SAPWAT

A COMPUTER PROGRAM FOR ESTABLISHING IRRIGATION REQUIREMENTS AND SCHEDULING STRATEGIES IN SOUTH AFRICA

by

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EXECUTIVE SUMMARY

Report to the Water Research Commission on the Project:

"A personal computer based procedure for the estimation of irrigation requirements of crops in Southern Africa"

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WRC Report No: 624/1/99
ISBN: 1 86845 502 5

ACKNOWLEDGEMENTS

The SAPWAT program is the product of the Water Research Commission funded project entitled "A personal computer based procedure for the estimation of irrigation requirements of crops in Southern Africa".

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The project was only possible because of the active co-operation of members of the Steering Committee and their direct associates who together with academics, researchers and practitioners in the irrigation industry gave generously of their time, and provided information, encouragement and advice.

The project team would like to thank the Water Research Commission for funding the project and specifically for the tolerance and understanding shown when the project proved to be more comprehensive than was originally envisaged. The guidance and support provided by the Chairman, Dr GC Green, was noteworthy.

It was greatly appreciated that senior management of MBB in the persons of Mr JK Murray and Mr DJ van Rensburg were supportive throughout and ensured that the research had the full backing of the administrative services of the company.

It is not possible to personally acknowledge all who assisted the project but there are organisations and people over and above steering committee members and their associates that made major contributions:

- Mr Martin Smith, FAO Land and Water Development Division, Rome who advised and encouraged.
- Ms E Romanowska, Mr L de Lange and Mr H Hattingh who developed concepts and programs.
- Several Agricultural Research Council scientists who contributed data or methods notably Dr AS du Toit (summer grains), Dr JL Purchase (winter grains), Mr K Monnik (weather data) and Dr S Walker (physiology and small-scale farmers).
- Dr A Comrie of Hygrotech, Mr WF van Wyk of the Gauteng DOA, Mr F du Plessis and Mr H Stander of MBB and Mr N Jovanovic of the University of Pretoria who created or provided data on horticultural crops .
- Mr D Haarhof of Griqualand West Cooperative who made data from their scheduling service available

1 INTRODUCTION

The need to rehabilitate existing small-scale farmer irrigation schemes and to plan new schemes, as well as the implementation of Catchment Management Agencies and Water User Associations has emphasised the importance of managing irrigation water effectively. The estimation of crop water requirements is an essential starting point when both farm scale and major irrigation projects are planned or upgraded.

The past two decades have seen significant progress in irrigation technology. Moving systems, largely centre pivots, have been installed in their thousands for irrigating field crops while micro and drip systems, many computer controlled, now dominate in horticulture. Similarly there is now a greater appreciation for the effectiveness of flood irrigation systems utilised by small-scale farmers. There have been parallel advances in the on-farm management of irrigation with the introduction, for example, of automatic weather stations and the measurement of soil water status by neutron probe.

Unfortunately the methodology for estimating crop irrigation requirements has not kept pace with these developments. The first publication on estimating crop irrigation requirements in South Africa was the *Green Book* (1973). This was expanded, updated and published with the title *Estimated Irrigation Requirements of Crops in South Africa,* a publication known as the *Green Book* (1985). The models utilised in developing the tables in this publication, while adequate for conventional flood and sprinkler irrigation, do not have the flexibility to cater for the new short-cycle methods. This was a contributory factor to outputs lacking in credibility in practice. This tendency was aggravated, at times, because outputs were difficult to interpret by practitioners.

This project has addressed needs and to a large extent overcome difficulties associated with existing tools. A user-friendly methodology, described in this report, has been developed to help designers and planners arrive at reasonable estimates along a carefully structured route.

2 OBJECTIVES

A pilot study (Crosby, 1996) undertaken prior to the commencement of this project, aimed at establishing a decision making procedure for the estimation of crop water requirements by irrigation engineers, planners and agriculturalists. The intention was that the procedure should be suitable for use by practitioners, be in line with current international practice and incorporate both interpreted research results and the practical experience of specialists.

As a result of the pilot study the following project objectives were formulated:

- The development of an up-to-date program that will estimate irrigation requirements and will retain desirable features of and be compatible with CROPWAT *A computer program for irrigation planning and management*, FAO Irrigation Paper No 46, M.Smith (1992) while catering specifically for Southern African requirements.
- The provision of comprehensive "built-in" databases that obviate the need to seek climate or crop data elsewhere.
- The use of an approach that is sufficiently similar to current practice to be immediately acceptable to practitioners.
- The achievement of accuracy in line with practical requirements.
- Transfer of technology developed through research and modern on-farm scheduling techniques.
- Provision for the specific circumstances and requirements of emerging irrigation farmers and community gardens.

The computer program SAPWAT, which is the product of this project, meets these objectives. It incorporates comprehensive "What to Do" functions.

SAPWAT is not a crop growth model. It is a planning and management tool relying heavily on an extensive South African climate and crop database. It is general in applicability in that the same procedure is utilised for vegetable and field crops, annual and perennial crops and pasture and tree crops. It is possible to simulate wide-bed planting, inter-cropping and different irrigation methods. In addition, the effect of soil water management options such as deficit irrigation can be evaluated. It extends the facilities provided by CROPWAT and is a tool that can facilitate "designing for management". It also facilitates consultation and interaction with farmers and advisors.

3 THE DEVELOPMENT OF SAPWAT

The development process can best be appreciated by starting with the *Green Book* (1985), which was for many years the accepted South African standard for estimating crop irrigation requirements for planning and design purposes.

3.1 The *Green Book (1985)*

The introduction to this publication presents an authoritative summary of the factors that influence the evapotranspiration process and of the limitations of the procedure adopted to estimate crop water requirements. Appropriate excerpts follow:

- The water requirements of different crops grown under the same environmental conditions may differ widely, depending on genetic factors, plant population density and planting configuration. However, for a given crop with a canopy completely covering the ground or a constant leaf area index the rate of water consumption will depend mainly on external factors. These, broadly speaking, are atmospheric factors which provide the driving force for the evapotranspiration process, and soil factors which govern the supply of water to plant roots.
- At and above ground level, the leaf area index affects the ratio of the two processes that constitute evapotranspiration, viz., transpiration from plants and evaporation from the soil surface.
- Ideally there are a large number of weather, soil, water, crop, management and even economic factors that should be considered when crop irrigation requirements are to be estimated. At present, however, the ideal solution is out of reach because of a lack, both of sufficiently general mathematical models and of sufficiently general input data.

The method that is still in general use in South Africa for estimating daily water use is then outlined:

- Of the empirical methods that are available for the estimation of evapotranspiration, the one most widely tried and tested in South Africa has been the method based on pan evaporation, and more specifically, on evaporation from the American Class A evaporation pan.
- This method assumes that over a given period, evapotranspiration Etcrop is directly proportional to pan evaporation (Eo). **Stated differently, ETcrop = f.Eo, where f is the empirical constant of proportionality known as the crop factor.**

There is a pertinent word of warning in respect of the limitations of crop factor values:

- **Present lack of knowledge does not, as a general rule, permit the crop factors used in this manual to be adjusted for differences in climate or growing season.** In other words, the series of crop factors considered applicable for deciduous fruit in the south-western Cape were also used to compute water requirements of deciduous fruit grown in the Transvaal. **Furthermore, estimates for a given vegetable crop were based on crop factors which remained the same, irrespective of whether summer or winter, autumn or spring planting was under consideration.**
- **This inability to adjust crop factors to specific seasonal and climatic conditions is a weakness which cannot be ignored. Once decided upon, the crop factors were used in the main without modification in all production areas and growing seasons considered.**
- Consequently the estimates of evapotranspiration and irrigation requirements must still be regarded as first-approximation working estimates, with considerable margin for refinement.

It is emphasised that the accuracy of evapotranspiration estimation is dependent not only on the validity of crop factors, but also on the use of strictly representative (pan) evaporation data.

3.2 *The FAO Irrigation and Drainage Paper No 24 (1977).*

This paper *Guidelines for predicting crop water requirements* (Doorenbos and Pruitt,1977) included two important concepts that had the potential to alleviate some of the vulnerabilities outlined in the *Green Book* introduction. It recognised the limitations of using A-pan evaporation and introduced "short grass" as the reference evaporation in association with a related and less empirical four stage approach to developing crop factors. The reference evaporation is in harmony with a growing plant so that there is automatic compensation for climatic differences. When there is full effective ground cover the crop factor will be in the order of 1.0.

The four stages of crop development are described as:

(1) initial stage: germination and early growth, when the soil surface is hardly covered by the crop (groundcover < 10%)
(2) crop development stage: from the end of initial stage to attainment of effective full groundcover (groundcover 70 - 80%)
(3) mid-season stage: from attainment of full effective groundcover, to time of start of maturing as indicated by discolouring of leaves or leaves dropping.
(4) late season stage: from end of mid-season stage until full maturity or harvest

The basic approach to estimating crop water use was not changed.

Now ETcrop = Kc * ETo, where ETo is the "short grass" reference evaporation and Kc is the equivalent crop factor.

The value of ETo was originally established by means of weighing lysimeters and various methods of calculating these values using climatic data were developed. These included methods of deriving ETo from A-pan evaporation Eo. Eventually the Penman-Monteith equation for calculating ETo was recognised internationally and standard calculation methods published in *FAO Irrigation and Drainage Paper No 56.*

3.3 FAO consultation / CROPWAT, FAO Irrig. and Drainage paper No 46.

Smith (1991) reported on the expert consultation held in Rome to evaluate FAO No 24 in 1990

> In the Irrigation and Drainage Paper series the FAO methodology for the prediction of crop water requirements has proved to be quite outstanding. FAO 24 has become an international standard, extensively used worldwide by irrigation engineers, agronomists, hydrologists and environmentalists. More than 20 000 copies of the publication have been distributed in four languages.

FAO No 24 was combined with FAO Irrigation and Drainage Paper No 33 *Yield response to water,* Doorenbos and Pruitt (1979), and published in the form of a computer program CROPWAT, Smith (1992). This program has even further enhanced the acceptance of the FAO procedures.

The consultation considered that the crop factors were still valid, but an update was justified and that the following should be considered:

- review, in particular, crop factors for tree and fruit crops, as well as several of the perennial crops;
- review of the crop factors at the initial stage by evaluating soil evaporation and basal crop transpiration separately;
- review of the effect of climate and advective conditions on the crop factor;
- review and update of the length of the various growth stages, possibly introducing a growth function related to temperature and dry matter production.

Progress has been made on these aspects in the years since the consultation. Recommended procedures and data have been published in FAO No 56.
However, as far as is known, this progress has not as yet been directly integrated in design and planning programs.

3.4 SAPWAT and reference evaporation ETo

Crosby (1996), in developing the pilot program SAPWAT 1.0 (now replaced by SAPWAT) made use of the estimated irrigation requirement for 712 climatic zones as calculated by Dent, Shulze and Angus (1988) for specific crop factors applied to equivalent A-pan evaporation. Crosby (1996) converted from an A-pan to a short grass reference through modifying the crop factors by applying a factor of 5/7 derived from the Linacre (1977) equation. This was recognised as a temporary expedient. It was generally believed that there were not sufficient data available to make it possible to calculate Penman-Monteith ETo values for a significant number of sites in South Africa. This was the main reason why the short grass reference evaporation had not been adopted in South Africa.

The FAO database CLIMWAT (Smith, 1993) became known at about this time and contained monthly ETo data for a number of stations in South Africa. These were generally not in irrigation areas, but the monthly ETo values were compared to A-pan values. It was found that the ratios varied from month to month for a station and from one region to another. It was possible, however, to derive reasonable values for ETo from these ratios which opened up the possibility of utilising A-pan data to provide an extensive ETo network. Schulze (1997) further refined this procedure and ETo values were included in the South African Atlas of Agrohydrology and - Climatology (1997).

Average monthly ETo values can be calculated directly for a station provided maximum and minimum temperatures, relative humidity, wind run and solar radiation data (that can be measured directly, or derived from sunshine hours) are available. Approximately 200 strategically located weather stations with ten or more years of applicable data were identified in 1996. This obviated the need to use indirect ETo data, and monthly average Penman-Monteith Eto values were calculated for these stations, using the FAO-recommended procedure. The availability of data over a reasonable period permits limited statistical output. An increasing number of automatic weather stations providing hourly and daily output are now in operation and it has been possible to validate the monthly values derived from the manual stations. The results have been gratifying.

3.5 SAPWAT and Crop Factors

Smith (1994) made a strong recommendation that the four stage FAO procedure for determining crop factors be maintained in SAPWAT, ensuring a transparent and internationally comparable methodology. He recognised that the "standard" crop factors would require adjustments for regional climatic conditions and new varieties, for deviating planting densities, and for the full range of irrigation methods. One of the weaknesses of similar programs is that they were developed in the days of long-cycle flood and sprinkler irrigation and do not reflect the irrigation requirements of crops irrigated by centre pivot, micro or drip systems. This is equally true for the techniques applied by emerging farmers, such as wide-spaced short-furrow surface irrigation.

Evaluating soil evaporation and plant transpiration separately: The need for this was identified at the expert consultation (Smith, 1991) and a recommended methodology was later published (Allen et al, 1996).. At about the same time a similar procedure was developed for SAPWAT based on work done by De Jager and van Zyl (1989) and Stroosnijder (1987). The SAPWAT procedure has the advantage that it is independent of soil texture.

Once soil evaporation and plant transpiration are considered independently it becomes possible to manipulate the basic crop factor to allow for canopy coverage, wetted surface area, frequency of irrigation, cover crops, fruit and perennial crops and the various irrigation methods. SAPWAT is the first program to apply this facility in a user oriented crop irrigation planning programs.

"Growing" crop factors: A great deal of attention needs to be given to crop factor values, particularly peak values. There is a tendency to regard a default crop factor curve or table as being a fixed physiologically based property of a crop. Nothing could be further from the truth. Unrealistic or incorrectly applied crop factors are probably the main cause of inaccuracies in estimating irrigation requirements. The introduction to the *Green Book* highlights this danger.

Particular attention was paid, therefore, to crop factors in the development of SAPWAT. The ideal would be to "grow" the crop, as is done in crop growth models, so that stage lengths would react to climate and planting dates. However, this would not be achievable in a program of this nature because of the exhaustive inputs required to simulate crop growth. The use of the "short grass" reference evaporation reduces the impact of climatic variations on crop water use but has no influence on the length of crop growth stages.

The solution was to divide the country into seven agro-climatic regions and to develop default crop factors for each crop for each region. Default planting dates for each region and crop are also specified and where planting date has a significant influence on crop stages, individual crop factor files are developed by planting month by region. In addition, where there are significant differences in varieties (early or late for example), each is dealt with as a separate crop. The crop factor files have been developed empirically in accordance with "rules" derived with the assistance of crop specialists. The authentication of these values is on-going, and is based on field practice and the experience of scheduling consultants. The crop factor default files, in addition, provide for "manipulation" as discussed in the previous section.

There are presently approximately 100 individual default crop files for each region and there are seven regions. Not all the crops are grown in all regions but on the assumption that on average they would be found in five regions, there are about 500 individual default crop factor sets. This still does not cover the full needs of the country and the program allows users to develop custom crop factor files for their own areas with the help of templates and an editor.

3.6 ETo, ETcrop, effective rainfall and irrigation requirements.

Monthly reference evaporation values have been calculated for each year of record for the approximately 350 weather stations currently utilised and are on file. The ETcrop for each month is calculated by multiplying ETo by the crop factor synthesised by the program in accordance with the factors derived from the parameters discussed in the previous section. Effective rain is calculated for each month utilising a well-established Soil Conservation Service routine quoted by Jensen, Burman and Allen (1989). This method takes into account the extraction of water from the profile by the crop in arriving at effective rain. Monthly irrigation requirement is obtained by subtracting effective rain from evapotranspiration

As an aid to judgement the 20th percentile, median and 80th percentile monthly evapotranspiration, effective rain, and irrigation requirement are calculated. In addition a similar calculation is done for the full season. This provides an indication of the position in a "favourable", "normal" or "severe" season.

3.7 The balance between a management and a planning tool.

In a report Smith (1994) expressed the opinion that the distinction between a planning and management tool is often difficult to make. To include all management options in a planning tool may make it too complex for the practitioner and a line may need to be drawn. He made the following recommendation to the management team:

> It is recommended that there should be a careful evaluation of the various management options to be standardised in a planning tool. Possibly the solution chosen in CROPWAT should be given further thought. A standard procedure for calculating irrigation requirements is based on the calculated crop water requirements and an effective rainfall value only. In a separate water balance procedure various irrigation management options are included, resulting in different irrigation (management) options.

SAPWAT was developed in accordance with these recommendations as a planning tool and compatibility with CROPWAT was maintained. Field testing indicated, however, that the planning function suffers if there is no integration with management. It was possible to link SAPWAT with the CROPWAT management module and good results were achieved. The linkage was cumbersome, however, and the needs identified during field testing justified programming a SAPWAT management module from scratch.

It was found possible to concentrate inputs and outputs for the management module on one "Irrigation Scheduling" screen. This facilitates sensitivity evaluations ("what-iffing"). Rainfall values forwarded from the planning modules conform to "favourable", "normal" or "severe" seasons and provision is made for editing the expected number of rain days in a specific month. Particular attention is paid to providing linkages to conventional spread sheet programs so that users can manipulate SAPWAT output to provide for their specific requirements.

4 USING SAPWAT

What is provided here is an overview of how SAPWAT can be used and of the functional value of the output. Instructions on operating the program can be obtained by clicking on the "What to Do" button on each screen while right clicking on items on the screens provides more detailed information. SAPWAT requires Microsoft®

Windows 95/98/NT, approximately 10MB of disk space and 8 MB of RAM.

4.1 Climatic data

Select one or more weather stations from the 350 plotted on the on-screen map by double clicking on or near the station(s). The user HAS to use his judgement and experience when selecting a representative weather station. It is important to select a weather station that is representative of weather conditions at the site of interest, even if it is not the closest site. Micro-climate effects are very significant, and need to be taken into account.

4.2 Short grass reference evaporation

Calculated Penman-Monteith reference evaporation values for all the weather stations selected on the map are plotted. For the particular weather station selected from the drop down list, A-pan evaporation for comparison is also plotted. As a further aid to choosing a representative weather station, the altitudes (in metres) and mean annual precipitation values (mm) are given.

4.3 Default crop factors

The Crop Factor window enables the user to select the required crop from a menu, and to adjust the crop factor to account for operational conditions. Clicking on the "Plot" button updates the crop factor graph, which illustrates how the crop factor changes during the season. Appropriate details, including Crop Type, Options, Geographical Region and Planting Date need to be selected from drop-down menus before the crop factor can be plotted.

4.4 Modifying crop factors

By modifying the crop factors it is possible to simulate the influence of a variety of irrigation methods and crop production practices. The following inputs can be varied to adjust the crop factor:

- If the cover at full growth is reduced to less than 100%, the effective Leaf Area Index is reduced, and consequently also the maximum effective crop factor value.
- If the time between irrigation events is increased, the soil is allowed to dry out, which reduces the soil evaporation and hence the crop factor mainly during the first growing stage. Wetting frequencies for the initial and later growth stages can be specified separately for non-perennial crops.
- Reducing the wetted area to less than 100% reduces soil evaporation, and thus also the crop factor. The effect is most significant in the early growth stages, where soil evaporation predominates.

4.5 Irrigation requirements

The Water Requirement Window displays the results of the water requirement calculation performed using the crop factors generated on the Crop Factor Window, and the weather data from the selected weather station. Results are calculated for available historical weather data, on a monthly basis. The user can select one of three possibilities from the "Season" options. A "Normal" season displays median results. "Favourable" represents a "one in five" favourable value and "Severe" a “one in five" unfavourable value.

- The conventional application efficiency factor used to convert crop evapotranspiration to irrigation requirement is divided into two components namely "spray loss" and "distribution uniformity factor".
- Bar graphs are displayed for crop evaporative demand, rainfall, effective rainfall and irrigation requirement. Seasonal totals for these properties are displayed in tabulated format. It should be noted that these values do not necessarily "add up", because even a "median" season does not in general consist of a series of median months.

5 THE MANAGEMENT MODULE

The Irrigation Scheduling Window is used to simulate the effects of different practical irrigation scheduling strategies.

5.1 Soils

The user can select one of five "typical" soils. The relevant soil properties are displayed, but cannot be changed.

By selecting the "Custom" soil type, the soil properties can be changed. For any soil, the initial percentage depletion and effective rooting depth can be specified. It is important to note that the initial depletion has a very significant effect on the total irrigation requirement. Starting with 100 % initial depletion can dramatically increase the total irrigation requirement, as the profile has to be filled.

5.2 Rainfall event frequency

The user can vary the number of predicted rainfall events per month. Monthly rainfall is divided evenly between the different rainfall events. Setting the number of rainfall events to zero suppresses all rainfall for the month.

5.3 Irrigation strategies

Three irrigation Application Strategies are available.

- If "Fixed Depth" is selected, a specified amount of water is applied at each irrigation, regardless of the soil moisture content. The irrigation timing is specified by the appropriate Irrigation Timing Option selected.
- The alternative strategy is to "Refill to Specified Level Below Field Capacity", that is, water is applied until a certain soil water deficit is attained. If the profile is already full, due to rain for example, no irrigation is applied. Filling to a specified level below field capacity (say 40mm, to allow for rainfall) at timing determined by reaching a percentage (say 80%) of critical depletion, yields a close to optimum irrigation strategy, to which other simpler strategies can be compared.
- Select User Defined irrigation if an irregular irrigation schedule is required. An irrigation schedule editing window will be displayed, and the customised irrigation schedule can be specified. Appropriate defaults are taken from the Irrigation Scheduling window. Using this option, the effect of missing an irrigation application, for example due to equipment failure, can be "investigated". In addition farmer scheduling patterns can be evaluated.

5.4 Effective rainfall

Water use is tabulated as an output on the scheduling screen. Total Rainfall is the rain that fell during the growth period. It will differ significantly from the figure given in the Water Requirement window only if the rainfall was suppressed during one or more months, using the Rain Events per Month inputs. The Total Rain Loss is the rainfall lost to run-off and deep percolation. It does not include rainwater stored between the current rooting depth and the maximum rooting depth. Effective Rainfall is the difference between Total Rainfall and Total Rain Loss, and is thus explicitly calculated, as opposed to the figure given in the Water Requirement window, which is calculated from an empirical formula. Rainfall efficiency is the ratio of Effective Rainfall to Total Rainfall, expressed as a percentage. It can be improved by not filling the profile to capacity at each irrigation, thus leaving room for rainfall.

5.5 Crop yield losses

These values are calculated by multiplying the yield loss coefficient Ky for a given stage by (actual water use / potential water use). If the plant is never under stress, ie. the soil water content never drops below the lower limit of readily available water, no yield loss should occur.

5.6 Evaluating the results

The soil water content is plotted on a graph that can be edited or printed. The lines plotted on the graph are the Soil Moisture Deficit, Readily Available Soil Water, Total Available Soil Water and a smoothed curve of the Soil Water Content. This, in conjunction with yield losses, enables the implications of management strategies to be assessed. Alternative scenarios can then be evaluated.

6 THE APPLICATION OF SAPWAT IN PRACTICE

In the course of the development and field testing of the program it became apparent that the impact of the original "Objective", *namely to update and refine the methodology of estimating crop irrigation requirements* had been underestimated. The two most important aspects are the recognition in South Africa of the Penman-Monteith based international standard for reference evaporation and the FAO "four stage" crop factor methodology. For the first time there is the opportunity to develop countrywide crop irrigation requirement estimates on a basis that is both transparent and defensible. SAPWAT provides a vehicle for this process. Based on field-testing and workshops it is only possible to provide a preliminary indication of possible applications

6.1 Macro planning

Irrigation accounts for the major share of water requirements so that the irrigation component is important in catchment planning. SAPWAT principles have been recognised by the Department of Water Affairs and Forestry (DWAF) and incorporated in the irrigation inputs into the National Water Balance Model. It is anticipated that there will be further refinements to the model in the future and that SAPWAT will make a major contribution. A similar approach has been adopted for the lower Colorado river water accounting system where the evapotranspiration of not only crops but riverine vegetation is estimated. Similarly evaporation from dams, rivers and canals is being estimated by means of Penman-Monteith ETo and appropriate coefficients (Jensen, 1998). This "one stop" approach can be incorporated in SAPWAT and has considerable potential.

6.2 Water pricing strategy

In terms of the National Water Act users are required to register the use of irrigation water for pricing purposes and DWAF have indicated that the method for determining the annual irrigation requirement is the SAPWAT computer program "currently being developed under the auspices of the WRC". SAPWAT, in the absence of general metering, enables all water use for irrigation to be quantified equally so ensuring a cost recovery in "a fair and systematic" manner.

6.3 Water demand management strategy

In the 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.

6.4 Small-scale farmer irrigation schemes and community gardens.

One of the primary objectives of the SAPWAT development programme was "provision 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 Land Care initiatives of the National Department of Agriculture are basing designs for sustainable rehabilitation of irrigation schemes on SAPWAT predictions.

6.5 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 inbuilt routines for undertaking sensitivity analyses of alternative strategies.

6.6 Support for irrigation scheduling

SAPWAT is not a real-time scheduling model but can be a valuable complement to instrumented soil water content methods. It is being realised that for farmers, advisors and consultants scheduling can be a labour intensive and expensive operation. An atmospheric demand based program can provide pre-season irrigation programmes based on historic weather data that can go a long way towards alleviating much of the urgency of short-term real time scheduling. SAPWAT is designed to accommodate updated historic weather data to the present, should this be required.

7 LESSONS LEARNED THROUGH THE FIELD EVALUATIONS

As part of the final stages of the development of SAPWAT several workshops were held in various irrigation areas and these were followed up by visits and discussions with people concerned with most aspects of irrigation. A number of individuals were provided with installation discs that were also made freely available on a website established and maintained privately by one of the authors. These activities lead to a considerable amount of further development in order to meet the requirements of users, particularly in respect to making output suitable for transfer to applications that had been developed by managers, planners and designers.

One became very aware of the pitfalls facing the developers of a Windows program intended for general distribution. Unexpected incompatibilities between versions of Windows were encountered and non-SAPWAT related problems with the installation program caused user frustration. The lesson that was learned was the obvious one that it is not possible to release a program of this nature and "leave it". It is only too easy to be overtaken by unannounced global developments. . SAPWAT has reached the stage of being reasonably robust but it is essential to provide on going debugging and programming support.

The positive reaction of potential users of the program has been most encouraging. The advent of the National Water Act with all the implications and the major changes in Governments policy towards farmer support and the marketing of agricultural products appears to have influenced attitudes throughout the irrigation sector. There is a realisation that demand management is here to stay and that survival depends on greater efficiency in agricultural production.

The estimation of irrigation requirements is, however, a serious business with legal and financial implications. Mistakes can be costly. The adoption of Penman-Monteith and the FAO four stage crop factors in SAPWAT has the implication that under some circumstances there are significant changes in irrigation estimates. Users accept the changes but there is a natural uneasiness arising from uncertainty. SAPWAT does not represent a major deviation from the way in which irrigation estimates were done in the past but some of the values are different. Users need to develop confidence not only in the methodology but in their own competence to handle the change.

This is essentially a technology transfer matter that will be discussed in the next section.

8 PROGRAM RELEASE, TECHNOLOGY TRANSFER AND FURTHER RESEARCH

There is a degree of interaction between these aspects, and the ultimate success of the project depends on how effectively they are implemented and co-ordinated.

8.1 Program release

SAPWAT is not difficult to apply from the operational point of view and demands minimum computer expertise. A user with some knowledge of irrigation should be able to come up unaided with crop irrigation requirement estimates that would be more valid than those achieved in the past. SAPWAT should, however, be regarded as an aid to judgement and the user should be comfortable with its application and feel free to contribute local knowledge and experience. It is felt that user registration is highly desirable and that directly or indirectly there should be personal contact with the user. A user with irrigation experience and knowledge of crops may only need a short "one on one" familiarisation session while a user new to irrigation might require a short course and contact with a more experienced practitioner for a period. Probably the most effective medium for technology transfer would be a discussion forum on a web site but there will be users that will need initial guidance if they are not yet comfortable with Internet.

It is recommended that the release of SAPWAT be announced through normal channels and users requested to apply for installation discs that will be made available after completion of a form that will make it possible to assess the support that the user will require. It should be possible to follow much the same procedure if the program is down loaded from a web site. It might be advisable to publish, from time to time, a list of registered users.

8.2 Technology transfer

The proposal is that technology transfer comprise the training of key people throughout the country, the setting up of a WRC based web site with a discussion forum and a program for the presentation of papers at Institute and Society meetings and symposia. The objective would be to ensure that there is a nucleus of informed and interested people in all provinces and that through the web discussion forum a culture of mutual support and information sharing be developed over time.

- The planning of training of DWAF officials in the application of SAPWAT in the water use registration process and demand management strategy is far advanced as is a programme for the training of provincial DOA officials. These activities will be financed by the organisations and undertaken through the Institute for Agricultural Engineering of the Agricultural Research Council (ILI/ARC). Training will be semi-formal and will feature one-on-one support on the specific needs of the officials. It is envisaged that should other individuals or organisations request training this would be dealt with on an ad hoc basis.
- The WRC based web site would be the core of technology transfer. SAPWAT would be downloaded and users registered and updates for program executables as well as for crop and weather data made available. It is envisaged that each crop will have its own page with "approved" data but that users will be encouraged to include crop files they have developed. The web site would include a discussion forum that would also cater for on-line support.
- The presentation of papers at meetings and symposia and subsequent publication in journals and proceedings is important. SAPWAT quantifies in crop evapotranspiration estimates information derived from several disciplines in agriculture and engineering. It has not always been easy to acquire this data. Sometimes it is not available in a format applicable to irrigation and sometimes it is not available at all. The papers would concentrate on how component information was accessed or derived and on identified gaps in present knowledge.

8.3 Further research

It is believed that in general priority should be given to tapping available research information and practical experience using the web site as the nucleus for the maintenance and refinement of SAPWAT. There is, however, an area that internationally has lagged namely "irrigation efficiency". This is the conversion from "net" to "gross" water use, from crop evapotranspiration to irrigation requirements. An MSc project has been registered at the School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg entitled "Procedures for estimating the conversion of crop water requirements into irrigation water requirements at a field scale" that it is hoped will go some way fill this gap in the South African context.

9 REFERENCES

Allen, RG, Pereira, L, Raes, D, and Smith, M (1998) “Crop evapotranspiration: guidelines for computing crop water requirements”, FAO Irrig. and Drainage Paper No 56, FAO, Rome.

Crosby, CT (1996) “SAPWAT 1.0 - A computer program for estimating irrigation requirements in Southern Africa,” WRC Report No.379/1/96.

De Jager, JM and van Zyl, WH (1989) “Atmospheric evaporative demand and evaporation coefficient concepts,” Water SA, vol 15, no 2, April 1989.

Dent, MC, Schulze, RE and Angus,GR (1998) “Crop water requirements, deficits and water yield for irrigation planning in Southern Africa”, WRC Report No 118/1/88.

Doorenbos, J and Kassam, AH (1979) “Yield response to water”, FAO Irrig.and Drainage Paper No 33, FAO, Rome.

Doorenbos, J and Pruit, WO (1977) “Guidelines for predicting crop water requirements”, FAO Irrig and Drainage Paper No 24, FAO, Rome.

Green Book (1973) “Estimated irrigation requirements of crops”, Departments of Agricultural Technical Services and Water Affairs, Pretoria.

Green Book (1985) “Estimated irrigation requirements of crops”, editor Green, GC. SIRI, Department of Agriculture and Water Supply, Pretoria.

Jensen, ME, Burman, RD, and Allen, RG (1989) “Evapotranspiration and irrigation water requirements”, American Society of Civil Engineers, New York.

Jensen, ME (1998) "Coefficients for vegetative evapotranspiration and open water evaporation for the lower

Colorado river system", US Bureau of Reclamation, Boulder City, Nevada.

Linacre, ET (1977) "A simple formula for estimating evaporation rates in various climates using temperature data alone", Agricultural Meteorology, vol 18.

Smith, M (1991) "Report on the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements", FAO Land and Water Development Division, Rome.

Smith, M (1992) "CROPWAT a computer program for irrigation and management", FAO Irrig and Drainage Paper No 46, FAO, Rome.

Smith, M (1993) "CLIMWAT for CROPWAT, a climatic data base for irrigation planning and management", FAO Irrig and Drainage Paper No 49, FAO, Rome

Smith, M (1994) Unpublished duty trip report, Pretoria, South Africa, FAO Land and Water development Division, Rome.

Schulze, RE, (1997) "South African atlas of agrohydrology and -climatology", WRC Report No TT82/96.

Strooisnijder, L (1987) "Soil evaporation: test of a practical approach under semi-arid conditions", Netherlands Journal of Agricultural Science.