research areas included in the study, many farmers have become aware of what irrigation scheduling really entails. They have also been reminded of the importance of the regular maintenance of their irrigation systems and the use of rain gauges, etc. The opportunities are dependent upon the willingness of the farmer and the enumerator to gain from such an experience and thereby build capacity.

- Personal enrichment and gaining of practical experience: Over the three year period the research team, students and extensionists have gained tremendously in terms of practical experience and technical knowledge from the many interactions and interventions with small-scale and commercial farmers. These research opportunities in the field have provided research institutions like University of Pretoria with some insight into the "world of the farmer", and also to appreciate the importance of knowledge and experience of the irrigation farmer in the management of irrigation. Lessons learned in the field were often relayed back to the classroom and some have been added to the textbooks and also included in the curriculum offered.

- Two students were targeted for post graduate studies in this project:

  - Welbelovered Marobane was enrolled for an M Inst Agrar. Degree in Extension at the University of Pretoria. The aim of his study was to determine the general perceptions of food plot farmers regarding the application of irrigation scheduling. He also investigated whether the wetting front detector as a new irrigation scheduling tool, helped small-scale farmers at Driekop, Limpopo to improve their decision-making regarding irrigation applications. The general perceptions of farmers regarding this study were collected by means of a survey conducted at Maputlesebope, Arethusaneng and Moroke food plots in Driekop. Trained as an Animal Scientist, this student gained tremendously in terms of knowledge, skills, and competence in the practising of irrigation and irrigation scheduling.

  - Joe Stevens registered for a PhD at the University of Pretoria in Extension, will incorporate much of the data collected in this project to complete his studies.

- Ronald Phaswane, a final year student enrolled for a B Inst Agrar. Degree assisted with data capturing on the computer, and coding of the questionnaire.

Appendix A: Perceptions of the acceptability of irrigation scheduling at Driekop food plots (*Maputlesebope, Arethusaneng and Moroke*

INTRODUCTION

It is estimated that two thirds of the small irrigation schemes are allocated to food plot production for the purpose of subsistence production, and that approximately 2 400 000 rural people are dependant upon, at least partially, for a livelihood on such schemes (de Lange, 2004). Food plots are intended to enhance food security and provide some semi-economic activities for the residents. The total number of food plots in South Africa is not known, but there are a great many of them.

A food plot in a community garden is a small area (0.16-0.25 ha) that provides the holder with an opportunity to grow food for subsistence and a small cash profit (Loxton & Venn, 1983 as cited by van Averbeke *et al*, 1998). From this definition it is clear that the intention with the introduction of the food plot concept was to produce crops that generate cash income, whereby the cash income generated could be sufficient to pay for all production costs and in addition provide the farmer with a small profit.

A variety of irrigation technologies are employed on these community gardens. These include buckets used to irrigate directly from a tap stand or borehole, as well as short earth furrows and basin irrigation. Some gardens have pumping equipment and the water is pumped either into a reservoir or directly into a distribution network of pipes and tap stands. Furrow irrigation is widely used on many of the community gardens and this system, according to Crosby *et al* (2000), works well, although alternative methods need to be developed to limit water loss from supply furrows in low-clay soils.

Three food plots in the Driekop area (between Burgersfort and Polokwane), in Limpopo Province were selected as part of the post graduate studies by Mr. Marobane, a post graduate students in Agricultural Extension. The three food plots namely: *Maputlesebope, Arethusaneng and Moroke* were selected for the testing of farmers' perception regarding the adoption of irrigation scheduling and for identifying possible constraints that could prevent farmers from sustainable use of irrigation scheduling approaches on the food plots. The characteristics of the three projects are shown in Table A.1.

Table A1 Characteristics of the three foods plot projects in Driekop, Limpopo

	Maputlesebope	Arethusaneng	Moroke
Number of farmers	40	41	184
Size of project (ha)	1.2	2	5.6
Source of irrigation water	Dilokong Chrome Mine	Borehole	Canal from the Motse river
Method of irrigation	Bucket system, short furrow system	Hosepipes and bucket system, short furrow	Short furrow irrigation
Energy source	No electricity	Diesel	Gravitation
Crops produced	Vegetables	Vegetables	Vegetables
Soil types	Red, well drained, SaLm	Black to dark greyish, Clay	Black clay, calcareous, reddish brown, SaCl Lm

The main vegetable crops that are produced on the different food plots include cabbages, onions, tomatoes, beans, spinach and sweet potatoes. The food plots were generally sited on good irrigable soils, and no limitations were identified.

The majority of the farmers at Maputlesebope are women and although boreholes were drilled to supply water to the project, no electricity supply is currently available. Farmers are therefore receiving irrigation water from the Dilokong Chrome Mine nearby free of charge. At the Arethusaneng project all the farmers are women and, due to the remoteness of this project, the vegetable production plays an essential role in the supplying of fresh vegetables. Irrigation water is pumped from a borehole and farmers are collectively responsible for the costs of diesel needed to pump the irrigation water. These direct costs that are involved in the pumping of irrigation water also contribute towards making this group of farmers more aware of the costs involved in irrigation. According to the local extension officer, many of the farmers are guilty of under-irrigating rather than over-irrigating.

The irrigation water at Moroke is supplied through a canal from the Motse River free of charge. Seven different farmer groups are actively engaged in farming in the Moroke area, and the seven farmer groups are also linked with the seven different villages to be found in the area. A full-time appointed extension officer is responsible for this project, which was established on land previously used for sisal production.

IRRIGATION SCHEDULING METHODS

In general farmers on these food plots are experiencing relative poor irrigation infrastructure and some farmers even relying on water obtained from nearby schools to water their gardens.

Table A2 Frequency of irrigation methods used by the respondents (N=50)

Irrigation method	Number of respondents	% Respondents
Furrow irrigation	22	44
Hand water (hosepipe & bucket)	18	36
Furrow and handwatering	10	20
Total	**50**	**100**

Forty-four (44) percent of the respondents indicated the use of furrow irrigation, while respondents from Maputlesebope and Arethusaneng reported the use of mainly hand watering systems. All of the farmers are irrigating food plots on a daily basis, and one of the problems that farmers identified, was the difficulty experienced in estimating the accuracy of application of water for a specific crop. Therefore, over- as well as under-irrigation is a common occurrence. The majority of respondents (93%) are irrigating on a specific allocated day as allowed, while 7% respondents indicated actually measuring the number of buckets used to fill the furrow. In Moroke it was found that farmers followed a specific timetable according to the seven villages or groupings of farmers to ensure equal opportunity to every group for irrigation.

Farmers in all three projects were not using any objective irrigation scheduling method before the introduction of the wetting front detector during 2002. The majority of farmers on the Maputlesebope and Arethusaneng schemes followed a fixed schedule of watering every day, by filling the basins or furrows as applicable.

INFORMATION SOURCES

Each of the three food plots has its own management committee that is responsible for the handling of organisational and production matters, keeping records and support farmers to explore possible marketing opportunities. The extension officers are members of the management committee and play an important role in the dissemination of information and also act as an important link between the farmers and the Department of Agriculture of Limpopo.

Farmers were asked which information sources they usually contact to guide them in their decision making regarding crop production, marketing strategies and irrigation management. The various information sources consulted are indicated in Table A.3.

Table A3 Information sources used by respondents for crop production, marketing and irrigation management in Driekop (N=50)

	Crops			Markets			Irrigation scheduling		
Information source	Maput. (N=15)	Arethu (N=15)	Maroke (N=20)	Maput. (N=15)	Arethu (N=15)	Maroke (N=20)	Maput. (N=15)	Arethu (N=15)	Maroke (N=20)
	%	%	%	%	%	%	%	%	%
Management committee	13	13	5	0	7	0	27	13	10
Local extension officer	13	47	95	53	60	60	47	0	5
Farmers themselves	27	0	0	13	13	10	7	80	80
Group discussions	47	27	0	34	20	25	0	7	5
Group discussion & extension officer		13	0	0	0	5	20	0	0
Total	100	100	100	100	100	100	100	100	100

From Table A3 it appears that the majority of farmers rely on the local extension officer to supply them with the necessary information on crop production, and market information.

However, as far as irrigation scheduling is concerned, the majority of farmers rely on their fellow farmers or themselves for decision-making. Exceptions are the Maputselebope farmers, who rely primarily on the local extension officer. This finding confirms the general observation made by Bembridge (2000), namely that the majority of extension workers working in small-scale irrigation areas are usually lacking the necessary knowledge and skills in irrigation farming, and therefore are not in a position to support small-scale irrigation farmers.

Photo A.1 The extension officer plays an important role in the dissemination of new information through well-organized farmer groups

BARRIERS AND CONSTRAINTS AS PERCEIVED BY RESPONDENTS FOR THE ADOPTION OF IRRIGATION SCHEDULING

Water availability and competition for water were two aspects that were often raised by farmers that withhold them from impelementing irrigation scheduling methods.

Table A4 Perceptions of the constraints and problems that influence farmers in their application of irrigation scheduling in Driekop (N=50)

Constraints	Maputlesebope (N=15)	Arethusaneng (N=15)	Maroke (N=20)
Water availability	100	53	20
Competition for water	0	47	80
Total	**100**	**100**	**100**

Water availability and distribution of irrigation water at peak times are perceived as constraints in Maputselebope and Arethusaneng that prevent farmers from implementing objective scheduling methods. The Maroke farmers identified competition between farmers for irrigation water as a major constraint.

Other findings regarding the acceptability of an irrigation-scheduling device like the wetting front detector are the following:

- A general unwillingness to test the wetting front detector.
- Farmers who are not incurring any costs in getting water are more reluctant or resistant to adopt (Moroke) the use of objective scheduling methods.
- Perceptions in terms of possible relative advantages are unfavourable.
- Farmers in very scarce water projects are not very willing to make full use of the device since it forces them to put extra effort in increasing their irrigation water. (Maputlesebope)
- Farmers in general are hesitant towards showing interest where the extension officer is not aware of the new technology. (Maputselebope & Moroke)

PERCEPTIONS OF RESPONDENTS FOR THE ADOPTION OF IRRIGATION SCHEDULING

Relative advantages

Table A5 indicates the major advantages that farmers perceived by using the wetting front detector as an irrigation scheduling method.

Table A5 Percentage distribution of respondents on three projects according to their awareness of advantages of irrigation scheduling by means of the wetting front detector (N=50)

Perception of benefits or relative advantages	Projects		
	Maputlesebope (N=15)	Arethusaneng (N=15)	Moroke (N=20)
I cannot actually tell since it was not in my plot	13.3	6.7	10
I can save water	33.3	33.3	25
I am able to determine if sufficient water was irrigated	0	6.7	0
I can see some saving on diesel	0	6.7	0
I can see improvement on the yield	46.7	33.3	55
I think I am now applying more water than before	6.7	13.3	10
Total	**100**	**100**	**100**

According to the results indicated in Table A5, forty five percent of the respondents perceived an increase in the vegetable production while 31% of the respondents perceived saving of water as the major relative advantages. The seven percent respondents (from Arethusaneng) that perceived a saving in the use of diesel to pump irrigation water from the borehole were either members of the project management committee or were interacting regularly with the relevant extension officers. Some farmers (10%) also indicated a relative disadvantage in the use of the wetting front detector in that they perceived they were applying much more water than in the past before the WFD responded to an irrigation application.

Other related WRC reports available:

The development of an integrated information system for irrigation water management using the WAS, SWB and RISKMAN computer models

N Benadé; JG Annandale; NZ Jovanovic; JA Meiring; CI Crous

The development of an integrated information system using the Water Administration System (WAS), Soil Water Balance (SWB) model and RiskMan computer model is about further development and implementation of research from three different research projects (WRC Report Nos. 513/1/97, 753/1/99 and 894/1/02). All three models make extensive use of databases and the idea of this project was to consolidate the information into an integrated information system that links to a geographical information system (GIS).

The main aim of this project was to integrate the WAS, the SWB model and the RiskMan model in such a way that they can be used as tools on an irrigation scheme to:

- Minimise water distribution losses
- Maximise efficient water-use on farm level by means of irrigation scheduling
- Incorporate risk in crop- rotation and cash-flow planning.

The different model can be used alone or where necessary read information directly from the other models. WAS saves crop survey data that can be accessed by RiskMan. SWB can create simulated crop yield records that can be accessed by RiskMan. SWB can generate water request forms that can be used by WAS. Once a farmer has used RiskMan to decide on the best crops to plant, SWB can be used for the day-to-day irrigation scheduling.

The geographic information system (GIS) was developed and implemented successfully at the Loskop and Orange-Riet Irrigation Schemes. The canal networks of both schemes are captured and it is possible to query the different databases and display the information on the GIS map. This map consists of different layers that can be enabled or disabled depending on the amount of detail the user wants to see. The layers that were created for both schemes are a canal network layer, a farms layer and a river layer. The user can add additional layers and edit the objects on any layer such as lines, areas and points. The GIS program has a built-in help file that gives the basic information on how to operate the program.

Although the project team did not implement all the modules of the integrated information system on both irrigation schemes successfully, it managed to transfer new technology to both the schemes that will definitely grow and make a difference in their daily operations. Some of the technologies are new and it will take some time before the majority of farmers will accept it. This project has definitely proved that a visual tool such as the GIS program is easily accepted by irrigation schemes and has great potential in managing irrigation schemes and communicating information. The GIS program was the only program that was used without much persuasion by both irrigation schemes. It is therefore important to do the implementation in stages and in manageable parts. Factors that have an effect on the success rate are available resources such as hardware and personnel. Experience has shown that once a user has started using a model successfully they seldom go back to the old methods.

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