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TECHNOLOGY TRANSFER OF THE SOIL WATER BALANCE (SWB) MODEL FOR IRRIGATION SCHEDULING

by

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Technology transfer of the Soil Water Balance (SWB) model for irrigation scheduling

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The interest in improving irrigation water use efficiency is increasing in South Africa, mainly due to phasing out of subsidies on agricultural production inputs, changing policies on the ownership of land and water resources as well as increased public awareness of soil and water ecological issues. Implementation of irrigation scheduling technologies could play a big role in improving water use efficiency and reducing production costs. The Soil Water Balance (SWB) computer model (Dept. Plant Production and Soil Science, University of Pretoria, South Africa) was identified by the Water Research Commission (Pretoria, South Africa) as a potential technology that could be adopted for real-time irrigation scheduling country-wide. SWB is a mechanistic, generic crop growth model, making use of weather, crop, management and soil data to output irrigation recommendations. In 2001, a technology transfer project was initiated to promote and facilitate the use of SWB as a real-time irrigation scheduling tool. The approach used in this project includes: i) An initial workshop aimed at finalizing the development of SWB; ii) Country-wide courses for irrigation consultants and extension officers; iii) Country-wide courses for commercial farmers; iv) Development of irrigation scheduling guidelines for resource poor farmers; v) Country-wide courses for resource poor farmers; vi) Compilation of a multi-media package for tertiary level teaching of practices and principles of irrigation management. The initial workshop was attended by consultants and researchers that used SWB in order to identify shortcomings of the model. Improvements in the technical aspects and user-friendliness of the model were then carried out based on users' feedback. Two advanced three-day courses were held in centres close to two key irrigation areas (Pretoria and Stellenbosch) to train consultants and extension officers in the basics of irrigation principles through theoretical lectures and in the operation of the model through practical exercises. A network of consultants with an advisory role to farmers was therefore established. Although their perception of the course was generally positive, the attendees indicated that more practical exercise is required with a demonstration of the model and help file at the beginning of the course. The attendees also suggested that more time should be dedicated to case studies including crops of interest and interpretation of simulation results, and that required assistance could take place via e-mail, telephone or through visits. Two one-day courses, coordinated and arranged by consultants (Groblersdal and Malelane), were also presented to train farmers in the basics of irrigation scheduling and operation of the model. More courses of this type are envisaged in the near future. Resource poor farmers and their advisors are often computer illiterate and do not have

access to this sort of modelling approach that requires computers and automatic weather stations. A database of long-term weather data generated with the CLIMGEN weather data generator (GS Campbell, Washington State University, USA) is being developed for key irrigation sites. These weather data, combined with the database of crop parameters already included in SWB, will be used to calculate seasonal water requirements at a specified probability of exceedence, and generate calendar-type output for irrigation scheduling. Farmers will be expected to adjust irrigation applications for rain, and cheap and simple wetting front detectors will be used to ensure irrigations are well managed. A multi-media package, including pictures, video clips, animations and links to computer software, is being developed for teaching principles and practices of irrigation management. The main target audience is tertiary level students, but the package is also suitable for teaching irrigation officers, consultants and farmers, as it includes two levels of complexity (basic and advanced). Ultimately, the number of users of the SWB model for irrigation scheduling will depend on the commitment of the interested parties. It is clear, however, that the development actions undertaken to promote and facilitate the use of SWB has increased the level of awareness towards better water management by whatever means, enormously.

Introduction

The challenge to produce more food with less water can partially be met by more efficient water use through the implementation of irrigation scheduling (Backeberg and Odendaal, 1998). Irrigation scheduling is a decision-making activity to determine when and how much to irrigate in order to achieve optimal and sustainable crop production. This can be based on soil, plant and/or atmospheric measurements and is commonly known as scientific irrigation scheduling (SIS) (Lieb et al., 2002). In recent years, acceptance of SIS has grown worldwide (Fereres, 1996). The main purpose of implementation of irrigation scheduling is water, energy, fertilizer and labour conservation, as well as maximization of profits (Buchleiter et al. 1996; Stevens, 2002). However, the various examples of SIS found in the literature were aimed at solving specific problems, as technology transfer of irrigation scheduling depends on producers' on-farm needs (Howell, 1996).

In particular, the application of computers for irrigation scheduling is becoming popular, as there is a need to describe complex planning, information and farming systems, and data acquisition technology has developed a great deal in recent years. Several papers on water and energy conservation technologies using computers were delivered at the 4th International Conference on Computers in Agricultural Extension Programs (Watson et al., 1992).

The implementation of irrigation scheduling technologies was not always fully successful. A study conducted at Oregon State University (Shearer and Vomocil, 1981) indicated that behavioural patterns and attitudes of people, as well as the need for continuous technical support of the farmers, who generally dedicate time to other high-priority activities, are the major obstacles to the implementation of irrigation scheduling. However, attempting to implement irrigation scheduling leads to irrigators learning certain irrigation management principles. Very often, the complexity of computerized systems is an obstacle to implementation. De Jager and Kennedy (1996) indicated that three levels of technology (high, intermediate and minimum) could be adopted for dissemination of irrigation scheduling advice.

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

The interest in improving irrigation water use efficiency is also increasing in South Africa, mainly due to phasing out of subsidies on agricultural production inputs, changing policies on the ownership of land and water resources as well as increased public awareness of soil and water ecological issues. Implementation of irrigation scheduling technologies could play a big role in improving water use efficiency and reducing production costs. Stevens (2002) reported that the introduction of these technologies requires management skills, knowledge and labour, and that most farmers currently irrigate by intuition and experience. Stevens (2002) also carried out semi-structured interviews with fifty irrigation professionals to investigate what requirements an irrigation scheduling technology has to fulfil to be applied in practice. He concluded that the scheduling practice must offer visible advantages to the farmer, be simple and easy to apply, be compatible with the farmers' irrigation and management systems, be affordable and the promoter of the scheduling practice must be credible. All these factors were borne in mind in the technology transfer activities dealt with in this paper.

Background

During the last few years, a research project has been carried out to develop Soil Water Balance (SWB), a computer program for irrigation scheduling (Dept. Plant Production and Soil Science, University of Pretoria, South Africa; Annandale et al., 1999a). This model includes a wide range of crops commonly cultivated in South Africa. Validation studies indicated that, although some modifications may be necessary, the model generally performed well under a range of conditions. Although the model follows a scientifically based mechanistic approach, the user-friendly interface should make it accessible to any person with basic computer training. However, since the first official release of SWB in 1998, the model was used by a relatively small number of people. The feedback from the current users indicated several shortcomings, in spite of the developers' perception that SWB is a user-friendly tool. In addition, resource poor irrigation farmers and advisors do not have access to facilities and training to benefit from this technology. It became clear, therefore, that in order to make SWB usable and accessible to more potential users, changes to the computer software were required as well as training of potential users on a national scale to enable them to use the model independently.

SWB was identified by the Water Research Commission (Pretoria, South Africa) as a potential technology that could be adopted for real-time irrigation scheduling country-wide. A technology transfer project was therefore initiated in 2001 to refine, promote and facilitate the use of SWB as a real-time irrigation scheduling tool. The approach used in this project includes: i) An initial workshop aimed at finalizing the development of SWB; ii) Country-wide courses for irrigation consultants and extension officers; iii) Country-wide courses for commercial farmers; iv) Development of irrigation scheduling guidelines for resource poor farmers; v) Country-wide courses for resource poor farmers; vi) Compilation of a multi-media package for tertiary level teaching of practices and principles of irrigation management.

The Soil Water Balance (SWB) model

Theory

SWB is a mechanistic, real time, generic crop, daily time step, soil water balance, irrigation scheduling model, based on the improved generic crop version of the soil water balance described by Campbell and Diaz (1988). It gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop databases. SWB performs the calculation of the water balance and crop growth using three units, namely weather, soil and crop.

The weather unit of SWB calculates the Penman-Monteith grass reference daily evapotranspiration according to the recommendations of the Food and Agriculture Organization (FAO) of the United Nations (Allen et al., 1998).

In the soil unit of SWB, potential evapotranspiration is partitioned into potential evaporation and potential transpiration by calculating canopy radiant interception from simulated leaf area (Ritchie, 1972). This represents the upper limits of evaporation and transpiration and these processes will only proceed at these rates if atmospheric demand is limiting. Supply of water to the soil surface or plant root system may, however, be limiting. This is simulated in the case of soil water evaporation, by relating evaporation rate to the water content of the surface soil layer. In the case of transpiration, a dimensionless solution to the water potential based water uptake equation is used. This procedure comes up with a root density weighted average soil water potential which characterizes the water supply capabilities of the soil-root system. This solution has been shown to work extremely well by Annandale et al. (2000). If actual transpiration is less than potential transpiration, the crop has undergone stress and leaf area development will be reduced. The multi-layer soil component of the model ensures a realistic simulation of the infiltration and crop water uptake processes. A cascading soil water balance is used once canopy interception and surface runoff have been accounted for. Each soil layer is assumed to fill to saturation, and then pass on a fraction of the water above field capacity to the layer below. Any water that passes beyond the bottom layer is assumed lost to deep percolation.

In the Crop unit, SWB calculates crop dry matter accumulation in direct proportion to transpiration corrected for vapour pressure deficit (Tanner and Sinclair, 1983). It also calculates radiation limited growth (Monteith, 1977) and takes the lower of the two. This dry matter is partitioned to roots, stems, leaves and grain or fruits. Partitioning depends on phenology calculated with thermal time and modified by water stress. SWB also includes a model based on the FAO crop factor approach (Allen et al., 1998). This FAO-based model can also be used to calculate the soil water balance for crops with limited growth analysis data and for which growth model parameters could not be determined.

Required input data are: planting date, latitude, altitude, rainfall and irrigation water amounts, maximum and minimum daily temperatures, initial water contents of the soil layers, bulk density and two points on the water release curve, usually field capacity and wilting point. In the absence of measured data, SWB estimates solar radiation, vapour pressure and wind speed according to FAO recommendations (Allen et al., 1998). A database of specific crop growth parameters and FAO basal crop coefficients for the most important commercial crops cultivated in South Africa is also included (Annandale et al., 1999a). A detailed technical description and algorithms of SWB can be found in Annandale et al. (1999a).

Operation

The SWB model includes three modes, namely Irrigation, Consultant and Researcher. This, combined with the user-friendly interface, facilitates the operation of SWB.

Irrigation is the most basic mode of SWB. When the program is installed from the CD, SWB runs in Irrigation mode. The following operations can be performed in the Irrigation mode: run simulations, enter real-time weather and irrigation data, and view results and recommendations. In order to run a simulation, however, management (field), weather station and soil input data need to be entered. The Irrigation mode is meant to be used real-time by farmers whose management, weather station and soil input data have been previously set up by irrigation advisors (private consultants and extension officers) in the Consultant mode. Figure 1 shows two input screens for entering weather and irrigation input data. During simulations, these screens pop up on the first date when weather and irrigation data are not available. If the simulation is run real-time on a daily basis, the user will be required to enter yesterday's weather and irrigation data in the forms in Figure 1. These data will then be stored in the database and the simulation will proceed until the present day. Figure 2 shows an example of the output screen of the SWB summary graphs. Figure 3 is an example of the recommendations output screen. Fields for which irrigation is overdue are in red (shaded blocks).

The second level of SWB (Consultant mode) performs the same operations as the Irrigation mode. In addition, the following operations can be performed in the Consultant mode: enter input data for management, weather station and soil, use special features of SWB (ETo calculator, enter and plot measured data on output graphs, neutron probe scheduler, tensiometer scheduler, gravimetric scheduler, field capacity and permanent wilting point calculator from texture data, update volumetric soil water content and canopy cover, generate or change specific crop growth parameters and FAO crop factors, import weather data). The Consultant mode is meant to be used by irrigation advisors and those farmers who run SWB independently.

The Researcher mode is the most complex mode of SWB. The Researcher mode performs the same operations as the Irrigation and Consultant modes. In addition, the following operations can be performed in the Researcher mode: link to the weather data generator, run long-term simulations, see yield summary for long-term simulations, run salt balance simulations (Annandale et al., 1999b), run the two-dimensional canopy radiation interception model, run the one- and two-dimensional finite-difference water movement model (Annandale et al., 2001a). The Researcher mode is meant to be used only for research purposes and, due to the complexity, it is not recommended to be used by irrigation advisors and farmers.

SWB also includes a comprehensive on-line help file that explains the theoretical background and how to operate the model. The help file, written in HelpScribble (www.jgsoft.com), is context sensitive and can be accessed from the main menu or by pressing F1 on the keyboard. It includes bitmaps with hotspots, pop-up screens and links to other help topics.

Measured data can be plotted as points in output graphs and the model calculates parameters of the statistical analysis between measured and simulated data. This allows quick, efficient and quantitative evaluation of model performance. Standard errors of measured data can also be displayed in the output graphs. SWB displays hints with ranges for input data, checks the ranges of input data, and generates error messages and warnings when operational errors are committed (e.g. input data out of range are entered). This prevents accidental typing errors and errors in units.

The SWB model is written in user-friendly format in Delphi v. 5.0 (Inprise Corp.) and uses a Paradox database. The software is available for use with Windows 95 on an IBM-PC or compatible computer. The minimum requirement is 16 Mb RAM and a CD-ROM drive. The time required to complete a seasonal simulation is 3 to 5 s on a Pentium 166 MHz. The program is supplied in executable code on CD, with a quick reference user's guide and technical manual. On installation, the user is prompted to register the copy of the model. The registration number is provided via e-mail and linked to the serial number of the hard drive of the computer. This allows the developers to keep a record of SWB users.

Initial workshop

A two-day, initial workshop was held in Pretoria to receive inputs from a range of stakeholders on how to improve the SWB model as well as on training and technology transfer requirements. The workshop approach was also used by Fereres et al. (1981) to introduce the Irrigation Management Program (IMP) to interested parties and train them in its use in California (USA), as well as by Stevens (2002) to introduce irrigation scheduling methods to irrigation farmers, advisors and undergraduate students in South Africa.

The audience at the Pretoria workshop included 28 private irrigation consultants as well as representatives of academic, research and government institutions with specific interests in irrigation scheduling, and that were already familiar with, or used SWB for different purposes. The content of the workshop included background and philosophy of SWB, hardware requirements, demonstration of the program and experiences of current users. A general discussion followed to reach consensus on what the final product should be.

Some operational errors were pointed out by the users. These errors were mainly related to the interface, and not to calculations performed in the code. Several improvements in user-friendliness were suggested (e.g. changes in the choice of irrigation timing for recommendations, upgrading of the database structure automatically when the executable file is upgraded, printing graphs of weather data, including a function to export data to spreadsheets etc.). Technical improvements were also suggested, like accounting for irrigation system efficiency in the calculation of the soil water balance, including the Diviner soil water monitoring system in the special features of SWB for updating simulations, and updating the crop parameter database using work of other research groups.

Several questions were raised on how to adapt or use SWB for specific requirements and field conditions (e.g. choice of initial stage for evergreen perennial crops, prediction of fruit quality, fertilizer requirements, water retention of stony soils, estimation of initial volumetric soil water content to be used as input, effects of spatial variability on soil water measurements used to update the simulations, effects of field micro-climate, link of % soil water depletion to soil water potential, estimation of drainage rate in soils with different textures, application of deficit irrigation, adjustment of basal crop coefficients and length of growth stage). Advice was given by the research team on how the SWB model could handle these specific conditions. The initial workshop, therefore, also had an educational and training character to it.

The general conclusions were that it was necessary to release a standardized version of SWB and compile a step-by-step manual. It was suggested that a document outlining scenarios such as expected savings and improved cash flow that could be used to get the farmers interested, be drawn up. There was also discussion on the use of weather station networks and advisors were encouraged to advise farmers as to the closest weather stations to their farms. The attendees were encouraged to continue interacting with the research team and suggest further improvements to SWB. The aim with the SWB model was not to replace other irrigation scheduling soil water measuring methods, but was seen to be an additional, value-adding tool that could reduce the required frequency of measurement.

At the initial workshop, it was decided that the way forward should consist of two phases. The first phase was to update the model and was completed by making the modifications recommended in the initial workshop. The second phase should include training courses across the country, targeting irrigation advisors and farmers who were interested in using the SWB model. The need for two types of courses was identified, a more advanced one for advisors and a simpler one for farmers. The purpose of the training would be to create awareness and momentum by enabling consultants in different areas to introduce the model to their farmers. This process would close the cycle of research, development, application and implementation. It was envisaged that the research team would build up a network with the consultants during the process of technology transfer, and that this would form the basis of a national forum on irrigation scheduling. The attendees of the initial workshop were used as contacts to establish a list of possible candidates for the courses. It was suggested that, before a course, the project team should get to know the specific area in which it would be presented, with its specific problems, and compile case studies that course attendees could relate to. It was also recommended that SWB should be introduced to other academic institutions, Irrigation Boards and Water Users Associations and any other institution that possibly would want to implement it. Promotion of SWB should also be followed up by other research and academic institutions in the country.

Consultants' courses

Two three-day consultants' courses were held in centres close to two key irrigation areas (Pretoria and Stellenbosch). The aims were to teach consultants and extension officers basic irrigation principles through theoretical lectures and to train them to operate the model through practical exercises. The theoretical lectures included the philosophy behind SWB, the soil environment and modelling the soil water balance, determination of soil input parameters, plant water relations and crop modelling, the atmospheric environment and modelling the atmospheric component, hardware and software philosophy, use of the SWB user's manual and help file as well as advanced topics for scientific research. The practical sessions included an initial brief demonstration of SWB and practical exercises on how to install SWB and run simulations, how to determine and enter soil input data, how to refine/add crop input parameters, how to set up and run a new simulation from scratch as well as how to use the special features of SWB. The final session of both courses was dedicated to discussion.

The course material included all slide shows used in the theoretical sessions, the step-by-step procedure used in the practical sessions and CDs including a set-up copy of SWB and the user's manual. The user's manual was compiled to facilitate the operational and technical understanding of SWB and includes the following topics: use of SWB (installation, modes and functions, entering input data, running simulations, viewing results and recommendations, troubleshooting), use of special features of SWB, technical manual (calculations and algorithms) as well as guidelines for the determination of specific crop growth parameters and FAO crop factors.

The course in Pretoria was attended by 33 people, whilst the course in Stellenbosch had 30 delegates. These were private consultants, company representatives and extension officers as well as post-graduate students and academics. After completing the course, attendees were presented with certificates declaring their successful completion of the course and asked to complete an evaluation form. The course evaluation results and feedback are summarized in Tables 1 and 2. Course attendees were generally very positive about the standard of presentations and the organization of the course, and felt that new or worthwhile information had been gained. The evaluation by the course attendees gave a good indication to the research team what theoretical topics should be improved in the presentations (Table 1). The relatively low marks given for the practical sessions (Table 1) did not reflect the quality of the practical exercises, but rather referred to the perception that more time should have been spent on practical work with a clearer demonstration of the model and help file at the beginning of the course (Table 2). Some attendees asked for specific problems to be dealt with (e.g. interpreting simulation results for specific case studies and specific crops, including fertilization recommendations). The large majority of attendees indicated that they would use SWB as an irrigation scheduling tool. They also indicated that assistance should be provided mainly via e-mail or telephonically as well as through field visits and training sessions (Table 2). The consultants' courses were the first step in the implementation of a service network beneficial to commercial farmers that use SWB to schedule their irrigations.

Commercial farmers' courses

Commercial farmers' training courses were scheduled in conjunction with consultants in different provinces of South Africa. To date, two courses for commercial farmers were organized in two key irrigation areas of the country, one in Groblersdal (Northern Province, adjacent to the Loskop Dam irrigation scheme) lasting one day, and the other in Malelane (Mpumalanga Province, adjacent to a vast irrigated sugarcane farming area) lasting one and a half days. The courses were aimed at teaching farmers the basic principles of irrigation management and training them in the operational, day-to-day use of SWB. Farmers were not expected to set up their own simulations but merely to run them once the instructor or consultant had set them up for them. Two private consultants acted as the link between the research team and the commercial farmers. The consultants helped the research team in compiling the courses depending on the specific requirements of the area, as well as the level of computer literacy and background knowledge of the farmers. Much more emphasis was given to practical work than in the consultants' courses. The courses were timed not to coincide with peak activities in the production season of major crops, e.g. planting or harvesting, as this would have prevented farmers from attending.

The course in Groblersdal was attended by 19 farmers and advisors, whilst the course in Malelane was attended by 15 farmers, advisors, company representatives and researchers in the sugarcane industry. The consultants attended the courses with their potential clients as they will be the contact persons for the individual farmers and will supply them with backup support. It was felt that the research team should not attempt to support individual farmers directly, as they would be unable to dedicate the time needed to support them properly. The consultants will also be able to present follow-up courses to their clients, if so required. More courses to commercial farmers are envisaged in the near future in major irrigation areas and schemes.

Guidelines and courses for resource poor farmers

Research scientists agree that it is unrealistic to expect resource poor farmers to readily adopt complex tool like SWB for irrigation scheduling. For one to understand and use such a complex tool, a degree of computer literacy and scientific data interpretation is required. Also, access to automatic weather station data and computer facilities are required. On the other hand, on-farm management of water should be based on sound management of the soil water balance. Farmers only adopt scientifically based systems if they are affordable, reasonably easy to implement and will result in considerable production improvement and/or water and energy savings. It has therefore become a universal challenge to simplify complex modelling approaches into easily understandable and more usable instruments.

The SWB approach used for real-time scheduling by commercial farmers is being modified to accommodate the needs of resource poor farmers. SWB can be linked to the CLIMGEN weather data generator (Campbell, 1990), a two-component weather generator based on WGEN (Richardson and Wright, 1984). The first component, CLIMPAR, determines statistical parameters required for long-term daily weather data generation from historic data. The second component, CLIMGEN, then generates daily maximum and minimum air temperatures, as well as precipitation using the parameters determined in CLIMPAR. The weather generator was assessed at South African sites by Clemence (1997), who showed the estimations to be quite satisfactory. The weather generator will be used to generate long sequences of climatic data for key irrigation areas and include them in the SWB weather database. These weather data, combined with the database of crop parameters already included in SWB, will be used to calculate seasonal water requirements at a specified probability of exceedence, and generate calendar-type guidelines for water applications. The information that will be required is site specific and will include a database of historic weather data, soil properties, cropping system, type of irrigation system and management practices. Farmers will be expected to adjust irrigation applications for rain, and cheap and simple wetting front detectors (Annandale et al., 2001b) will be used to make real-time decisions on whether to irrigate and whether to adjust recommended irrigation amounts. An example guideline sheet to be used by the farmer is shown in Figure 4.

In order to implement the system and make it reliable, one-day training sessions are planned in different irrigation areas. Contact was also made with scientists for advice on weather station networks (Agricultural Research Council - Institute for Soil, Climate and Water, Pretoria, South Africa) and irrigation system distribution uniformity (Agricultural Research Council - Institute for Agricultural Engineering, Silverton, South Africa), as accurate measurements of irrigations applied are required in order to generate accurate irrigation scheduling guidelines.

Multi-media educational package

A multi-media package is also being developed for teaching principles and practices of irrigation management. The content of this course includes basics on the following topics: the soil environment and field water balance, the atmospheric environment and energy balance, plant water relations, estimation of crop water requirements for planning purposes, real-time irrigation scheduling, management aspects of irrigation systems, management aspects of fertigation and saline irrigation water management. Problems are also included at the end of each chapter for self-evaluation. The main target audience is tertiary level students, but the course is also suitable for teaching irrigation officers, consultants and farmers, as it includes two levels of complexity (basic and advanced). The course is self-paced and suitable for learners with differing backgrounds.

The training package is developed in conjunction with the Department of Telematic Education at the University of Pretoria. The professional and structural design is used for visual stimulation through pictures, video clips, animations and computer software. The SWB model and other computer software are linked to the package and used to present case studies and complete problem-solving exercises. Another advantage compared to traditional teaching tools is that this course is relatively easy to update. The program is written in QUEST and will be available on CD. Although Web-based education may have many advantages, it was decided not to follow that route as a large proportion of resource poor students may not currently have access to the Internet. The package will form part of the material supplied in future at the consultants’ and farmers’ courses.

Conclusions

It is clear that the technology transfer actions undertaken in this work were extremely beneficial in many ways. Firstly, the implementation of SWB as an irrigation scheduling tool can benefit everybody through saving water at national scale. This will inevitably improve the quality of life of many people who do not currently have access to running water. Secondly, commercial and resource poor farmers as well as advisors involved in the irrigation of agricultural crops will benefit from the project. The availability of a reliable irrigation tool to trained farmers and irrigation consultants implies that these users will be able to produce crops more efficiently. Less water per hectare will therefore be required to produce a certain yield. This factor is becoming increasingly important as farmers are expected to pay significantly more for irrigation water under the new water law. Apart from the physical cost of water, pumping costs also form a substantial part of production costs. Nitrate leaching and fertilizer expenses could also be significantly reduced. Thirdly, SWB will be used as a training tool for undergraduate students.

Attendees of the consultants' and farmers' courses were generally very positive about the course contents and gave valuable feedback for the on-going refinement of the SWB model and future courses. Some of the course attendees are unlikely to use SWB as they are not irrigation advisors or farmers. A lag can be expected from the time the courses were presented to the implementation of SWB on farms due to logistical and organizational issues. However, it is clear that, regardless whether the course attendees are going to use SWB or not, the understanding of irrigation scheduling principles was communicated and the level of awareness increased. After attending these courses, the participants became more familiar with the dynamics of the soil-plant-atmosphere continuum and capable of making informed irrigation scheduling decisions using SWB or any other method to improve their management of irrigation water.

The tertiary level irrigation course will be presented at the University of Pretoria in 2002. Other tertiary institutions have also shown interest in using this package as teaching material at a graduate level, but it is expected that advisors and progressive farmers will also benefit from this material. After completing this course, the students should have the required insight and technical knowledge to advise irrigation consultants and farmers. They will also be in a position to suggest valid modifications or actions required to promote sound water use in developing agriculture.

Apart from the scheduled training sessions and development of the multi-media training package, several other technology transfer actions were undertaken. These include exhibitions and demonstrations at farmers' days and congresses, as well as visits by and to individuals who have shown interest in SWB.

The final question is "Can SWB be used in practice?" This will depend on the commitment of the interested parties. A network of irrigation advisors was established to support farmers and will act as a link between the research team and the end users. Technical modifications to SWB and improvements in user-friendliness will be an on-going process depending on the feedback of users.

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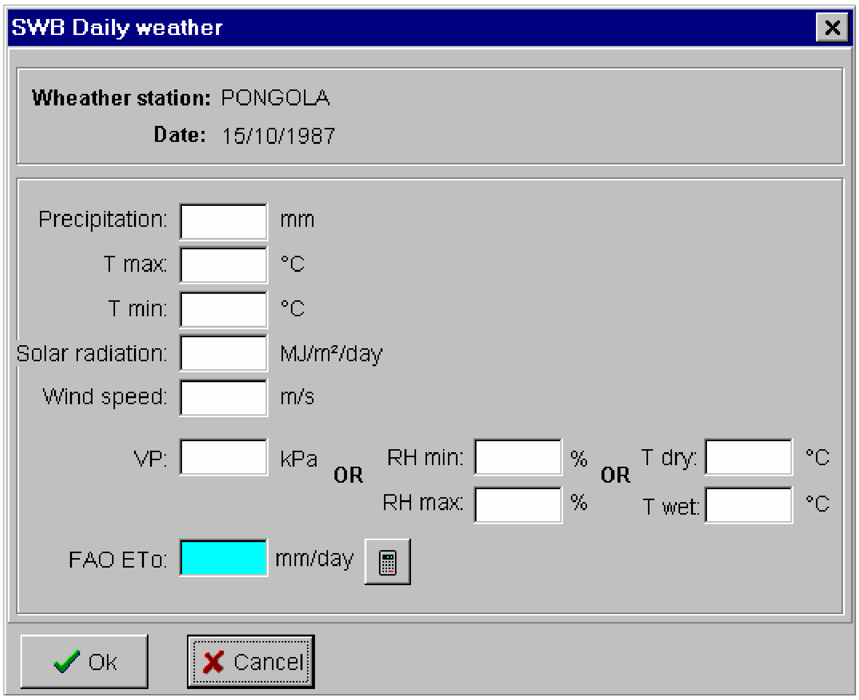
(a)



(b)

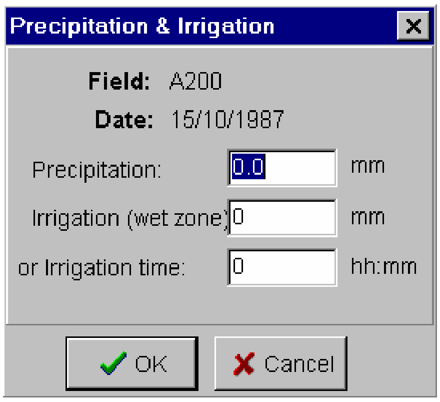


Figure 1 Screen printout of weather (a) and irrigation (b) input data forms. Essential data are precipitation, maximum (Tmax) and minimum temperature (Tmin) and irrigation amount (mm) or time (hh:min). If not available, SWB estimates solar radiation, wind speed and vapour pressure (VP) according to the FAO recommendations (Allen et al., 1998). Minimum (RHmin) and maximum (RHmax) relative humidity as well as dry (Tdry) and wet (Twet) bulb temperatures can also be used to calculate VP.

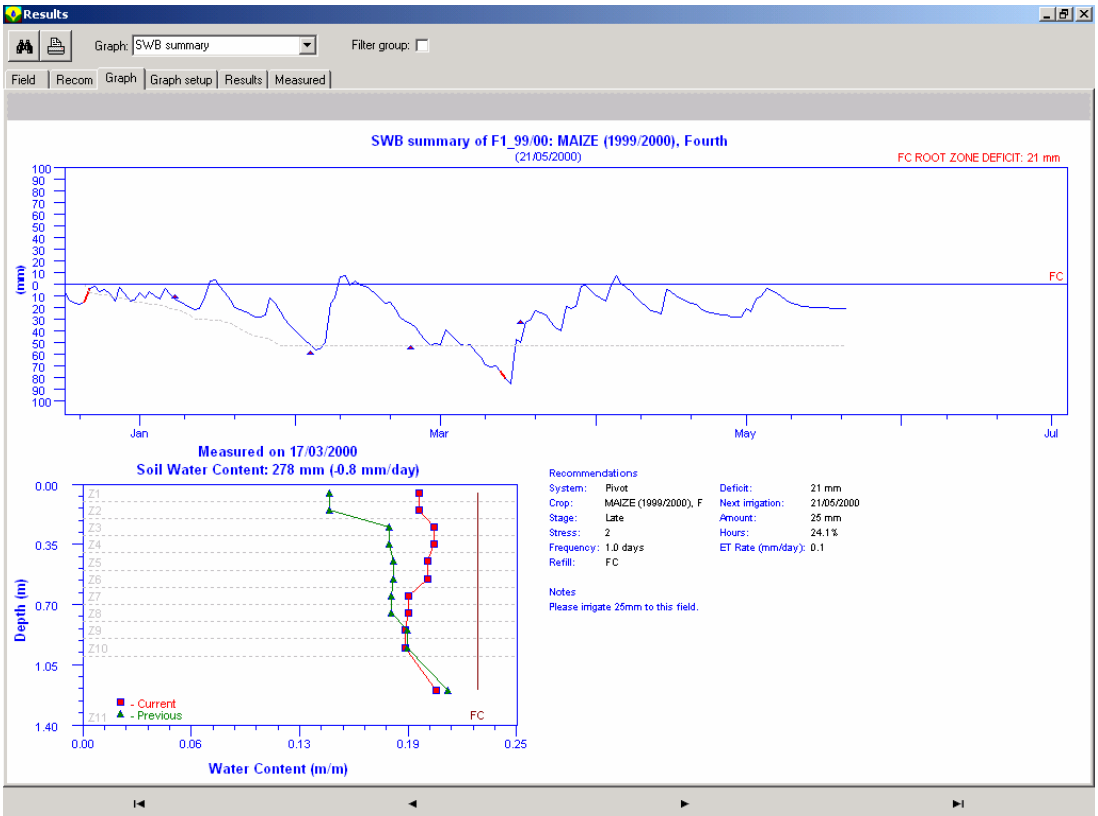
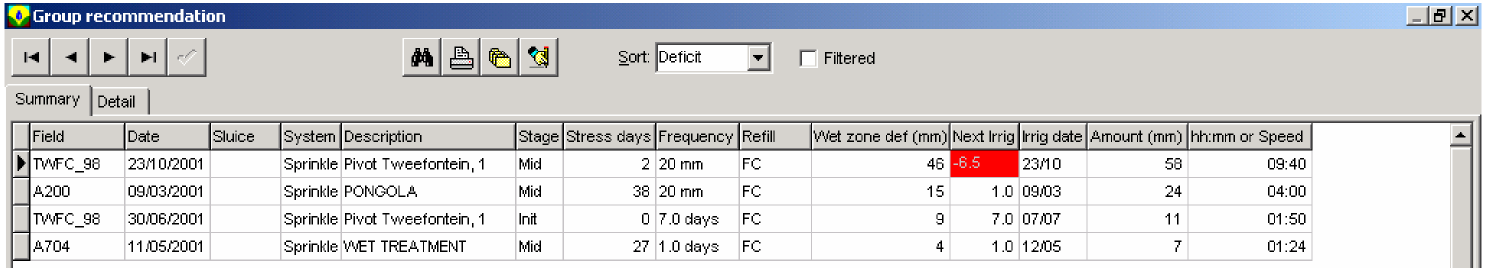


Figure 2 Screen printout with example of soil water balance summary graphs. FC is field capacity and ET is actual evapotranspiration.



Field	Date	Sluice	System	Description	Stage	Stress days	Frequency	Refill	Wet zone def (mm)	Next Irrig	Irrig date	Amount (mm)	hh:mm or Speed
TWFC_98	23/10/2001		Sprinkle	Pivot Tweefontein, 1	Mid	2	20 mm	FC	46	-6.5	23/10	58	09:40
A200	09/03/2001		Sprinkle	PONGOLA	Mid	38	20 mm	FC	15	1.0	09/03	24	04:00
TWFC_98	30/06/2001		Sprinkle	Pivot Tweefontein, 1	Init	0	7.0 days	FC	9	7.0	07/07	11	01:50
A704	11/05/2001		Sprinkle	WET TREATMENT	Mid	27	1.0 days	FC	4	1.0	12/05	7	01:24

Figure 3 Screen printout with examples of recommendations. The user can select the columns to be displayed and these are from left to right: field identification number, date, sluice, irrigation system, general description, crop stage, stress days, selected frequency of irrigation and refill option, water deficit in the wetted volume of soil for micro-irrigation, days to next irrigation (in red, shaded blocks if irrigation is overdue), date of next irrigation, irrigation amount required as well as time of irrigation or speed (%) of centre pivot required.

<table>
<tr><td>Farmer</td><td>Mr Tshabalala</td><td>Crop</td><td>Wheat</td><td colspan="2">Planting date</td><td>01/06/2002</td></tr>
<tr><td colspan="2">Management option</td><td colspan="5">Fixed frequency: 7 days
Room for rain: 20 mm</td></tr>
<tr><td rowspan="2">Date</td><td rowspan="2">Crop water requirement (CWR, mm) 20% probability of exceedence</td><td rowspan="2">Rain (mm)</td><td rowspan="2">Irrigation requirement (CWR - Rain, mm)</td><td colspan="3">Wetting front detector</td></tr>
<tr><td>Deep</td><td colspan="2">Shallow</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
</table>

Figure 4 Example of calendar-type guideline sheet to be used by resource poor farmers for irrigation scheduling.

Table 1. Evaluation of the consultants' courses at Pretoria (33 participants) and Stellenbosch (30 participants). Average, standard deviation, maximum and minimum marks are reported for each question (1 = very poor; 2 = poor; 3 = reasonable; 4 = good; 5 = very good).

Questions	Pretoria				Stellenbosch			
	Average	Std Dev.	Max.	Min.	Average	Std Dev.	Max.	Min.
1. General course arrangements	4.4	0.6	5	3	4.4	0.6	5	3
2. How would you evaluate the course content of the following								
a. Philosophy behind SWB	-	-	-	-	4.2	0.7	5	3
b. Brief SWB demo	3.9	0.6	5	3	3.8	0.5	5	3
c. Soil water relations	4.2	0.5	5	3	4.3	0.6	5	3
d. Soil parameter estimation	4.1	0.6	5	3	4.1	0.6	5	3
e. Crop water relations	4.1	0.7	5	3	4.0	0.7	5	3
f. FAO model	-	-	-	-	3.5	0.8	5	2
g. Case study: Crop parameters	-	-	-	-	3.7	0.6	5	3
h. The atmospheric environment	4.1	0.7	5	3	4.1	0.6	5	3
i. Hardware and software philosophy	3.8	0.6	5	3	3.8	0.8	5	2
j. SWB users manual and help file	3.9	0.5	5	2	3.7	0.7	5	2
k. Advanced topics	-	-	-	-	3.5	0.6	5	2
l. Practical exercises	3.7	0.7	5	2	3.8	0.6	5	3
3. Standard of the presentations	4.3	0.6	5	3	3.9	0.6	5	3
4. Has the course met your expectations?	3.9	0.8	5	2	3.9	0.6	5	3
5. Were the course objectives met?	4.0	0.7	5	3	-	-	-	-
6. New or worthwhile information gained	4.5	0.6	5	3	4.1	0.5	5	3
7. Course organisation	4.3	0.6	5	3	4.3	0.6	5	3
8. Course venue	4.4	0.6	5	3	4.3	0.6	5	3
9. Length of course	3.9	0.8	5	2	-	-	-	-
10. Professional contacts made	4.1	0.8	5	3	3.8	0.7	5	3

Table 2. Evaluation of the consultants' courses at Pretoria (33 participants) and Stellenbosch (30 participants). The figures indicate the number of participants answering a specific question.

<table>
<tr><th>Questions</th><th colspan="3">Pretoria</th><th colspan="3">Stellenbosch</th></tr>
<tr><td rowspan="2">Should the duration of similar courses in the future be shorter, longer, or kept the same?</td><td colspan="3" rowspan="2">-</td><td>Shorter</td><td>Longer</td><td>Same</td></tr>
<tr><td>4</td><td>2</td><td>16</td></tr>
<tr><td rowspan="2">Have you used SWB before this course?</td><td colspan="3" rowspan="2">-</td><td>Yes</td><td>No</td><td>Indecisive</td></tr>
<tr><td>4</td><td>18</td><td>-</td></tr>
<tr><td rowspan="2">If you have <u>not</u> used SWB before, will you try to use it after this course?</td><td>Yes</td><td>No</td><td>Indecisive</td><td>Yes</td><td>No</td><td>Indecisive</td></tr>
<tr><td>28</td><td>0</td><td>2</td><td>17</td><td>0</td><td>1</td></tr>
<tr><td>What changes, do you think, could help to improve similar courses in the future?
i) More practical exercises
ii) Show demo and help file first
iii) Compile case studies and interpret simulation results
iv) Target the audience interest through specific crop</td><td colspan="3">
15
5
3
-</td><td colspan="3">
11
2
1
2</td></tr>
<tr><td rowspan="2">Do you think you will be able to set-up simulations and help farmers schedule with SWB?</td><td>Yes</td><td>No</td><td>Indecisive</td><td>Yes</td><td>No</td><td>Indecisive</td></tr>
<tr><td>17</td><td>3</td><td>8</td><td>12</td><td>2</td><td>8</td></tr>
<tr><td rowspan="2">If you intend servicing clients with SWB, would you appreciate assistance from the research team?</td><td>Yes</td><td>No</td><td>Indecisive</td><td>Yes</td><td>No</td><td>Indecisive</td></tr>
<tr><td>26</td><td>0</td><td>0</td><td>20</td><td>0</td><td>0</td></tr>
<tr><td>If so, what form should this assistance take?
i) E-mail and telephone
ii) Visits (training)
iii) Backup of data
iv) Full assistance, discussion (questions-answers) forum, help desk
v) Solving practical problems
vi) Input data
vii) Evaluation and interpretation of data
viii) Update versions through Web
ix) Troubleshooting</td><td colspan="3">
17
5
-
-
2
1
-
-
1</td><td colspan="3">
11
3
2
4
3
1
1
3
1</td></tr>
<tr><td>Other general comments
i) Include fertilization recommendations
ii) Improve user-friendliness</td><td colspan="3">
1
1</td><td colspan="3">
1
1</td></tr>
</table>