QUANTIFYING THE IMPACT OF WRC-FUNDED RESEARCH IN IRRIGATION SCHEDULING

REPORT TO THE

WATER RESEARCH COMMISSION

by

JB Stevens & PS van Heerden

WRC PROJECT NO KV 318/13

ISBN 978-1-4312-0466-3

August 2013

Obtainable from

Water Research Commission
Private Bag X03
GEZINA, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project titled *Quantifying the Impact of WRC-funded Research in Irrigation Scheduling* (WRC Project No. K8/918).

Executive summary

One of the greatest challenges facing the world is to ensure that everybody has access to adequate food that is healthy, affordable and safe. With the planet's population expected to reach 9 billion by 2050, agriculture must rise to the challenge of meeting the massive food demand.

During 2011 the National Development Plan was released where a number of recommendations were published to expand the agriculture potential of South Africa. Amongst these recommendations was a substantial increase in the investment in water resource and irrigation infrastructure where natural resource base allows and to improve the efficiency of existing irrigation to make water available. Although the regulatory framework and institutional arrangements have changed significantly since 1994, one aspect remains constant: *water scarcity* – whether qualitative, quantitative or both. This originates as much from inefficient use and poor management as from real physical limits (NWRS, 2012). In addition the influence of changing weather patterns and elevated CO_2 on crop production growth processes and water availability remains to be much uncertain, which project additional challenges to the irrigation industry (NWRS, 2012).

The development, improvement and promoting of irrigation scheduling tools over the last four decades through WRC-funded research efforts have been impressive, but this report highlights also challenges to research and development that could have a profound effect on the priorities of WRC research policies and practices in future. The use of the McMaster matrix in combination with the Technology Acceptance model (TAM) of Davis (1985) illustrated the advantage to assess decision-making impact of irrigation scheduling research funded by the WRC and help to understand how to facilitate the use of research knowledge to inform decision making.

The study was conducted in three phases, which also resulted in four separate products namely:

- A literature study and description of the conceptual framework (McMaster University Research Impact Assessment model)
- A brief background and mapping of relative research reports to each of the seven irrigation scheduling methods and models included in the study
- Qualitative and quantitative assessment of the research impact applying the McMaster Model
- Recommendations regarding the transfer and facilitation of the uptake of research.

The output of the research indicated in the first place that it is important to recognise that different target audiences (irrigators, water administrators, irrigation engineers, academics and educators) have different needs and it is therefore crucial to warrant different measures of impact. Some scheduling tools/methods like SAPWAT, WFD, BEWAB and Mycanesim are more appropriate for decisions to be taken at the irrigation field level, while tools like SAPWAT, ACRU and SWB are more popular to be used by water administrators for the planning of irrigation water management strategies at scheme level and by engineers in the designing of irrigation systems. Secondly, due the number of paradigm shifts and transformation that has taken place in the research and development arena over the last couple of years, the way that irrigation water management research is conceived, designed, implemented and how results are disseminated and used to generate innovations, changed. What changes constantly is the environment in which discovery and innovation occurs, and this has impacted on the organisation and the social process of discovery and innovation. It is no longer enough to know *whether* research was used, but rather *how* research was used in the agricultural value chain.

Often research organisations like the WRC produce new knowledge or ”solutions to a problem” referred to as an innovation. However, it usually requires a major effort to ensure that a brilliant idea becomes something widely used, and involves many more steps and use of resources and problem solving on the way (referred to as the innovation process). Important in the uptake of an innovation like irrigation scheduling, is that this innovation is strongly embedded in a specific prevailing socio-economic structure, which largely determines what is going to be learned and where the innovation are going to take place.

The type of decisions that are influenced by the uptake of irrigation scheduling innovations differed across the various users. Scheduling tools can either be used for *instrumental* purposes in the identification and solving of problems at catchment, scheme and field level. It can also be used *conceptually* where concepts are enlightened and where knowledge capacity is built through training or teaching like what we have witnessed in the cases of SWB, WFD, BEWAB, PUTU and ACRU. The frequency of use of scheduling research knowledge also depends largely for what purpose the research output is used.

The perceived ease of use of research knowledge is crucial in the uptake of irrigation scheduling knowledge. Clearly some scheduling tools and methods are more user friendly and do not require too much additional skills and knowledge of the potential user like MyCanesim and WFD. The role of understandable research reports, appropriate user manuals where applicable and flexibility of a specific irrigation scheduling tool are important factors that determine the acceptance and uptake of research.

This research highlights that the research knowledge will only lead to useful outcomes if emphasis is placed on development, and therefore the innovation process has to be purposefully managed with expertise, time, efforts and funds budget for both research and knowledge brokering (Backeberg & Sanewe, 2006). Research uptake is important, and knowledge brokering is an essential function, but should be accompanied by and integrated within the function of innovation brokering, which more broadly focuses on rearranging all technical, social and institutional relationships needed for innovation and change.

Acknowledgements

- The Water Research Commission and Dr Gerhard Backeberg as Executive Manager for guidance and continued support.
- Prof Alan Bennie and Prof Leon van Rensburg, University of Free State for their advice and support on BEWAB.
- Mr James Kennedy (Kennedy Besproeiing) for support and advice on PUTU.
- Dr Abraham Singels (SASRI) for advice and support on MyCanesim.
- Prof Roland Schulze and his team, University KwaZulu-Natal for support and advice on ACRU.
- Prof John Annandale and Prof Martin Steyn, University Pretoria for their support and advice on SWB.
- All the users of irrigation scheduling tools and methods who participated in the survey and eagerly shared their experience and knowledge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The importance of research to water resource management is of utmost importance and the WRC as a statutory body, has over many years ensured that the strategic direction of water research is attuned to the country's needs. Appropriate water resource management technology can only be effective within the very small window of opportunity irrigation farmers and researchers have. Over the past four decades the WRC has invested substantially into the developing and adoption of various irrigation scheduling methods like PUTU, BEWAB, SWB, SAPWAT, MyCaneSim, Wetting Front Detector and the ACRU agrohydrological model which estimate the behaviour of southern Africa hydrological systems in a physical conceptual manner.

The starting point selected for the development of the specific research knowledge influences the application of research results. This can either be *"supply driven"* where the research is initiated by the interest of the researcher and funders, and therefore a very paternalistic approach is followed with the identification and defining of the problem. Or the starting point can be based on the real needs of the potential client (user) *("client-driven"),* where clients are enabled to raise concerns and in general the barriers to the application of the research knowledge is relatively low (Backeberg, 2003). Unobstructed knowledge flow between science (often considered as the arena of the scientist or "specialists") and management (similarly seen as the domain of "decision makers") is particularly important during times of change, such as policy and implementation.

The alignment, compatibility and flow of knowledge between researchers, policy makers and irrigation water resource managers are often far from optimal. Instead, we often observe misunderstandings, frustration, even conflict and misalignment. Although all the parties are generally keen to contribute to the formulation and effective implementation of research, the synergy between them is often poor. Clearly it is important for each party to understand what they can contribute to the process, and how best to integrate these contributions to achieve effective outcomes.

Enormous progress has been made over the four decades of research, and the scientific elements of the irrigation scheduling package seem to be in place. However, the adoption by irrigators is very limited in South Africa (Stevens *et al.,* 2005). A survey amongst 332 irrigation schemes in South Africa by Stevens (2005) illustrated that objective scheduling was being applied by 18% of the irrigators, with the rest relying on intuitive approaches based on experience, instinct, confidence and knowledge gained over many years of farming. This

implies that irrigators in practice irrigate often with fixed amounts or at constant interval with little flexibility to take weather conditions and actual crop water requirements into account.
The study was commissioned by the WRC to quantify and assess the impact of research funding has had by considering the adoption and implementation of irrigation scheduling tools and methods developed. The study is not about the evaluation of the quality of research conducted by the various research organisations.

The study was conducted in three phases, which also resulted in four separate products namely:

- A literature study and description of the conceptual framework (Mc Master University Research Impact Assessment model)
- A brief background and mapping of relative research reports to each of the seven irrigation scheduling methods and models included in the study
- Qualitative and quantitative assessment of the research impact applying the McMaster Model
- Recommendations regarding the transfer and facilitation of the uptake of research

The aim is to develop a research impact measurement tool that would be generic enough for application by the WRC on other research sites to judge the effectiveness of its R&D policy according to the specific research context. The development of the research impact tool is underpinned by five assumptions namely:

- the impact measures should be based on an evolving understanding of how best to transfer and facilitate the uptake of research knowledge and which cultural shifts are required for the up-take and transferring of the research knowledge
- the impact measures should also involve meaningful assessments by peer groups or reviewers that fund similar research knowledge for similar decision making
- the use of the research knowledge to inform decision-making constitutes the most appropriate generic measure of research impact and this could be assessed routinely
- realizing there are certain cultural shifts that could facilitate the on-going use of research knowledge in decision-making, such as the creation of **research-attuned culture** among decision-makers or a **decision-relevant culture** amongst researchers.
- the tool that would be developed should capture a wide range of traditions in which irrigation management research knowledge is created and used, but could not capture all the traditions necessarily due to the selection of the specific models and programs.

2. LITERATURE OVERVIEW: ASSESSMENT METHODS

To what extent science and technology (S&T) policies successfully meet their objectives is an issue that has been increasingly tackled among industrialised countries since the 1970s (Capron, 1992). Existing methods of evaluating science and technology policies include a toolbox of evaluation tools, which are calibrated to shed light on specific issues of the S&T policy.

Evaluation practices generally occur at one of three different stages of an R&D project:

- *Ex-ante* evaluation: evaluation practices aim at mainly improving the research selection, for instance it can occur prior to the launching of a project
- On-going evaluation: evaluation concentrates on work and the results obtained during implementation process
- *Ex-post* evaluations: takes place once the research project has been completed and its effects and/or results can be tracked

Gibbons and Georghiou (1987), Danila (1989) and Kostoff (1993, 1994) present a critical review of existing evaluation methods. In general, one can distinguish between three types of evaluation tools:

- Qualitative methods e.g. peer review
- Semi-quantitative methods: e.g. historical tracing of scientific events
- Quantitative methods e.g. econometrics, cost benefit analysis and bibliometrics (number of publication citations, number of hits in searches, etc.)

Kostoff (1994) in his assessing of research impact identified peer review, the expert judgement by research specialists, as the traditional qualitative method used for S&T accountability. Performance metrics (the counting of research activities, quantification of outcome, outputs and impacts) tend to be advocated by S&T decision-makers who may not be technical experts, but want independent credible measures of S&T quality and progress that could support resource allocation decisions. The consensus of most of the S&T community is that peer review is the preferred approach to be used for S&T accountability (evaluation), strongly supported by the use of “appropriate metrics” (Kostoff, 1997).

Capron (1992) provided the following synthesis of the main evaluation methods (Table 1), where for each method cited the relevance and drawbacks, as well as their main field of application were identified.

Table 2.1. Synthesis of evaluation methods (Capron, 1992)

Method	Relevance	Drawbacks	Field of application	Analytical level of study
1. Peer review	Screening of projects and research orientations	• Subjectivity of experts • Partial forecasts • Lack of independence of experts	• Selection, ongoing and impact • Technological forecasting	Micro level
2. Matrix approaches				
• Analysis matrices	Rich information	Difficult to collect the required information	Impact	Meso level
• Decision making	Rationalise and simplify choices	Subjectivity Lack of flexibility	Selection	Micro level
• Multi-criteria analysis	Profile projects and R&D planning	Constitution of a group of experts Subjectivity in the choice of weightings	Selection	Micro: integrated
• Relevance trees	Provides lots of information	Subjectivity in the allocation of quantitative values	Selection	Integrated
3. Systematic approaches				
• Systematic analysis	Can be used to implement an evaluation: • R&D strategies	Not really suitable for evaluating as such	Selection	Integrated
• Dynamic modelling	Include social, historical and ecological structures: • Take feedback phenomena into account	Very difficult to implement	Impact	Integrated
4. Financial methods				
• Cost benefit	Measures marketable outputs and commercial resources	Difficult to collect the information	Selection/Impact	Micro
• Ratios methods	Simple instrument	Some factors cannot be financially assessed	Selection/Impact	Micro
• Risk profiles	Simple instrument	Results sensitive arbitrary choices	Selection/Impact	Micro
• Portfolio models	Simple instrument	Purely financial aspects	Selection/Impact	Micro
5. Technological forecasting methods				
• Scenario method	Allows the causality chain to be reversed	Subjectivity	Selection/forecasting	Integrated
• Cross impact	Takes social transformations into account	Subjectivity	Selection/forecasting	Integrated
6. Quantitative indicators				

• S&T indicators	Easy measurement	Purely descriptive indicators	Selection	Integrated
• Bibliometrics	Build up fundamental	Partially descriptive indicators	Impact/ selection	Micro/Meso
• Technometrics	Measures technology characteristics	Mainly descriptive indicators	Selection/impact	Micro
• Econometrics	Measure the full range of socio-economic inputs	Theoretical and methodological	Impact	Integrated

From Table 2.1 it is clear that each qualitative and quantitative approach shed light on certain specific aspects of S&T and should therefore be viewed as adding one piece of information to the *"puzzle"* of assessment. It is also true that some methods answer specific questions better than others. It must also be accepted that some characteristics are not easily quantifiable; even though they are critically important (like for instance social consequences of research on a specific society or environment and improvement of product qualities). Therefore qualitative assessment methods are often used, although they may lack the necessary objectivity for the measurement of R&D outputs. As it is revealed in Table 2.1, these methods are often more relevant for measuring technical output quality and the extent to which precise technology objectives have been attained. Capron (1992) is of opinion that where several resources are used and where there is more certainty as to the outputs, the measurements used should be more quantitative and complex.

According to the OECD (1995) "economic evaluation of impacts is problematic and not adequately covered in most formal evaluation". They recognise the importance of quantitative analysis in the evaluation of national programmes, but OECD (1995) concludes "however, it does not easily lend itself to the evaluation of specific programs, except perhaps with broad direct ones." The report by Toulemonde (1990) on the European Community R&D programmes revealed that the main problem often lies in how to evaluate the impact of economic variables or, the modifications in economic performance that are induced by R&D expenditures.

With this as background, three impact assessment methods are discussed. The first model represents the work by Eliezer Geisler, from the Stuart Graduate School of Business, Illinois Institute of Technology, which includes evaluation methods that is a mixture of quantitative metrics method (economic, financial, bibliometrics) and qualitative metrics (peer review). Geisler (2001) suggests that metrics used to measure inputs, outputs and outcomes of research should be integrated spatially and temporally in a process that links the S&T process with the social and economic systems, and allows tracking of the innovation process from inputs/activity to outputs, impacts and outcomes. Four stages of outputs and transformation were identified:

- Intermediate stage
- Intermediate
- Pre-ultimate
- Ultimate

The model used by Geisler (2001) traces retrospectively and prospectively by estimation, the flow of research through the four stages of the innovation continuum. The model allows the user (whether a scientist or technologist) with their respective objectives and responsibilities in the innovation continuum to apply different metrics.

The second evaluation assessment model was developed and described by Kostoff (1994) and distinguish between three approaches namely qualitative, semi quantitative and quantitative methods. The qualitative methods include peer review and here a panel of experts are appointed to review the outputs of research conducted. Kostoff (1994) showed that the nearer-term research impacts typically played a more important role in the peer review outcome than longer-term impacts. Three important intangible factors for high-quality peer review are motivation of the review leader, competence and independence of the review team members. The semi-quantitative methods make minimal use of mathematical tools. Three types of semi-quantitative evaluation methods included in this approach are:

- Classic retrospective (Project hindsight),
- Traces and follow on as a second retrospective approach
- Accomplishment Book

The first two techniques reflect on the history of the project (factors that influence productivity and impact of research), while the third method (Accomplishment Books) measure the impact of R&D on project advancements or scientific accomplishments as a result of R&D. Kostoff (1997) is of opinion that although peer review in its broadest sense is the most widely used method in research selection, review and ex post assessment, it has deficiencies. The quantitative methods referred to use cost benefit analyses (where the social internal rate of return is calculated) and bibliometrics. Bibliometrics involves the number of counts of publication citations, number of hits in searches, and different applications of the R&D in other field of research. Kostoff (1997: 2000) is of opinion that there is no single method that provides a complete evaluation and recommends the simultaneous use of all three techniques as the preferred approach.

The McMaster University research impact assessment tool is the third assessment method described and is the proposed research tool to be used towards assessment and accountability in the irrigation water management sector. This tool is described by Lavis (2002), Lavis *et al.* (2003), Lavis *et al.* (2005) and Lavis *et al.* (2006) and on the website of the McMaster University, Centre for Health Economics and Policy Analysis [on line]http://www.chepa.org/. The assessment tool is extensively being used in the health sector in Canada where different target audiences warrant different measures of impact. This tool is based on the principle that a basic understanding of the target audience is essential in the transfer and facilitation of the uptake of the research knowledge, and secondly provides the opportunity to make meaningful assessments within different peer groups that either fund or produce similar types of research knowledge. It also includes measures for cultural shifts required that would facilitate the on-going use of the research knowledge in decision-making, which is a very important generic measure for future impact of research. The developers of the tool admit that this tool does not capture the full range of traditions in which research knowledge is created and acted upon like for example not doing justice to traditions like action-research or social constructivist research. However, the assessment tool provides the opportunity to move beyond the assessment of WHETHER research was used to HOW research was used. This tool provides a basic framework that support decision-making on the selection of the most appropriate assessment tool for a specific condition (user pull, user push or exchange). It is therefore more flexible than the previous two methods described.

The tool comprises of the following seven steps:

1. Identification of the target audience for the research knowledge has been funded or produced
    - Policy decision makers
    - Professionals (researchers, engineers, advisors, hydrologists, extensionists, irrigation scheme managers and water administrators)
    - Private sector

2. Select appropriate category of measures (producer-push, user-pull or exchange)
    - Producer push: active role by researcher to make research available to decision maker
    - User-pull: Decision-makers and in general users active efforts to identify research and research expertise. The active acquiring of information to support their decision-making.
    - Exchange measures capture joint active efforts by researchers and decision makers to ask and answer more decision relevant questions.

3. Operationalisation of measures given the target audience and resources available to measure the impact and other constraints.

    The following impact measures are proposed:

Category **Measure**	**Process**	**Intermediate output**	**Output**
Producer push	• Number of products published and products targeted at specific decision makers • Number of interactions with various stakeholders and interactions with stakeholders • Desktop based analysis	• Target audience's awareness of research and its resources	• Case study and survey based evidence of decision makers actual use of research products
User pull	• Number of data requests (information requests by decision makers looking for specific research, website hits) • Desktop based analysis	• Decision-makers awareness of research organisations and data available • Attitudes of decision makers towards research organisations	• Audience (researchers and decision makers) use of data
Exchange process	• Research organisations involve decision makers in research process and *vice versa*	• Decision makers assessment of involvement in research process and *vice versa*	• Research organisations' research reflect partially needs and context of decision makers

4. Identification of possible data sources:
    - Given the operational method selected the identification of potential data sources is important which could vary from list of telephone calls to research organisations, research organisations website records, researchers' calendars and diary, reports on the number of interactions between research staff and target audience and surveys within a case study approach with decision makers (These surveys can either be structured or semi-structured).

5. Analysis whether the research knowledge was used in decision making, especially in the context of competing influences:
    - During this step it is important to establish whether the research knowledge was used and for what purpose.

6. Analysis of how the research knowledge was used in decision making:
    - It is important to determine from the assessment conducted how the research knowledge was used. Was it used instrumentally (acting on

research in a direct and specific way); conceptually (more indirect form of enlightment) or symbolic use (use of research knowledge but not to inform decision making but rather to justify a position).

7. Identify areas for improvement and provide feedback

The McMaster research impact assessment tool was refined and adapted with the addition of two important motivators for the use of research knowledge namely "perceived usefulness: and ""perceived ease of use" taken from the work of Davis (1985-1989). According to the Technology Acceptance Model of Davis (1985) users acceptance is often the pivotal factor determining the success or failure of an information system. Therefore, whether and how research knowledge will be used depends on the *perceived usefulness* of the information or technology (the degree to which an individual believes that using specific information or technology would enhance his performance) and *perceived ease of use* (the degree which an individual believes that using a particular technology would be free of physical and mental effort) that influence the general attitude of the user to either use or not use research knowledge. Since these two aspects are so important in the assessing of the impact of the use of research knowledge, it was used to attune the Mc Master Model and the following conceptual framework was developed for the research.

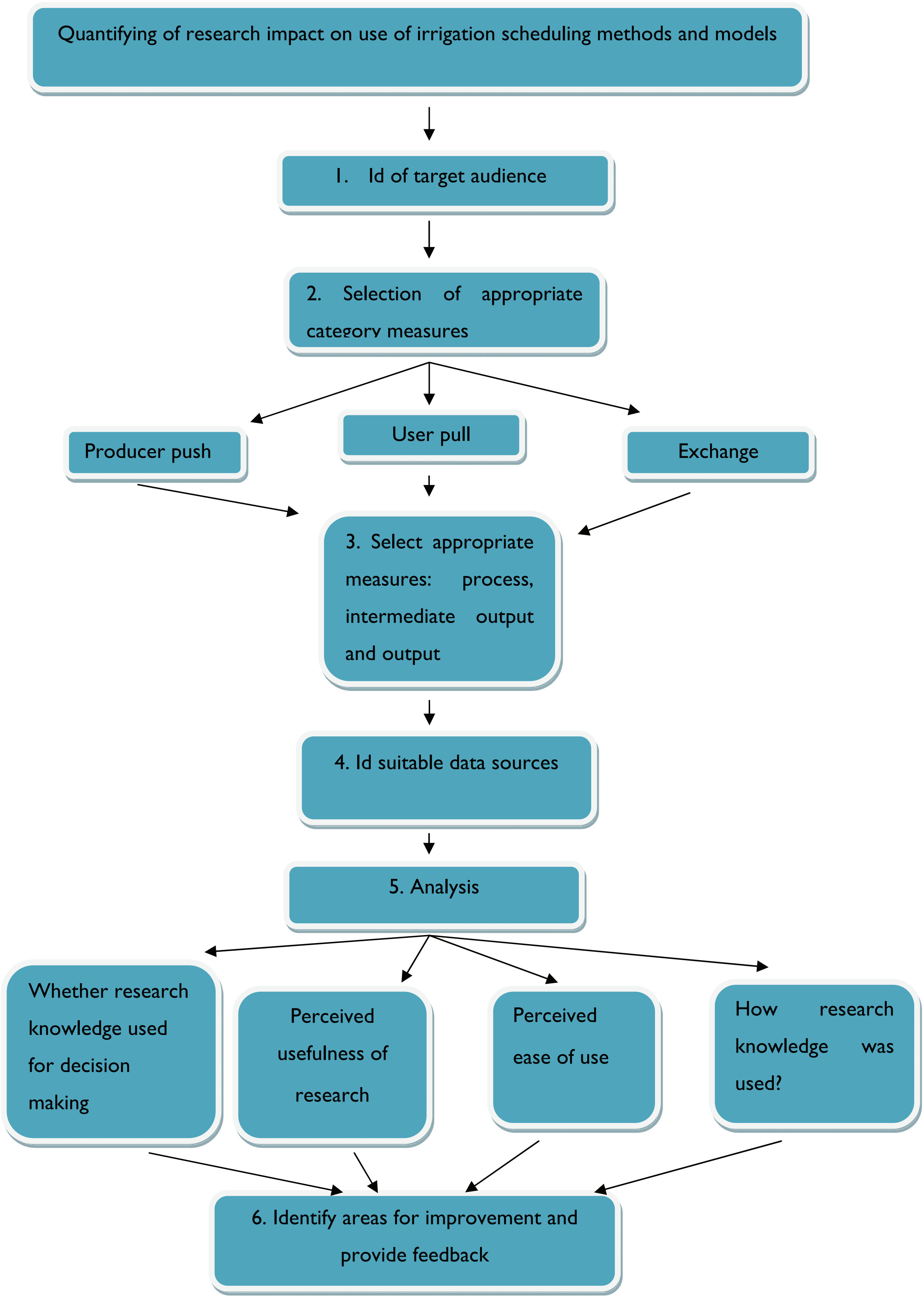


Figure 2.1. Conceptual framework for research study

3. RESEARCH METHODOLOGY

The study was conducted on a national basis where the various irrigation-scheduling methods (BEWAB, PUTU, SWB, WFD, MyCaneSim and SAPWAT) and the Agro Hydrological model ACRU were implemented. Two surveys were conducted namely the first was more quantitative of nature with a formal questionnaire (Annexure A) that was used while the second was more qualitative where semi-structured interviews were conducted and transcribed. The questionnaire was designed in accordance with the McMaster research impact method being described. Following the adapted McMaster model, a five point Likert semantic scale was deployed to determine the respondent's perceptions and opinions based on the Technology Acceptance Model of Davis (1985).

With the applying of the McMaster matrix to assess the impact of the WRC research conducted and funded by them, the following considerations become apparent:

- The target population includes researchers, engineers, irrigation scheme managers and administrators, hydrologists, irrigation consultants/advisors/ extensionists as well farmers.
- According to the McMaster model the category of impact measures that can be used is mainly *producer-push* since the WRC has promoted and funded the research and the researchers involved have made concerted effort to make research results available to potential users. A few the irrigation scheduling tools or models were developed through active efforts made by researchers to involve decision-makers like farmers and irrigation managers. Examples of linkages with end users in the development of new research knowledge are the action research processes followed with the development of the Wetting Front Detector (WFD) as well as with the development of SAPWAT and SWB newer versions.
- The operational measure chosen for the assessment is a combination of the output-driven measures.

Three important aspects of assessment of the research impact were determined:

- Whether the research knowledge was used in decision-making and also the perceived easiness of the use of the knowledge.
- Secondly, who use the research knowledge? Some research knowledge is basic or of pure contribution to scientific knowledge or methodologies, and therefore appropriate for researchers. Applied research knowledge on the other hand is more appropriate to inform the decisions of farmers, irrigation designers and planners, irrigation administrators and policy makers.

- Thirdly, how the research knowledge was used in decision-making? Identify the conditions under which research knowledge was used. Also determine the competition factors (political or organizational) regarding the use of the specific research knowledge. Public policy makers like DWA, NDA, WUAs and CMAs must not only contend with the research knowledge, but also with the values of the governing party. This assessment also includes the determining of the perceived usefulness of research knowledge.

The principle method of data gathering included the distribution of questionnaires via e mail, telephonic and face-to-face interviews with key informants. Secondary data was collected via published and on-line reports and information regarding the seven irrigation scheduling methods and tools. The primary research method involved the conducting of a survey among decision-makers (engineers, administrators, planners, advisors, farmers, researchers) to identify their awareness of the research knowledge and whether they make use of the research in daily decision-making and how they apply this research knowledge. The questionnaire used for the survey is attached as Annexure A. The perceived usefulness and easiness of use of the research knowledge were assessed in this survey by using a five point semantic scale (Likert scale), which is scientifically accepted way of quantifying perceptions.

The questionnaire was discussed and tested amongst peers and research colleagues after it was drafted and attuned accordingly. In general the feedback on the questionnaire was positive, but it was clearly stated that it is very comprehensive and therefore will require time and commitment from the respondents to complete. This is perhaps also the reason why initially a relative disappointed feedback was received from the questionnaires distributed by e-mail and postage. This necessitated a follow up with various field visits to researchers and users at the University of KwaZulu-Natal, University of the Free State, private irrigation consultants in KwaZulu-Natal, Limpopo, Northern Cape, Northwest and Mpumalanga.

The stratified target audience (respondents) was identified with the help of researchers and research assistants involved in the initial research programs of the irrigation scheduling tools /methods at the University of the Free State, University of Pretoria, University of KwaZulu-Natal, University of Stellenbosch, University of Fort Hare and private companies like Arcus Gibb and Aurecon. The respondents included reflect decision makers, both those directly involved in agriculture as well as decision makers/users only associated with agriculture (classified as non-agriculture respondents for this purpose) like planners, designers, administrators:

- Researchers (private, ARC, universities)
- Engineers

- Policy makers and administrators
- Irrigation scheme managers and administrators (water control officers)
- Hydrologists
- Irrigation consultants/advisors/ extensionists
- Academic staff involved in training
- Project managers (TSB, wine estates)
- Representatives from seed companies
- Farmers

Table 3.1 illustrates the number of respondents sampled in the survey as per irrigation scheduling tool or method.

Table 3.1. Target audience sampled as per irrigation method/tool

Irrigation scheduling method/tool	No of respondents
ACRU-Mike Basin	12
BEWAB	8
SAPWAT	226
SWB	56
PUTU	8
MYCANESIM	8
WFD	50
TOTAL	**368**

Although it was stated by Bennie (1998) that approximately 500 irrigators were using BEWAB and nearly 125 users used PUTU (de Jager and Kennedy, 2001), the research team found it very challenging to identify current users or any listed previous users for the irrigation scheduling programs BEWAB and PUTU. It appears that these lists with the contact details of users got lost with the retirement of Prof A Bennie and Prof Jimmy de Jager of the University of the Free State. Regarding MYCANESIM, which is a program especially designed and created to help small scale farmers with decision making, only researchers and scientists currently using the program were involved due to the comprehensiveness of the questionnaire and the language barrier that prevent Zulu speaking small scale sugarcane farmers (in KwaZulu-Natal and Mpumalanga) to be interviewed. The list of SAPWAT users initially registered and later been updated by SABI branches indicated that the program is used by approximately 226 users. However it appears that many of these users either are no longer involved in the irrigation industry or were no longer using SAPWAT, since only 44 responded to the survey.

Due to the initial slow response and feedback from respondents on the distributed questionnaire, respondents were contacted as a follow up on more than one occasion and several face-to-face interviews and focus group discussions were conducted with key respondents during July 2010 - February 2011. These interviews helped the research team with the improvement of the depth, quality and accuracy of information. 118 respondents (32%) provided feedback on the survey, which was used for analyses of the data and the drafting of conclusions, and therefore is reflecting fair representativeness of the population (Figure 3.1).

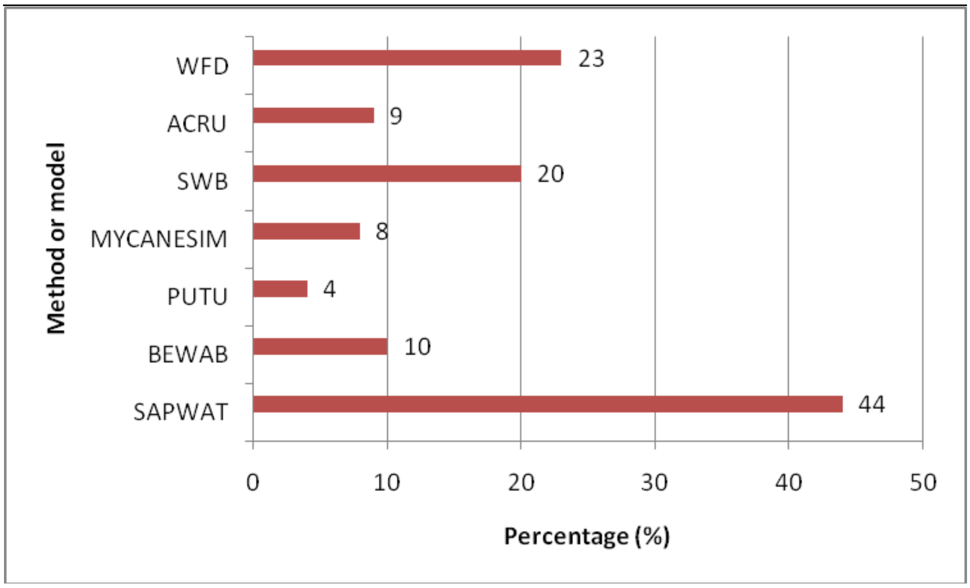


Figure 3.1. Distribution of respondents involved in the survey (N=118)

Respondents presented all nine provinces but as was explained were selected on base of the potential use of a specific irrigation scheduling method or tool (Figure 3.2).

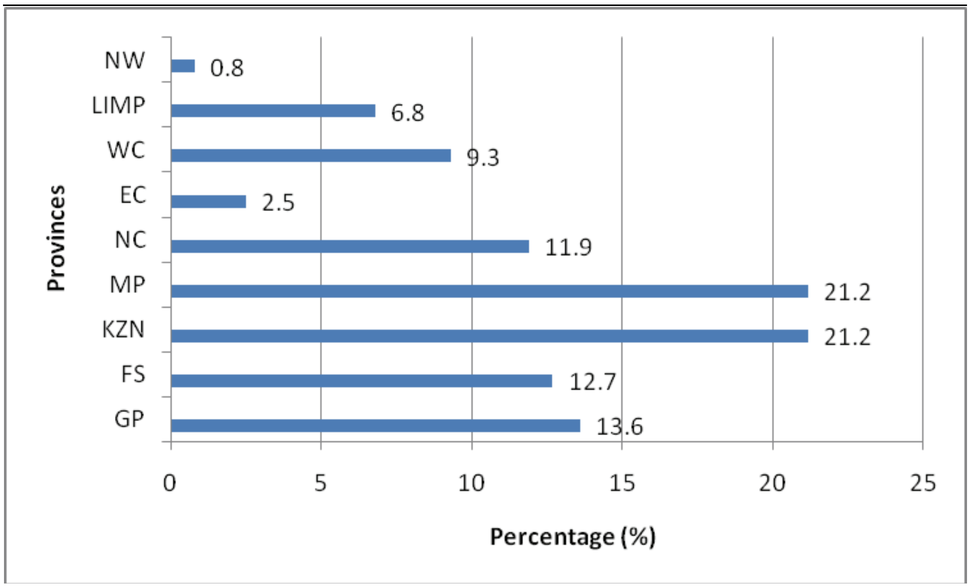


Figure 3.2. Distribution of respondents involved in the survey as per province (N=118)

The analysis of the data involved the use of the statistical package for social science (SPSS version 14). Before the data was analysed, it was coded, edited and cleansed and modified where necessary.

The questionnaire and the subsequent results were validated and weighed through focus group meetings with the peer researchers as well as with WRC staff. The research team worked in close collaboration with the WRC and therefore view this not as a product for the WRC, but as a study carried out in collaboration with the WRC. The opportunities for improvement that are identified through this research can inform the next steps taken the WRC as research funder and organisation.

4. DESCRIPTION AND OVERVIEW OF IRRIGATION SCHEDULING MODELS AND METHODS FUNDED BY WRC

The aim of irrigation scheduling is to minimize water losses of water (percolation beyond what is required for salt leaching, surface runoff and evaporation) and maximize transpiration (Tanner & Sinclair, 1983). Irrigation scheduling is therefore critical for the determining of crop water productivity, which is a performance benchmark used to describe the relationship between irrigation water applied and product output.

Gardner (1960), Demead and Shaw (1962) and Passioura (1988) set the fundamental theoretical framework for soil-plant-water relations, and much of the research the past few decades focused on how to operationalise this framework so that irrigation farmers can apply it. This has involved the characterisation of soil water holding properties, the development of soil water monitoring tools and methods to predict plant water use (Annandale *et al*, 2011).

The research knowledge on irrigation scheduling funded by the WRC focused on the following technical aspects of the soil-plant-atmosphere continuum:

- *Plant available water:* it is important to know when to irrigate i.e. the optimum stage in the drying cycle at which to apply water and how much plant-available water the soil profile can hold. This was the era when researchers determined the 'Profile Available Water Capacity" (PAWC) concept and models to derive at PAWC values for different crop-soil combinations (Hensley & de Jager, 1982; Bennie, 1995). Soil water potential at 'field capacity" differs widely between soils, and therefore single soil water potential value cannot be used for all soils. This initiated the research to determine "drained upper limits" (DUL) for the different soils (Hensley & de Jager, 1982; Boedt &Laker, 1985); Bennie *et al.* 1988; Bennie, 1995).

- *Plant based measuring techniques:* measurement of a number of plant indicators can be used for determining whether to irrigate like for instance leaf water potential. The "pistol type infrared thermometer" for measuring canopy temperature received much attention as a potential practical tool for irrigation scheduling, because of its apparent ease of use (Reginato, 1995). The University of KwaZulu-Natal is renowned for their work on the use of thermocouple psychrometers as a method to determine leaf water potential (Savage & Wiebe, 1987). Phytomonitoring and the Scholander type pressure chamber have received much attention to produce threshold values which is important for decision information systems used on a limited scale like in the wine and horticulture industry in the Western Cape (Stevens *et al*., 2005; Annandale *et al.*, 2011).

- *Soil based measuring techniques*: the measurement of soil water status (water extraction and availability) has a long history which ranges from the development of tools to measure soil water potential like with tensiometers in the early 1930s (Richard &Neal, 1936), to the development of the neutron probe in the 1950s, through a range of tools based on the measurement of dielectric properties of soil water like the capacitance sensors (Charlesworth, 2005). Streutker (1978) promoted the use of tensiometers in the Loskop irrigation area during the early 1980s, and was successful at improving irrigation management (Stevens *et al.,* 2005)

  The wetting front detector was developed in the early 2000s against the background of poor adoption of commonly available irrigation scheduling techniques. It refrained the traditional question of “when to irrigate” to “when to turn the irrigation off” (Stirzaker *et al*., 2004)

- *Atmospheric based irrigation scheduling approaches:* this approach is based on estimating evapotranspiration to schedule irrigation. The work by Doorenbos & Pruitt (1977) was based on evaporation measured from a pan together with crop coefficients which were used to estimate evapotranspiration. The standard Class A evaporation pan was most widely used in South Africa, and Stevens *et al*. (2005) reported that it is still very popular in certain areas.

  The evaporation pan and crop coefficient approach was later shown to have serious shortcomings (van Zyl *et. al.,* 1989, van Zyl & de Jager, 1992). Since the 1980’s it was replaced by using a reference crop to represent atmospheric evaporative demand. The work of van Zyl & de Jager (1987) and van Zyl *et al*. (1990) illustrated the accuracy of using the Penman Monteith equation for estimating evaporation from an unstressed wheat crop (Annandale *et al*., 2011).

- *Soil water balance modeling:* the approaches to the modeling of soil water balance have either mechanistic or empiric aspects to them. Models are either crop specific or can be generic in nature when it can be used for several crops, with pre-programmed (i.e. irrigation calendars) or real time output (Stevens *et al.,* 2005). The WRC-funded irrigation scheduling models that will be discussed in this report are PUTU, BEWAB, SWB, MyCanesim and SAPWAT (initially been developed as crop water use planning tool but later (1999) also changed to support irrigation scheduling decisions).

The WRC has invested substantially in irrigation scheduling research and technology transfer projects over the last four decades. The aim with this part of the report is to provide a brief background and mapping of important characteristics of each of the following models and methods: ACRU-Mike Basin, PUTU, BEWAB, SWB, SAPWAT, MyCaneSim and the Wetting Front Detector.

4.1 ACRU MIKE-BASIN

Background

ACRU is an integrated agro hydrological modeling system capable of being used for amongst others, water resource assessments, design flood estimations, crop yield assessments and irrigation water demand and supply evaluations. ACRU is derived from the Agricultural Catchments Research Unit within the Department of Agricultural Engineering of the University of Natal in Pietermaritzburg. It has its hydrological origins in a distributed catchment evapotranspiration based study carried out in the Natal Drakensberg in the early 1970's (Schulze, 1975). The agricultural component of ACRU first came to the fore during research on an Agrohydrological and Agroclimatological Atlas for Natal (Schulze, 1983), and since then the model has developed, through the cooperation of role-players like the WRC.

ACRU is a multipurpose model that integrates the various water budgeting components of terrestrial hydrological system. It can be applied for crop yield modeling, runoff estimation, design hydrology, ecological water requirements, reservoir yield stimulation, water resource assessment, planning of optimum water resource utilization and allocation, conflict management in water resources and climate change and land use impacts.

User documentation of ACRU was first published in 1984 (Schulze, 1984) and updated in 1989 (Schulze *et al*., 1989). The paper by Schulze (1986) provided an overview of the major developmental aspects while an overview of afforestation effects as a dynamic simulator on runoff was published by Schulze and George (1987). Schulze *et al. (*1995) stated that the ACRU model has been applied since 1986 to provide answers to a range of water resources related problems. In 1988 Schultz (1988) provided a synthesis on its status and in 1992 an unpublished report to the WRC was submitted on the new development to the model up to then, mainly on the new development to the model in regard to flow routing, wetlands, shallow ground water routines, a forest Decision Support System and model linkage to GIS.

The model (ACRU 2) was developed as part of the research project entitled *"Applied Hydrological Process and Modeling Studies for the Determination of*

Water and Sediment Yield" in 1989 (Schulze, 1989). The ACRU model is continually being updated as new knowledge and understanding of the physical processes within the hydrological cycle is enhanced and the present text "Hydrology and Agrohydrology: A text to accompany the ACRU 3.00 modeling system" supersedes and replaces the 1989 ACRU: Background, Concepts and Theory" (Schulze, 1989a). The companion volume to the present text is the "ACRU 3.00 User Manual" under editorship of Schulze *et al.* (1995) which in turn supersedes the "ACRU 2: User Manual" by Schulze *et al*. (1989).

ACRU agrohydrological modeling system is a physical conceptual model and the parameters used are generally estimated from physical characteristics of a catchment being simulated. ACRU runs on a daily time step and revolves around a multi-layer soil water budget, which results in ACRU being a versatile total evaporation model. This attributes makes ACRU soil water budget sensitive to climate and land use changes. It can also be adjusted to take into account any agricultural management practices such as different irrigation management and soil tillage practices. The initial considerations and philosophies in the developing of ACRU model were stated as follow:

- Developing of a multipurpose model
- Develop a multilevel model (i.e. able to operate at different levels of sophistication according to available input or required output)
- Daily soil water budgeting modeling system developed as an aid to objective water resources related planning, along deterministic (i.e. non parameter optimizing) lines
- Can be used at a point or on lumped or on distributed (heterogeneous) catchments, stimulating with risk analysis
- Various levels of stream flow and peak discharges, peak discharges, reservoir yield, sediment loss and reservoir situation, irrigation water supply and demand, crop yield analyses and impact resulting from changes in land use /management as well as changes in climate
- User friendly mode through an interactive Menubuilder which contains different options and pathways

The stream flow that is an output from the ACRU model, termed RUNOFF, is a combination of storm flow (called QUICKFLOW) and base flow store (called BASEFLOW). These three outputs can be used a daily inputs into the MIKE-BASIN Model, either as separate components, or as combined runoff. The stream flow was used into the MIKE-BASIN model and was develop by Danish Hydraulic Institute.

Although MIKE-BASIN was not primarily funded and developed by the WRC, the WRC has funded research projects where MIKE-BASIN has been used. ACRU is a physical conceptual rainfall-runoff model, whereas MIKE-BASIN is a node-and-channel network model used to allocate water based on the hydrology occurring in a catchment (Pott *et al.*, 2008). This function links water users with sources of water for given operating rules, but it however requires stream flow. MIKE-BASIN operates within the GIS environment and therefore exploiting the spatial capabilities of the GIS framework. The added functionality of *Temporal Analyst* adds the time dimension to the space dimension, which is ideal for data management in a catchment (DHI, 2005). All the information concerned with the configuration of the catchment, such as river branch network, locations of water users, channels for intake and outlets of water to and from water users and reservoirs are all defined within the GIS system (Pott *et al*., 2008).

The Automated ACRU Menu Generator (AAMG) was later developed and facilitates the setting up initial ACRU runs from a GIS environment which links allow the use of the functionality of MIKE-BASIN. This was necessitated because of the National Water Act (1998), which requires assessing of the impact of various land and water use activities on a catchment as a whole. ACRU is able to simulate the impact of the rainfed landuse and management practices, while MIKE-BASIN can simulate the operating rules associated with water users requiring abstraction licenses.

This development combined the strengths of ACRU and MIKE-BASIN. It enables within a GIS environment to integrate the inputs of ACRU runoff time series into MIKE-BASIN and implement operating rules at catchment and sub-catchment scale. These coverage's have been developed UKZN-BEEH over many years with WRC funding (Lynch 2004, Schulze, 1997).

The model has been verified widely on data from southern Africa and the USA (Schulze, 1995), and is used extensively in decision making in southern Africa (South Africa, Botswana, Lesotho, Namibia, Swaziland and Zimbabwe) and since 1994 also had been applied internationally in research in Chile, Germany, and the USA. Examples provided by Schulze *et al* (1995) where the ACRU model has successfully been implemented:

- Water resource assessments
- Design flood estimation
- Irrigation water supply and demand scenarios
- Crop yield and primary production modeling
- Assessments of impacts of land use changes on water resources
- Assessment of hydrological impact of wetlands
- Groundwater modeling
- Assessment of potential impacts of global climate change on crop production and hydrological responses

Purpose and objectives

ACRU simulates the impact of dry land use and management practices while MIKE-BASIN simulates the operating rules associated with water users taking water from dams and river resources.

Secondly it provides a tool for the quick and easy testing of scenarios related to dry land activities, irrigated activities, dams and inter-basin transfers as well as various operating rules. This functionality is especially valuable in over-allocated catchments where stakeholders may want a quick and easy, yet scientifically credible system of assessing various courses of action to address the over allocation of water use entitlements in the stressed catchments.

Developer (s) of model

The ACRU model was initially been developed by RE Schulze and the School of Biosources Engineering and Environmental Hydrology, University of KwaZulu-Natal with the funding from the WRC, while the Danish Hydraulic Institute developed the MIKE-BASIN model.

Potential application

Before the development of AAMG water resource planners in South Africa made use of the Water Resources Yield Model (WRYM), which is also a node-and-channel network model. This model is fed with stream flow generated from the Pitman model. According to Pott *et a*l. (2008) the ACRU MIKE-BASIN linkage (AAMG) provides an alternative to the Pitman-WRYM linkage, and has the following potential applications:

- ACRU is a process based on hydrological model, which allows land use and management practice scenarios to be considered which are not suited to the Pitman modeling framework since it is a regression model.
- The ACRU MIKE-BASIN models are ideal to help us to examine possible solutions to questions posed by the National Water Act like the need for assessment of impacts of land use change and daily hydrological modeling. It was adapted over time to enable ACRU to be easily set-up from within a GIS environment. It is not perceived that the ACRU MIKE-BASIN software will be used directly by WUA's and IBs themselves, as the models need to be operated by experienced hydrologists or irrigation engineers. Therefore the WUAs and IBs will most probably make use of consultants who have access to ACRU MIKE-BASIN.
- Assessment of water license applications and environmental management including the water quality aspects.

- Help with stakeholder interaction and communication.
- It lends itself perfectly as a learning/educational tool because it simulates processes based on soil-plant-atmosphere and hydrological and hydraulic principles. ACRU is compulsory for agricultural engineering students at UKZN, and optional for agriculture students.

Challenges and future developments

The ultimate vision is to develop ACRU MIKE-BASIN *via* the use of AAMG in an easy, intuitive, scientifically, credible fine-time step modeling system to be used by DWA, CMAs and consultants for water supply and water demand operation scenarios. The temporal scale at which the model runs is a daily time step, where operations can be appropriately be reflected as they occur. The spatial scale of scenarios can range from broad catchment scale scenarios to far more detailed scheme and farm scale scenarios and should therefore accommodate scenarios pertaining to various conditions and changes experience in the field.

WRC Reports

Integrated studies of the generation of runoff, solutes and sediment in tributary catchment of the Great Fish River
WRC Report No 100/1/88
CB Schultz
Hydrological Research Unit
Rhodes University
March 1987

ACRU: Background, Concepts and Theory
RE Schulze
WRC Report No 154/1/89
Department of Agricultural Engineering
University of Natal
Agricultural Catchments Research Unit
March 1990

ACRU 2.0: User Manual
RE Schulze, WJ George, SD Lynch & GR Angus
WRC Report No 154/2/89
Department of Agricultural Engineering
University of Natal
Agricultural Catchments Research Unit
March 1990

4.2 PUTU MODEL

Background

The use of automatic weather stations (AWS) and crop growth models (CGM) have been demonstrated to be a successful method for management of irrigation. Similar decision support systems have been developed overseas and are functioning effectively (Ritchie *et al*, 1976; Francis and Pidgeon, 1982; Walley and Hussein, 1982). The majority of these, which include the work of de Jager *et al.*, 1987, were designed to provide estimates of soil water deficits for irrigators and some were very specific with respect to local climate, soil type and crop phenology (Mottram and de Jager, 1994).

The PUTU models evolved from work done on leaf photosynthesis in 1968 (de Jager, 1968) PUTU was first developed for maize in 1973 and the initial development was described by de Jager (1974) and de Jager and King (1974). PUTU was named after the Zulu word for *"maize porridge".* The model was developed under South African semi-arid conditions and demonstrated an acceptable degree of reliability in simulating crop yields. The model describes the proportionate limitation on growth due to each of the climatic variables for each day. The PUTU model attempts to explain the combined effect of light and temperature on leaf photosynthesis. Mathematical equations were developed to illustrate the effect of these factors, as well as water limitation on the rate of photosynthesis and crop growth. The efficiency of radiation use in photosynthesis was computed and converted into carbohydrate in the first version of PUTU dynamic maize crop growth simulation (de Jager, 1976). The theory, definitions, concepts and parameter values for maize were documented by de Jager and King (1974).

A version (PUTU 6) especially developed for wheat, followed in 1981 and was described by de Jager *et al*. (1981). This version of the model simulated water balance by extracting daily transpiration losses from the water present in each soil layer. PUTU 6 was modified for irrigation scheduling and renamed PUTU 9 (de Jager *et al.*, 1982). Concepts developed by de Jager *et al.* (1987) were incorporated into the PUTU wheat model, which was mainly used for weekly irrigation scheduling advice to wheat farmers at Vaalharts. This version of PUTU utilises most of the functions of PUTU 6 but also computes hourly time steps, which later became apparent not necessary where irrigation scheduling is concerned.

The further development of PUTU 6 included better mathematical equations for hydraulic conductance and an iterative routine. This led to the development of PUTU 9.86, which took it a step further and made some practical adaptations for the practical implementation of it. Electronically recorded weather data were downloaded via telephone modems and landlines. The model was run by the research team to generate crop and soil-water status information (e.g. expected onset of water stress, water use of the past 7 days, deep drainage out of the root zone, expected date of next irrigation and current soil water status).This information was faxed to the local extension officer, who used it in their advice to farmers when they phoned. This approach to the dissemination of information via the extension officer was not very successful, and the project highlighted the need for personal interaction with farmers and for the marketing of the service to ensure better uptake. This version of PUTU was later refined and adjusted to include maize crop growth simulation also and was named, PUTU 12 (de Jager *et al.*, 1986).

PUTU – any crop is a generic crop simulation model and was used to simulate daily values of crop transpiration as the product of reference crop evaporation and empirical crop specific evaporation coefficients as well as daily soil profile water deficits for various crops (de Jager & Singels, 1994, de Jager *et al*., 2001). This model was used by irrigation consultants and extension officers for weather based irrigation scheduling advice in Bergville and Winterton in KwaZulu-Natal, Rietriver irrigation scheme in Northern Cape, as well as in Limpopo Province (de Jager & Mottram, 1996; de Jager & Kennedy, 1996). Water-saving irrigation scheduling advice was transmitted from central computing centres linked by telecommunication network to distant automatic weather stations and farm managers located in other provinces and countries. This information was then disseminated in sufficient time to allow irrigators to act before crop water stress with associated yield reductions was induced. Validation test by Singels and de Jager (1991), Singels and de Jager (1995), Mottram and de Jager (1994) proved that given suitable yield-water stress response parameters, the models provided accurate decision support to irrigation farmers. This technology was proved to be suited to extensive commercial as well as low-input small-scale operations, with the biggest advantage the use of a single weather station and its application to numerous neighbouring farms.

These models contained both previously published algorithms (for example Doorenbos *et al.*, 1979; Jones and Kiniry, 1986; Seligman and van Keulen, 1995) and newly developed algorithms. The WRC Report No 1049/1/02 used the PUTU growth model together with deterministic runoff model for risk assessment of maize yield under different scenarios – water harvesting, basin tillage, no till, mulching (WHBM) and total soil tillage production techniques. It became clear from this research that when the initial soil water content at planting is relatively low, huge differences occur in terms of the yield between the water harvesting method (WHBM) and conventional tillage (CT) production techniques. In some circumstances, the conclusion was that small-scale developing farmers in semi-arid regions could even double their maize yields. This research team recommended that a complete computer simulation model for long-term crop production risk with different production techniques like water harvesting and conventional total soil tillage should be developed. This led to the PUTURUN Model (KV 142/03), which is a simulator for rainfall runoff-yield processes with in-field water harvesting. This simulator links the combination of rainfall-runoff processes to the crop model. The final product is a user-friendly simulating model that supports crop scientists, soil scientists and agro-meteorologists who are not computer literate in their work.

Purpose and objectives

The overall aims with the development of PUTU was to design, develop and establish an effective automatic weather station network and computerised irrigation decision support system (IDSS) to help with irrigation scheduling planning and practising.

Developer (s) of model

- The PUTU was first developed for maize in 1973 and the initial development was described by de Jager (1974) and de Jager and King (1974).
- PUTU 6 especially developed for wheat followed in 1981 (Bristow and de Jager, 1981)
- PUTU 9 (de Jager *et al.,* 1982) and later PUTU 9.86 (de Jager *et al.*, 1986) version was developed and refined to accommodate irrigation scheduling of crops. Major modifications, which include multi-layered soil and water extraction routine, were incorporated.
- PUTU 12, which is a slightly modified version of the model, which can estimate crop total evaporation from data provided by the automatic weather station, was used for maize crop growth simulation (de Jager *et al.,* 1986).
- PUTU anycrop, generic crop model used for determining water and irrigation requirements of various crops (de Jager & Singels, 1994, de Jager *et al*., 2001)
- PUTURUN Model: a simulator for rainfall runoff yield processes with in-field water harvesting (Walker and Tsubo, 2003).

Potential application

The potential application of PUTU includes the following:

- PUTU models have been used in consultation to provide quantitative weather based irrigation scheduling advice to irrigators. The irrigation decision support system comprised of irrigation advisors in Bloemfontein and Pietermaritzburg who were telephonically and/or computer linked to various participants in the country. Approximately 125 clients and 1900 plots of land were irrigated from centres at the Department of Agrometeorology, UOFS, and Bloemfontein and in Pietermaritzburg. Three farming Cooperatives and the Free State Department of Agriculture also ran similar operations and nearly 34 AWS's were purchased by private entrepreneurs, who were involved in the operation. This service enabled irrigation managers to:
    - schedule irrigation on individual lands for a variety of crops for maximum water use efficiency,
    - derive the most efficient seasonal water use strategies for given water supply-climate-soil-crop scenarios and apportion limited water, fairly and sparingly, between numerous clients with differing crops and land areas,
    - extract information from a database with respect to atmospheric evaporative demand which may be used together with information on given dam, catchment or river water supplies (hydrological resources), so as to determine, for example, the feasibility of irrigated agriculture in a specific area.
- The PUTU modelling principles and program structure forms the core of the modelling courses presented to graduate and post-graduate students in Agriculture at the Free State University since 1980 (du Preez, 2010).
- Used for ENSO based drought monitoring (Lourens and de Jager, 1996; Fouché *et al.*, 1985)
- Identifying of mitigation crop production strategies (Singels and Potgieter, 1996)
- Forecasting of wheat, maize and grazing yield by consultants that use these models
- Quantifying production potential and production risk of different wheat and maize production strategies (Singels and de Jager, 1991, de Jager and Singels, 1988)

Challenges and future developments

The PUTU programme required the following improvements:

- PUTU 9 was originally developed for crop growth simulation but the need quickly developed for an irrigation scheduling simulation model based on atmospheric demand.
- The need exist for software to make the PUTU-IDSS available on Internet and a Website, which will make it readily accessible to a large number of irrigation farmers as been identified in K581/1/01.
- The sparse canopy and partial cover routines in the irrigation simulation model require refinement and validation.
- Inability of PUTU to predict high yields in certain ecotopes
- Unsatisfactory runoff subroutines by PUTU
- Long-term cumulative distribution yields computed requires to be improving to increase the model reliability (WRC report 506/1/97).
- PUTU 12 version (de Jager *et al.*, 1986) addressed the need for the development of maize crop growth simulation while PUTURUN (KV 142/03) addressed the unsatisfactory simulation of run-off by PUTU.
- Apart from pastures, maize, soybeans, wheat, peas, dry beans, potatoes, runner beans, sugarcane, barley, cotton and vegetable crops; the PUTU-IDSS was adapted to handle high income crops such as apples, asparagus, tulip bulbs, tomatoes, onions, seed maize and mange tout peas. Envisaged expansion includes: the eastern Free State (asparagus, apples, and cherries), Zimbabwe (potatoes), Komatipoort, Mpumalanga (plantations), Delmonte, Cameroon (bananas) and Tanzania (diverse).

WRC Reports

Research on a weather service for scheduling the irrigation of winter wheat in the Orange Free State Region
JM de Jager, WH van Zyl, BE Kelbe & A Singels
WRC Report No 117/1/87
Department of Agrometeorology
University of the Orange Free State
1987

Correction factors for evaporimeter coefficients used for scheduling irrigation of wheat
WH van Zyl, JM de Jager & CJ Maree
WRC Report No 151/1/89
Department of Agrometeorology
University of the Orange Free State
1989

Maximizing Irrigation Project Efficiency in different soil climate irrigation situations
R Mottram & JM de Jager
WRC Report No 226/1/94
Department of Agrometeorology
University of the Orange Free State
1994

Estimation of plant and soil evaporation from cropped lands
WH van Zyl & JM de Jager
WRC Report No 507/1/97
Department of Agrometeorology
University of the Orange Free State
1997

PUTURUN: A simulator for rainfall with In-Field Water Harvesting
S Walker & M Tsubo
WRC Report No KV 142/03
Department of Soil, Crop and Climate Sciences
University of the Free State
March 2003

Research on computerized weather based irrigation water management system
JM de Jager, R Mottram & JA Kennedy
WRC Report No 581/1/01
Department of Agrometeorology
University of the Orange Free State
August 2001

Estimation of rainfall intensity for potential crop production on clay soil with in-field water harvesting practices in a semi-arid area
S Walker & M Tsubo
WRC Report No 1049/1/02
Department of Soil, Crop and Climate Sciences
University of the Free State
February 2003

4.3 BESPROEIINGSWATERBESTUURSPROGRAM (BEWAB)

Background

The BEWAB (Besproeiingswaterbestuursprogram) is a pre-programmed soil-water balance model to assist farmers with decision-making by supplying them with pre-plant recommendations on how much water should be applied throughout the season and when to apply it. Irrigation scheduling is practiced through the applying of pre-determined irrigation amounts at prescribed intervals.

The program is based on soil-water budgeting principles. Upper and lower limits of plant available water for different soils were estimated from textural properties. Built into the model are crop water production functions and non-linear crop water demand functions for different crops and planting dates for each locality, based on water use measurements.

The first version of BEWAB (BEWAB 1.2, 1988) includes research knowledge on long-term average irrigation water requirements and effective water management strategies for various crops (wheat, maize, groundnuts, cotton and peas) for irrigation schemes in the semi-arid regions of South Africa. This model provided seasonal irrigation requirements and pre-plant schedules of irrigation for specific crop/site/soil/planting date scenarios. The development of the model was the result of intensive monitoring and measuring of PAWC (Plant Available Water Capacity) of soils in three irrigation areas namely: Sandvet, Vaalharts and Ramah (Riet River) for field crops like maize, wheat, groundnuts, cotton, potatoes and peas. The data used to develop the procedure were obtained under well-watered conditions (high target yield). This version made therefore provision for the maintenance of relatively full soil water profile from early season to provide for the peak demand periods of ET during the mid season. Different irrigation options of plant available water were developed for the user. The different options include the starting and ending of a season with a full or wet profile (wet-wet), starting the season with a wet and ending with a dry soil profile (wet-dry), starting and ending the season with a dry soil profile (dry-dry) and starting with a dry soil profile and ending with a wet profile (dry-wet).

However often irrigation water is short in supply, for instance during dry periods of restrictions on the use of water, and farmers have to revert to deficit irrigation conditions, and thereby aiming at lower target yields in order to benefit more from the rain. The need for the revision of the first version of BEWAB arose from the need to account for the effect of water stress on growing season length (BEWAB 2.1, 1997). The objectives with the development of BEWAB 2.1 were:

- Test of BEWAB irrigation management under both well watered (high target yield) and deficit supply (low target yield) conditions.

- Determine the extent to which crops adapt to the drier soil conditions resulting from deficit irrigation
- Quantify the effect of wet and dry pre-plant root zones on evapotranspiration and crop development under well watered and deficit conditions
- Investigate the most efficient intervals between irrigations for different target yields and soils, for incorporation in the BEWAB irrigation scheduling

BEWAB 2.1 (1997) ensured more accurate and effective use of irrigation water under deficit irrigation supply conditions at target yield lower than would be obtained under optimum conditions of water supply. This model incorporated data required on the interaction between pre-determined levels of deficit irrigation and the degree of adaptation of crops and crop yields to the drier soil conditions. The following aspects were identified for future development after the project was ended, as this could improve the value and applicability of the program:

- The procedure proposed for estimation of unproductive water losses through evaporation from the soil surface needs further refinement.
- More cost effective procedure required for obtaining or estimating of input variables for crops not presently included in BEWAB. The possible use of crop growth models was considered.
- The upper limit of plant available water in the soil profile for irrigation still needs further clarification under various irrigation conditions.
- The development of computer model that can be used for the management of agricultural water at ecotope, farm and regional level.

Some of these shortcomings and the empirical nature of the model were addressed in a follow up research during 1998 with the project "Gebruik van rekenaarmodelle vir landboukundige waterbestuur op ekotoopvlak" (WRC Report TT 102/98). The related irrigation requirements and schedules to a user specific target yield through linear production functions derived from experimental data. Strydom (1998) incorporated transpiration efficiency concepts developed by de Wit (1958), Hanks (1983) and Tanner and Sinclair (1983) into BEWAB, which made it more applicable to any site where maximum biomass yield and maximum evapotranspiration information are available. This research development integrated the available research results and practical experience of 22 years on soil water balance into recognized computer models that could be used to manage agricultural water at ecotope, farm and regional levels.

The research focused on the need for a practical computer program that could be run by farmers or agricultural advisors themselves. Procedures were developed to estimate evaporation of water from the soil surface, runoff, and water uptake by crops at specific target or actual yields and water loss by drainage below the deepest roots. The separate estimation procedures, for each of the components of soil water balance, were therefore linked to a single computer program called

SWAMP (Soil Water Management Program). SWAMP was developed in an effort to address the need to integrate knowledge of the water balance components related to dryland farming. This program included the separate estimation procedures, for each component of the soil water balance. Procedures were developed to estimate the evaporation of water from the soil surface, runoff, and water uptake by crops at specific target or actual yields and water loss by drainage below the deepest roots. This model has the ability to estimate the amount of water that will be stored in the soil during fallow periods and also provides insight into water conservation processes so that tillage practices can be optimized accordingly.

The model was scientifically evaluated by van Rensburg *et al.*, (1995), Bennie *et al.*, (1997) and Stevens *et al.*, 2005. The main features that users perceive to find attractive are the user friendliness and the efficacy of its proposed irrigation schedules. The initial figures showed that more than 500 farmers and extension officers/consultants bought the program since 1988.

The program was upgraded during 2008 by van Rensburg and Zerisghy and is now available as BEWAB+. The main changes to the program included the inclusion of new research findings and the converting of the programming code from DOS based GWBasic to Windows based VisualBasic 6. These changes contributed to the user friendliness and efficiency of processing of the new BEWAB+ program.

Purpose and objectives

- To develop an irrigation management program for various options under both well watered (high target yield) and deficit supply (low target yield) conditions. It should include different options for managing the plant available water in the soil like starting the season with a wet soil and ending it with either a wet or dry or starting with a dry soil and ending it with a dry or wet soil.
- To develop a procedure with which the most effective interval between irrigations can be calculated taking into account crop and soil type, target yield and the selected management option.
- An irrigation management program which can be used to estimate or measure real time plant available water capacity (PAWC) for various soil types in combination with various crop types to help with the designing of irrigation systems
- To supply farmers and agriculturalists with an easy to use computer program that can provide them with decision-making support for efficient water management and crop production at field level under dryland and irrigated conditions.

Developer (s) of model

- BEWAB 1.2: Prof ATP Bennie, MJ Coetzee, R van Antwerpen, LD van Rensburg and R du T Burger, University of Free State
- BEWAB 2.1: Prof ATP Bennie, LD van Rensburg, CC du Preez and MG Strydom, University of Free State
- BEWAB +: Prof LD van Rensburg , University of Free State

Potential application

- Use for the planning and implementation of different irrigation strategies for the depletion or recharge of plant available water in the root zone by irrigation managers, farmers and advisors.
- The revised versions of BEWAB (BEWAB 2.1 and BEWAB+) ensure more accurate and effective use of irrigation water under deficit supply conditions.
- The BEWAB model can be applied on any irrigation scheme if the required input information like soil depth, texture, rainfall, maximum evapotranspiration and maximum biomass yield are available for the specific location.
- It helps the farmer with a decision making and to estimate the amount of unused plant available water in the soil, at the end of the growing season.
- Also used as an educational tool in undergraduate and post graduate water management courses

Challenges and future developments

- The software package had to be refined and upgraded after thorough evaluation in the field.
- Continuous upgrading of the program to include new research findings and the converting of the programming code from DOS based GWBasic to Windows based VisualBasic6 to make it more user friendliness.

WRC Reports

‘n Waterbalansmodel vir besproeiing gebaseer op profielwatervoorsieningstempo en gewaswaterbehoeftes
ATP Bennie, MJ Coetzee, R van Antwerpen, LD van Rensburg & R du T Burger
WRC Report No 144/1/88
Department Soil Sciences
University Free State
February 1988

Reaksie van gewasse op voorafgeprogrameerde tekortbesproeiing
ATP Bennie, LD van Rensburg, MG Strydom & CC du Preez
WRC Report No 423/1/97
Department Soil Sciences
University Free State
1997

An evaluation of the seasonal water use of spring wheat as predicted with BEWAB irrigation model
LD van Rensburg, ATP Bennie & S Walker
WRC Report No TT 71/95
Department Soil Sciences
University Free State
1995

Gebruik van rekenaarmodelle vir landboukundige waterbestuur op ekotoopvlak
ATP Bennie, MG Strydom & HS Very
WRC Report No TT 102/98
Department Soil Sciences
University Free State
1998

4.4 SAPWAT (SOUTHERN AFRICAN PROCEDURE FOR ESTIMATING IRRIGATION WATER REQUIREMENTS)

Background

SAPWAT is a crop water use-planning model, which is generally used for planning and decision-making purposes at various spatial scales (e.g. WUA scale to field scale) by irrigation engineers, planners and agriculturalists. SAPWAT was developed and tested with WRC funding in 1996 (Crosby, 1999), although some of the background information included as data in the program is based upon 15 years of WRC research and projects related to irrigation and crop production.

The objectives for the development of SAPWAT 1.0 in 1996 were to assess the feasibility of establishing a personal computer based decision support system for the estimation of crop water requirements under irrigation. The designers followed an inter-disciplinary approach, where there was close contact with a wide spectrum of disciplines. In addition to the incorporation of international recommendations (FAO procedures) as the foundation, SAPWAT leaned on research supported by the WRC, particularly Dent *et al*. (1988), Schulze (1989) and Bennie *et al*. (1988). Right from the start of the development of this program the emphasis was *"..to be acceptable to the ordinary practitioner"*. The first edition of SAPWAT was in a pilot form and Crosby (1996) made use of estimated irrigation requirements of 712 climatic zones for specific crop factors, applied on equivalent A-pan evaporation, as calculated by Dent *et al*., (1988). Crosby (1996) converted the A-pan evaporation to short grass reference evaporation by adjusting the crop factor with a factor of 5/7, derived from the Linacre equation (1977). This approach has been recognized as being only of a temporary nature, since it was believed that not enough data was available to calculate the Penman Monteith ET_0 values for a significant number of places in South Africa at that time.

SAPWAT 1 was followed in 1999 with the development of the SAPWAT computer-planning model (WRC Report No 624/1/99), which was strongly linked with the FAO database CLIMWAT (Smith, 1993), containing monthly ET_0-data for several stations in South Africa. Although these stations were not necessarily situated in irrigation areas, the monthly ET_0 values were compared with A-pan values. Through this approach it was possible to derive reasonable values for ET_0 from these ratios, which made it possible to develop an extensive ET_0 network. This procedure was further refined by Schulze (1997) and ET_0 values were presented in the "South African Atlas of Agrohydrology and Climatology". The four stage FAO procedure for the determination of crop factors as recommended by Smith (1994) was applied in SAPWAT to ensure transparent and internationally comparable methodology. SAPWAT was developed as a planning aid. The compatibility with CROPWAT provided management options like different irrigation management options. Field evaluations during this project cycle showed that a planning function is not complete if not integrated with management. This field-testing showed that the development of a management module for SAPWAT was justified, and therefore an irrigation-scheduling module was developed, which enables the user to evaluate different irrigation strategies in order to identify a "best" strategy for a specific situation.

SAPWAT, as a further development of CROPWAT (Smith 1992), filled a need in the field estimation of irrigation requirements of crops under varying crop production approaches and climates in South Africa. Both SAPWAT (Crosby & Crosby, 1999) and CROPWAT (Smith 1992) make use of long-term average monthly weather data, probably because the data required in this format can be stored in a relatively small space. The inclusion of extensive climate data in CLIMWAT (Smith, 1993), which was developed as a weather data set for CROPWAT enhanced the user friendliness of SAPWAT. It used average monthly ET_0 data sourced from the South African CLIMWAT data as well as data supplied by the Agricultural Research Council's Institute of Soil, Climate and Water (ARC-ISCW), to calculate irrigation requirements on a daily basis. This opportunity provided SAPWAT users the opportunity to select up to six weather stations out of 350 indicated on a map; comparative reference evaporation graphs; crop factors for a selected crop, and a screen which shows the water requirement for that crop, effective rainfall and irrigation requirement.

Feedback after testing of SAPWAT in the field lead to the integrating of SAPWAT and PLANWAT and the upgrading to a user-friendly irrigation-planning tool SAPWAT3 (2008). SAPWAT 3 (van Heerden *et al.*, 2008) is an enhanced and improved version of SAPWAT (Crosby & Crosby, 1999) that is extensively applied in South Africa. Like SAPWAT, SAPWAT3 is a tool for use in irrigation policy development, planning, design, management and analysis. The data required to run the program is included in the installation software and a minimum of computer literacy is required. Subsequent to the development of the SAPWAT program, the core of FAO No 56 was incorporated in SAPWAT 3, which required reprogramming. The irrigation requirements of crops are dominated by weather, and therefore SAPWAT3 installed a database of comprehensive weather data that is immediately available to the user. It furthermore provides the provision for the importing of additional weather stations where required. SAPWAT3 also addressed the need for the provision of export and storing of output data. It can also be applied for the estimation of irrigation requirements of a single crop, for a field with multi cropping, for a single farm for a group of farms or Water User Association or for Water Management Areas. The SAPWAT3 version incorporates the internationally recognized Köppen-Geiger climatic system. Adaptations to the original international codes regarding rainfall seasonality were required to fit situations in South Africa. The inclusion of economic analysis module in SAPWAT3 enhances its capability as a planning tool. It also addresses the need regarding rainwater harvesting and includes a specific module on typical small farm and household garden scenarios.

Purpose and objectives

a. The stated objectives for the development of SAPWAT (1999) were:
   - Development of an up-to-date program to estimate irrigation requirements and retain desirable features of and compatible with CROPWAT, FAO Irrigation paper No 46 (Smith, 1992) while catering for specifically South African requirements
   - Provision of comprehensive built-in databases that obviate the need to seek climate or crop data elsewhere
   - Use of an approach that is sufficiently similar to current practice to be immediately acceptable to practitioners
   - Achievement of accuracy in-line with practical requirements

- Implement transfer of technology through research and modern on-farm scheduling advice

b. The objectives for the development of SAPWAT3 (2008) were to address the shortcomings that were identified with the testing of SAPWAT:

- The first objective was to integrate SAPWAT (1999) and PLANWAT (2004) into a user friendly planning and teaching aid in relation to irrigation water requirements and gross margins for the backyard and community gardens, fields, farms and water user associations
- Upgrade SAPWAT weather stations capabilities to include the importation of weather station data
- Build an interactive module for calculating of gross margin based on COMBUD approach
- Improve and expand PLANWAT water harvesting module to include the calculation of ratio between planted areas and harvest areas for Infield Rainwater Harvesting (IRWH)
- Integrate SAPWAT and PLANWAT into user-friendly unit
- Create output data tables that could be exported to XBase type database programs and spreadsheet type programs where it can be used for further calculations of system irrigation requirements

The purpose of the development of SAPWAT3 was to establish a planning and management tool for irrigation engineers, planners and agriculturalists. SAPWAT3 is also used to estimate the total annual and monthly crop irrigation requirements, which can be compared to the water available to the area. This enables farmers and WUA managers to ensure that the right amount is applied at the right time. SAPWAT is also used to identify possible limitations in the conveyance and delivery infrastructure, which could have negative consequences, associated with the crops being stressed during certain periods resulting from the limitations. It is also used to estimate the crop water use requirements of different crops under different irrigation systems and different irrigation management regimes throughout South Africa and neighbouring countries like Namibia, Botswana.

Developer (s) of model

SAPWAT was developed by Mr C Crosby at Murray Biesenbach and Badenhorst and subsequently further developed by Mr P van Heerden of PICWAT consultants with contributions of JW Badenhorst, CP Crosby, RE Schulze, B Grove, E Romanowska, N Benade, E Theron and MH Tewolde.

Potential application

SAPWAT became an accepted methodology for estimating crop irrigation requirements in a number of aspects of water management and play an important role for the following seven areas (Van Heerden *et al.,* 2008):

- Macro planning: Irrigation accounts for the major share of water requirements in South Africa, therefore the Department of Water Affairs (DWA) has recognized SAPWAT principles and it is incorporated in the irrigation inputs into the National Water Balance Model of DWA and associated studies.
- Water pricing strategy, registration of water use and verification of legal water use: In terms of the National Water Act (DWAF, 1998) users are required to register the use of irrigation water and DWA have indicated that the SAPWAT computer program for determining the annual irrigation requirement is the method to be used.
- Water Demand Management Strategy**:** In future, Water User Associations (WUAs) will be required to develop Water Management Plans on a regular basis. The impact of irrigation practices and strategies on water budgets requires the assessment of impact on crop irrigation requirements. This is one of the functions for which SAPWAT was developed.
- Small-scale farmer irrigation schemes, household and community gardens: One of the primary objectives of the SAPWAT development program was providing for the specific circumstances and requirements of emerging irrigation farmers and community gardens. Particular attention was paid to this aspect and presently consultants engaged in the initiatives of the National Department of Agriculture base designs for sustainable rehabilitation of irrigation schemes on SAPWAT predictions.
- Irrigation planning and management: Planning how much irrigation water is required and when, is a prerequisite for individual farmers, designers, WUAs, irrigation schemes and reservoir management. The strength of SAPWAT lies in an extensive database that saves the user the chore of looking for figures and built-in routines for undertaking sensitivity analyses of alternative strategies.
- Support for irrigation scheduling: SAPWAT is not a real-time scheduling model, but can be a valuable complement to instrumented soil water content methods. An atmospheric demand-based program can provide pre-season irrigation programs based on historic weather data that can go a long way towards alleviating much of the urgency of short-term real time scheduling.
- Irrigation system design: Designers utilize SAPWAT in preliminary planning discussions with clients and to check system capacity and management. SAPWAT can be used to set benchmarks for irrigation water requirements not only as a single figure, but also give ranges of expected irrigation

requirement by doing standard deviation analysis on up to 50 years of historic data.

This innovation was awarded with international recognition in 2011 through the WATSAVE award from the International Commission for Irrigation and Drainage.

Challenges and Future developments

SAPWAT has been well accepted as indicated by van Heerden (2009). 300 users from 13 countries used the program as an aid to the planning of irrigation requirements of crops and for the training of farmers and students in both the commercial and beginner-farmer categories according to van Heerden (2009).

The following shortcomings were identified with the testing of SAPWAT and addressed in the development of SAPWAT3:

- The inability of SAPWAT to store the results of calculations and the inability to import weather station data for the expansion and updating of its existing weather station data. These needs were first addressed through PLANWAT (van Heerden, 2004) and later through SAPWAT3.
- Although PLANWAT has a water harvest module where the output of SAPWAT is used to calculate the required water harvest areas and required storage capacities for the run-on situations of water harvesting, the one shortcoming was that it did not provide for infield water harvesting situations. As a planning tool the combination of the two programs (SAPWAT and PLANWAT) did not provide for interactively determining of the best potential scenarios of irrigation water use coupled to gross crop margin to enable the farmer to select the best option for his circumstances.
- When a researcher visits a farmer and obtains field data (crop production and irrigation strategy data), it has to be entered manually into SAPWAT for calculation of irrigation requirements. This frustration could possibly be addressed by the development of an electronic questionnaire that could serve as input data for the calculation of irrigation requirements.

With the writing of this report, SAPWAT3 was tested in the field by the developers to identify shortcomings for further attention and development

WRC Reports

SAPWAT 1.0: A computer programme for estimating irrigation requirements in Southern Africa
Crosby CT
WRC Report No 379/1/96
Murray Biesenbach & Badenhorst Incorporated Consulting Engineers, Pretoria
1996

Using SAPWAT to estimate water requirements of crops in selected irrigation areas managed by the Orange-Vaal and Orange-Riet Water User Association
PS van Heerden, CT Crosby & CP Crosby
WRC Report No TT163/01
PICWAT Consultants
October 2001

The upgrading and updating of SAPWAT program and website in 2003/2004
PS van Heerden and CT Crosby
WRC Report No KV 201/05
PICWAT Consultants
2005

Technology Transfer and Integrated Implementation of Water Management Models in Commercial Farming
A Pott, N Benade, PS van Heerden, B Grove , JG Annandale & M Steyn
WRC Report No TT 267/08
April 2008

Integrating and updating of SAPWAT and PLANWAT to create a powerful and user-friendly irrigation planning tool
PS van Heerden, CT Crosby, B Grové, N Benadé, E Theron, RE Schulze & MH Tewolde
WRC Report No TT391/08
March 2009

Technology Transfer of SAPWAT3, verifying correctness of program output and evaluation of its adoption potential
PS van Heerden & CT Crosby
WRC Report No KV 271/11
April 2011

4.5 SOIL WATER BALANCE (SWB) MODEL

Background

SWB is a generic, mechanistic model for real time irrigation scheduling at field scale (i.e. operational purposes). It is an irrigation-scheduling tool that is based on the improved generic crop version of the soil water balance model first described by Campbell and Diaz (1988). The model has since been improved and reprogrammed with a user-friendly interface by researchers from the University of Pretoria, following several research projects funded by the WRC.

SWB gives a detailed description of the soil-plant-atmosphere continuum. Crop water use is estimated using a mechanistic and therefore a universally valid approach to estimate the crop water use. It has several advantages over the more empirical models generally found, which usually use different crop factors for different planting dates and regions. The use of thermal time to describe crop development requires crop parameters that are transferable to other environments. Evaporation and transpiration are split in SWB, which solves the problem of taking irrigation frequency into account. Deficit irrigation strategies can also be more accurately described. Evapotranspiration is calculated according to the Penman Monteith grass reference method according to the FAO standards described by Allen *et al.* (1988). The soil water balance can be modeled either using a cascading soil water balance or a finite difference model (Annandale, 1999). Daily crop dry matter accumulation was taken as the lower value of either radiation limited growth or water limited growth (Tanner &Sinclair, 1983). Thermal time was used to calculate phenology and partitioning with the effect of water stress accounted for through the use of a stress factor.

Databases are used to store crop, weather, field, and water and soil parameter data. The crop database is populated with default crop parameters for a range of commonly irrigated crops in South Africa. The crop and soil water components of the model have undergone extensive testing and parameterisation for the commonly grown South African crops including potatoes, sunflower, maize, soybeans, canola, fescue, lucerne and a wide range of vegetable crops (Jovanovic & Annandale, 1999; Jovanovic *et al.,* 1999; Annandale *et al.,* 2000; Jovanovic & Annandale, 2000; Jovanovic *et al*., 2000; Jovanovic *et al*., 2002; Tesfamariam, 2004; Annandale *et al.,* 2007). The FAO crop factor approach that was included in the model made it possible to include crops with limited data available and also for tree crops which cannot be grown using the simple crop model (Jovanovic & Annandale, 1999). This, together with the function that several fields can be simulated simultaneously, contributes to its function as a scheduling tool for large-scale farmers, irrigation consultants or WUAs.

Three levels of operation modes, namely the Irrigation, Consultant and Researcher modes were introduced. These can be selected in the main menu and ensure that only information applicable to a certain level of user is accessible. The promotion of SWB amongst irrigation farmers and consultants had limited success (Annandale *et al*., 2005). Only a very small percentage of consultants and irrigation farmers use SWB as a scheduling tool (Pott *et al.*, 2008).
In an approach to make the implementation of SWB more user-friendly to small-scale farmers and even commercial farmers, SWB Irrigation calendars were also developed as an alternative for real time irrigation scheduling. This is where the irrigator has not access to daily weather data or computers. In such instances the long-term temperature, as well as soil and management inputs for a specific locality are used to generate site-specific irrigation calendars. This can be printed and supplied to farmers. This product is especially of big aid to small-scale farmers who are without computers and access to real time weather data. However, large-scale farmers could also apply irrigation calendars as a simpler irrigation scheduling method. The research team does not promote the replacement of real time irrigation scheduling with irrigation calendars, but rather as a site specific simplified application of the SWB model.

The model has been renamed in 2008 after some definite adjustments and improvements were made which included the changing of the database to Firebird instead of Paradox, development of a single setup input screen, development of a Quick setup screen for default soils, weather database improvements, and the extending of the use of SWB for planning purposes. The model has been renamed to SWB-Pro to differentiate from the previous version.

Purpose and objectives

The following broad objectives were stated during the development of SWB:

- To develop a quick, simple and reliable irrigation scheduling technique.
- To develop a user friendly interface for easy technology transfer. Although this model follows a scientifically sound mechanistic approach, a user-friendly interface makes it accessible to any person with basic computer literacy. SWB is a generic crop model and therefore differs in approach to the species-specific crop growth models such as PUTU/CERES MAIZE (Jones and Kiniry, 1986) and Canegro (Inman Bamber, 1991). SWB could also be used for the prediction of crop water use for a wide array of crops, but was not really designed for other purposes, such as highly accurate yield predictions.
- To compile a comprehensive user manual and user help facility
- To generate site specific Irrigation Calendars for use by farmers who are not interested in real time irrigation scheduling.

Developer (s) of model

Prof John Annandale and various researchers from the University of Pretoria, following several research projects funded over many years (Annandale *et al.*, 1996; Benadė *et al.*, 1997; Annandale *et al*., 1999; Annandale *et al*., 2000; Annandale *et al*., 2002a; Annandale *et al.,* 2002b; Annandale *et al.,* 2002c; Benadė *et al.*, 2002; Annandale *et al.*, 2005; Annandale *et al.*, 2007 Jovanovic & Annandale, 1999; Jovanovic *et al.,* 1999; Annandale *et al.,*2000; Jovanovic & Annandale, 2000; Jovanovic *et al*.,2000; Jovanovic *et al*.,2002;Tesfamariam, 2004) have developed the SWB model.

Potential application

- Leader irrigation farmers and irrigation consultants are the main users of this irrigation-scheduling tool.
- The improvements opened the use of the model for the running of long term simulations in the planning mode and the development of Irrigation Calendars (also by Irrigation Boards).
- The use of SWB Pro has been developed to provide model outputs, which can be readily fed into the RISKMAN model. The SWB-Pro and RISKMAN models combined offer WUAs and water resource managers a tool to help assess the hydro-economic implications of various water management and land use decisions.
- Irrigation Boards like Loskop, Gamtoos and Vaalharts can run an irrigation scheduling service to irrigators interested.
- Irrigation Calendars were specifically developed to assist resource poor farmers who are without computers and access to real-time weather data and also commercial farmers who are interested in the simpler management option.

Challenges and future development

The SWB technology transfer project indicated that SWB was successful in generating knowledge of users, but in general it was perceived to be not user friendly. Many attended training courses on SWB not to implement SWB as an irrigation scheduling tool, but rather to improve their knowledge regarding plant/water relations. Some felt that the model was too complex and required too many input parameters.

The technology transfer actions of SWB identified certain shortcomings to simplify the model, especially for real-time scheduling. These shortcomings were addressed by SWB Pro and with the development of Irrigation Calendars:

- Users experienced problems in setting up the new fields, soils and weather files. This requires the creation of a single simplified simulation setup screen.

- The Paradox database used in SWB used for in- and output data was replaced with Firebird database. This action will make the setting up of new fields easier and ensure a sustainable future for SWB as it is the same database used in WAS.
- Improvement of the weather database and populating it with long term weather data for almost 1000 weather stations in South Africa for the use of scenario modeling and development of Irrigation Calendars for specific irrigation sites.
- Inclusion of default soil types and scenario modeling for economic analysis
- The need exist for the demonstration of SWB as an irrigation scheduling tool. This can be best demonstrated with different irrigation management scenarios, which can give outputs of water usage and crop yield and with the development of a scenario modeling for economic analysis.

WRC Reports

Die fasilitering van tegnologie oordrag deur verbeterde besproeiingsriglyne vir groente en 'n meganistiese gewasmodelering benadering
JG Annandale, AJ vd Westhuizen & FC Olivier
WRC Report No 476/1/96
Department Plant Production and Soil Sciences
University of Pretoria
1996

Predicting the impact and sustainability of irrigation with gypsiferous mine water
JG Annandale, NZ Jovanovic, AM vd Westhuizen, JM Steyn, A Claassens, NFG Rethman, CF Reinhardt, PC de Jager, TA Mpuisnag, PC Modisane, PS Hammes, L Masike, HJ le Roux, N Benade, FDI Hodgson, B Usher & S Lorentz
WRC Report No.206/99
Department Plant Production and Soil Sciences
University of Pretoria
1999

Facilitating irrigation scheduling by means of the soil water balance model
JG Annandale, N Benade, NZ Jovanovic, JM Steyn & N du Sautoy
WRC Report No 753/1/99
Department Plant Production and Soil Sciences
University of Pretoria
1999

Two dimensional energy interception and water balance model for hedgerow tree crops
JG Annandale, NZ Jovanovic, NS Mpandeli, P Lobit & N du Sautoy
WRC Report No 945/1/02
Department Plant Production and Soil Sciences
University of Pretoria
2002

The development of an integrated information system for irrigation water management using WAS, SWB and RISKMAN
N Benade, JG Annandale, NZ Jovanovic, JA Meiring & CI Crous
WRC Report No 946/1/02
NB System
2002

The influence of irrigation with gypsiferous mine water on soil properties and drainage water
JG Annandale, NZ Jovanovic & A Claassens
WRC Report No 858/1/02
Department Plant Production and Soil Sciences
University of Pretoria
2002

Technology transfer of Soil Water Balance (SWB) as a user friendly Irrigation Scheduling Tool
JG Annandale, JM Steyn, N Benade, NZ Jovanovic & P Soundy
WRC Report No TT 251/05
Department Plant Production and Soil Sciences
University of Pretoria
2005

Predicting the environmental impact and sustainability of irrigation with coal mine water
JG Annandale, YG Beletse, PC de Jager, NZ Jovanovic, JM Steyn, N Benade, SA Lorentz, FDI Hodgson, B Usher, D Vermeulen & ME Aken
WRC Report No 1149/1/07
Department Plant Production and Soil Sciences
University of Pretoria
2007

Technology Transfer and Integrated Implementation of Water Management Models in Commercial Farming
A Pott, N Benade, PS van Heerden, B Grove , JG Annandale & M Steyn
WRC Report No TT 267/08
April 2008

4.6 MYCANESIM

Background

Olivier and Singels (2004) indicated that water use efficiency amongst sugarcane growers is very low since 70% of the sugarcane farmers use dragline irrigation of which 50% farmers use a fixed irrigation schedule. This in general leads to over irrigation and impact negatively on the profitability of sugarcane production and on the environment. In order to address these needs, Canesim was developed.

Canegro was described by Inman-Bamber (1991) and was primarily developed as a tool to assist and direct research regarding irrigation scheduling and management (McGlinchey *et al*., 1995; McGlinchey and Inman Bamber, 1996); crop forecasting (McGlinchey, 1999); determining of potential yield and attainable yield (Inman Bamber, 1995), optimizing of harvest age (Bezuidenhout *et al*., 2002) and for the use by consultation to farmers by millers to estimate climate yield potential, yield loss potential due to mill shutdowns and interruptions in irrigation water supply and the impact of changing milling season length on productivity. Canegro received international recognition by the incorporation in DSSAT (Version 3.1) (Inman Bamber & Kiker, 1997) and Version 4.5 (Jones *et al.,* 2007)).

The South African Sugarcane Research Institute (SASRI) developed the Canesim model with the aim of making sugarcane modelling more accessible to the bigger target audience. The focus with this model was simplifying the inputs required for the running of a model and on providing a user-friendly interface to encourage wider use of a model. Canesim uses a single layer soil model and a thermal time driven canopy cover development (Singels and Donaldson, 2000), which circumvents the need for detailed input data, simulation of layer specific water redistribution and extraction and leaf and tiller development. This model is available on the Internet (http://sasri.sasa.org.za/iircane/index.htm) to calculate crop water use and cane yield for specified South African climate, soil and cropping seasons, either in hind – or forecast mode (Singels *et al.,* 1999).

The rapid progression of communications technology (cellular communication and Internet) promotes quick transfer of large amounts of data and information. This enabled SASRI to develop a model, which provides real-time irrigation advice to small-scale and commercial sugarcane farmers (Singels and Smith, 2006) called MyCanesim.

The MyCanesim system comprises of the following:

- A database of model inputs and outputs;
- An on-line weather database;

- A sugarcane model (***Canesim***) that simulates the recent, current and future water balance, crop status and yield for a number of positions in a field;

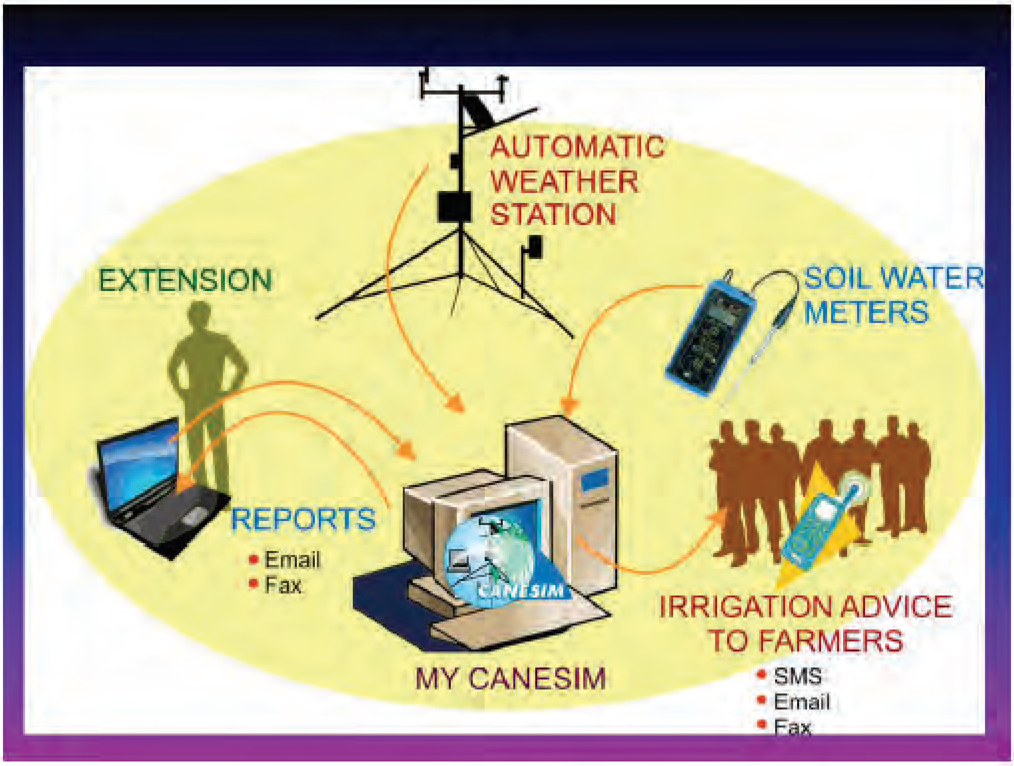


Figure 4.1. Schematic presentation of MyCanesim irrigation scheduling system (Singels and Smith, 2006)

An irrigation scheduling and advice which indicates the ideal irrigation schedule based on water balance of various positions in each field can be downloaded by subscribers through web downloads to extension staff and advisors or by cellular text message for small scale farmers. The system outputs daily values of cane yield and quality, crop and soil water status, canopy cover, cumulative water balance totals and irrigation advice. This data are used via the interface, to produce reports that summarize data in numerical and graphical form at the irrigation scheme or field level. The output can be printed as hard copy or exported into Microsoft Excel for further analysis. The output can also be disseminated to farmers in the form of a SMS whenever action is required (for example to start or stop irrigation), and to extension staff and mill management on a weekly basis. The fax summary of irrigation advice contains information for each field in a given scheme, on the current irrigation action (irrigating or not), expected date of next action (stop or resume), the expected date of last irrigation, current cane yield and rainfall and irrigation totals to date.

Type of information	Level	Delivery method	Primary user
Irrigation advice	Field	SMS	Farmer
Farm report	Scheme	Web	
Field report	Field	Web	
Irrigation report	Field	Web	
Rainfall report	Field	Web	
Irrigation advice	Farm, scheme	Web/fax	Extension
Yield estimates	Farm, scheme	Web/fax	Extension/mill staff

The ***MyCanesim*** system was developed and improved with the support of extension officers from SASRI and other stakeholders (farmers, researchers). The following aspects received special attention in the development of the system:

- A user friendly, web-based graphical user interface was developed that allows users to set up simulation runs, manipulate simulation input data and view various system reports (including irrigation advice).
- A control module which allows the smooth operation and monitoring of the MyCanesim system – it allows the administrator to activate and deactivate schemes and fields listed for batch running, edit key field input variables such as cell numbers and harvest dates.
- The facility for farmers to send a blank SMS reply to the MyCanesim system exists where they can choose not to or could follow advice. This reply is automatically interpreted in the context of the specific advice and then used to adjust assumed irrigation records used in the simulation input.

This innovation was awarded with international recognition in 2007 through the WATSAVE award from the International Commission for Irrigation and Drainage. Singels (2007) illustrated the use of MyCanesim in the assisting of extension staff to benchmark yields and water use and to address practical problems in the irrigation field.

Purpose and objectives

The following objectives were stated for the development of MyCaneSim:

- Development and refining of an automatic irrigation advice system consisting of automatic weather stations, a web-based crop model and cellular communication network
- Implementation of the system for small scale farmers in Pongola and Makhatini flats
- Evaluation of the stability of the system for providing useful irrigation advice and to determine likely adoption rates and impacts on water use. To provide a simple, practical and useful advice to small scale farmers using state of

the art technology such as crop models and weather stations, and to convince farmers of the benefits of irrigation scheduling through on-farm demonstration.

Developer (s) of model

AT Singels and MT Smith from the South African Sugarcane Research Institute, Mount Edgecombe with the support of extension workers from SASRI and stakeholders like farmers, researchers, and mill cane supply management.

Potential application

The following application was identified for the specific technology:

- Help extension staff and farmers to gain better understanding of the important factors that determined the crop water balance and how irrigation can be scheduled to impact positively on productivity and sustainability. With the full implementation of the system on the Pongola small-scale irrigation scheme, subscription to the service grew from 10% in 2005 to 87% in 2008 (Pongola: 47 farmers, 508 ha; Makahathini: 268 farmers, 3000 ha)
- The various reports from the system provide concrete information for extension staff to benchmark irrigation practices, growth and yield of individual fields
- Farmers can obtain a positive net benefit from the 'advice only' service. The benefit of the more costly 'advice plus monitoring' is more doubtful.
- Significant direct monetary benefits are possible, provided the following are in place:
    - Reliable and adequate supply of water
    - Adequate irrigation systems
    - Adequate control over water supply and irrigation at field level
    - As sense of ownership of land and infrastructure
    - Monetary incentives for farmers to benefit from water savings
    - Willingness of farmers or water user agencies to contribute to the cost of service delivery
    - Competent and committed support from field staff required to assist farmer with the implementation of advice and to obtain accurate field data
    - Adequate internet access and fax facilities for field support staff
    - Adequate computer processing power and optimal system code to reduce system run time and enable system expansion
- An advisory service that provides real time irrigation scheduling advice based on weather data could be implemented on other sugarcane irrigation schemes, provided that specific constraints are addressed.

Challenges and future developments

The following challenges were identified:

- Although the system operates successfully almost 95% of the time, room exists for code optimization to reduce runtime.
- Also a need for more powerful processing power to speed up execution speed to accommodate all prospective users.
- Unreliable fax and Internet facilities amongst extension staff should be addressed.
- Difficulty obtaining good quality irrigation and rainfall data timeously from farmers, which affects the accuracy of simulations and the relevance of advice.
- At Pongola irrigation scheme, the majority of growers share pumps and the associated costs with one or two neighbours. Hence all members of a pump group were not subscribed to the service offered by MyCanesim, they did not receive the same advice, which often created conflict.
- Observation of canopy cover, soil water status and cane yield during 2005-2007 in 13 cane fields showed that the simulations were reasonably accurate when the Canesim model was supplied with accurate input data. The Wetting Front Detector responses suggest that the Canesim model sometimes underestimated the soil water status and it is recommended that this problem be further investigated to improve the model.
- The system was refined to accommodate SMS reply from farmers when they could not or would not follow the advice. This information is interpreted in the context of the advice sent and adjusts irrigation input data accordingly. This feature requires testing.
- The current system provides largely information based on weather data applicable for relative large areas, and lacks the detail required for irrigation management at field level. The quality of advice could be improved if the system is integrated with real time electronic monitoring of resources at field level. This will also address the challenges in obtaining accurate feedback from farmers in time.
- The system provides information on cane yield, cane quality and crop water to assess the readiness of fields on a scheme or farm level for harvesting. The schedule of harvesting could be adjusted to maximize sucrose production at a mill level or to accommodate other practical considerations.
- Another potential application is to provide advice on fertilizer management, especially Nitrogen (N). The possibility to include a simple N model in the system to simulate soil and plant N content is possible to advise the best application strategy, according to the N management approach advocated.
- The possible extension of the service to large-scale farmers. The specific situation and needs of these farmers (i.e. multiple fields per farm and drip and centre pivot irrigation systems) should be taken into account.

WRC Reports

Real Time Irrigation advice for small-scale sugarcane production using a crop model
A Singels& M Smith
WRC Report No 1576/1/08
South African Sugarcane Research Institute
Mount Edgecombe
November 2008

Increasing water use efficiency of irrigated sugarcane by means of specific agronomic practices
FC Olivier, NL Lecler & A Singels
WRC Report No 1577/1/09
South African Sugarcane Research Institute
Mount Edgecombe
July 2009

4.7 WETTING FRONT DETECTOR (WFD)

Background

The Wetting Front Detector (WFD) was developed to overcome some of the perceived complexities of irrigation scheduling, by simplifying the irrigation decision (Stirzaker, 2003). It filled a perceived gap in the market namely to develop a tool that "made intuitive sense" to farmers and linked water management with salt and nutrient management. The WFD refrained the traditional irrigation scheduling question of "when to turn on the water" to "when to turn it off" (Strirzaker *et al.,* 2004) .The traditional focus of soil water monitoring had been to specify refill points, i.e. how dry the soil can be allowed to get without affecting production of the crop. Long intervals between irrigation events meant that sprinklers could be moved less often. With the development if micro irrigation, the perspective changed and irrigation can occur at any time per day.

During irrigation, water infiltrates into the soil forming a wetting front, defined as the boundary between wet soil above and drier soil below. Stirzaker and Hutchinson (2005) showed that irrigation could be scheduled accurately and inexpensively by terminating each irrigation event when the wetting front reached a set depth in the soil. The technique is based on the theory of Philip (1969), which states that the time it takes for a wetting front to reach a set depth in the soil, and hence the duration of irrigation, is inversely proportional to the initial water content.

The Wetting Front Detector (WFD) is a funnel-shaped instrument that is buried in the soil. The funnel concentrates the downward movement of water so that saturation occurs at the base of the funnel. The WFD (commercially known as FullStop) provides a visual signal when the soil at its base reaches saturation when matric potential of the soil outside the funnel is around 2-3 kPa, which corresponds to relatively strong wetting front. Once saturation occurs the free (liquid) water produced from the unsaturated soil activates a mechanical float, alerting the farmer that water has penetrated to or past the desired depth. The detector retains a sample of soil water that is used for nutrient and salt monitoring. The detectors are often installed at various depths and used in a similar way as tensiometry, namely a shallow detector indicating water entering the root zone and a deeper detector possibly warning of over irrigation. This is used for measuring of electrical conductivity of the water and its nitrate concentration. The working of the WFD is explained more fully at the WFD website: www.fullstop.com.au. Wetting Front Detectors are usually used in pairs and by watching how shallow and deep detectors respond through the season, the irrigator can get an idea if they are applying too much or too little water, as described in the diagram below.

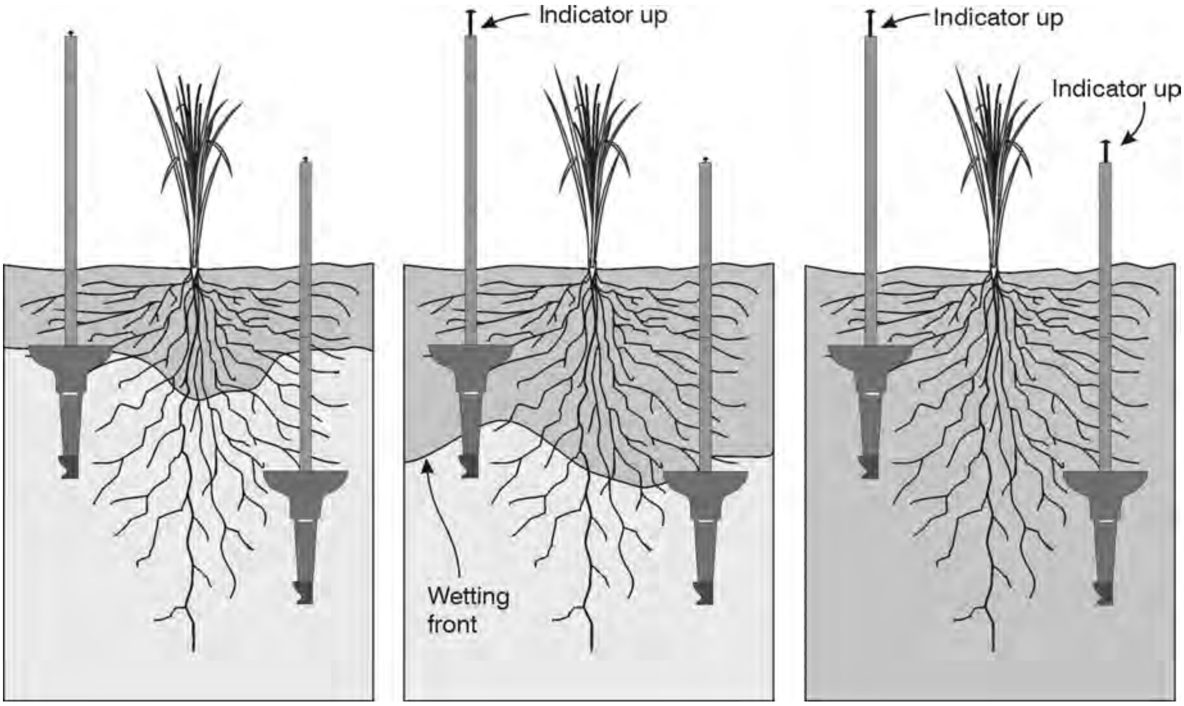


Figure 4.2 Wetting Front Detector responses in soil

Much progress was made between 2000 and 2003 through the WRC Project No 230/04, which involved the testing of the device under controlled conditions, on-farm evaluation, and obtaining feedback from irrigators. The initial research and on-farm experience showed enormous potential, and therefore the device was commercialised in a relatively short space of time. In 2003, the Fullstop won an international prize for *"Outstanding contribution to water saving and water* *conservation in Agriculture"* presented by the International Commission on Irrigation and Drainage in France. It was released in 2004 and over 15 000 units have been sold worldwide, mostly in south Africa, Australia, Argentinia, Chile, Peru, Spain and Greece.

The fieldwork and consultancy that followed this project showed that the device was well suited for drip irrigation and sprinklers, but not well suited for furrow irrigation. Deep placement, cracking soils or where soil disturbance must be minimized required a different design. The Tube Detector has been specifically designed in 2005 to overcome above shortcomings. The modified WFD is called a Tube Detector (TD). This device was developed at the Hatfield experimental farm, University of Pretoria and at UNIVEN and in farmer's fields in Dzindzi irrigation scheme. The Tube Detector proved to be extremely sensitive wetting front detector and operated exactly according to theory. The Tube Detector identified severe over-irrigation in farmer fields, although the researchers admitted more work is required to evaluate the potential for the small-scale farmers' use. The testing of the Tube Detector on soil water solution monitoring carried out in a stone fruit and citrus orchard indicated that WFDs are more indicative of solute concentrations in moving water, while the use of suction cups (lysimeters) are more appropriate for measuring what crop roots are exposed to (resident water). The biggest advantage in using the WFD to collect samples for soil water solution monitoring was that the operator did not have to prime the cup with suction to obtain a sample – it was collected and stored automatically.

Purpose and objectives

- The development of a simple irrigation-scheduling tool, which could assist farmers to improve their understanding of irrigation. The mode of operation had to make 'intuitive' sense to the irrigator and it had to be easy to trial
- The tool should create a dialogue between researchers and farmers, challenging the perceptions of both parties, and simultaneously simulate changes to the irrigation practice. The tool had to work interactively with the user – to challenge and build on their existing knowledge
- The parameter measured needed to be simple: depth of water penetration, rather than measures of volumetric water content or suction
- A tool that could link water management with nutrient and salt management

Developer (s) of model

Stirzaker and Hutchinson (2005) showed that irrigation could be scheduled accurately and inexpensively by terminating each irrigation event when the wetting front reached a set depth in the soil. The technique is based on the theory of Philip (1969), which states that the time it takes for a wetting front to reach a set depth in the soil, and hence the duration of irrigation, is inversely proportional to the initial water content.

The further development of the original wetting front detector took place by Stirzaker in partnership with researchers from the University of Pretoria and with funding from the WRC and with the help of the Rural Industries Research and Development Corporation (Australia) (Stirzaker *et al*., 2004; Stirzaker *et al*., 2010a; Stirzaker *et al*., 2010b). The development of the tube detector took place in partnership between CSIRO, University of Pretoria and the WRC funded it.

Potential application

- The WFD plays a valuable role as a learning tool among farmers of different skills levels. The focus shifted from initially a delivering tool, which will solve irrigator's problems regarding irrigation scheduling to a tool that encourages a journey of learning and discovery. It helps to understand the current irrigation strategy, and to organise the irrigators' experiential knowledge. The irrigators usually build their own rules of thumb around the WFD.
- Monitoring of nutrients and salts for analysis. The ability of the WFD to provide a soil solution sample is seeing them used increasingly for salt and nitrate monitoring.
- The WFD could be used as a check on the recipe (reference) supplied by any appropriate irrigation decision support model, which provides irrigation 'recipes'. It should be possible to use WFD to correct for this.
- The WFD can also be deployed alongside real time monitoring of capacitance or granular matrix sensors used by the top echelon of growers. They can be spread out to capture some of the spatial variability while the more expensive methods can provide the detail in a few locations
- The using of a WFD to evaluate system performance. Irrigators puzzled by the non-response of the detector have subsequently found out that drippers were blocked, or pressures were lower than expected, or sprinklers were far from uniform.
- The development of educational material, both written and web based that could be used for the training of extension workers and farmers. The development of an interactive CD for the use and explaining of the installation and for the answering of frequent questions by users were developed during 2006. A comprehensive learning package was also developed for farmers and advisors that will help to organize irrigators' existing knowledge, and help them to make sense of new information and develop irrigation strategies that will improve water, salt and nutrient management.

Challenges and future development

The following challenges were identified during the development of the device:

- The WFD also has a sensitivity limitation. After irrigation has ceases and redistribution of water occurs down the profile, the wetting fronts become weaker and can fall below the detection limits of the WFD. In some situations it was observed water passing deep detectors without activating them. The development of a Tube Detector with greater sensitivity and more suited for deep placement (low flux and low weak fronts) addressed this need.
- The disadvantages of the Tube Detector compared to a FullStop include:
  - ✓ More time needed for installation because a deeper hole is required because of the increased length
  - ✓ The response time is slower
  - ✓ It is harder to interpret the solute measurements because of the long residence time of water in the instrument
- Initially with the development of the WFD the following challenges were identified and addressed:
  - ✓ Changing of the filter sand in an attempt to increase the sensitivity of the detector.
  - ✓ The improvement of some parts of the device (plastic fittings) for easier assembling of the tool.
  - ✓ Reviewing of the placement depths for different applications. The depth placements of WFD under sprinkler, micro jet and centre pivot irrigation were adjusted 15cm and 30 cm instead of the original 20cm and 40 cm recommended) to accommodate the small amounts of water applied.
  - ✓ The placement of detectors for furrow irrigation was also adjusted and stipulated that detectors should be positioned half under the furrow and half under the bed with the extension tube rising through the shoulder of the bed. The suggested depth of placement for the shallow detector is 20-30cm and for the deep detector 40-60cm (from the base of the furrow). The placement for deep-rooted crops with less frequent irrigation was recommended to be deeper placement.
  - ✓ Development of a clear and easy understandable instruction sheet to accompany the commercial packaging of the device. A six-page instruction sheet has been re-written and re-published to incorporate the new learning, including a ‘troubleshooting’ section.
  - ✓ A web site was developed to accommodate the experiences from users and members of the project team. An interactive CD was developed which accommodate the assembling, installation and operation of the Wetting Front Detector.

- Another opportunity pursued by the researchers is an aid to help irrigators to become more quantitative about what they are doing. The intention is to add measuring vessels to the commercial WFD kit that can be used as a rain gauge and as a means for checking dripper application rates and uniformity. The aim is to show an irrigator that *x* mm of water moved past *y* depth.

WRC Reports

Building capacity in irrigation management with wetting front detectors
R Stirzaker, J Stevens, J Annandale, T Maeko, M Steyn, S Mpandeli,
W Marobane, J Nkgapele & N Jovanovic
WRC Report No TT 230/04
University of Pretoria
March 2004

Adapting the wetting front detector to small furrow irrigation and providing a basis for the interpretation of salt and nutrient measurement from the water sample
RJ Stirzaker, JG Annandale, JM Steyn, G Adhanom, M van der Laan &
C M'marete
WRC Report No 1547/1/10
University of Pretoria
2010

Wetting front detector transfer of technology
JB Stevens & RJ Stirzaker
WRC Report No KV 246/10
University of Pretoria
April 2010

5. SYNTHESIS OF RESEARCH FINDINGS

This part of the report presents an overview of the main research findings. The impact assessment conducted on the seven irrigation scheduling methods and tools has been separated into the following main categories:

- Whether the research knowledge was used and for what purpose?
- Perceived usefulness of the research knowledge (technical, economical, environmentally and socially).
- Perceived easiness of using the research knowledge (learning and support back-up required, interaction between research and users).
- How best to transfer WRC generated R&D knowledge? What culture shifts are required?
- General attitude towards irrigation management and awareness of WRC research and expectations.

5.1 OVERVIEW OF THE POTENTIAL USERS AND FOR WHAT PURPOSE

The following results provide an overview of the profile of the potential users of the seven irrigation scheduling methods and tools as well as the main purpose the research knowledge is used for.

5.1.1 Education level

It was important to identify the educational level of the potential users of irrigation scheduling methods and tools. The educational qualifications of the respondents are summarised in Figure 5.1 and it is clear that a great majority (86%) of the users have obtained a higher qualification than an agricultural diploma. This implies that these irrigation methods and tools are mainly used by regarded “specialists” involved in the knowledge support or planning of irrigation water management.

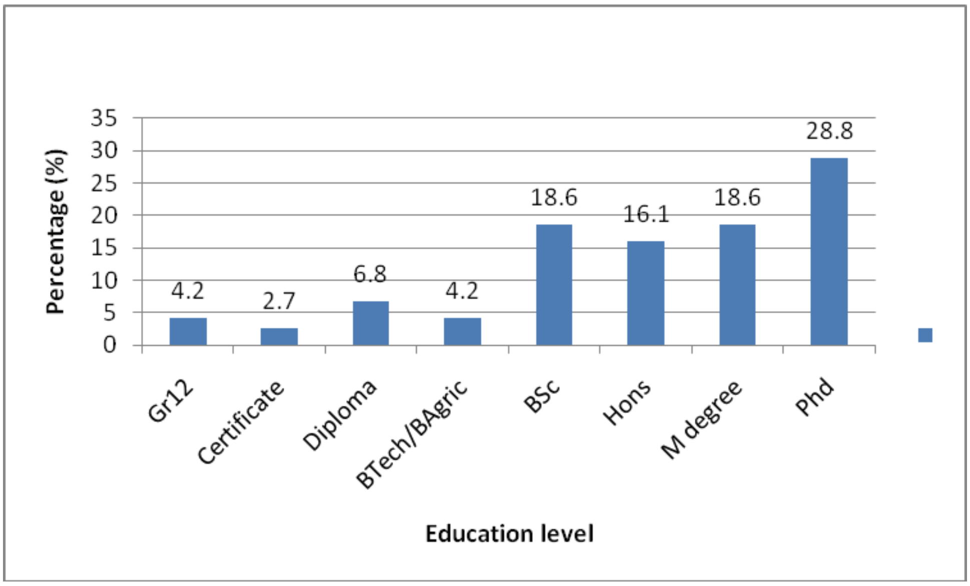


Figure 5.1. Frequency distribution of respondents according to the highest qualification (N=118)

5.1.2 Occupation

Nearly 28% of the respondents are involved in consultancy or advice giving to decision makers while 23% of the respondents are trained as engineers and mainly use SAPWAT and ACRU for the designing and planning of irrigation management strategies (Table 5.1).It is clear from the findings that the use of irrigation scheduling tools and methods is influenced by a specific occupational grouping as supported by a significant Gamma value (Gamma=0.198; p=0.017).

Table 5.1. Distribution of respondents according to their occupation and the main irrigations scheduling tools used in priority order (N=118)

Occupation	n	%	Irrigation scheduling models used (priority order)
Consultant /advisor /extensionists	33	27.9	SAPWAT,SWB, WFD, BEWAB, PUTU, ACRU
Engineer	27	22.9	SAPWAT,WFD, ACRU, MYCANESIM, SWB, PUTU, BEWAB
Water administrator	4	3.4	SAPWAT, WFD
Water control officer	6	5.1	SAPWAT, ACRU, WFD
Academic	23	19.5	SWB, SAPWAT, BEWAB,WFD, ACRU, MYCANESIM, PUTU
Farmer	6	5.1	SAPWAT, WFD, BEWAB,SWB,MYCANESIM
Researcher	19	16.1	WFD, SWB, SAPWAT, MYCANESIM, PUTU, BEWAB,ACRU
Total	**118**	**100**	

The irrigation scheduling tools and methods are overwhelmingly been used for agricultural purposes as only 5% of the respondents indicate alternative use for these tools (Table 5.2).

Table 5.2. Frequency distribution according to the main purpose for using of irrigations scheduling tools (N=118)

Use of model or tool	Frequency	Percentage (%)
Agriculture	112	94.9
Non agriculture	1	0.8
Mix (agriculture and non-agriculture)	5	4.3
Total	**118**	**100**

5.1.3 Experience in the use of computer irrigation water management programs

Previous experience regarding the use of computer programs and specifically irrigation water management programs is important as it impacts on the apprehensiveness of the potential user as well as the intrinsic motivation from users to feel competent or relatively competent in dealing with new challenges of learning and using a new method or tool. Table 5.3 illustrates that 78% of the respondents exist of previous experience in the use of computer irrigation water management programs.

Table 5.3. Frequency distribution of respondents' previous experience in the use of computer programs (N=118)

Model or Tool	Yes	No
SAPWAT	32	12
BEWAB	7	3
PUTU	4	0
MYCANESIM	8	0
SWB	17	3
ACRU	8	1
WFD	16	7
Total	**92**	**26**

5.1.4 Experience in irrigation water management and planning

The respondents' experience in irrigation water management and planning were assessed (Figure 5.2). The majority of respondents (79%) are involved with irrigation water management and planning for more than ten years, while only 10% have less than five years of experience in irrigation water management and planning.

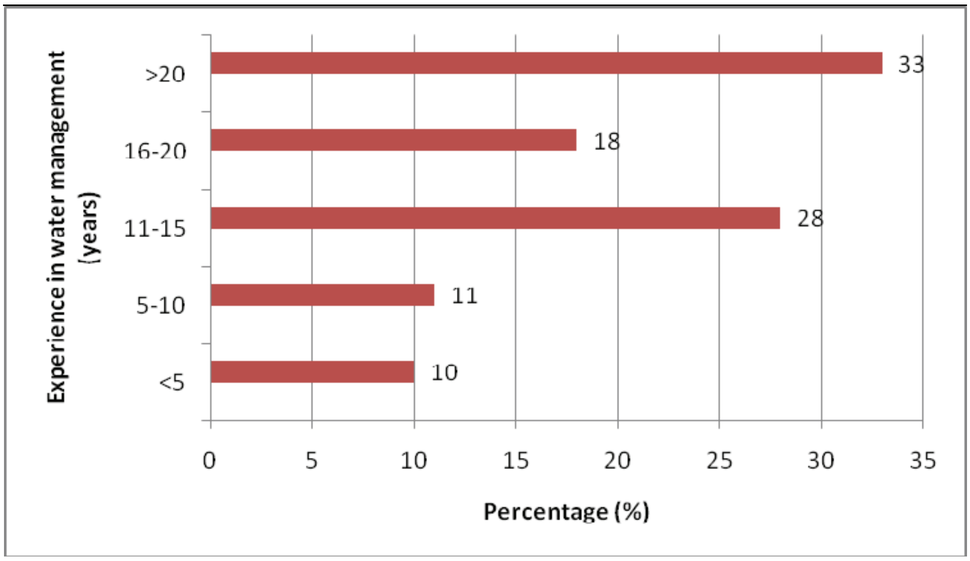


Figure 5.2. Frequency distribution of respondents according to their experience in management and planning of irrigation water (N=118)

The experience of respondents in irrigation water management and planning apparently has little influence on the selection of a specific irrigation scheduling tool as no statistical support was found for this relationship.

6. IDENTIFYING OF THE EXPLICIT USE OF THE IRRIGATION SCHEDULING TOOLS AND METHODS

The aim of this part of the study was to identify patterns of use of the specific research through identifying of the purpose for using a specific method or tool, and what type of decision making is influenced with it. This approach is also supported by research done Pitcher *et al.* (1995) and Lavis (1998).

6.1 PURPOSE FOR USING OF IRRIGATION SCHEDULING RESEARCH KNOWLEDGE

In the first place it was important to identify the explicit use of research knowledge by the respondents and create a typology of potential users. Figure 6.1 illustrates that the majority of respondents (62%) use a specific method or tool for the designing and planning of irrigation management strategies at field level *(instrumental use of research knowledge).* Interesting is the huge percentage (55%) of respondents that use the research knowledge for training or teaching purposes at universities, and other tertiary institutions *(conceptual use of research knowledge).* 52% of the respondents indicated the use research knowledge for irrigation scheduling on a field level *(instrumental use of research knowledge).*

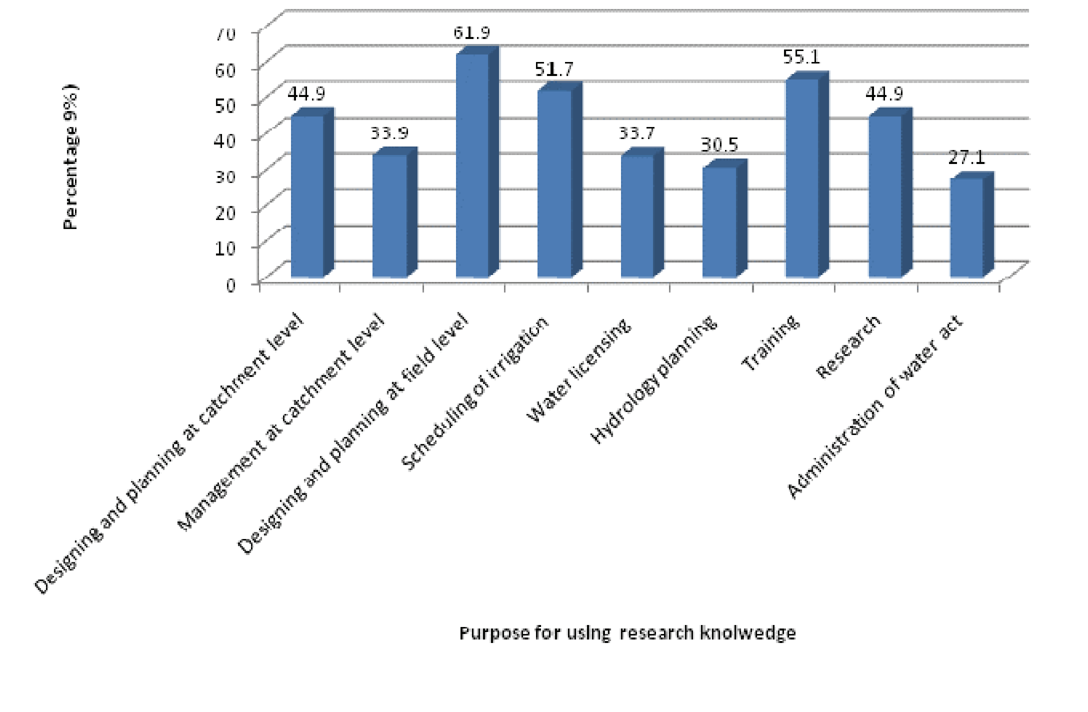
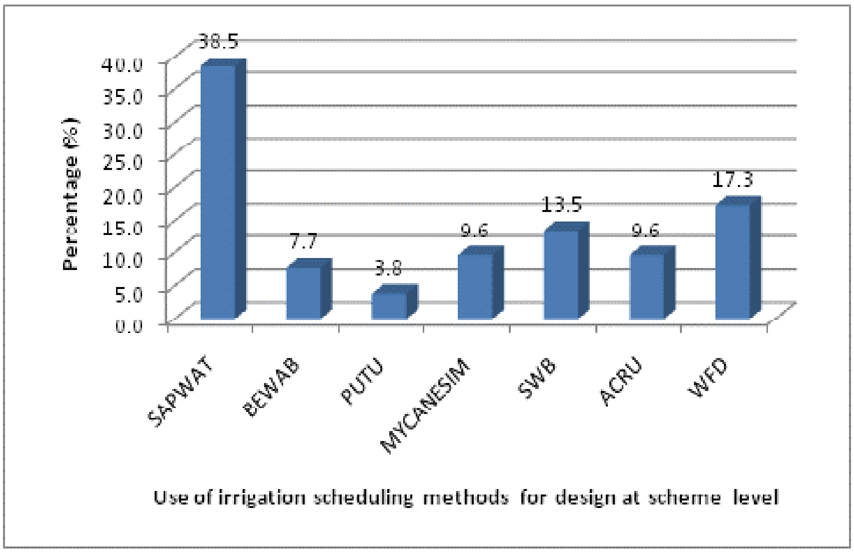
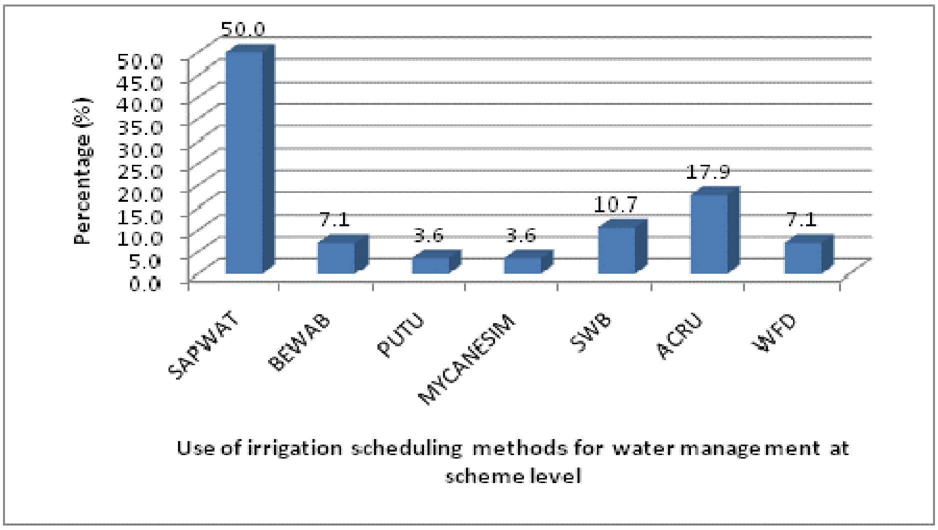


Figure 6.1. Frequency distribution of respondent's explicit use of the research knowledge (N=118)

Since the irrigation scheduling methods and tools analysed were developed with specific objectives in mind, it is important to reflect on the specific use of these tools and methods regarding irrigation management (Figures 6.2-6.10).

Use of research knowledge for designing and planning of water management strategies at catchment and scheme level (water user association and irrigation board level)	 **Figure 6.2. Frequency distribution of the use of research knowledge for designing and planning of water management strategies at catchment or scheme level (N=118)**
Use of research knowledge for irrigation water management at catchment and scheme level	 **Figure 6.3. Frequency distribution of the use of research knowledge for irrigation water management at catchment or scheme level (N=118)**

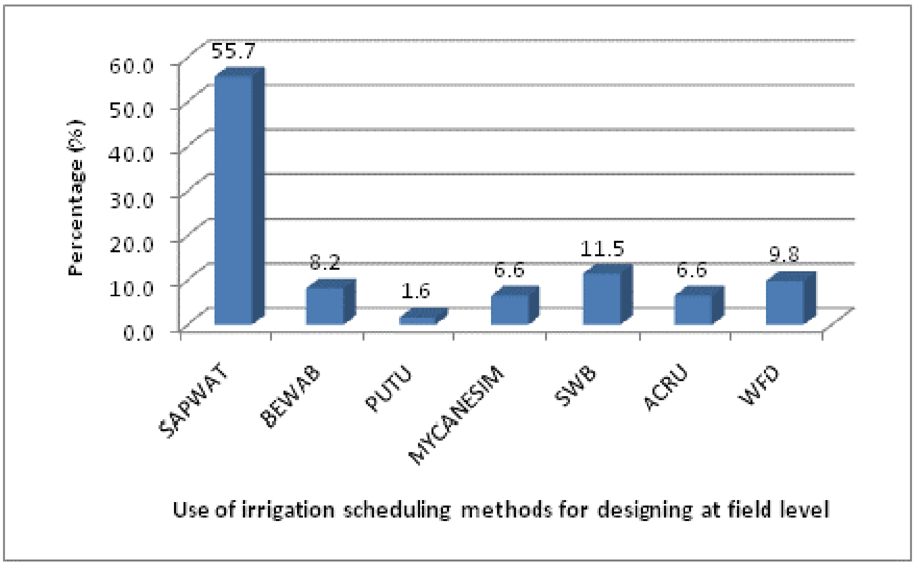
<table>
<tr>
<td>Use of research knowledge for designing and planning of irrigation water management at field level</td>
<td>

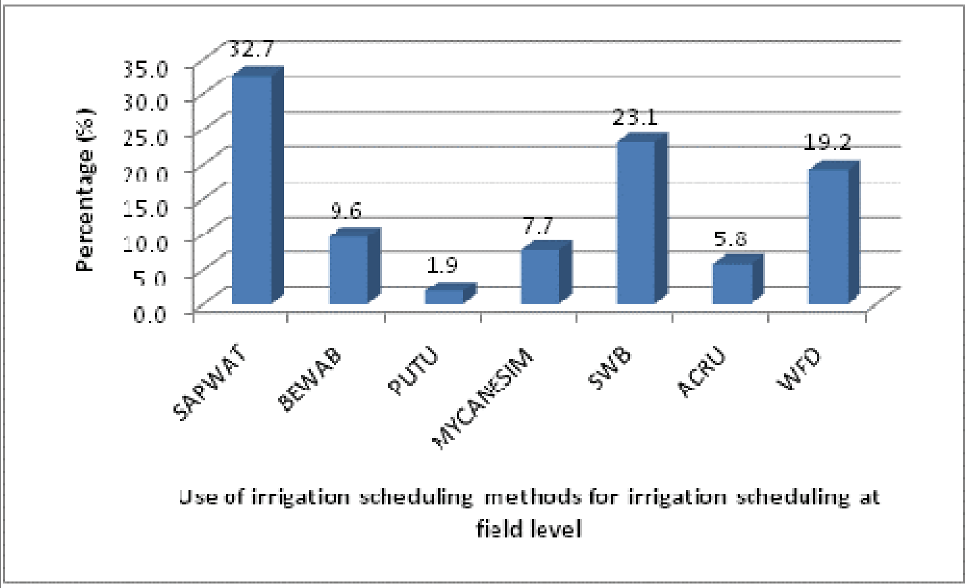
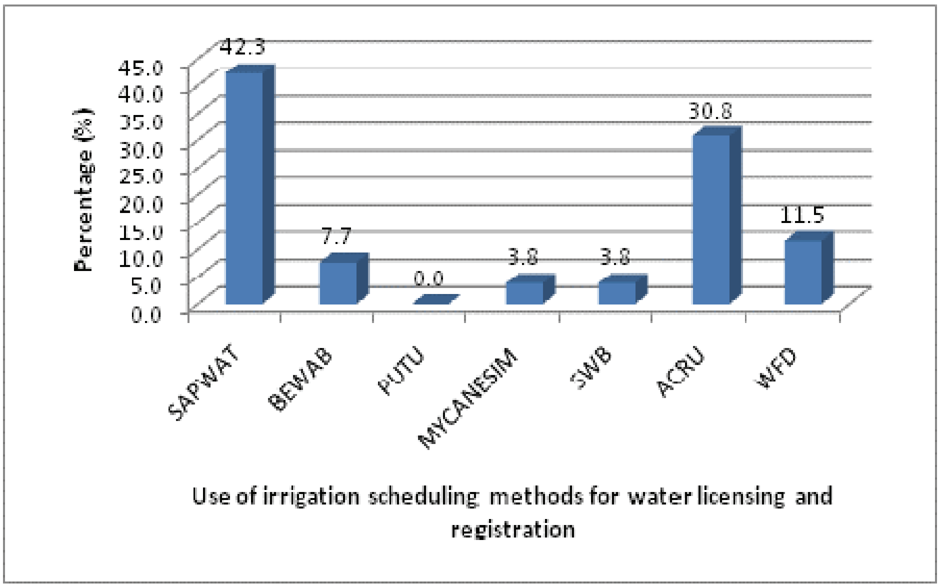
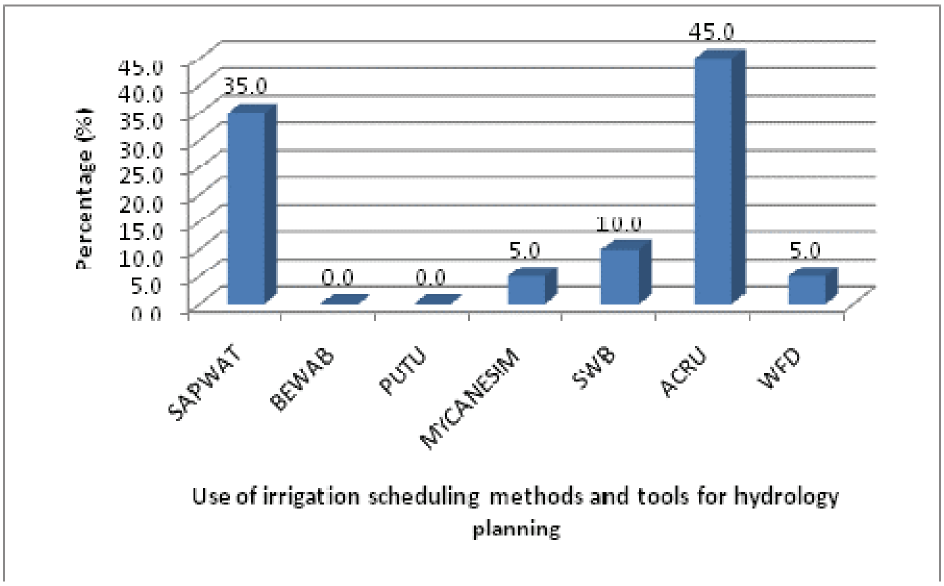
Figure 6.4. Frequency distribution of the use of research knowledge for designing and planning of irrigation water management at field level (N=118)</td>
</tr>
<tr>
<td>Use of research knowledge for irrigation scheduling at field level</td>
<td>

Figure 6.5. Frequency distribution of the use of research knowledge for irrigation scheduling at field level (N=118)</td>
</tr>
</table>

Use of research knowledge for water administration (licensing and registration)	 **Figure 6.6 Frequency distribution of the use of research knowledge for water licensing and registration (N=118)**
Use of research knowledge for hydrology planning	 **Figure 6.7 Frequency distribution of the use of research knowledge for hydrology planning (N=118)**

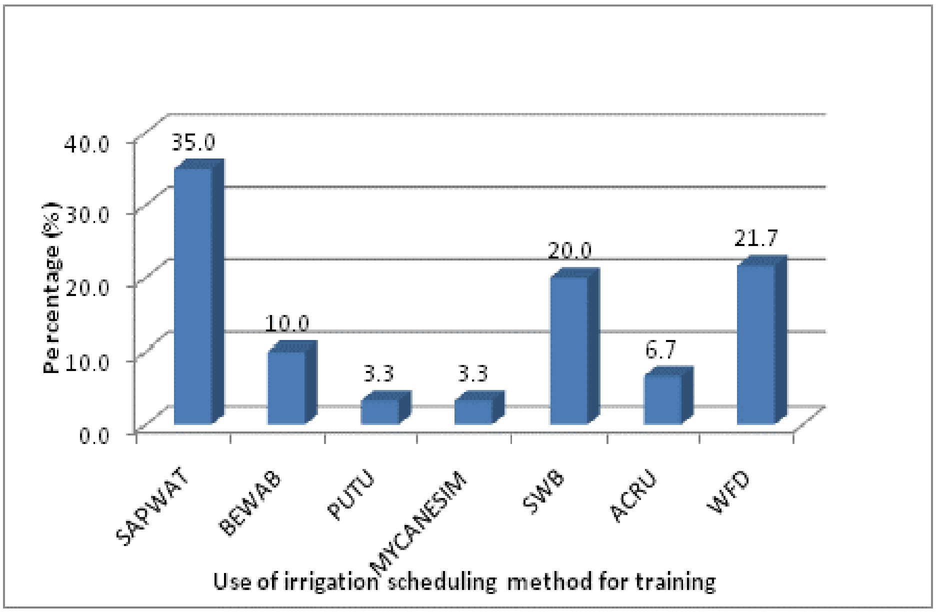
<table>
<tr><td>Use of research knowledge for training or teaching</td><td>

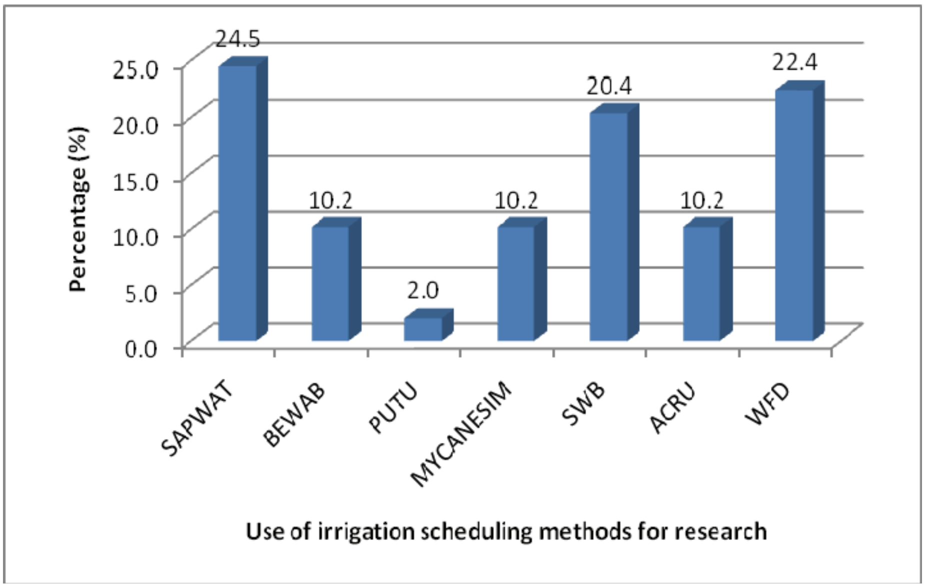
Figure 6.8. Frequency distribution of the use of research knowledge for training or teaching (N=118)</td></tr>
<tr><td>Use of research knowledge for other research programs e.g. (post graduate studies and other research programmes)</td><td>

Figure 6.9. Frequency distribution of the use of research knowledge for other research programs (N=118)</td></tr>
</table>

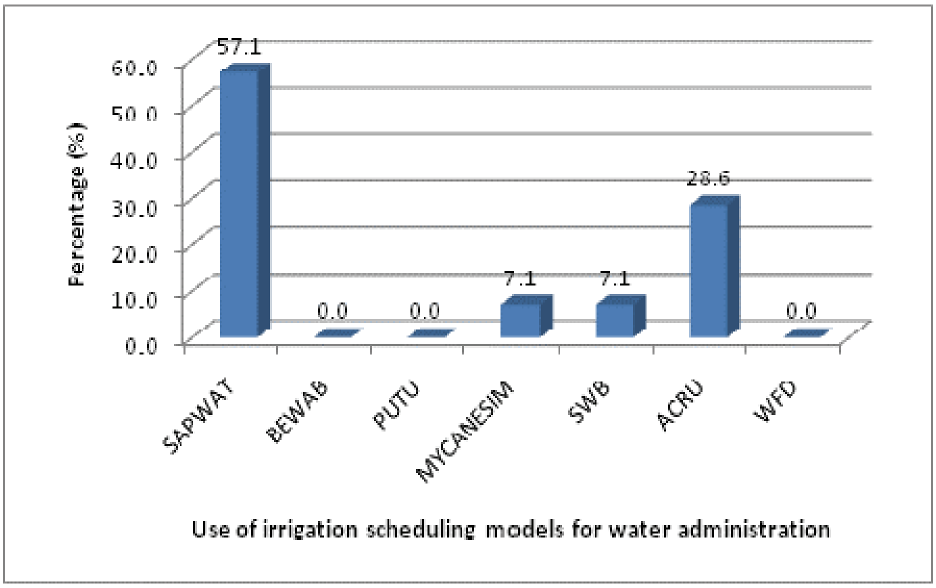
<table>
<tr>
<td>Use of research knowledge for administration of water act</td>
<td>


Figure 6.10. Frequency distribution of the use of research knowledge for administration of water act (N=118)
</td>
</tr>
</table>

It is clear from Figures 6.2-6.10 that certain programs and methods are more popular than others due to the variety of options it can be applied. Some irrigation scheduling methods and tools are used for *instrumental purposes* to help decision making and solving of problems like for instance a program like SAPWAT which is very popular for the use of designing and planning of irrigation management strategies at catchment and scheme level (χ^2=7.98, df=6, p=0.023) and field level (χ^2=18.67, df=6, p=0.005); implementing of irrigation water management at scheme level (χ^2=10.42, df=6, p=0.010); water licensing (χ^2=22.74, df=6, p=0.001) and water administration at scheme level (χ^2=10.793, df=6, p=0.058). Also SAPWAT together with SWB and the WFD are popular amongst respondents to be used for irrigation scheduling at field level (Figure 6.5). The fact that SWB is mentioned to be popular as a scheduling tool is interesting perhaps due to the fact that a great percentage of the sample of respondents is mainly non-farmers (consultants, academic staff, irrigation engineers, etc.). The WRC commissioned transfer of technology project on SWB indicated that farmers specifically felt that the model was still too complex and required too many input parameters.

A program like MyCanesim has limited application amongst the small scale sugarcane farmers of KwaZulu-Natal and Mpumalanga, and when it was tested in the field most of the small scale farmers found the advice useful and it helped them to better understand the value of irrigation scheduling. Frequent face to face interaction was however identified to be crucial in ensuring that the advice was understood correctly. ACRU is mainly a tool used for the hydrology planning at catchment and scheme level (X^2=12.53, df=5, p=0.028) and together with SAPWAT it is also used with regard to the implementation of water licensing and registration (Figure 6.6).

Figures 6.8 and 6.9 indicate that some of the models and tools like SAPWAT, SWB, BEWAB and WFD were very popular in the use of knowledge capacity building. Here it was *conceptually* used to enlighten certain concepts for instance the principles of the movement of a wetting front in the case of the WFD, and the principles on plant and water relations and crop physiology in the case of SWB (Jovanovic and Annandale, 2000). Scheduling tools like SWB, WFD, BEWAB and SAPWAT are regarded to be very popular for training of irrigators and advisors in soil/plant/water relationships and teaching of students at universities and tertiary institutions.

Respondents also indicated that there are alternative spin-offs for the research knowledge like the conceptual use of it for inclusion or stimulating of post graduate research programs e.g. the many postgraduate students that have been involved with the inclusion of new routines into the SWB model for specific research purposes. For example, the chemical equilibrium routine of Robbins (1991) has been included in the SWB model to enable salt simulations and was used to study the feasibility of irrigating crops with gypsiferous mine water (Annandale *et al.*, 1999; Annandale *et al.,* 2000 and Annandale *et al.,* 2002).

6.2 FREQUENCY OF USE OF THE IRRIGATION SCHEDULING TOOLS AND METHODS

The frequency of use of the irrigation scheduling tools and methods by respondents is important (Table 6.1). 32% of the respondents indicated that they use these tools and methods sporadically when required, while 50.9% indicated the use of methods and tools on a frequent basis (daily, weekly or monthly basis). This tendency should be interpreted taking into account the potential value respondents perceive the research knowledge has.

Table 6.1. Frequency distribution of the use of irrigation scheduling methods and tools (N=115)

Frequency of use	Irrigation scheduling tool/method	n	%
Daily	WFD, SWB	4	3.3
Weekly	SAPWAT, BEWAB, PUTU, MyCanesim, SWB, ACRU, WFD	32	27.2
Monthly	SAPWAT, BEWAB, PUTU, SWB, WFD	24	20.4
Yearly	SAPWAT, BEWAB, MyCanesim, SWB, ACRU, WFD	20	16.9
Sporadically	SAPWAT, PUTU, MyCanesim, SWB, ACRU, WFD	38	32.2
Total		**118**	**100**

6.3 TYPES OF DECISION MAKING INFLUENCED WITH IRRIGATION SCHEDULING TOOL OR METHOD AND AT WHICH LEVEL OF OPERATION

Respondents were asked to indicate the major type of decisions that are influenced by the various irrigation scheduling tools (Figure 6.11). The majority of respondents use the irrigation tools for instrumental decisions like troubleshooting of water irrigation management problems on the scheme and at irrigation field level (60.2%) or for solving of irrigation water management problems they encounter (57.6%). 50% respondents perceive the use of tools for confirmation of the appropriateness of the selected irrigation management strategy they follow. 51% of the respondents use the irrigation scheduling tools/models to enlighten certain aspects of irrigation water management through the conceptual use of the research knowledge (as already indicated with regard to SWB and WFD). The WFD and SWB are also used for the monitoring of nutrients and the identifying of salinity problems (16.9%). It is clear from these responses that the research knowledge created with the development of the various irrigation scheduling tools/models are either used *instrumentally* for solving of irrigation water management problems, planning of water balance at catchment level, designing of management strategies or *conceptually,* where concepts and theories are enlightened.

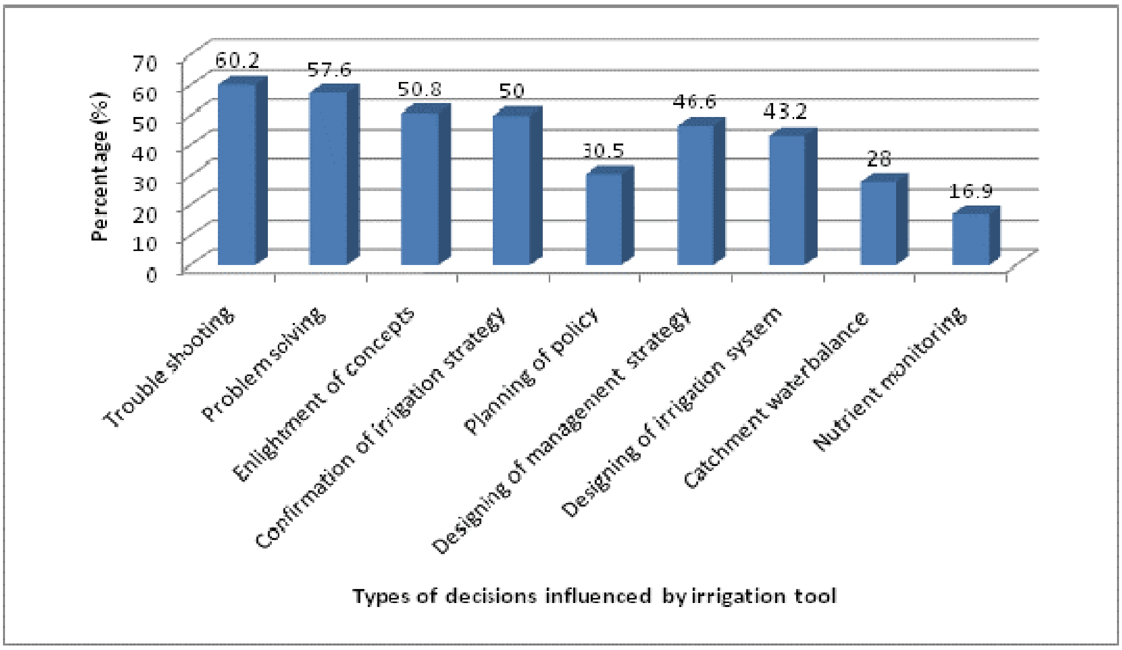


Figure 6.11. Frequency distribution of the types of decisions taken with the support of irrigation scheduling tools (N=118)

Figures 6.12-6.20 provide more detail analyses of the proportional contribution of specific irrigation scheduling methods and tools in the utilisation of research knowledge by respondents.

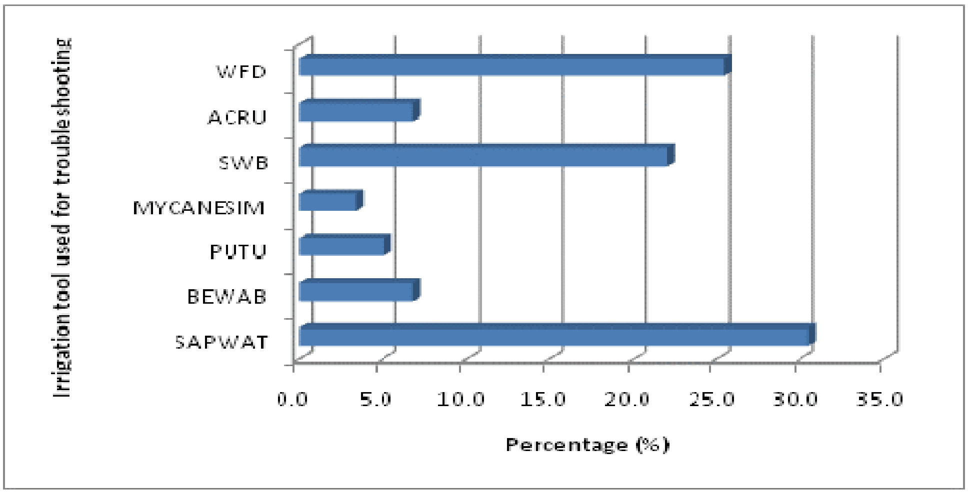
<table>
<tr>
<td>Troubleshooting of irrigation water management (Field level)</td>
<td>

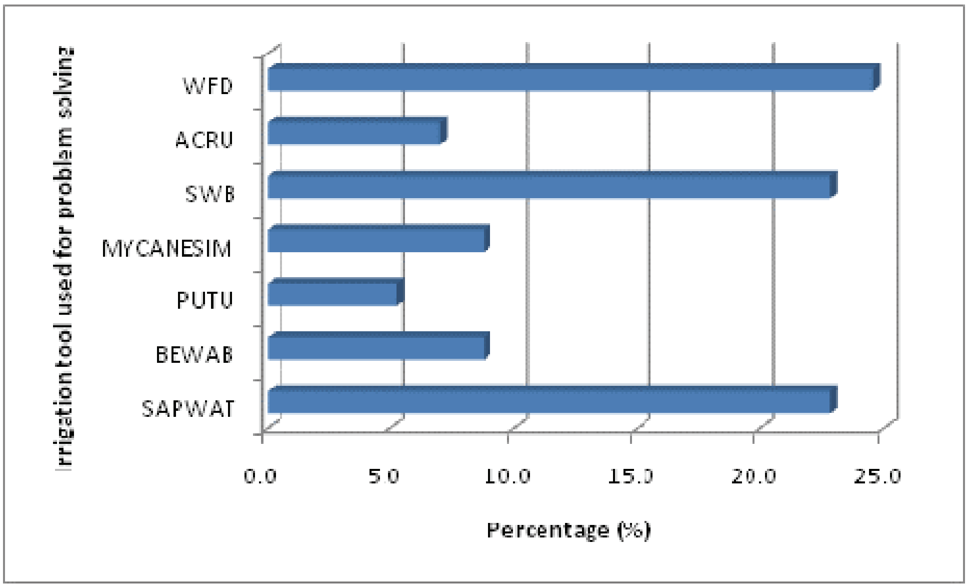
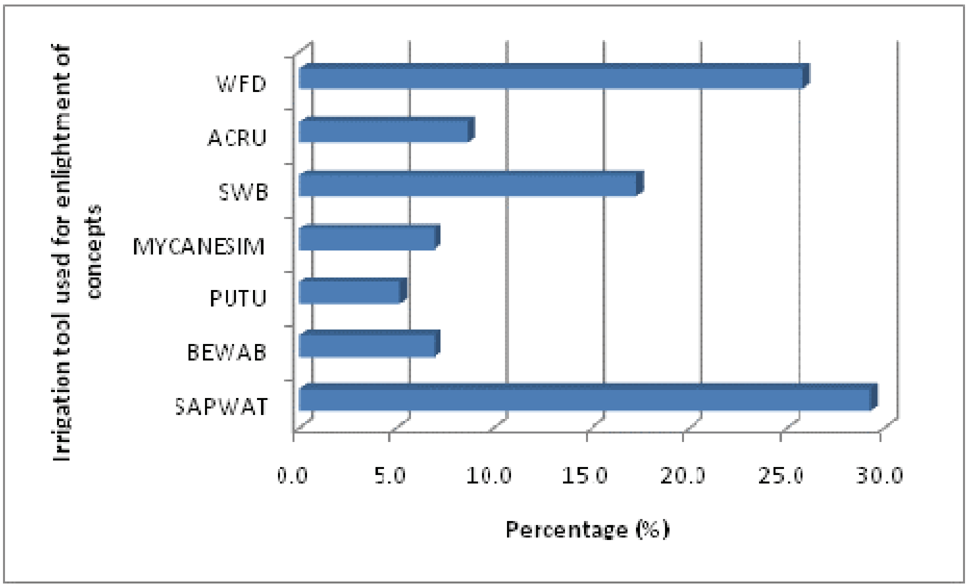
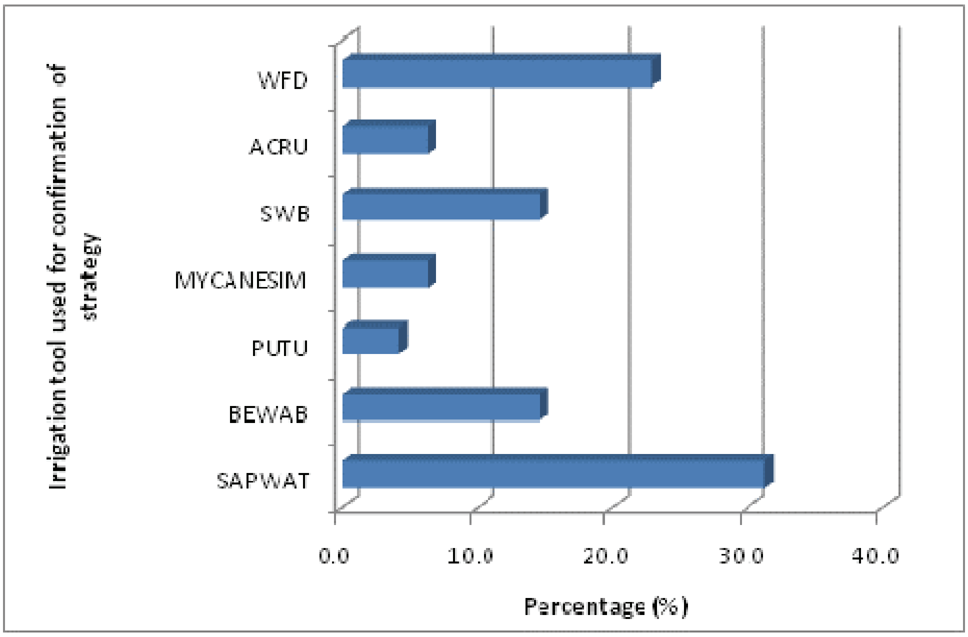
Figure 6.12. Frequency distribution of irrigation scheduling tools used for troubleshooting of irrigation water management (N=118)</td>
</tr>
<tr>
<td>Problem solving of irrigation water management problems (Field level)</td>
<td>

Figure 6.13. Frequency distribution of irrigation scheduling tools used for problem solving of irrigation water management problems (N=118)</td>
</tr>
</table>

Enlighten of certain aspects of irrigation water management	 **Figure 6.14. Frequency distribution of irrigation scheduling tools used for enlighten of certain aspects of irrigation water management (N=118)**
Confirmation of appropriateness of irrigation management strategy followed	 **Figure 6.15. Frequency distribution of irrigation scheduling tools used for confirmation of appropriateness of irrigation management strategy followed (N=118)**

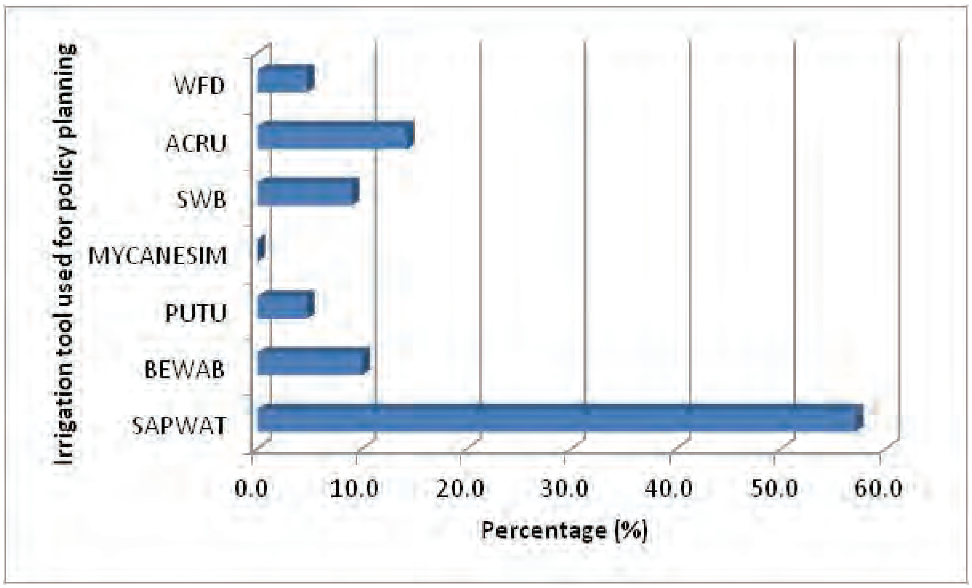
<table>
<tr>
<td>Water administration policy planning and implementation (scheme level)</td>
<td>

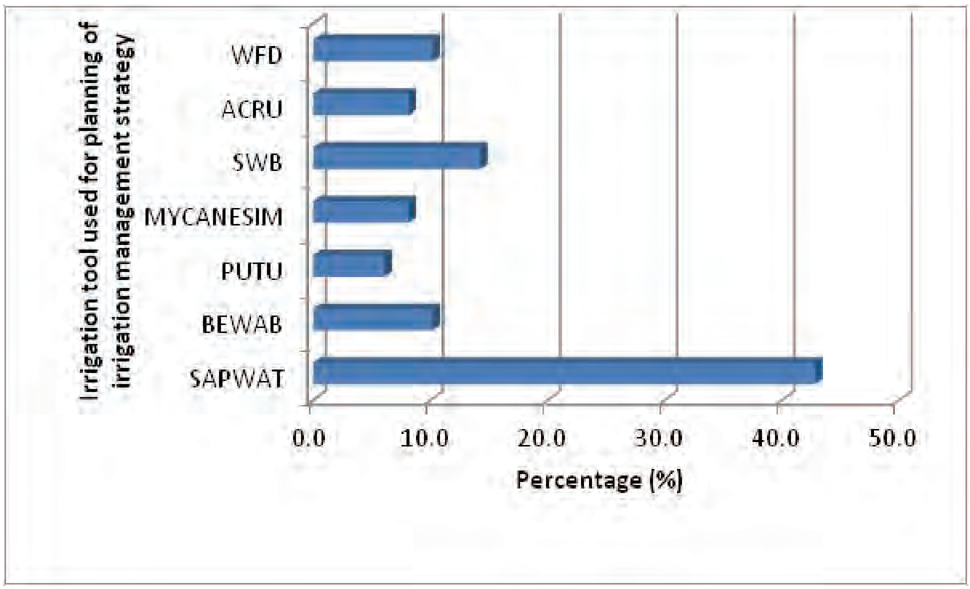
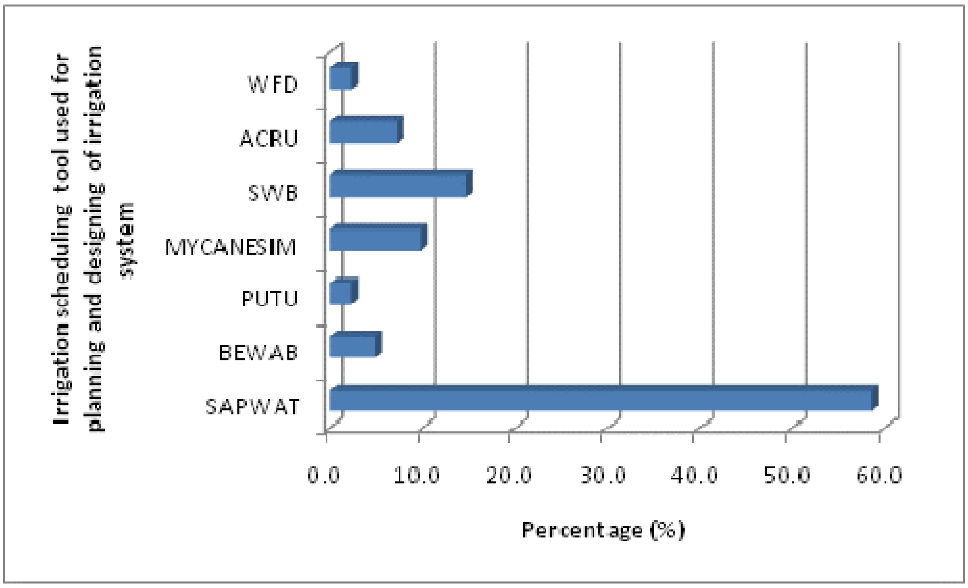
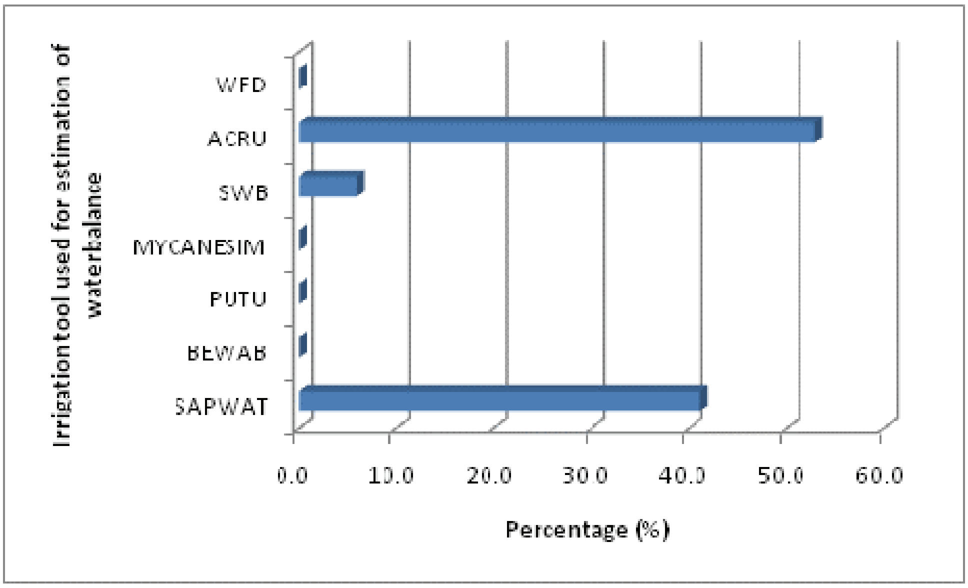
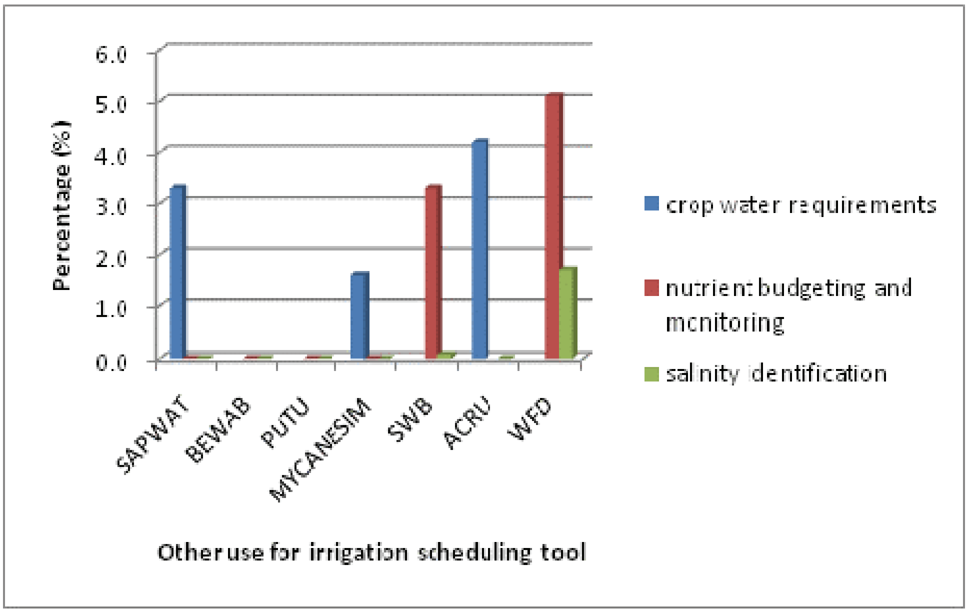
Figure 6.16. Frequency distribution of irrigation scheduling tools used for policy planning and implementation (N=118)</td>
</tr>
<tr>
<td>Planning and designing of irrigation management strategy</td>
<td>

Figure 6.17. Frequency distribution of irrigation scheduling tools used for planning and designing of irrigation management strategy (N=118)</td>
</tr>
</table>

Designing and planning of irrigation systems at field level	 **Figure 6.18. Frequency distribution of irrigation scheduling tools used for designing and planning of irrigation systems (N=118)**
Estimation of catchment water balances	 **Figure 6.19. Frequency distribution of irrigation scheduling tools used for estimation of catchment water balances (N=118)**

Nutrient monitoring (salinity identification)	 **Figure 6.20. Frequency distribution of irrigation scheduling tools used for nutrient monitoring (salinity identification) (N=118)**

Figures 6.12-6.20 reveals clearly that a program like SAPWAT is popular with regard to the following:

- Policy planning and implementation (X^2=19.31, df=6, p=0.004)
- Planning and designing of irrigation management strategy (X^2=11.28, df=6, p=0.084). Although not statistical significant, a very strong tendency exists.
- Designing and planning of irrigation systems at field level (X^2=23.19, df=6, p=0.001) while a tool like ACRU is mainly use for estimation of catchment water balances (X^2=19.94, df=5, p=0.001).
-

6.4 PERCEIVED REASONS FOR USING A SPECIFIC METHOD OR TOOL

Respondents provided the following additional reasons for the selection of a specific irrigation scheduling tool or method (Table 6.2).

Table 6.2. Reasons for the use of a specific irrigation scheduling tool or method as perceived by respondents

Irrigation scheduling tool or method	Reasons for use of specific method or tool
ACRU MikeBasin	Many parameters to describe runoff conditions
	Use for hydrological studies. The link between ACRU and Mike Basin allows for quick and accurate calculations
	Know the model – experience
	Interaction between supply and demand
	Extrapolation of local water use, water quality to catchment scale
	Student training
BEWAB	Basic concepts are introduced to students
	Valuable in the beginning of development in supporting water management by farmers – perhaps outdated
	Planning of new irrigation development
	Gives rough indication of water use by crops
	User friendly
	Easy to use in the planning of when and how much to irrigate
MyCanesim	Gives me valuable information
	Use where greater accuracy is required on sugar cane irrigation estimations
	Real time crop water use
	Specialised cane simulations
	Strategic interventions
PUTU	Still used for basic training of students (basic concepts)
	Use as planning and management tool to refine and support the Green Book (irrigation)
	Strategic investigations
SAPWAT	Easy to use
	Provides valuable information for planning
	Calculate crop water requirements
	Compare different irrigation strategies
	Simplicity
	Use SAPWAT to predict the peak and off-peak water requirements to plan dry weeks
	Student training
	Ability to store historical climate data
	To make sure that there is enough water for the relevant crops planted. Very important in financing
	Prescribed by Dept Water Affairs
	Planning of irrigation water management strategy
	It provides answers on many different scenarios that can be created (credible)
	Use SAPWAT for verification of existing lawful use because DWA has prescribed its use
	SAPWAT3 allows great accessibility to all relevant variables. A lot of information is poorly understood

	Basic concepts and use are introduced during training (scientific based)
	The program will help with designing orchard water needs and help with the planning of new systems
	Many options it offers with respect to various parameters
	Very good soil information, e.g. soil water holding capacity
	To determine water balance
	Easier to specify irrigation management strategies
SWB	Gives me valuable information
	Irrigation scheduling : use together with soil water probes
	Basic concepts are introduced to students
	Support available
	Scientific justification for publications
	Scientifically based
	Well-designed and well-developed model
	Generic mechanistic crop model that can be used to estimate seasonal crop water requirements /scheduling
	Used for the calculation of salt balance in profiles for research purposes.
	Real time irrigation scheduling
WFD	To determine moisture content of the soil
	Simple and understandable
	Student training
	Irrigation cycles
	Very simple to work with
	Basic concepts are introduced to students
	The wetting front detector gives an indication if the irrigation cycle was too long or too short.
	To monitor the depth of irrigation
	Simplicity for nutrients
	Gives you a practical estimate of the depth of the wetting front

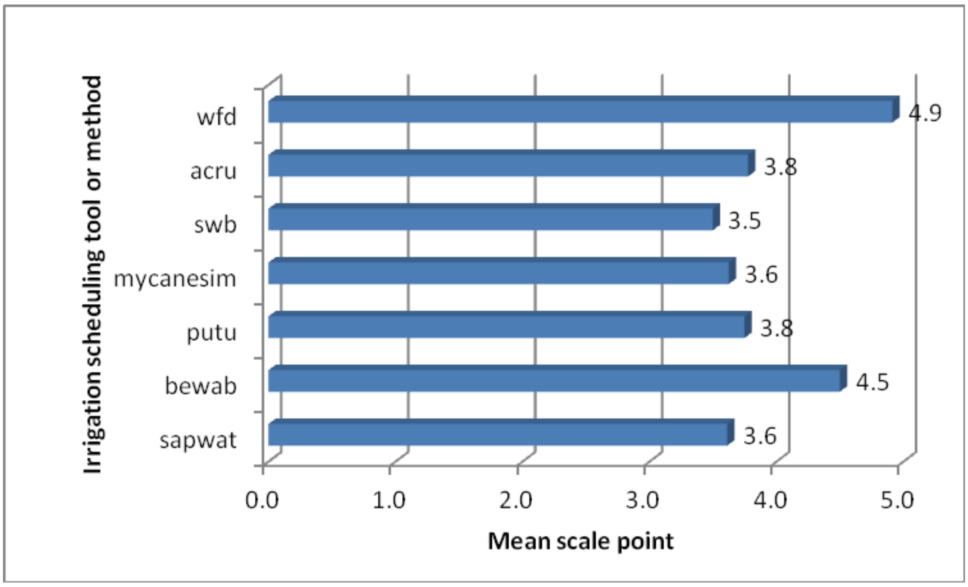
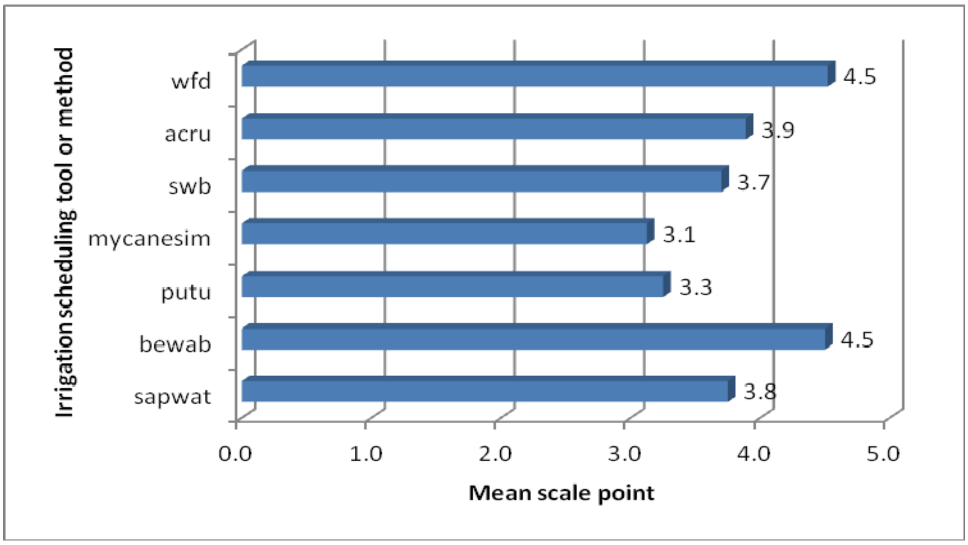
7. PERCEIVED EASE OF USING THE RESEARCH KNOWLEDGE

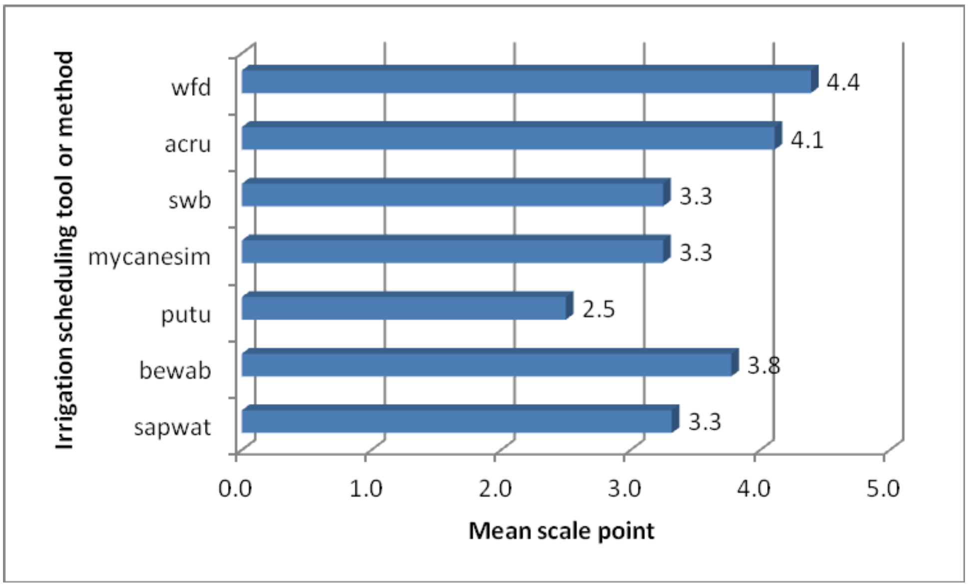
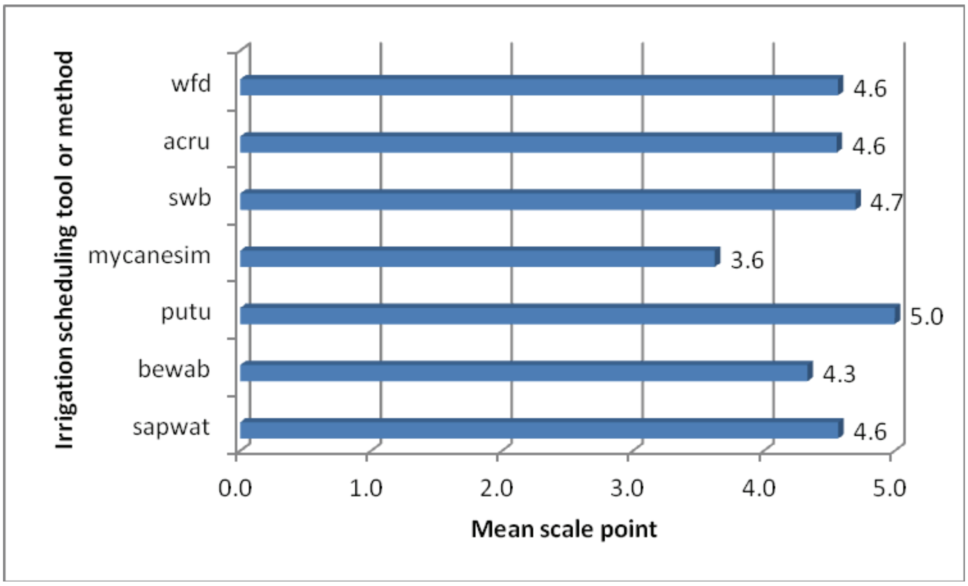
Perceived ease of use refers to the degree to which a person believes that using the particular innovation would be free of effort regarding its transfer and utilization. This follows from the definition of "ease", which is: "freedom from difficulty or great effort". Effort is a finite resource that a person may allocate to the various activities for which he or she is responsible. All else being equal, an application perceived to be easier to use than another is more likely to be accepted by users (Davis *et al.,* 1989; Goa, 2005).

The following variables were used to assess the perceived ease of use of these irrigation scheduling tools and methods using a five point semantic scale, with 1=not easy and 5=very easy:

- Ease of using a specific method or tool – allows you to do what is expected
- Ease of learning about to use and implement the specific tool or method
- Clear and understandable interaction with the method or tool (program) through the use of a research manual or report
- Flexibility in the use of a specific method or tool
- Ease with which the user could become skilled in its use and increasing of knowledge
- Overall ease of making decisions with the use of the scheduling tools

Figures 7.1-7.8 illustrate the perceived ease of using a specific irrigation scheduling method or tool and therefore reflect the potential difficulty for the user to apply the new research knowledge, as well as whether it is required from the individual to learn certain skills to use the new research knowledge.

Perceived ease of using a specific tool or method	 **Figure 7.1. Perceived ease of using irrigation scheduling tools for decision making (N=118)**
Perceived easiness to understand and use of research reports	 **Figure 7.2. Perceived easiness of understanding research reports on irrigation scheduling tools (N=118)**

Perceived easiness to understand and use the research manual	 **Figure 7.3. Perceived easiness of understanding research manuals on irrigation scheduling tools (N=118)**
Perceived importance of an appropriate user manual	 **Figure 7.4. Perceived importance of user manuals for application of irrigation scheduling tools (N=118)**

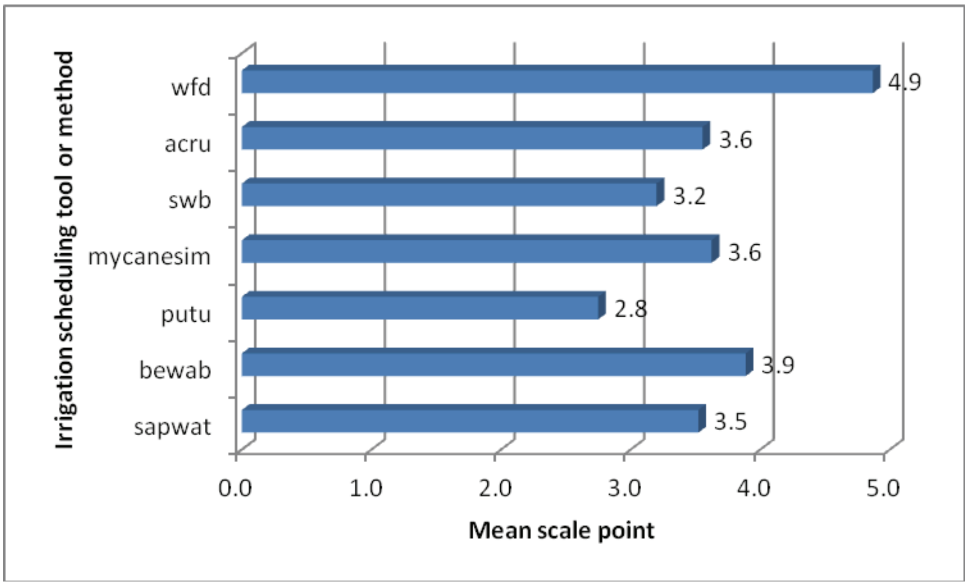
<table>
<tr>
<td>Perceived ease of learning about using a specific irrigation scheduling tool or method</td>
<td>


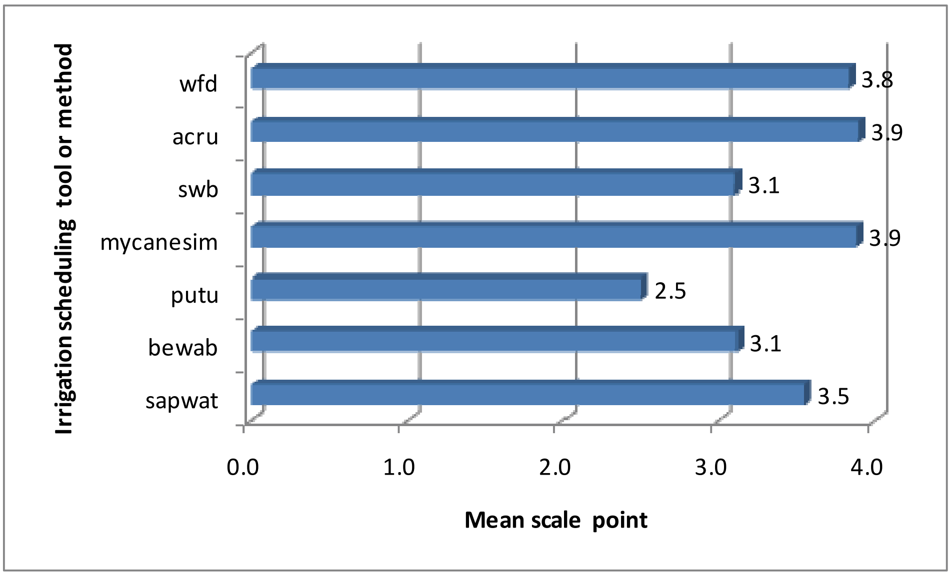
Figure 7.5. Perceived ease of learning to use irrigation scheduling tools (N=118)
</td>
</tr>
<tr>
<td>Perceived ease with which the users can increase knowledge</td>
<td>


Figure 7.6. Perceived easiness with which users can learn and increase knowledge through using of irrigation scheduling tools (N=118)
</td>
</tr>
</table>

<table>
<tr>
<td>

Perceived flexibility in applying of a specific method or tool

</td>
<td>

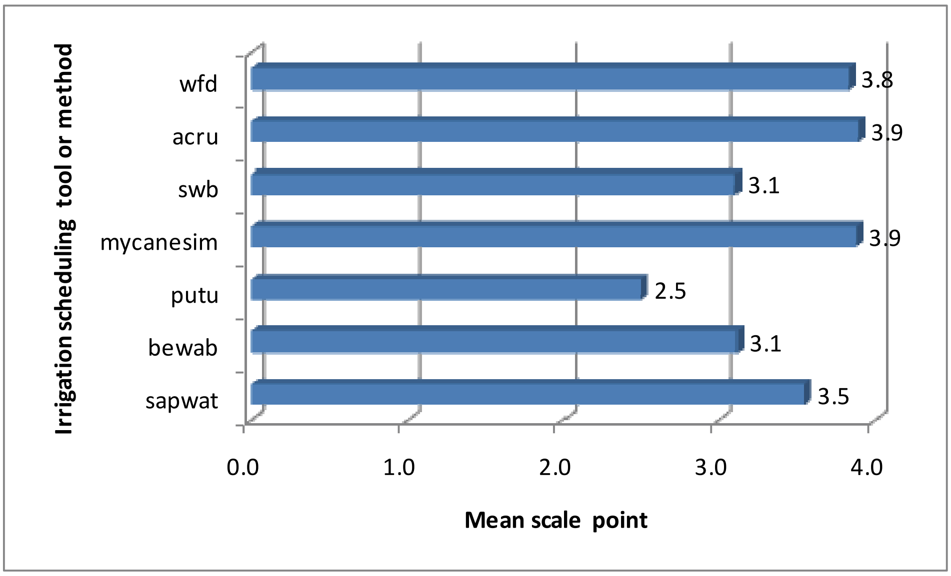


Figure 7.7. Perceived flexibility in applying of irrigation scheduling tools (N=118)

</td>
</tr>
<tr>
<td>

Perceived ease of making decisions with the use of irrigation scheduling tools and methods

</td>
<td>

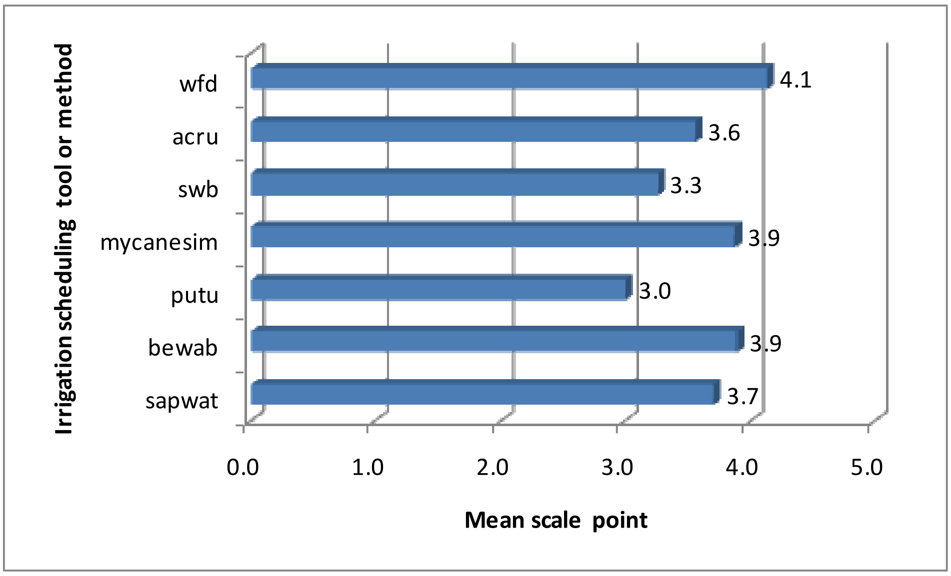


Figure 7.8. Perceived ease of making decisions with the use irrigation scheduling tools (N=118)

</td>
</tr>
</table>

The results portrayed in Figures 7.1-7.8 proof that a belief structure like perceived ease of use play an important role in determining the acceptance and usage behaviour of new technologies and research knowledge. The following statistical significant relationships were found between easiness of use and certain characteristics or aspects of a specific irrigation scheduling tool or method:

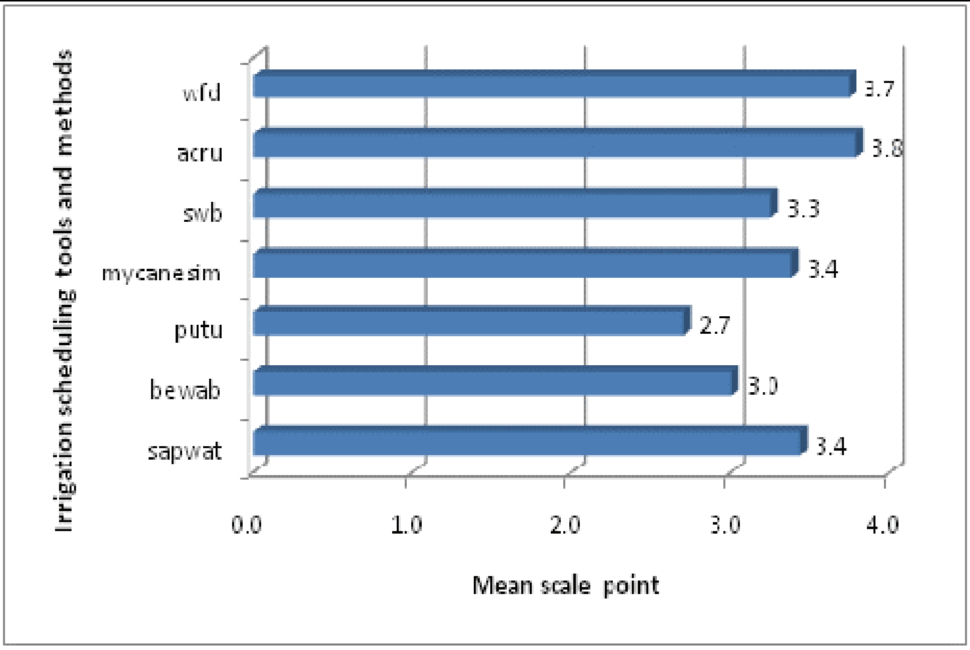
- Perceived easiness of using a specific tool or method (χ^2=29.92, df=12; p=0.003)
- Perceived easiness to understand the applicable research report(s) (Spearman r=0.224; p=0.013)
- Importance of an appropriate user manual (χ^2=13.47, df=12; p=0.036)
- Perceived understandability of an user manual (χ^2=24.86, df=12; p=0.015)
- Perceived easiness to learn and increase knowledge by using the specific irrigation scheduling method and tool (χ^2=21.73, df=12; p=0.041)
- Flexibility of a specific irrigation scheduling tool or method (χ^2=17.45, df=12; p=0.103). Although not statistical significant, a strong tendency exists.

8. PERCEIVED USEFULNESS OF USING THE TECHNOLOGY OR RESEARCH KNOWLEDGE

Perceived usefulness is operationally defined as the prospective adopter's subjective probability that applying the new technology will be beneficial to his personal and perhaps company or farm's well-being. The following variables were used to test the perceived usefulness of the new irrigation scheduling technology or program:

- Increase productivity
- Enhance the quality of the product
- Improve job performance
- Better control over decisions and work in general
- Enables to accomplish certain tasks quicker
- Improve effectiveness on the job and task completion
- Overall useful for specific job

Figures 8.1-8.8 illustrate the perceived usefulness of using a specific irrigation scheduling method or tool and therefore reflect the potential use of research outputs by the individual as well as the company or organization that applies the research knowledge. It is clear from the results that some of the research knowledge is mainly use on a catchment or scheme level, while other is more appropriate for application on a field level.

Perceived improvement of productivity	 **Figure 8.1. Perceived improvement of productivity with the use of irrigation scheduling tools (N=118)**

Enhance quality of the product (output)

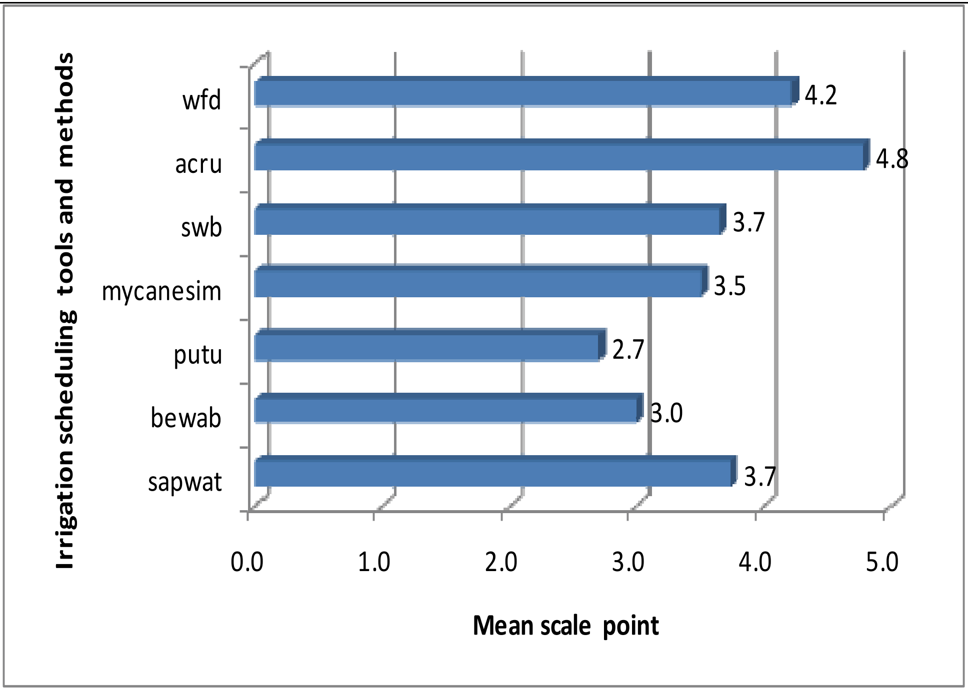


Figure 8.2. Perceived credibility of the output of irrigation scheduling tools and methods (N=118)

Improve job performance (Fig 8.3-8.5)

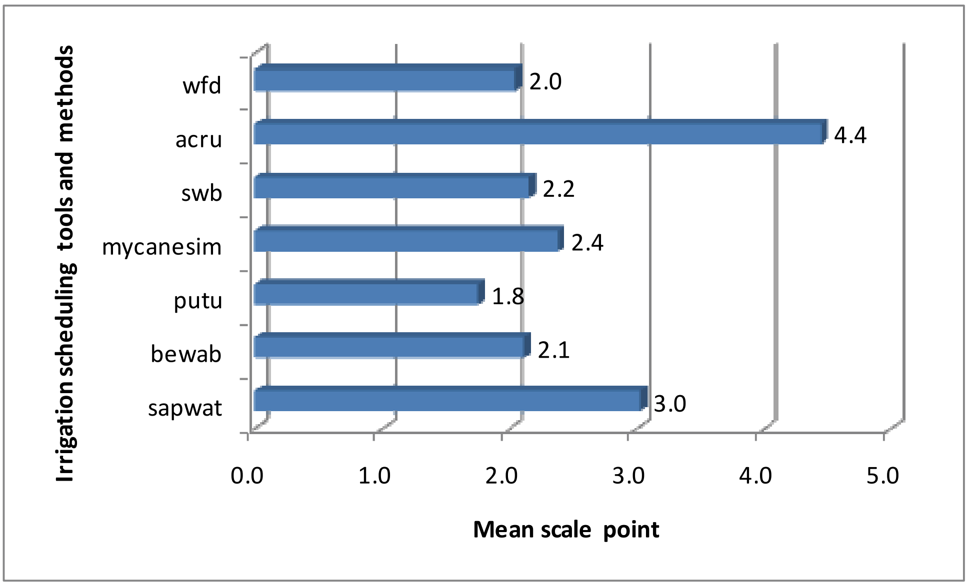


Figure 8.3. Perceived improvement of planning of water use with the use of irrigation scheduling tools (catchment and scheme level) (N=118)

Improve job performance (Fig 8.3-8.5)

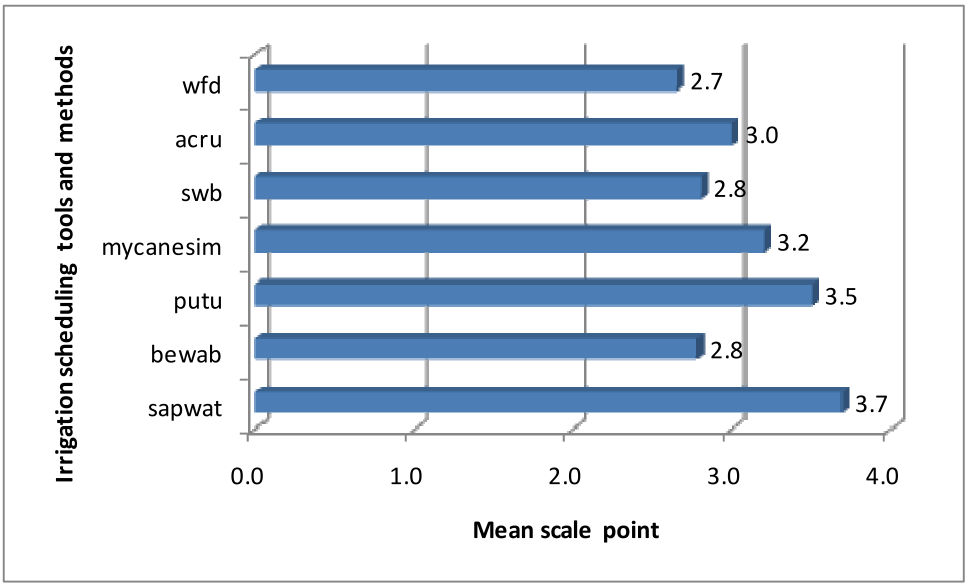


Figure 8.4. Perceived improvement of planning of irrigation system with the use of irrigation scheduling tools (field level) (N=118)

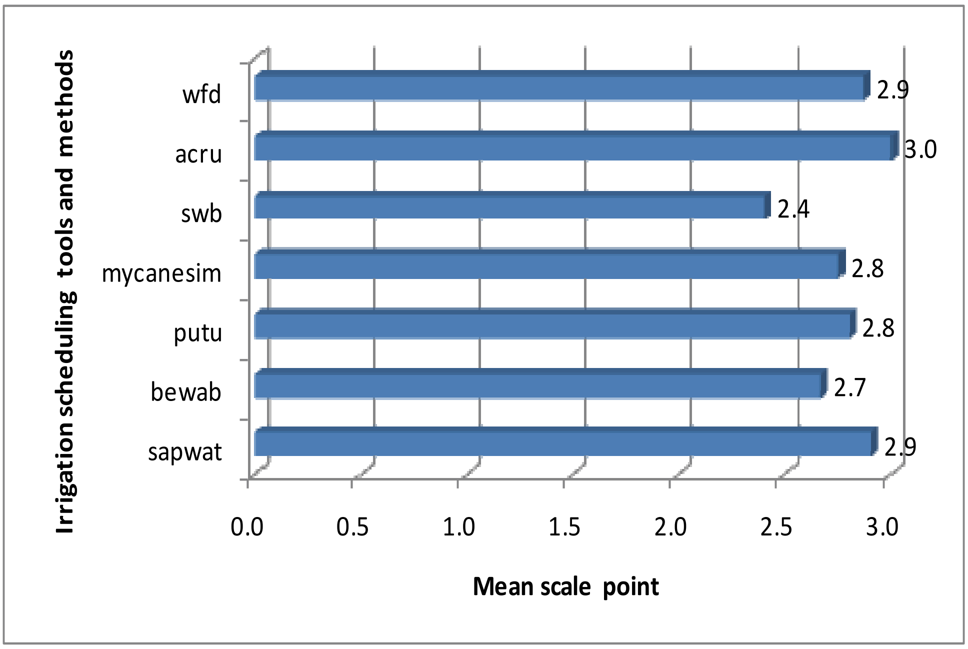


Figure 8.5. Perceived improvement of the evaluation of irrigation design at field level with the use of irrigation scheduling tools (N=118)

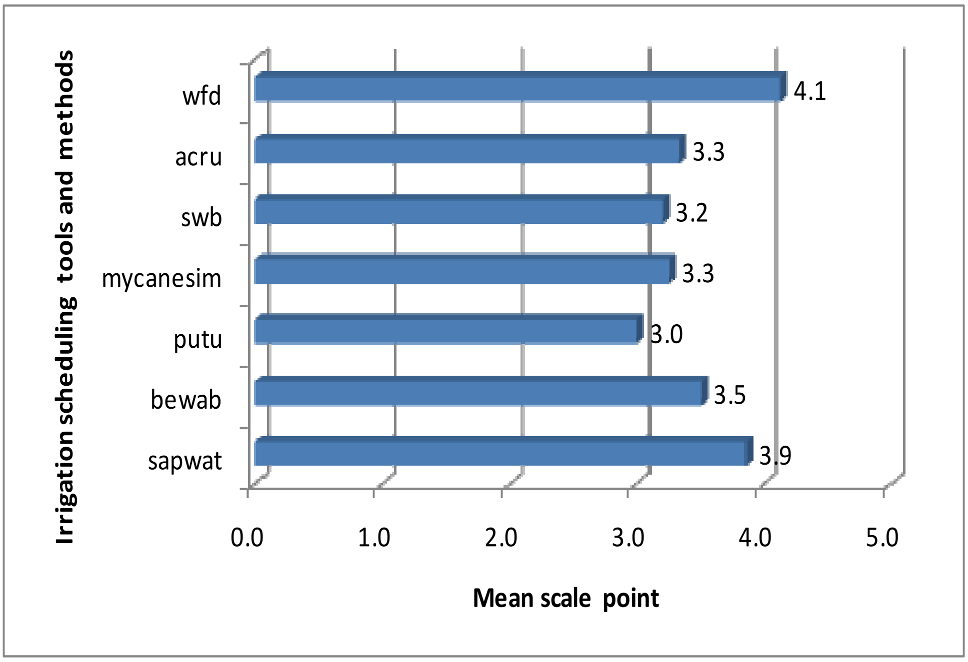
<table>
<tr>
<td>Better control over decisions and work in general</td>
<td>


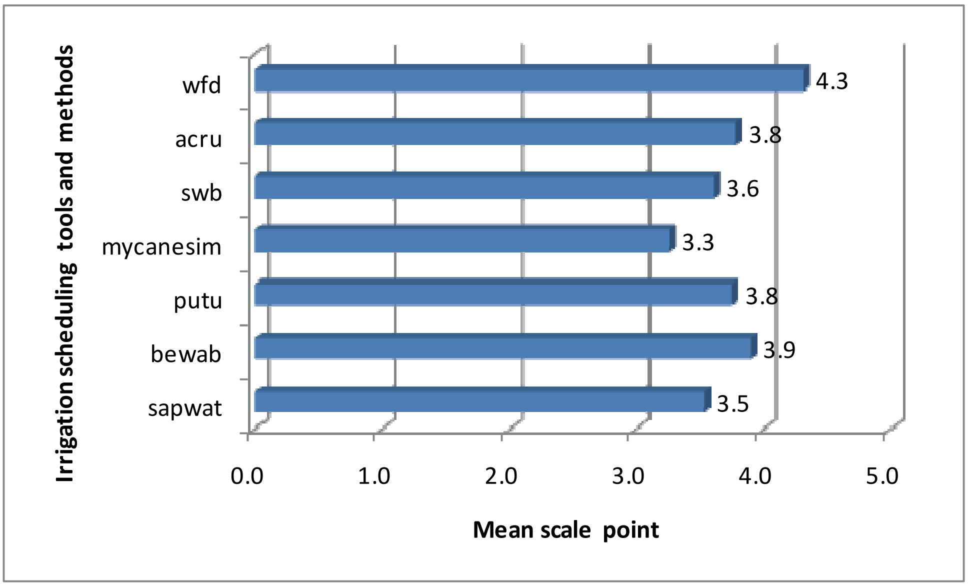
Figure 8.6. Perceived improvement of better control over the implementation of irrigation management strategies with the use of irrigation scheduling tools (N=118)
</td>
</tr>
<tr>
<td>Enables to accomplish quicker and easier decision making</td>
<td>


Figure 8.7. Perceived accomplishment quicker decisions regarding irrigation management with the use of irrigation scheduling tools (N=118)
</td>
</tr>
</table>

These figures reveal that respondents perceive these irrigation scheduling tools and methods to be useful with statistical significant proof found regarding:

- Improvement of productivity (χ^2=15.05, df=12; p=0.023) (χ^2=29.54, df=12; p=0.003)
- Job performance (χ^2=29.54, df=12; p=0.003)
- Quicker and easier making of decisions (χ^2=12.75, df=12; p=0.038)
- Better informed decisions taken (χ^2=15.05, df=12; p=0.024)

A strong tendency was found regarding the general perception that it helps users with decision making by saving time.

9. HOW USERS ACCESSED THE NEW RESEARCH KNOWLEDGE?

The next step in the analysis of the impact of research knowledge was to identify how users and potential users accessed the research knowledge? Have they only accessed citable research reports of what role does interaction with researchers, symposia, conferences, and peers etc. play in the uptake of research knowledge?

Respondents were asked to assess the importance of the following possible sources of information regarding the research knowledge:

- Research reports
- Scientific articles
- Popular articles
- Contact with researchers on own request (pull technology)
- Introduction to research knowledge through a peer or colleague
- Advisor or extensionists
- Training or short courses
- Action of researcher
- Website or internet
- Conference and symposia

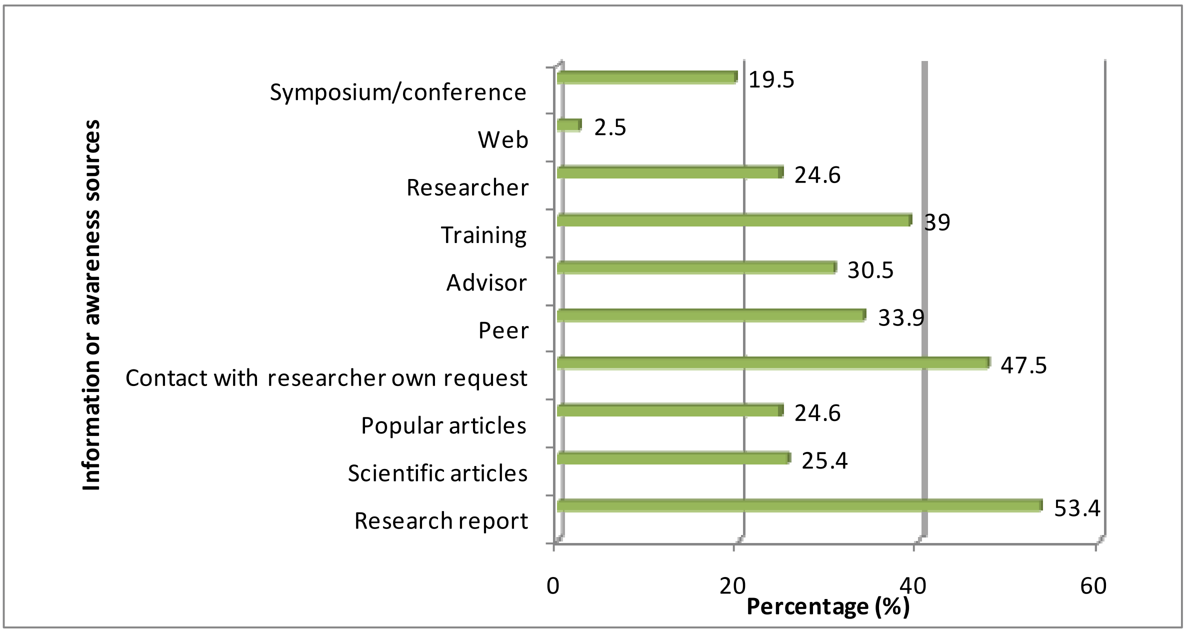


Figure 9.1 Frequency distribution of potential information sources of new research knowledge (N=118)

Figure 9.1 reveals that 54% of respondents made use of research reports to introduce them to new research knowledge and therefore this source of information is regarded as an important to make potential users aware of the research knowledge, ($\chi^2=17.98$, df=6; p=0.006). Surprisingly nearly 48% respondents indicated they made on their own initiative contact with the researchers (*user-pull*) to collect more information on the specific research knowledge ($\chi^2=16.75$, df=6; p=0.010). This illustrates that a significant number of users actually actively make efforts to identify research knowledge and to access it (*technology pull).* 39% of respondents became aware of specific research knowledge through training/short courses and information sessions offered.

Figures 9.2-9.10 illustrate the proportional role of the different awareness and information sources use as per irrigation scheduling method/tool to access new research knowledge.

Research reports

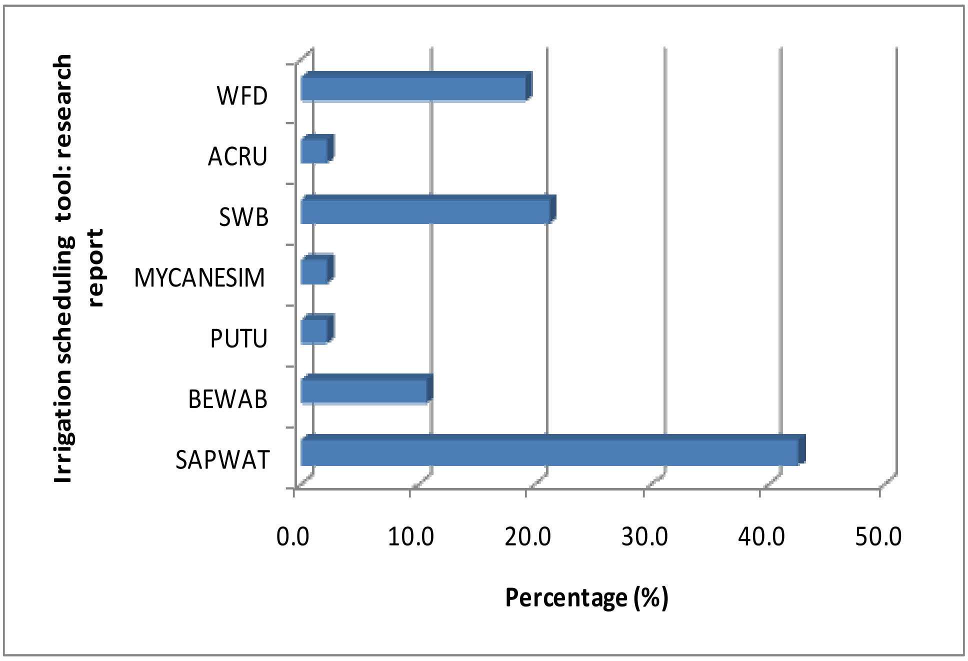
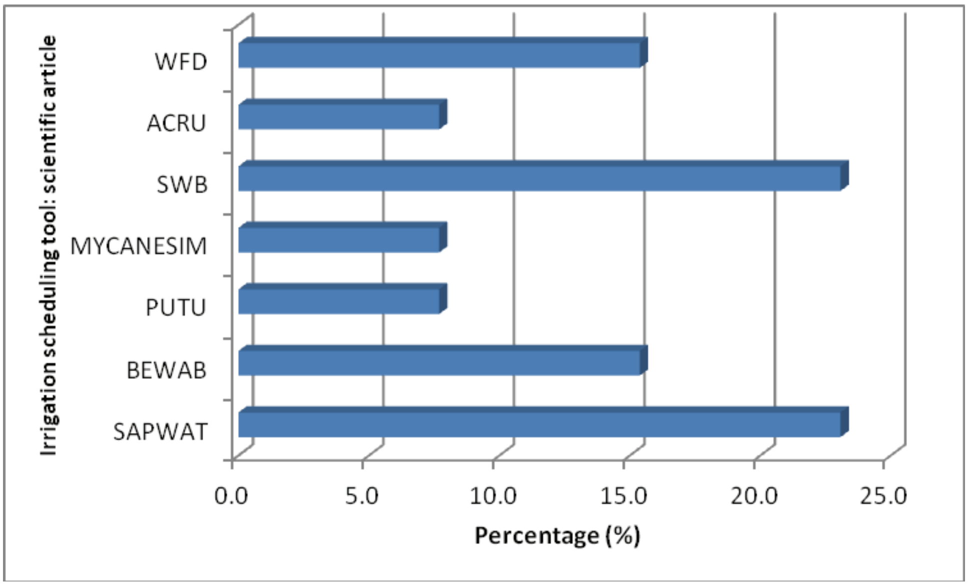
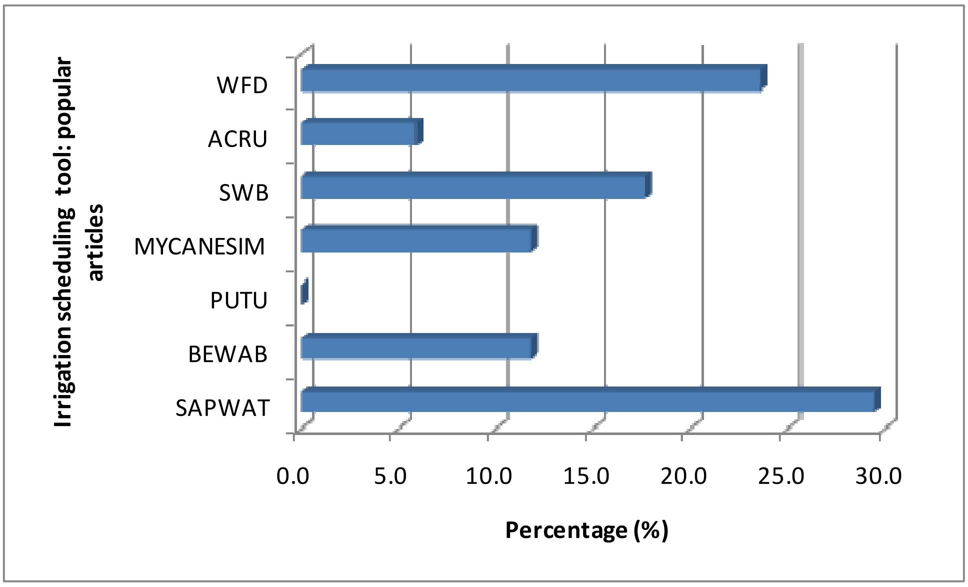


Figure 9.2. Frequency distribution of respondents accessing new research knowledge through research reports (N=118)

Scientific articles	 **Figure 9.3. Frequency distribution of respondents accessing new research knowledge through scientific articles (N=118)**
Popular articles	 **Figure 9.4. Frequency distribution of respondents accessing new research knowledge through popular articles (N=118)**

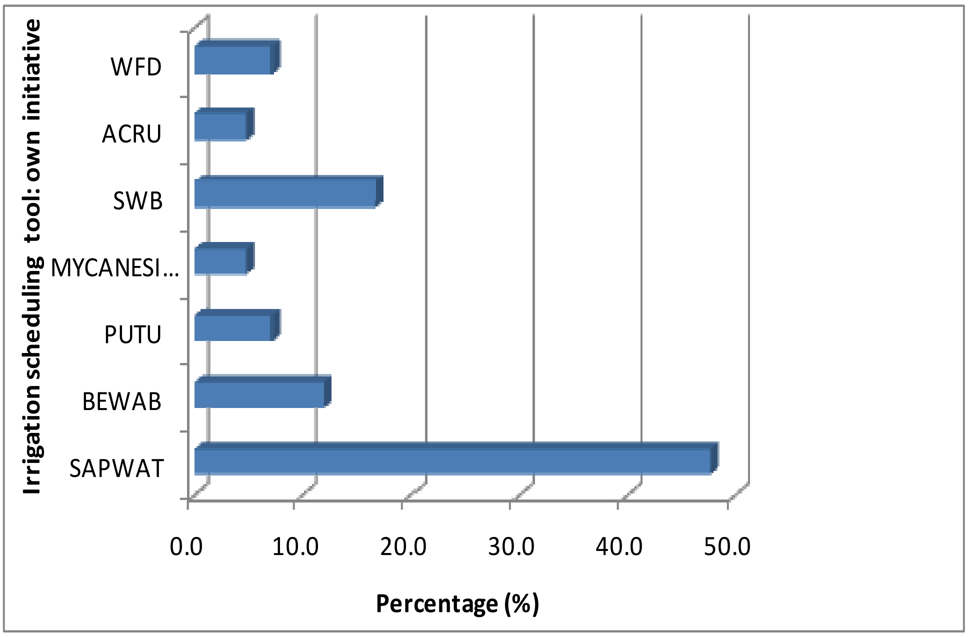
<table>
<tr>
<td>Contact with researchers on own request (pull technology)</td>
<td>

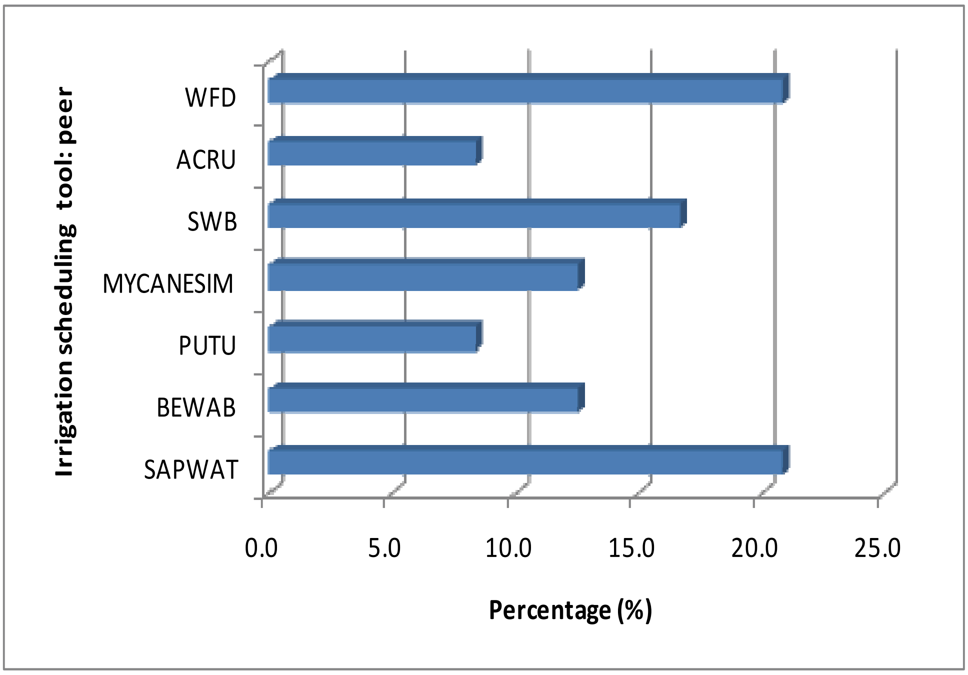
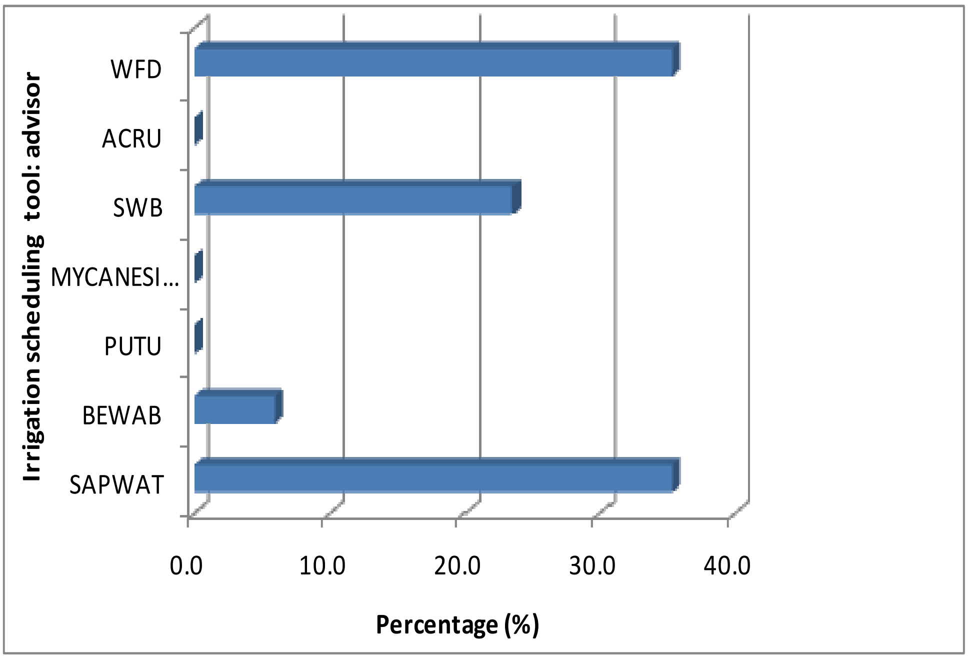
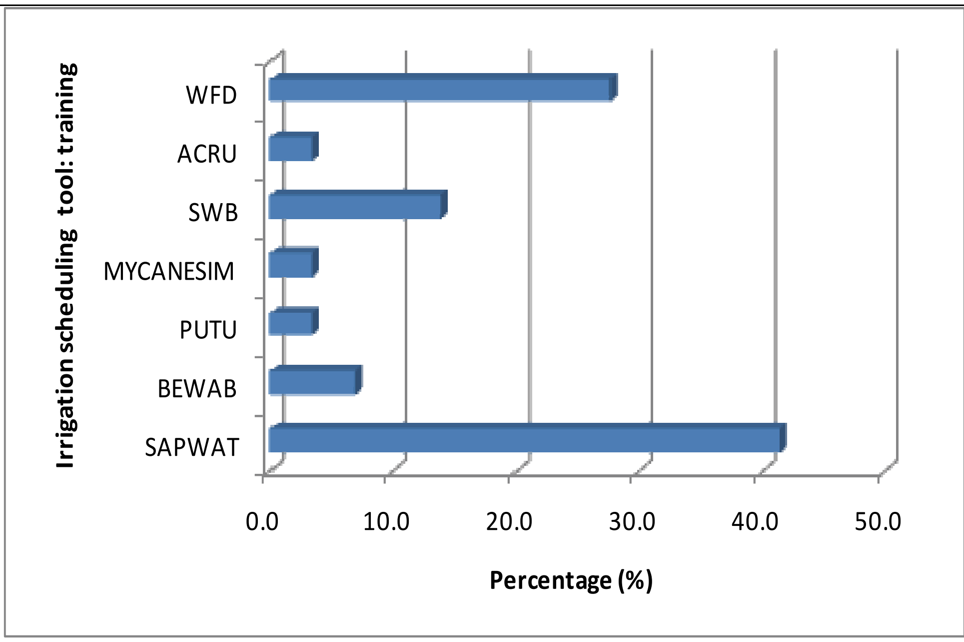
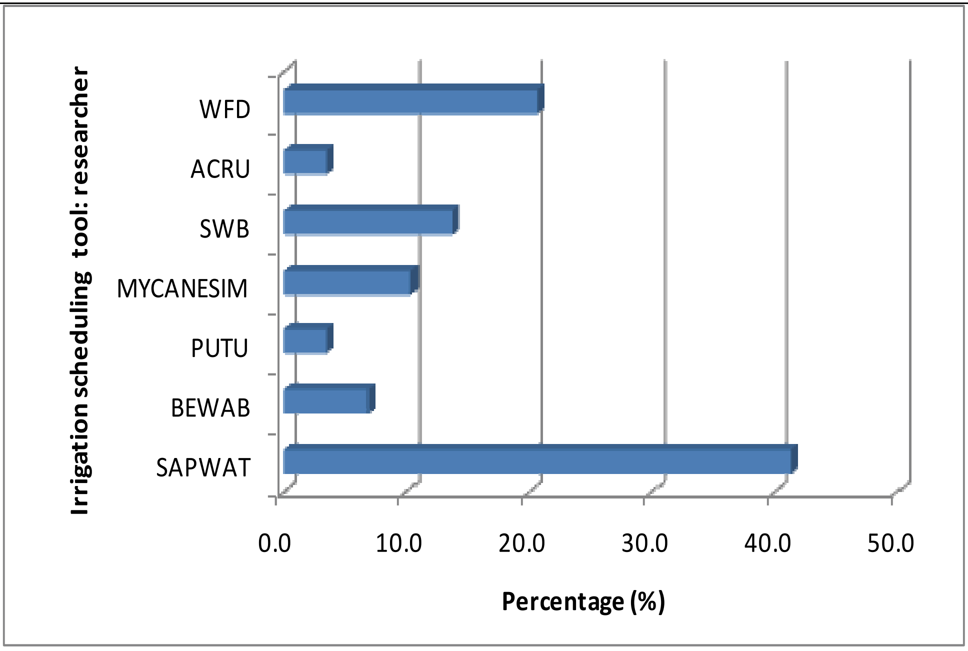
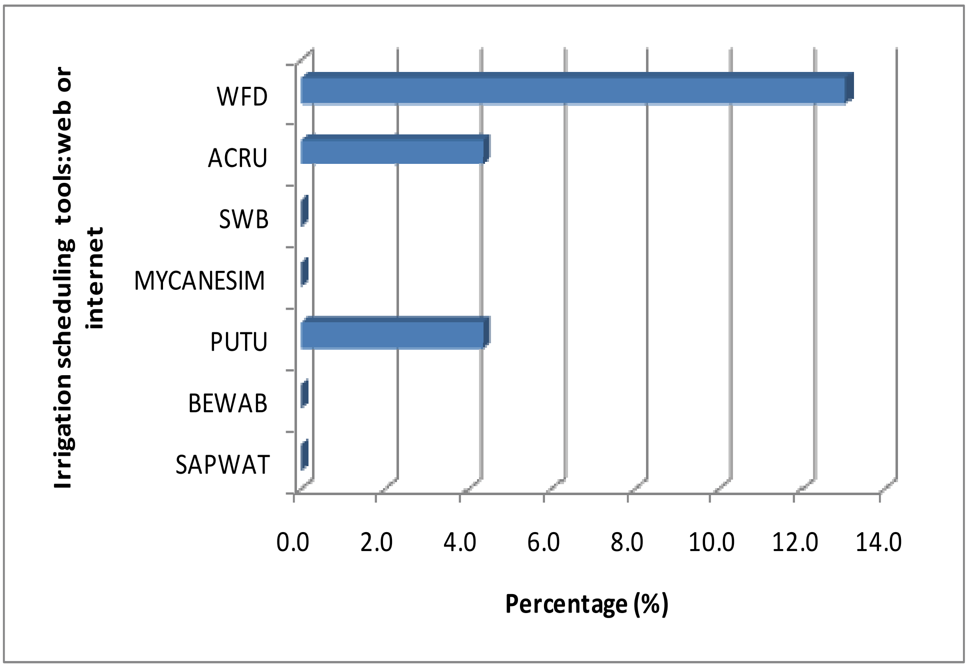
Figure 9.5. Frequency distribution of respondents accessing new research knowledge through own contact initiatives with researchers (N=118)</td>
</tr>
<tr>
<td>Introduction to research knowledge through a peer or colleague</td>
<td>

Figure 9.6. Frequency distribution of respondents accessing new research knowledge through peers (N=118)</td>
</tr>
</table>

Introduction to research knowledge through an advisor or extensionist	 **Figure 9.7. Frequency distribution of respondents accessing new research knowledge through advisor or extensionist (N=118)**
Training/ short courses and information sessions	 **Figure 9.8. Frequency distribution of respondents accessing new research knowledge through training/short courses and information sessions (N=118)**

Action of researcher (*push technology*)	 **Figure 9.9. Frequency distribution of respondents accessing new research knowledge through action by researcher (N=118)**
Web/Internet	 **Figure 9.10. Frequency distribution of respondents accessing new research knowledge through internet (N=118)**

Conference and symposia

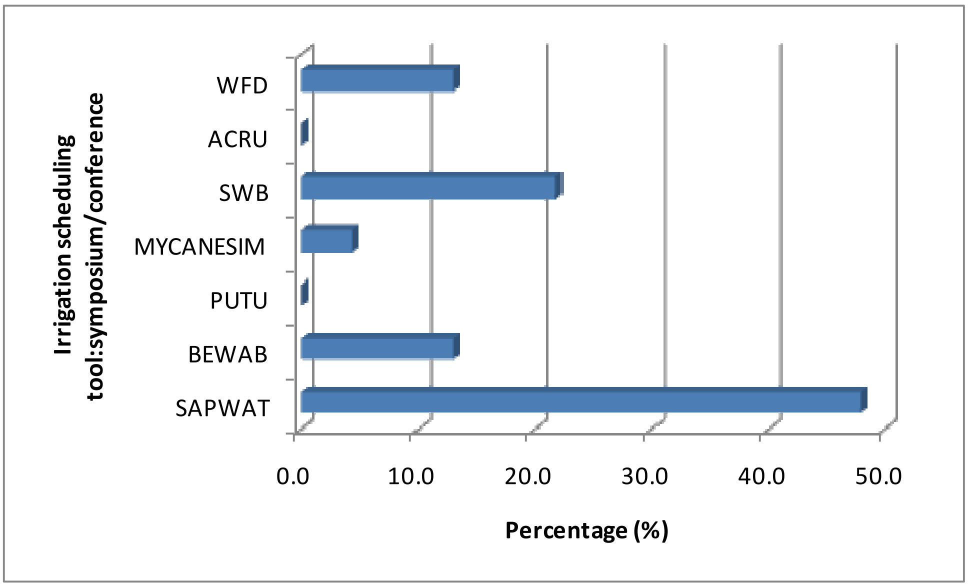


Figure 9.11. Frequency distribution of respondents accessing new research knowledge through conferences or symposia (N=118)

The information portrayed in Figures 9.2-9.11 is useful in the planning of research knowledge dissemination and implementation strategies by researchers as well as the WRC on how to make research products/outcomes available to decision-makers and potential users. It is clear from these findings that a paradigm shift is required amongst researchers and research organizations from the traditional approach where other agencies like extension, etc. was given the task to disseminate information to a situation where the uptake of research products is seen as a social process involving interactive learning based on relationships between different people and organizations.

10. WHAT TYPE OF ASSISTANCE IS FAVOURED BY USERS?

The major hindrances that influence the uptake of new research knowledge in priority order is the lacking of enough technical knowledge about the soil-plant-atmosphere continuum, poor water administration and communication at scheme level, inability to interact with electronic mail system, lack of computer skills to interact with computer programs effectively where applicable, and time available to learn a new program or understand new research knowledge (Figure 10.1.)

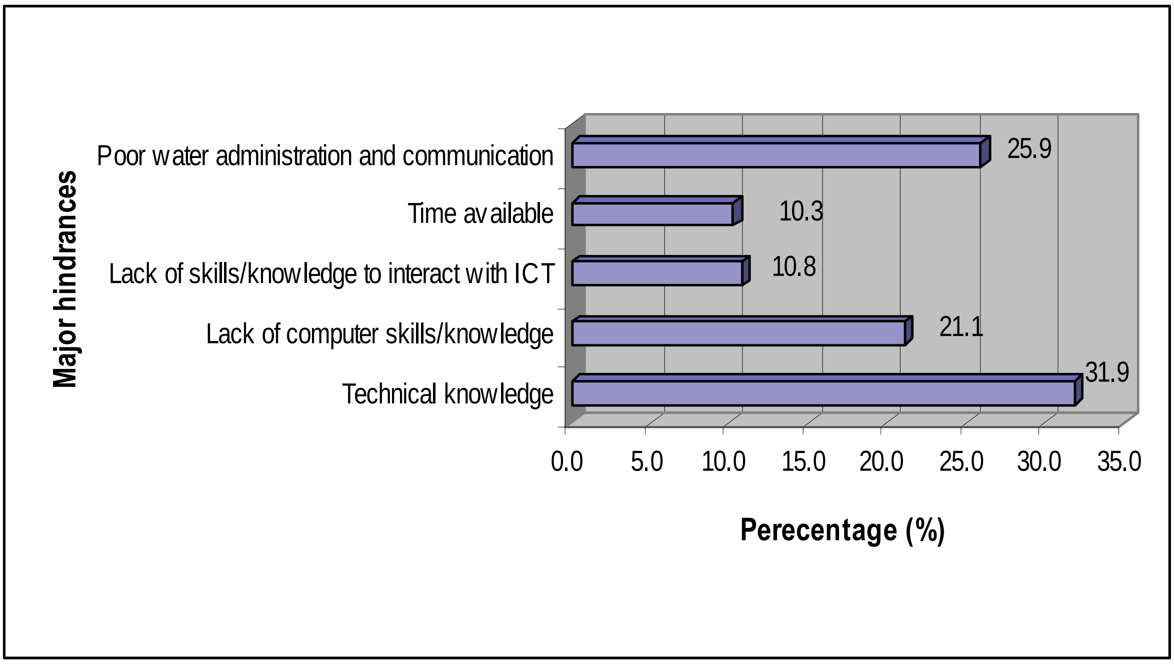


Figure 10.1. Major hindrances that influence the uptake of new research knowledge (N=118)

Respondents were asked to indicate their preferences regarding the offering of assistance with the uptake or using of new research knowledge (Figure 10.2)

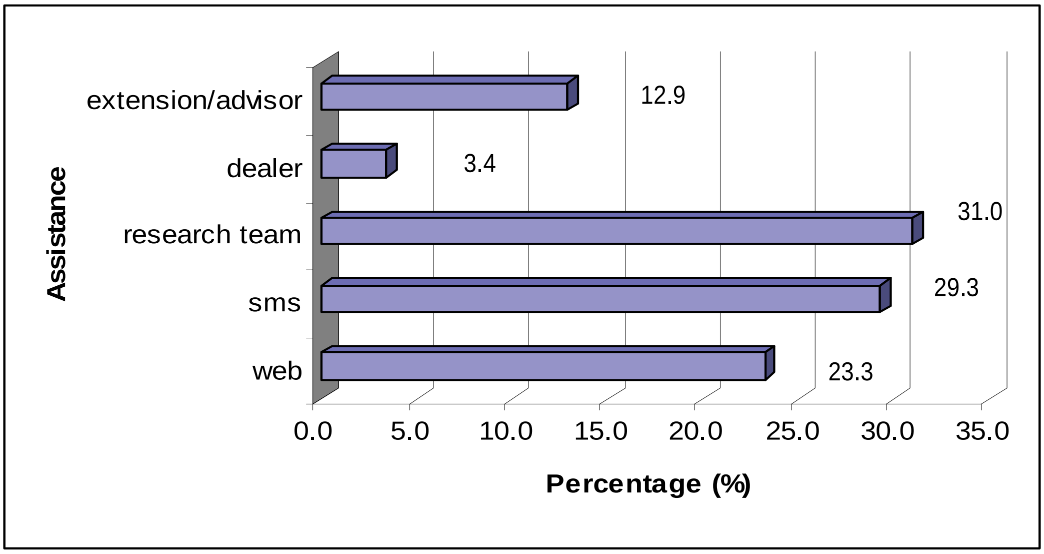


Figure 10.2. Type of assistance preferred by users of research knowledge

Significant positive relationships were found between the perceived importance of assistance provided by the research team (Spearman r=0.296; p=0.003), importance of internet communication technology like the use of web/SMS (Spearman r=0.314; p=0.009) with the uptake or use of new research knowledge. This emphasizes the important role that the research team has to play after research knowledge is generated as well as the potential use of internet communication technology (ICT) in information sharing.

In Table 10.1 the perceived importance of the various methods of offering assistance as per irrigation scheduling tool/method is revealed. The respondents were disappointed with the role that many dealers (where applicable) and cooperative personnel play regarding the offering of assistance with the uptake of irrigation management knowledge. Many respondents also raised their concern about the relative small role that extensionists and advisors play in the assistance of potential users, often because of a lack of knowledge and skills.

Table 10.1 Perceived assistance with the uptake of new research knowledge as per irrigation scheduling tool (N=118)

	Web	SMS	Research team	Dealer/Coop	Extension/ advisor
SAPWAT	40.8	27.3	20.5	2.3	9.1
BEWAB	10	30	50	0	10
PUTU	25	25	25	0	25
MYCANESIM	37.5	25	25	0	12.5
SWB	10	40	35	5	10
ACRU	0	0	66.7	0	33.3
WFD	13	34.8	30.5	8.7	13

11. ATTITUDE OF USERS TOWARDS WRC AND IRRIGATION WATER MANAGEMENT

A user's intrinsic motivation to either use or not use specific research knowledge is determined by his/her attitude towards the use of the specific research, perceived usefulness and perceived ease of use (Davis, 1985). Also Fishbein and Ajzen (1980) identified attitude as an important determinant of a persons' intention to a certain behaviour or implementing of research knowledge. Attitude in this discussion refers to the potential users' positive or negative feelings about:

- irrigation water management in general,
- the National Water Act (NWA) and
- the implementation of sustainable irrigation water use practices through practising of irrigation scheduling,
- whether irrigation scheduling is cost effective and
- if farmers are skilled and knowledgeable enough to apply irrigation scheduling on their own.

The general attitude towards sustainable irrigation water management will determine the anxiety of using new research knowledge and technology.

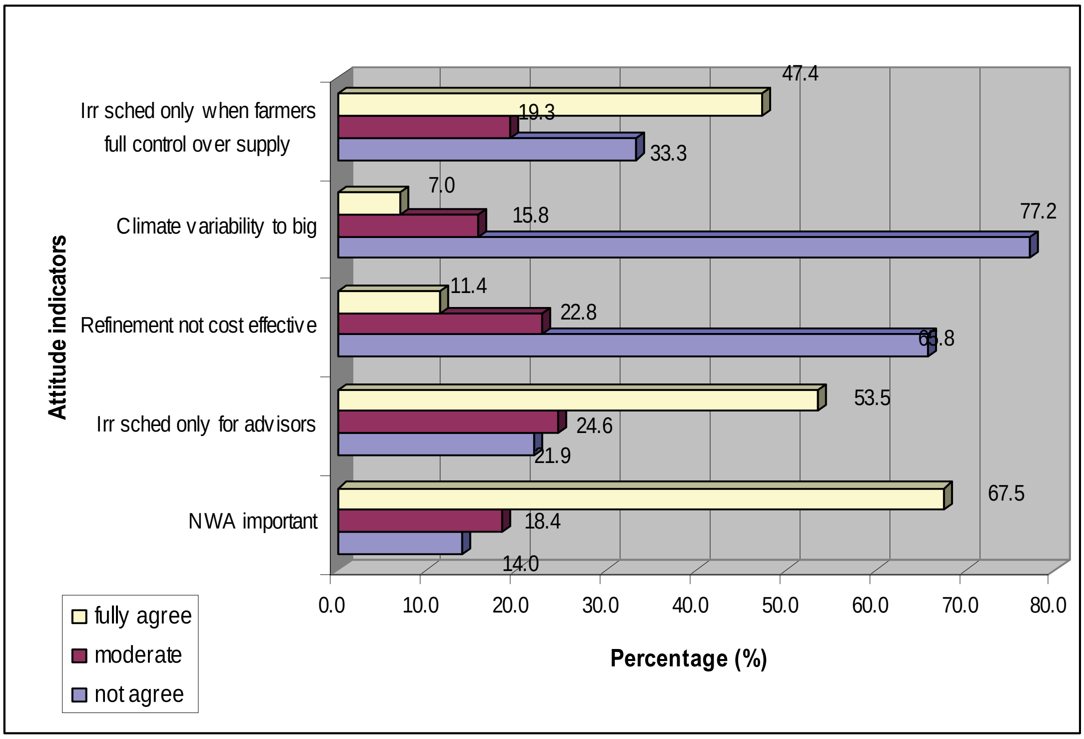


Figure 11.1 Frequency distribution of respondents' attitude towards irrigation water management (N=118)

Respondents in general agree that:

- The National Water Act imposes the necessary regulations and context on irrigation water users for the application of efficient water management (67.5%)
- Irrigation scheduling methods and tools are mainly developed for the use by irrigation advisors and researchers (54%)
- That irrigation scheduling could only be effectively applied where farmers have full control over their water supply (47%)

Respondents however disagrees that the climate variability is too complex and difficult to accommodate in irrigation scheduling tools (77%) and that the management refinement through the applying of irrigation scheduling tools is not cost effective (69%).

The next part of the report deals with the general attitude of respondents towards research knowledge generated and disseminated by the WRC as well as their perception regarding the participation of potential role players in the generating of new research knowledge.

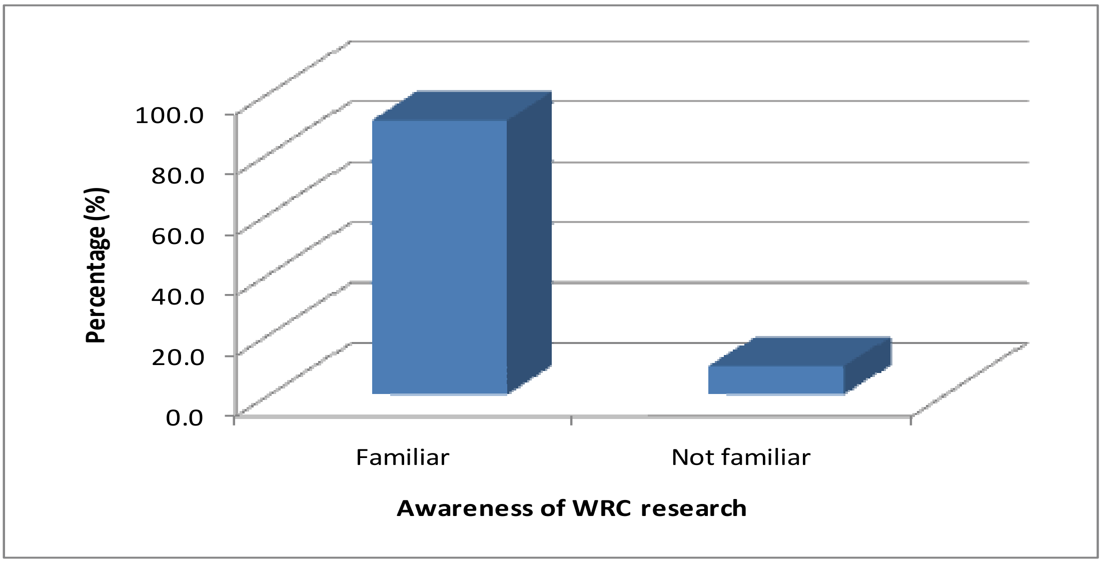


Figure 11.2 Respondents' awareness of WRC-funded research knowledge (N=118)

Figure 11.2 illustrates that 85% of the respondents are familiar with the research conducted by the WRC, and that 80% of them use the research knowledge regularly in their decision making (Figure 11.3).

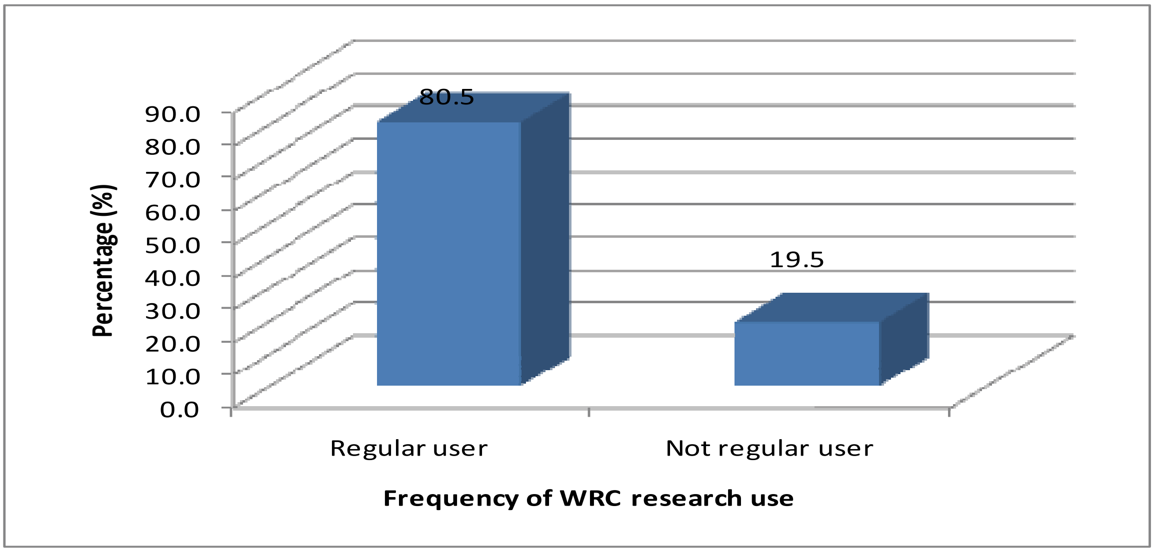


Figure 11.3 Frequency distribution of the use of WRC-funded research outputs (N=118)

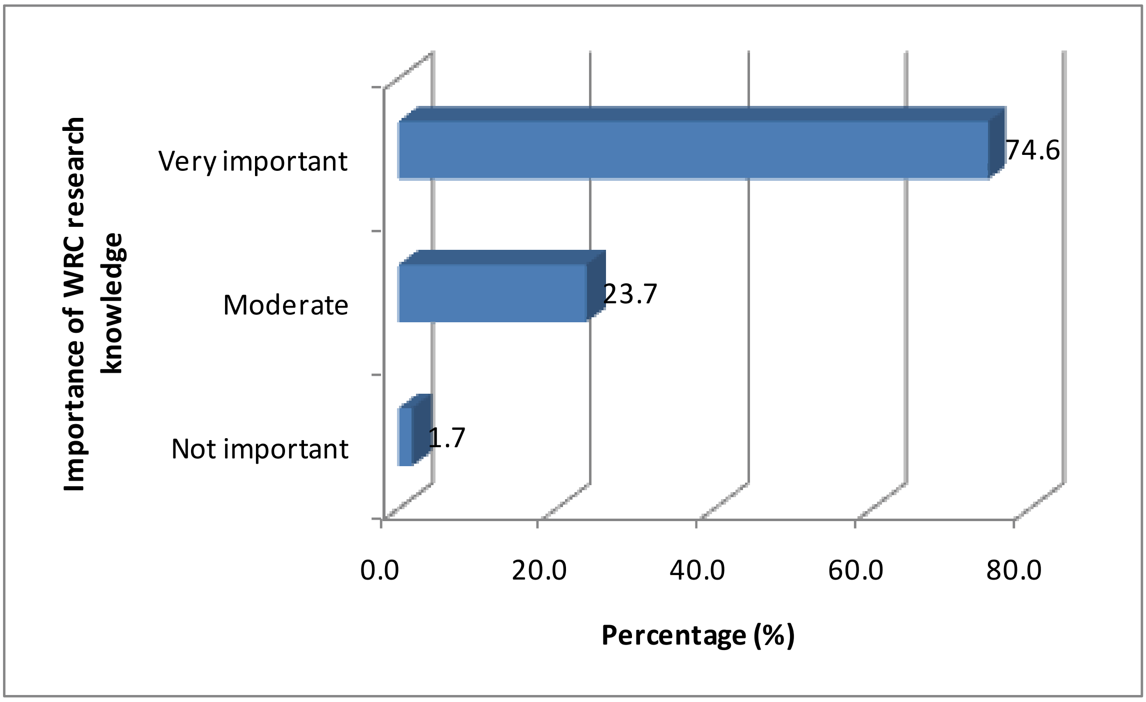


Figure 11.4 Perceived importance of WRC-funded research knowledge for decision making (N=118)

Water users in various subsectors are the clients or target groups of research output and are therefore important stakeholders in the generating and application of research. It was therefore crucial to identify the general perception of respondents regarding their involvement in the research process by using a five point semantic scale. Multistakeholder involvement is important for the determination of focus and direction of the research and how knowledge should be disseminated (Backeberg, 2000; Backeberg & Sanewe, 2006). In general respondents were positive about the idea that potential users of irrigation scheduling research outputs should be more involved in the development and generating of the research knowledge. This however requires the purposefully catalyzing of innovation through bringing together actors and facilitating their interaction. As an organisation and function, innovation brokering differs from the traditional research and development because it represents the institutionalizing of the facilitation role, with a broad, multi-stakeholder, innovation perspective. The innovation cycle used in this discussion can be described as a process of creativity (scientific research by testing ideas, experiments), invention (when new discoveries have practical application) and exploitation (taking place by utilizing the commercial potential in a business concept that will generate profits) (Mc Bain, 2004; Backeberg &Sanewe, 2006).

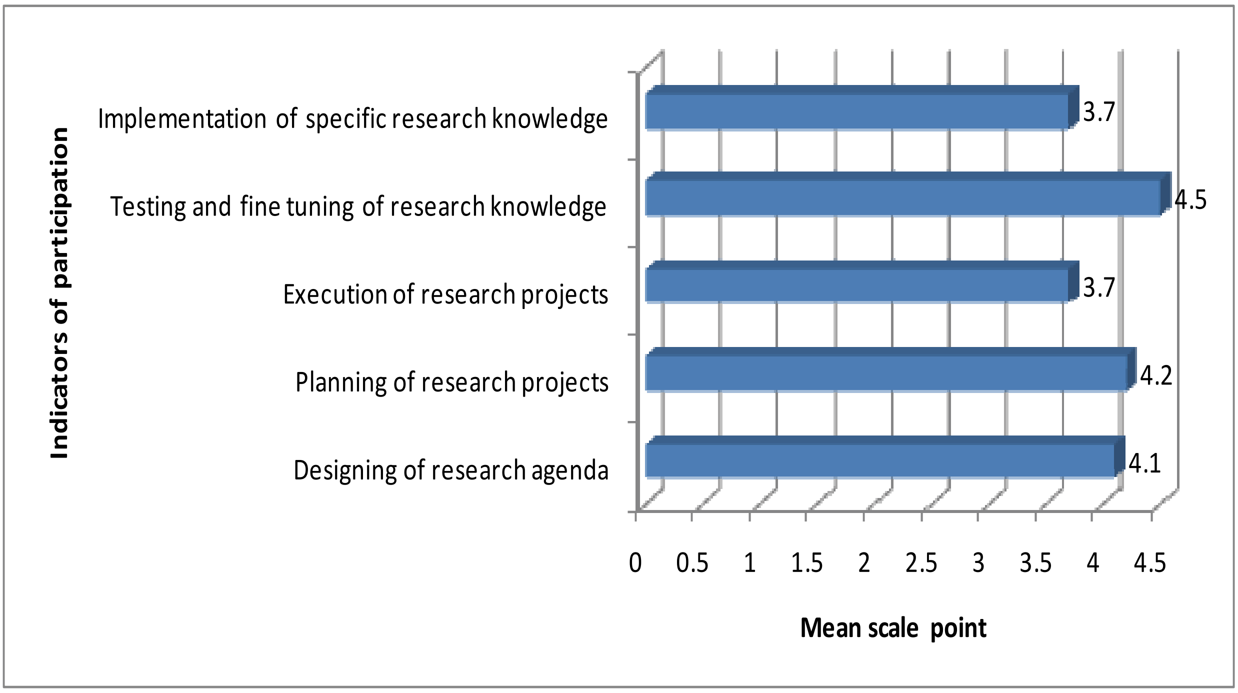


Figure 11.5 Perceived importance of participation by potential users in the development and generating of irrigation scheduling research knowledge (N=118)

12. CONCLUSION

One of the greatest challenges facing the world is to ensure that everybody has access to adequate food that is healthy, affordable and safe. With the planet's population expected to reach 9 billion by 2050, agriculture must rise to the challenge of meeting the massive food demand.

During 2011 the National Development Plan was released where a number of recommendations were published to expand the agriculture potential of South Africa. Amongst these recommendations was a substantial increase in the investment in water resource and irrigation infrastructure where natural resource base allows and to improve the efficiency of existing irrigation to make water available. Although the regulatory framework and institutional arrangements have changed significantly since 1994, one aspect remains constant: *water scarcity* – whether qualitative, quantitative or both. This originates as much from inefficient use and poor management as from real physical limits (NWRS, 2012). In addition the influence of changing weather patterns and elevated CO_2 on crop production growth processes and water availability remains to be much uncertain, which project additional challenges to the irrigation industry (NWRS, 2012).

The development, improvement and promoting of irrigation scheduling tools over the last four decades through WRC-funded research efforts have been impressive. This report highlights also challenges to research and development that could have a profound effect on the priorities of WRC research policies and practices in future. The use of the McMaster matrix in combination with the Technology Acceptance model (TAM) of Davis (1985) illustrated the advantage to assess decision-making impact of irrigation scheduling research funded by the WRC and help to understand how to facilitate the use of research knowledge to inform decision making. In the first place it is important to recognise that different target audiences (irrigators, water administrators, irrigation engineers, academics and educators) have different needs and therefore crucial to warrant different measures of impact. Some scheduling tools/methods like SAPWAT, WFD, BEWAB and Mycanesim are more appropriate for decisions to be taken at the irrigation field level, while some tools like SAPWAT, ACRU and SWB are more popular to be used by water administrators for the planning of irrigation water management strategies at scheme level and by engineers in the designing of irrigation systems. Secondly, due the number of paradigm shifts and transformation that has taken place in the research and development arena over the last couple of years, the way that irrigation water management research is conceived, designed, implemented and how results are disseminated and used to generate innovations changed. What changes constantly is the environment in which discovery and innovation occurs, and this has impacted on the organisation and the social process of discovery and innovation. It is no longer enough to know *whether* research was used, but rather *how* research was used in the agricultural value chain.

Stevens *et al.* (2005) illustrated that there is no single method of irrigation scheduling that has met all the needs of the South African irrigation industry. Research organisations like the WRC produce new knowledge or ”solutions to a problem” referred to as research output as part of the innovation process. However, it usually requires a major effort to ensure that a brilliant idea becomes something widely used, and involves many more steps and use of resources and problem solving on the way. This allows us to distinguish between knowledge and the application of knowledge as part of the innovation process. Important in the uptake of research knowledge on irrigation scheduling, is that it is strongly embedded in a specific prevailing socio-economic structure, which largely determines what is going to be learned and where the innovation are going to take place. The uptake of irrigation scheduling methods/tools has clearly been more successful where back-up was provided by researchers and/or consultants/advisors over an extensive period. This was illustrated in the cases of BEWAB where Prof Alan Bennie, who has the ability to translate basic scientific findings into practical solutions for farm management decisions, played a distinctive role in the uptake of irrigation scheduling and the use of BEWAB in the Vaalharts and other irrigation schemes. The same applies for the uptake of PUTU when Prof Jimmy de Jager, dr Abraham Singels and Mr James Kennedy were still actively promoting the use of PUTU. However, it is clear from the assessment that the uptake of PUTU and BEWAB has declined severely since the retirement of these key people, and was replaced by new irrigation scheduling tools and methods.

The type of decisions that are influenced by the uptake of irrigation scheduling innovations differed across the various users. Scheduling tools can either be used for *instrumental purposes* in the identification and solving of problems (scheme and field level). It can also be used *conceptually* where concepts are enlightened and where knowledge capacity is built through training or teaching as witnessed in the cases of SWB, WFD, BEWAB, PUTU and ACRU. The frequency of use of scheduling research knowledge also depends largely for what purpose the research output is used.

The perceived ease of use of research knowledge is crucial in the uptake of irrigation scheduling knowledge. Clearly some scheduling tools and methods are easier to use (user friendly) and do not require too much additional skills and knowledge of the potential user like MyCanesim and WFD. The role of understandable research reports, appropriate user manuals where applicable and flexibility of a specific irrigation scheduling tool are important factors that determine the acceptance and uptake of research. The habits and practices that are critical to innovation are learned behaviours which may change gradually or suddenly and often requires new partners and ways of working.

In general the perception exists that the use of irrigation scheduling tools/methods is beneficial or useful either for a specific person using the tool or for the organisation as a whole with regard to:

- Improvement of productivity (χ^2=15.05, df=12; p=0.023) (χ^2=29.54, df=12; p=0.003)
- Job performance (χ^2=29.54, df=12; p=0.003)
- Quicker and easier making of decisions (χ^2=12.75, df=12; p=0.038)
- Better informed decisions taken (χ^2=15.05, df=12; p=0.024)

In accessing how users and potential users accessed the research knowledge, it was clear that research reports, contact with the researcher or research teams and attending of training or short courses were main routes. It is however important to realize that institutional settings play an important role in the interaction, learning and sharing of knowledge.

The major hindrances in the uptake of irrigation scheduling research products are in priority order:

- Lack of technical knowledge about soil-plant-atmosphere continuum
- Poor water administration and communication at scheme level
- Lack of computer skills and knowledge
- Lack of knowledge and skills to use ICT

The importance of research team intervention in the assistance with the use of the scheduling tools was emphasized. The roles that Proff Bennie and de Jager played in the uptake of research knowledge (BEWAB and PUTU respectively) can again serve as support for this finding.

In the generation of research knowledge different approaches can be followed, either the research team comprising of mainly/only researchers generate new knowledge which is then transferred via advisors/consultants to potential users OR potential users are included in the generation and dissemination of research knowledge. Demand shapes the focus of the innovation, and it is not only articulated by the market but also by non-market drivers such as collaborative relationships between users and producers of research knowledge.

Rothwell (1992) identify the following factors that characterize successful innovations:

- Successful innovations have taken the understanding of the user's needs into consideration

- Successful innovations developed processes and structures that integrate development, production and uptake of research/interventions through proper communication
- Successful innovations are characterised by performing the research/development work more efficiently, but not necessarily quicker
- Successful innovations, apart from using their own in-house research capacity, also make frequently use of outside technology and scientific advice, not necessarily in general but in a specific area
- Success was highly correlated with quality research and development resources and committed research teams
- Success was also found to be linked to the status, experience, and seniority of the innovator or entrepreneur responsible for the innovation.

This research highlights that the research knowledge will only lead to useful outcomes if emphasis is placed on development, and therefore the innovation process has to be purposefully managed with expertise, time, efforts and funds budget for both research and knowledge brokering (Backeberg & Sanewe, 2006). The literature on knowledge brokering in a wide range of fields acknowledge that “producer” and “user” of knowledge are not rigid categories and that interactivity is required; moving form transfer, dissemination and consulting to engagement and collaboration (Lavis *et al*., 2006). Research uptake is important, and knowledge brokering is an essential function, but should be accompanied by and integrated within the function of innovation brokering, which more broadly focuses on rearranging all technical, social and institutional relationships needed for innovation and change. Moving towards such a paradigm requires that ideas from innovation system are adapted to irrigation water management research and to think again as to what such an innovation broker role implies in terms of identity, capacities and mandate of those to fulfil this role, and how it differs from a knowledge broker role.

REFERENCES

Allen RG, Pereira LS, Raes D & Smith M, 1988. Crop Evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No56, FAO, Rome, Italy.

Annandale JG, van der Westhuizen AJ & Olivier FC, 1996. Die fasilitering van tegnologie oordrag deur verbeterde besproeiingriglyne vir groente en ‘n meganistiese gewasmodeleringbenadering. Water Research Commission, Pretoria. WRC Report No 476/1/96.

Annandale JG, Benadė N, Jovanovic NZ, Steyn JM & du Sautoy N, 1999.Facilitating irrigation scheduling by means of soil water balance model. Water Research Commission, Pretoria. WRC Report No 753/1/99.

Annandale JG, Campbell GS, Olivier FC & Jovanovic NZ, 2000.Predicting crop water uptake under full and deficit irrigation: An example using pea (*Pisum sativum cv* Puget). *Irr. Sci.* 19:65-72.

Annandale JG, Jovanovic NZ & Claasens AS, 2002a. The influence of irrigation with gypsiferous mine water on soil properties and drainage water. Water Research Commission, Pretoria. WRC Report No 858/1/02

Annandale JG, Jovanovic NZ, Mpandeli NS, Lobit P & du Sautoy N, 2002b. Two dimensional energy interception and water balance model for hedgerow tree crops. Water Research Commission, Pretoria. WRC Report No 945/1/02

Annandale JG, Jovanovic NZ, vd Westhuizen AM, Steyn JM, Claasens AS, Rethman NFG, Reinhardt CF, de Jager PC, Mpuisnag TA, Modisane PC, Hammes PS, Masike L, le Roux HJ, Benadė N, Hodgson FDI, Usher B & Lorentz SA, 2002c. Predicting the impact and sustainability of irrigation with gypsiferous mine water. Water Research Commission, Pretoria. WRC Report No 206/99

Annandale JG, Steyn JM, Benadė N, Jovanovic NZ & Soundy P, 2005. Technology Transfer of Soil Water Balance (SWB) model as a user friendly irrigation scheduling tool. Water Research Commission, Pretoria. WRC Report No TT251/05.

Annandale JG, Beletse YG, de Jager PC, Jovanovic NZ, Steyn JM, Benadė N, Lorentz SA, Hodgson FDI, Usher B, Vermeulen D & Aken ME, 2007. Predicting the environmental impact and sustainability of irrigation with coal mine water. Water Research Commission, Pretoria. WRC Report No 1149/07

Backeberg GR, 2000. Planning of research in the field of agricultural water management. Paper presented at an IPTRID workshop on management of irrigation and drainage research. Wallingford, UK

Backeberg GR, 2003. Water usage and irrigation policy. In: The challenge of change: Agriculture, Land and the South African economy. Nieuwoudt WL, Groenewald JA (eds). University of Natal Press, Pietermaritzburg.

Backeberg GR & Sanewe AJ, 2006. The research and development strategy for water utilisation in agriculture – responding to diverse needs of farmers in South Africa. Irr and Drain,55:281-290

Benadė N, Annandale JG, Jovanovich NZ, Meiring JA and Crous CI 2002. The development of an integrated information system for irrigation water management using the WAS, SWB and RISKMAN models. Water Research Commission, Pretoria. WRC Report No 946/1/02.

Bennie ATP, Coetzee MJ, van Antwerpen R, van Rensburg LD & du T Burger R, 1988. ‘n Waterbalansmodel vir Besproeiing gebaseer op Profielwatervoorsieningstempo en Gewaswaterbehoeftes. Water Research Commission, Pretoria. WRC Report No. 144/1/88

Bennie ATP, 1995. Sound water management concepts and their application at farm level. *Proc Southern Africa Irrigation Symposium, 4-6 June 1991. Durban, South Africa.*

Bennie ATP, van Rensburg LD, Strydom MG & du Preez CC, 1997. Reaksie van gewasse op voorafgeprogrameerde tekortbesproeiing. Water Research Commission, Pretoria. WRC Report No 423/1/97

Bennie ATP, Strydom MG & Vrey HS, 1998. Gebruik van rekenaarmodelle vir landboukundige waterbestuur op ekotoopvlak. Water Research Commission, Pretoria. WRC Report No. TT102/98.

Bezuidenhout CN, Singels A & Hellmann D, 2002. Whole farm harvesting strategy optimization using the CANEGRO model: A case study for irrigated and dryland sugarcane. *Proc S Afr Technol Ass 74:250-259*

Boedt LJJ & Laker MC, 1985. The development of profile available water capacity models. WRC Report No 98/1/85. Water Research Commission, Pretoria.

Bristow KL, de Jager JM & van Zyl WH,1981. The leaf water potential – crop leaf diffusive resistance relationship of a wheat crop. *Agrochemophysica 13:21-23*

Bristow KL & de Jager JM, 1981. Proposed technique to measure evapotranspiration using micrometeorological methods. *Water SA 7(1):49-53*

Campbel GS & Diaz R, 1988. Simplified soil water balance models to predict crop transpiration . In: Bidginger FR and Johansen C (eds). Drought research priorities for dryland tropics. ICRISAT, India.

Capron H, 1992. Economic quantitative methods for the assessment of R&D Programmes: A state of Art. Monitor-Spear Series, European Community Commission, Brussels.

Charlesworth PB, 2005. Irrigation insights No 1-Soil water monitoring (2nd edition). National Program for irrigation Research and development, CSIRO Publishing, Melbourne, Australia.

Clark DJ, Kiker GA & Schulze RE, 2001. Object oriented restructuring of the ACRU Agrohydrological modeling system. 10th South African Hydrology Symposium, 26-28 September 2001, Pietermaritzburg.

Crosby CT, 1996. SAPWAT 1.0 – A computer program for estimating irrigation requirements in South Africa. Water Research Commission, Pretoria. WRC Report No 379/1/96

Crosby, CT & Crosby, CP, 1999. *A Computer Programme for Establishing Irrigation Requirements and Scheduling Strategies in Southern Africa.* WRC Report No 624/1/99. Water Research Commission, Pretoria, South Africa.

Danilla N, 1989. Strategic evaluation and selection of R&D projects. R&D management. 19(1): 47-62

Davis F, 1985. A technology acceptance model for empirically testing new and end-user information systems: theory and results. Doctoral thesis, MIT Sloan School of Management, Cambridge, MA.

Davis F, 1989. Perceived usefulness, perceived ease of use and user acceptance of information technology. *MIS Quartely,* 13(3): 319-340

De Jager, 1968. Carbon dioxide exchange and photosynthetic activity in forage grasses. PhD thesis, University of Wales

De Jager JM & King KM, 1974. Calculation of photosynthesis rate of a maize crop from environmental variables. In: Guelph Project Final Report 1974. Training in agrometeorology and research on photosynthesis of crops in relation to productivity. *Canadian Committee for Int Biol. Progr: 321-343*

De Jager JM, 1974. In: Guelph Project Final Report 1974. Training in agreometeorology and research on photosynthesis of crops in relation to productivity. *Canadian Committee for Int Biol. Progr: 306-320*

De Jager JM, 1976. The environmental potential for maize production during the 1974/75 season at Bethlehem. *Crop Prod 5: 9-13*

De Jager JM, Botha DP & van Vuuren CJJ, 1981. Effective rainfall and the assessment of potential wheat yields in a shallow soil*. Proc, S Afr Soc. Crop Prod. 10:51-56*

De Jager JM, van Zyl WH, Bristow KL & van Rooyen A, 1982. Besproeiingskedulering van koring in die besproeiingsgebied van Vrystaatstreek. Report for WRC, Department Agrometeorology, UOFS

De Jager JM, Hoffman JE, van Eeden F, Pretorius J, Marais J, Erasmus JF, Cowley BF & Mottram R, 1983. Preliminary validation of PUTU crop growth model in different parts of South *Africa. S Crop Prod. (12) 3-6*

De Jager JM & Singels A, 1985. Development and validation of root distribution and soil extraction model for wheat. *Proc. XV Annual Congress of SASCP*, 1985, Cedara.

De Jager JM, Mottram R & Singels A, 1986. Refinement and validation of the PUTU 12 maize crop growth simulation model. Dept of Agrometeorology, UOFS, Bloemfontein.

De Jager JM, Van Zyl WH, Kelbe B & Singels A, 1987. Research on a weather service for scheduling the irrigation of winter wheat in the Orange Free State Region. Water Research Commission, Pretoria. WRC Report 117/1/87.

De Jager JM & van Zyl WH, 1987. Atmospheric Evaporative Demand and Evaporation Coefficient Concepts. *Water SA 15(2)*

De Jager JM & Singels A, 1994. Research report by Irrigation Planning Unit to Department of Agriculture, Pretoria, South Africa.

De Jager JM & Mottram R, 1996. Saving water by scheduling irrigation using weather data. IN; Sustainability of irrigated Agriculture-the Future of irrigation under Increased Demand from Competitive Uses of Water and Greater Needs for food Supply (special session). *Vol1 E: Transactions 16th Int. Congress on Irrigation and Drainage, Cairo, Egypt: 153-166*

De Jager JM, Howard MD & Fouche HJ, 2000. Computing drought severity and forecasting its future impact on grazing in a GIS. IN: Wilhite D (ed): Hazards and disaster: A series of definite works Volume on Drought. Routledge Publishers

De Jager JM, Mottram R & Kennedy JA, 2001. Research on a computerized weather based irrigation water management system. Dept of Agrometeorology, UOFS, Bloemfontein. WRC Report No 581/1/01.

Denmead OT & Shaw, 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. *Agron. J. 54:385-390*

Dent MC, Schulze RE & Angus GR, 1988. Crop Water Requirements, Deficits and Water Yield for Irrigation Planning in South Africa, WRC Report No. 118/1/88. Water Research Commission, Pretoria.

Department of Water Affairs, 2012. Proposed National Water Strategy 2. Department water Affairs, Pretoria.

De Wit CT, 1958. Transpiration and crop yields. Verslag Landbouk. Onderz. No 64, Wageningen, The Netherlands

DHI, 2005. MIKE BASIN – A versatile decision support tool for integrated water resource management and planning. User Guide. Danish Hydraulic Institute for Water and Environment (DHI), Denmark.

Doorenbos J & Pruitt WO, 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 33. FAO, Rome, Italy. pp193

Doorenbos J, Kassam AH, Bentvelsen CLM, Branscheid V & Plusje JMGA, 1979. Yield response to water. *IN: FAO Irrigation and Drainage Paper (FAO) No 33, Rome*

Du Preez CC, 2010. Personal communication. University of the Free State.

Fouche HJ, de Jager JM & Opperman DPJ, 1985. A mathematical model for assessing the influence of stocking rate on the incidence of droughts and for estimating optimal stocking rates. *Jnl of Grassl Soc of SA 2(3): 4-6*

Francis PE & Pidgeon JD, 1982. A model for estimating soil moisture deficits under cereal crops in Britain, Development. *J Agric Sci Camb. 98:651-661.*

Gardner WR, 1960. Dynamic aspects of water availability to plants. *Soil Sci. 89:63-73*

Giesler E, 2000. The Metrics of Science and Technology, Quorum Books, Westport, CT.

Gibbons M & Georghiou L, 1987.Evaluation of Research: A selection of current practices. OECD, Paris.

Hanks RJ, 1983. Yield and water use relationships. An Overview. In: HM Taylor, WR Jordan &TR Tanner 9eds.). Limitations to efficient water use in crop production. *Am. Soc. Agron*., Madison, Wisconsin.

Hensley M and de Jager JM, 1982. The determination of the profile available water capacities of soils. Department of Soil Science, University of Fort Hare, Alice, South Africa. p282

Inman Bamber NG, 1991. A growth model for sugarcane based on a simple carbon balance and CERES Maize water balance. *S Afr J Plant and Soil 8: 93-99*

Inman Bamber NG, 1995. Measured and simulated plant stress criteria for irrigation of sugarcane. *Proc S Afr irrigation Symposium 1991: 144-148*

Inman Bamber NG & Kiker G, 1997. CANEGRO 3.10 DSSAT Version 3.1. 1998 Distribution Software, ISBNAT, University of Hawaii, Honolulu, USA

Jones CA & Kiniry JR, 1986. CERES Maize: A simulation model of maize growth and development. Texas A7M University Press, College Station, Texas, USA

Jones M, Porter C, Jones JW, Hoogenboom G, Singels A, Shine J, Nayamuth R, Kingston G, Chinorumba M & van den Berg M, 2007. Incorporating the Canegro sugarcane model into DSSAT v4 crop modeling system. *Proc. Int. Soc. Sugar Cane Technol 26: 438-443*

Jovanovic NZ & Annandale JG, 1999. An FAO crop factor modification to SWB makes inclusion of crops with limited data possible: Examples for vegetable crops. *Water SA 25:181-190*

Jovanovic NZ, Annandale JG & Mhlauli NC, 1999. Field water balance and SWB parameter determination of six winter vegetable species. *Water SA 25: 191-196*

Jovanovic NZ & Annandale JG, 2000.Crop growth model parameters of 19 summer vegetable cultivars for use in mechanistic irrigation scheduling models. *Water SA 26: 67-76*

Jovanovic NZ, Annandale JG, Claasens AS, Lorentz SA, Tanner PD, Aken ME & Hodgson FDI, 2002. Commercial production of crops irrigated with gypsiferous mine water. *Water SA 28:413-421*

Kosthoff RN, 1993. Evaluating federal R&D in the US. In: B Bozeman and J Melkers (eds), Assessing R7D impacts: methods and practice. Kluver Academic Publishers, Norvell, MA

Kosthoff RN, 1994. Assessing Research Impact. *Evaluation Review* 18(1):11-19.

Kosthoff RN, Eberhart HJ, Toothman DR & Pellenbarg R, 1997. Database Tomography for Technical Intelligence: Comparative Roadmaps of the Research Impact Assessment Literature and the Journal of the American Chemical Society, *Scientometrics*, 40:1.

Kosthoff RN, 2000. The underpublishing of Science and Technology results. *The Scientists*, May 2000.

Laker MC ,Boedt LJJ & Hensley M, 1987. Predawn leaf water potential as indicator of plant water stress-with special reference to problems encountered under conditions of high evaporative demand. *Proc. Int. Conf. on Measurement of soil and Plant Water Status Vol 2, 6-10 July 1987. Utah State University, Logan, USA.pp25-29*

Laker MS, 2004. The effect of atmosphere and soil conditions on the grapevine water status. MSc dissertation. University of Stellenbosch.

Lavis JN, 2002. Ideas at the Margin or Marginalized Ideas? Nonmedical Determinants of health in Canada. *Health Affairs, 21(2):* 107-122

Lavis JN, Ross SE, Gregory LS, Hohenadel JM, Mcleod CB & Evans RG, 2003. Do Canadian Civil Servants care about the Health Population *Amer Jnl. of Publ. Health*, 93(4): 658-663

Lavis JN, Davies HTO, Oxman AD, Denis J-I, Golden Briddle K & Ferlie E, 2005. Towards systematic reviews that inform health care management and policy making. *J Health Serv Res Policy 10(1): 35-48*

Lavis JN, Lomas J, Hamid M & Sewankambo NK, 2006. Assessing country level efforts in linking research to action. *Bulletin of the World Health Organisation, 84(8);620-628*

Linacre ET, 1977. A simple formula for estimating evaporation rates in various climates using temperature data alone. *Agric Meteorol.* 18

Lourens UW &de Jager JM, 1986. A computerized crop specific drought monitoring system: concepts, design and initial testing. Agric Systems 53: 303-315

Lynch SD, 2004. Development of raster database of annual, monthly and daily rainfall for Southern Africa. Water Research Commission, Pretoria. WRC Report No. 1156/2/04.

Mayer K, 2005. *The dBASE Book.* Authorhouse, Bloomington, Ind. USA.

McBain H, 2004. Contracting for innovation: yours, mine and probably someone else's soon. Financial Mail, May 7,176(6)

McGlinchey MG, Inman Bamber NG, Culverwell TL & Els M, 1995. An irrigation scheduling model based on a crop model and an automatic weather station. *Proc S Afr. Sug. Technol. Ass. 69: 69-73*

McGlinchey MG & Inman Bamber NG, 1996. Predicting sugarcane water use with the Penman-Monteith equation. In: Champ CR, Sadler EJ, Yoder RE (eds), Evapotranspiration and irrigation scheduling. *Proc. Int. Conf., San Antonio, Texas, 592-598*

McGlinchey MG, 1999. Computer crop model applications. Development in Swaziland. *Proc. S Afr. Sug. Technol. Ass. 73:35-38*

Mottram R & de Jager JM, 1994. Maximising Irrigation Project Efficiency in Different Soil-Climate – Irrigation Situations. Water Research Commission, Pretoria. WRC Report No 226/1/94

Nel FJ, 1995. Irrigation management on large farms, with special reference to the use of a neutron hydroprobe. *Proc Southern African irrigation Symposium, 4-6 June 1991, Durban South Africa.*

OECD, 1995. Impacts of national Technology Programme. Paris

Olivier FC & Singels A, 2004. Survey of irrigation scheduling practices in South African Sugar Industry. *Proc S Afr Sug Technol Assoc.* 78:239-244

Olivier FC, Lecler NL & Singels A, 2009. Increasing Water Use Efficiency of irrigated sugarcane by means of special agronomic practices. Water Research Commission, Pretoria. Water Research Commission, Pretoria. WRC Report 1577/09

Passioura JB, 1988. Water transport in and to roots. *Ann Rev. Plant Phys. 39: 245-265*

Philip JR (1969) Theory of infiltration. *Advances in Hydroscience* 5: 215-296.

Pott A, Benade N, van Heerden PS, Grove B, Annandale JG & Steyn JM, 2008. Technology Transfer and Integrated Implementation of Water Management Models in Commercial Farming. Water Research Commission, Pretoria. WRC Report TT 267/08.

Reginato RJ, 1995. Crop water stress assessment for irrigation management. *Proc Southern African irrigation Symposium, 4-6 June 1991, Durban South Africa.*

Richards LA & Neal OR, 1936. Some field observations with tensiometers. *Soil Sci. Soc. Am. Proc. 1:71*

Ritchie JT, Rhoades ED &Richardson CW, 1976. Calculating evaporation from native grassland watersheds. *Trans ASAE 19*

Ritchie JT & Otter S, 1985. Description and performance of CERES Wheat: A user oriented wheat yield model. US Dept of Agriculture, ARS, 38: 159-175

Rothwell R, 1992. Successful industrial innovation: Critical success factors for the 1990's. *Research and Development Management 22(3):221-239*

Roux DJKH, Rogers HC, Biggs PJ, Ashton A & Sergeant A, 2006. Bridging the science-management divide. Moving from unidirectional knowledge transfer to knowledge interfacing and sharing. Ecology and Society 11 (1):4 [online] URL: http://www.ecologyandsociety.org/vol11/art4/

Savage MJ & Wiebe HJH, 1987. Effect of conductance on water vapor pressure determination of leaf water potential. *Proc .Int. Conf. on Measurement of soil and Plant Water Status Vol 2:6-10 July 1987.Utah, State Univ, Logon, USA.*

Schultz CB, 1983. ACRU1 Subroutine OBJFUN. In Schulze RE, 1984: Hydrological models for application to small rural catchments in southern Africa: Refinements and development. Water Research Commission, Pretoria. WRC Report 63/2/84

Schulze RE, 1983. Agrohydrology and Climatology of Natal. Water Research Commission, Pretoria.113

Schulze RE, 1984 Hydrological models for application to small rural catchments in southern Africa: Refinements and development. Water Research Commission, Pretoria. WRC Report 63/2/84

Schulze RE, 1986. The ACRU model for agrohydrological decision making: Structure, options and application. Proc of 2nd South African National Hydrology Symposium. University of Natal, Pietermaritzburg, Department of Agric Engineering, *ACRU Report 22:345-362*

Schulze RE & George WJ, 1987. A dynamic process based user-oriented model of forest effects on water yield. *Hydrological Processes 1: 293-307*

Schulze RE, 1988. Background to the structure and applications of ACRU – A multipurpose multilevel distributed agrohydrological model. Paper presented at NATO Advanced Study Institute on "Recent Advances in the Modeling of Hydrologic Systems" Sintra, Portugal.

Schultz CB, 1987. Integrated studies of the generation of runoff, solutes and sediment in tributary catchment of the Great Fish River. Water Research Commission, WRC Report No 100/1/88

Schulze RE, 1989. ACRU: Background, concepts and theory. Water Research Commission, Pretoria. WRC Report 154/1/89.
Schulze RE, George WJ. Lynch SD & Angus GR, 1989. ACRU 2.0: User Manual. Water Research Commission, Pretoria. WRC Report No 154/2/89.
Schulze RE, Angus GR, Lynch SD & Smithers JC, 1995. In: Schulze RE . Hydrology and Agrohydrology " A text to accompany the ACRU 3 Agrohydrological Modeling System. Water Research Commission, Pretoria. WRC Report TT69/95.
Seligman NG & van Keulen H, 1981. PAPRAN: a simulation model of annual pasture production limited by rainfall and nitrogen. IN: Simulation of nitrogen behaviour of soil-plant systems. Wageningen, The Netherlands
Singels A and de Jager JM, 1991a. Refinement and validation of the PUTU wheat crop growth model. 1 Phenology. *SA J Plant and Soil 8: 59-66*
Singels A & de Jager JM, 1991b. Refinement and validation of the PUTU wheat crop growth model. 2. Leaf area expansion. *SA J Plant and Soil 8: 67-72*
Singels A & de Jager JM, 1995. validation of the PUTU maize model. Final Research Report to the Central Research Committee, UOFS.
Singels A and Potgieter AB, 1996. A technique to evaluate ENSO based maize production strategies. *S Afr J Plant and Soil 14: 93-97*
Singels A, Kennedy AJ & Bezuidenhout CN, 1998. IRRICANE: a simple computerized irrigation scheduling method for sugarcane. *Proc S Afr Sug Technol Assoc.* 72:117-122
Singels A & Kennedy AJ, 1998. IRRICANE: Irrigation Scheduling Software for Sugarcane User's Manual. South African Sugar Association Experiment Station, Mount Edgecombe, South Africa.
Singels A, Kennedy AJ & Bezuidenhout CN, 1999. Weather based decision support through the Internet for agronomic management of sugarcane. *Proc S Afr Sug Technol Assoc.* 73:30-32
Singels A & Donaldson RA, 2000. A simple model of unstressed sugarcane canopy development. *Proc S Afr Sug Technol Assoc.* 74:151-154
Singels A & Smith MT, 2006. Provision of irrigation scheduling advice to small scale sugarcane farmers using a web based crop model and cellular technology: A South African case study. *Irr and Drain* 55: 363-372.
Singels A & Smith MT, 2008. Real time Irrigation Advice for Small scale sugarcane production using a crop model. Water Research Commission, Pretoria. WRC Report No. 1576/1/08.
Singels A, 2009. A new approach towards implementing computer based decision support for sugarcane farmers and extension staff. A MyCaneSim case study. *Proc. Int. Soc. Sugar Cane Technol*. 26: 211-219

Smith M. 1992. *CROPWAT, A Computer Programme for Irrigation Planning and Management.* FAO Irrigation and Drainage Paper no 46. FAO. Rome, Italy.

Smith M. 1993. CLIMWAT for CROPWAT, a Climatic Data Base for Irrigation Planning and Management. FAO Irrigation and Drainage Paper No 49. FAO. Rome, Italy.

Stevens JB, Duvel GH, Steyn GJ & Marobane W, 2005. The range, distribution and implementation of irrigation scheduling models and method in SA. Water Research Commission, Pretoria. WRC Report No 1137/1/05

Stevens JB, 2006. Adoption of irrigation scheduling methods in South Africa. PhD thesis, Department of Agricultural Economics, Extension and Rural Development, Faculty of Natural and Agricultural Science, University of Pretoria

Stevens JB & RJ Stirzaker, 2010. Wetting front detector transfer of technology. WRC Report KV 246/10

Stirzaker RJ & Wilkie J, 2002. Four lessons from a wetting front detector. Irrigation Australia 2002 conference, 21-23 May, Sydney. Accessed from www.fullstop.com.au

Stirzaker RJ, 2003. When to turn the water off: scheduling micro-irrigation with a wetting front detector. *Irrigation Science 22*, 177-185.

Stirzaker R, Stevens J, Annandale J, Maeko T, Steyn J, Mpandeli S, Maurobane W, Nkgapele J & Jovanovic N,2004. Building Capacity in Irrigation Management with Wetting Front Detectors. Report to the Water Research Commission No. TT 230/04.

Stirzaker R & Thompson T, 2004. FullStop at Angas Bremer: A report on the 2002-3 data to the Angas Bremer Water Management Committee. Accessed from www.fullstop.com.au

Stirzaker RJ, Sunassee S & Wilkie J (2004). Monitoring water, nitrate and salt on-farm: a comparison of methods. Irrigation Australia 2004 Conference, 11-13 May, Adelaide. Accessed from www.fullstop.com.au

Stirzaker R.J. & Hutchinson P.A. 2005. Irrigation controlled by a Wetting Front Detector: field evaluation under sprinkler irrigation. *Aust. J. of Soil Res. 43:* 935-943.

Stirzaker RJ, Annandale J, Steyn M, Adhanom G, van der Laan M & M'marete C,2010. Adapting the wetting front detector to small furrow irrigation and providing a basis for the interpretation of salt and nutrient measurement form the water sample. University of Pretoria, WRC Report No 1547/1/10

Streutker A, 1979. Tensiometer controlled medium frequency topsoil irrigation: a technique to improve agricultural water management. *Water SA 4:134-155*

Strooisnijder L, 1987. Soil Evaporation: test of a Practical Approach under Semi-Arid Conditions. *Neth J. of Agri-Sci.*

Strydom MG, 1998. Kwantifisering van insetparameters vir die besproeiingshedulerings program BEWAB vir aartappels en erte. MSc Agric dissertation, University of the Free State, Bloemfontein, South Africa.

Tanner CB & Sinclair TR, 1983. Efficient water use in crop production: Research or Re-search? In: HM Taylor, WR Jordan and TR Sinclair (eds). Chapter 1a: Limitations to efficient water use in cop production. *Am Soc of Agron,* Madison, Wisconsin.

Tesfamariam EH, 2004. Modelling the soil water balance of canola (*Brassica napus L* (Hyola 60). MSc Agric dissertation. University of Pretoria, South Africa.

Vanassche FMG & Laker MC, 1989. Research on improving irrigation management based on soil water monitoring and detailed knowledge of profile available water capacities. WRC Report No 166/1/89. Water Research Commission, Pretoria, South Africa.

Van Heerden PS, Crosby CT & Crosby CP, 1999. A computer program for establishing irrigation requirements and scheduling strategies in South Africa. WRC Report No. 624/1/99. Water Research Commission Pretoria, South Africa.

Van Heerden PS, Crosby CT & Crosby CP, 2001. Using SAPWAT to estimate water requirements of crops in selected irrigation areas managed by the Orange Vaal and Orange Riet water User Associations. Water Research Commission, Pretoria. WRC Report TT 163/01

Van Heerden PS, 2004. Estimating Irrigation requirements and Water Storage Requirements for Farms, community Gardens and Backyard Gardens, and for Large Irrigation Systems: a user manual for PLANWAT version 1.2.3b and a CD-ROM to install the program. Working Paper 82. International Water Management Institute. Colombo, Sri Lanka.

Van Heerden PS & Crosby CT, 2005. The upgrading and updating of the SAPWAT program and Web site in 2003/2004. Water Research Commission Report No KV 201/05. Water Research Commission. Pretoria.

Van Heerden PS, Crosby CT, Grové B, Benadé N, Theron E, Schulze RE & Tewolde MH, 2008. Integrating and upgrading of SAPWAT and PLANWAT to create a powerful and user-friendly irrigation water-planning tool. Water Research Commission Report No TT 391/08. Water Research Commission. Pretoria.

Van Heerden PS & Crosby CT, 2009. Technology Transfer of SAPWAT3, verifying correctness of program output and evaluation of its adoption potential. Interim Report to WRC No K8/879/4

Van Rensburg LD, Bennie ATP & Walker S, 1995. An evaluation of the seasonal water use of spring as predicted with BEWAB irrigation model. WRC Report No TT 71/95. Water Research Commission. Pretoria

Van Rensburg LD & Zerizghy MG, 2008. The upgrade version of the irrigation water management program called BEWAB+. Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein.

Van Zyl WH, De Jager JM & Maree CJ, 1989. Correction Factors for evaporimeter coefficients used for scheduling irrigation of wheat. Water Research Commission, Pretoria. WRC Report No 151/1/89

Van Zyl WH, de Jager JM, Maree CJ & Singels A, 1990. Canopy surface conductance of unstressed wheat and its weather dependence. *Water SA 16: 99-104*

Van Zyl WH & de Jager JM, 1992. Effect of climate on plant evaporation coefficients for potato crop. *Agric. For. Meteorol. 60: 167-179*

Van Zyl WH & de Jager JM, 1997. Estimation of Plant and Soil Evaporation from Cropped Lands. Water Research Commission, Pretoria. WRC Report No 507/1/97.

Walker S & Tsubo M, 2003. PUTURUN: A simulator for rainfall with in-field water harvesting. Water Research Commission, Pretoria. WRC Report KV 142/03.

Walker S & Tsubo M, 2004. Estimation of rainfall intensity for potential crop production on clay soil with in-filed water harvesting practice in a semi-arid area. Water Research Commission, Pretoria. WRC Report 1049/1/02.

Walley WJ & Hussein DEDA, 1982. Development and testing of a general purpose soil-moisture-plant model. *Hydrol. Sci J. 27:1-17*

ANNEXURE A: QUESTIONNAIRE

A. Personal Details

1. Title, Initials and Surname

2. Contact details

3. Highest qualification

4. Occupation

5. Years experience in irrigation water management and planning

6. Prior experience in the use of computer programs for water use planning and irrigation management

B. Irrigation tools and their use (Semantic scale 1-5)

7. What method or tool did you, do you or will you use for decision-making, for what purpose and when did you start using it?
8. For what purpose did or do you currently use the specific irrigation method or tool?
9. Give the main reasons (at least TWO) why you use the methods or tools for decision-making? (Own words)
10. What types of decision-making is mainly influenced by the specific irrigation scheduling tool or method?
11. At which level of operation are your decisions aimed?
12. Indicate how you became aware of the tool or method for the first time?
13. How often do you use the method or tool for decision-making and how important is it in your decision-making?

C. Perceived usefulness (Semantic scale 1-5)

To what extent does the method or tool you use help you with:

14. planning of irrigation water use?
15. evaluation of irrigation water use?
16. improve planning of system design?
17. improve the evaluation of system design?
18. improve water resource assessments of catchments?
19. improve water resource assessments for irrigation water demand and supply
20. better-informed decision-making in irrigation management?
21. better control over the implementation of an irrigation management strategy?
22. quicker decisions regarding irrigation management?
23. easier decisions regarding the implementation of irrigation management strategies?
24. To what extent does the information (output) produced by the specific method or tool help you to increase productivity?

25. To what degree is operation possible with the included data for the specific programme or method?
26. How important is the use of additional information not provided by the tool or method for decision making?
27. How available is additional information?
28. How do you rate the credibility of the output of the method or tool?
29. How easy did you find it to use the tool or method?
30. Was it easy to understand the research report?
31. Was the user manual easy to understand and follow?
32. How important is a user manual for the tool or method?
33. How easy is it to learn to use the tool or method?
34. To what extent does the tool or method increase my knowledge and skills of irrigation management?
35. How flexible is the tool or method to work with?
36. The method or tool saves you time in irrigation management decision making?
37. How available is input data for the effective operation of the method or tool used?
38. What type of user assistance is favoured?
39. a) What type of electronic mail support system do you prefer?
    b) Provide reasons for the preference indicated:
40. Is it important to meet the research team responsible for the specific irrigation scheduling tool or method?
41. How satisfied are you with communication and support by the research team?
42. How satisfied are you with communication and support by extension staff or irrigation advisors?
43. How satisfied are you with back-up support by dealer?
44. What are the major hindrances that influence the use of this specific research knowledge in decision making?

D. Attitude of user

45. The National Water Act imposes necessary regulations on irrigation water users to apply efficient irrigation water management strategies
46. Irrigation scheduling methods and tools are developed for the use by irrigation advisors and researchers.
47. The refinement in irrigation management offered with the implementation of irrigation scheduling tools and methods is not cost effective.
48. Variability (rainfall and climate) is too complex to accommodate in the irrigation scheduling computer models and programmes available.
49. Irrigation scheduling could only be effectively applied once farmers have full control of the water supply
50. Are you familiar with the research done by the WRC?
51. Are you a regular user of research knowledge generated by the WRC?
52. Indicate the main purpose for using of WRC research knowledge in your business.
53. Rate the importance of research knowledge generated by the WRC as a source of information in your business?
54. Rate whether the needs of irrigation water users are appropriately addressed in the WRC research (Thrust: Agricultural Water Management)?
55. How important is the following participation in the development of specific tools and methods for irrigation management?
    a. Active participation of potential users in the designing of WRC research agendas

b. Active participation of potential users in the planning of a WRC research projects
c. Participation of potential users in the execution of the WRC research
d. Participation of potential users in the testing and fine-tuning of new innovations derived from research
e. Participation of users only with the implementation of the specific method or tool.