Water Research Commission

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Improving Agricultural Water Management

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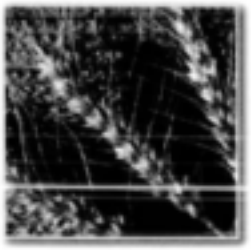

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Preview

The mandate of the Water Research Commission (WRC), in terms of the Water Research Act (Act 34 of 1971), is to commission research on all aspects of the hydrological cycle. In order to deal with this vast area of research in a manageable fashion, the WRC traditionally divides its research support and technology transfer activities into a number of research fields. For each research field the WRC's terms of reference are basically to promote co-ordination, communication and co-operation; to establish research needs and priorities; to fund research on a priority basis; and to promote the effective transfer of information and technology.

Agricultural Water Management is one of the research fields being addressed, and for various reasons research support for this field will have to be maintained in future.

People involved in irrigated agriculture, comprise a diverse group of subsistence, emerging and commercial farmers, and permanent and seasonal labourers and their dependants. Irrigated farming operations take place on 1.3 million hectare and use an estimated 12.3 x 10^9 m^3 of surface and groundwater per year. This comprises some 55,8% of the water being used in South Africa at present. The most important methods of irrigation being used are flood irrigation on 28.5% of the total area, sprinkler irrigation on 53% of the area and micro-irrigation on 18.5% of the area. Water is applied for the production of a wide range of field, industrial, horticultural, pasture and forage crops.

Under normal conditions irrigated agriculture makes a substantial contribution of between 25 to 30% to gross agricultural production. Although the contribution of agriculture to the gross domestic product is relatively small at 4 to 5%, backward and forward linkages and the multiplier effect of irrigated agriculture are of considerable importance for economic activities in rural areas. In this context both the intensive nature and stabilising effect of irrigation farming regarding food production, labour absorption and earning of foreign exchange are significant.

According to the Strategic Research Plan for Agricultural Water Management, the point of departure of applied research is the real-life problems experienced by users of water for livestock watering, rainfed agriculture, irrigation and aquaculture. Overall objectives are increased household food security and farming profitability, as well as efficient growth and

equitable distribution of wealth on a regional-economic and macro-economic level. The most important goals to be achieved over the medium-term are:

- Increased technical, biological and economical efficiency of water use,
- Alleviation and reduction of poverty amongst people in mainly rural areas, and
- Rehabilitation, protection and reclamation of water works and water resources.

These goals must be achieved through the creation of knowledge by means of research and influencing the decisions and actions of stakeholders through training and extension.

The focus areas for research are mainly rural sociology, resource economics, engineering, climatology, hydrology, soils and crops. The emphasis in the research is first and foremost to enhance the management capacity of agricultural water users. Needs-driven, problem-solving research also requires a balance between addressing issues of immediate concern and anticipating issues, which are expected to be of concern in the future. To achieve this, existing channels of communication with representatives of the farming communities, and with researchers themselves, are used to promote co-operation and co-ordination of research.

The purpose of this publication is to bring the practical information, technologies and models, which have been produced through WRC funded research projects, to the attention of farmers in agriculture. We welcome a response and discussion on ways and means to assist farmers and to ensure effective application of these research findings.

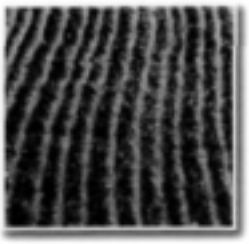
Piet Odendaal
Executive Director
Water Research Commission

Irrigation

A complete program for crop-irrigation planning

Irrigation technology has progressed significantly over the past two decades. Precision short-cycle systems such as centre pivots have been installed for irrigating field crops, micro and drip systems, many computer-controlled, dominate in horticulture, and effective flood irrigation is increasingly employed by small-scale farmers. Unfortunately, the methodology for estimating crop-irrigation requirements has not kept pace with these developments.

The importance of authoritative crop irrigation requirement estimates, including the requirement for irrigators to develop Water Management Plans, has been emphasised by the implementation of the National Water Act. In addition, there is farmer appreciation not only for the need to use scarce water resources efficiently, but also for the economic importance of effective irrigation strategies.



The Water Research Commission (WRC) funded a project by MBB Consulting Engineers in Pretoria to address these needs and to try to overcome the difficulties associated with existing tools. The intention was to design a procedure suitable for use by all practitioners, in line with current international practice and incorporating both interpreted research results and the practical experience of specialists. Messrs C T and C P Crosby, with project leader Ms M de Lange, developed a user-friendly computer program named SAPWAT. The primary function of SAPWAT is to estimate crop evapotranspiration (ETcrop), from which irrigation requirements for application in planning, design and management can be derived.

SAPWAT is a planning and management tool incorporating extensive South African climate and crop-data bases. 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, intercropping and different irrigation methods. In addition, the effect of soil-water management options such as deficit irrigation can be evaluated and alternative irrigation strategies developed. It is a tool that can facilitate 'designing for management' and consultation and interaction with farmers and advisers.

The core of the program is the 'short-grass' reference evaporation calculated from weather data according to international standards utilising the Penman-Monteith equation. This compensates for

climatic differences from one place to another and together with a crop factor developed by means of a set of simple rules ensures that comparable results are obtained anywhere in the country. Users can create crop files for a new crop or variety that may not be included in the extensive database that includes seven climatic regions and more than 500 default crop files.

SAPWAT allows the user to specify such items as frequency of irrigation, planting density and canopy cover, wetted area, and to select for favourable, normal and severe seasons. There is a scheduling mode that enables the sensitivity of any scheduling strategy to be assessed in minutes so that alterations can be made to the irrigation program. Output is in graphs and tables and particular attention has been paid to ensuring that data can be exported to conventional spread sheets for further manipulation should this be desired.

The WRC is establishing a fully interactive SAPWAT web site, by means of which contact between users and the software developers will be maintained and ensured. 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 will include a discussion forum that would also cater for on-line support.

Irrigation accounts for the major share of water usage 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. In terms of the National Water Act, users are required to register the use of irrigation water for pricing purposes.

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. 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.

One of the primary objectives of the SAPWAT development program 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.

Planning how much irrigation water is required and when, is a prerequisite for individual farmers, designers, WUAs, irrigation schemes and reservoir management. One of the strengths 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.

More information on this project can be obtained from the Water Research Commission, tel. (012) 330 0340, fax (012) 331 2565. Copies of the report are obtainable from the Water Research Commission, P. O. Box 824, Pretoria, 0001. Subscription to the software - R 50.00.

WRC Report No 624/1/99 SAPWAT, A Computer Program for Estabishing Irrigation Requirements and Scheduling Strategies in South Africa
C T Crosby, C P Crosby

Water and energy in irrigation - a decision support system

A research project aimed at developing a decision support system for increasing the economic efficiency of using water and energy for irrigation at whole-farm level in central RSA was undertaken by scientists at the Department of Agricultural Economics of the University of the Orange Free State. The research, which was funded by the Water Research Commission (WRC), and led by Professor Klopper Oosthuizen of the UOFS also took into account the risks irrigation farmers were willing to take.

The research described in a set of three reports follows on a previous project of the WRC on the economic evaluation of alternative irrigation strategies for wheat in the Free State. Instruments and methods developed during this project needed to be further refined, and the research was expanded to cover the advantages of improved irrigation scheduling to the whole-farm framework and the value of improved soil and weather information for farmers.

Research was carried out in central RSA in irrigation areas of the Vanderkloof Dam on either side of the Orange-Riet canal and the area on the Cape bank of the Orange River between the Vanderkloof Dam and Hopetown, and on approximately 7 000 ha in the Winterton area.

Data were collected initially by mailed questionnaires, followed up by questionnaires completed during personal interviews with farmers. This was followed by group discussions, and more data were supplied by agricultural organisations.

The results are reported in three volumes. Volume I contains an executive summary and summaries of Volumes II and III. Volume II discusses the research in the Winterton area, while Volume III reports on that undertaken in the Vanderkloof Dam area.

The first objective was to estimate the water requirement and yield levels of crops in semi-arid and humid areas by means of crop-growth simulation models. The most important crops in both areas were identified and wheat, maize, cotton, soybeans and lucerne were included. As a result of the requirements of further economic analyses, attention was not only given to water needs and yield levels of crops, but also to cultivation practices and production costs, and to the risk involved with each crop in terms of price and yield variability.

Information for this purpose was obtained by using crop-growth simulation models, and also by means of group discussions and from other secondary sources. Enterprise budgets for crops in both areas were compiled and can be used as a basis for economic analyses. Important work was also done with regard to testing of crop-growth models from an agricultural-economic viewpoint. This entailed the specification of a procedure as well as a comparison of the models.

The second objective was achieved by means of personal interviews in the research areas to measure the risk preferences of irrigation farmers, as well as their perceptions with regard to

the importance of alternative risk sources and management strategies. Information on risk preferences which previously had been unobtainable locally, was obtained and this enabled the research team to determine the value of information and preference strategies for decision makers with different risk preferences.

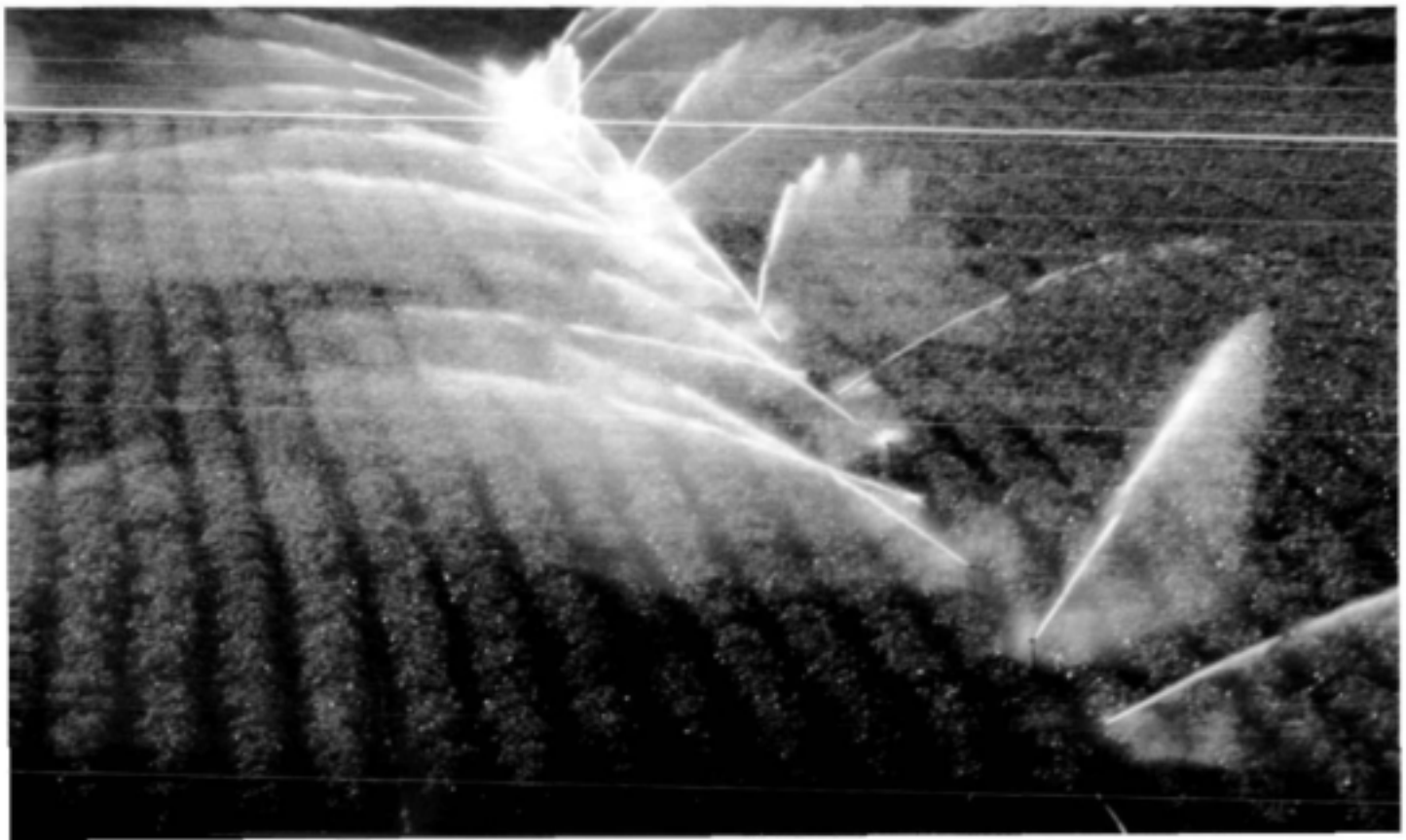
Once information on farmers' perceptions on risk sources and risk-management strategies was obtained, risk modelling could be done and risk management strategies were formulated.

The annual cost of representative farming systems at whole-farm level, was estimated. This was made possible by extending procedures at enterprise level to farm level where all overhead variables were taken into account. Procedures were developed to be as flexible as possible in order to handle various situations.

A methodology was illustrated where the value of information was determined by successfully linking irrigation, economic and crop-growth simulation models with an optimising model. This dynamic model (**SIMCOM**) took all the important variables into account and could enhance irrigation management through simulation of situations which occur in practice. The greatest advantage of this procedure is the fact that optimal solutions can be identified by linking with the optimisation model.

The effects of pumping restriction scenarios were determined by using the SIMCOM model, given the Ruraflex electricity option, where the cost of electricity is less during certain hours of the day. Profitability was adversely affected by pumping restrictions when pump capacities were restrictive and profile available water capacities of soils decreased. These results are important from a policy viewpoint, because the amount of compensation necessary to pump water during certain hours only, can be ascertained.

Because the main objective of this research was to develop methodologies, procedures and facilities to analyse and improve water and energy use, decision support models logically resulted from this. The SIMCOM model, used to determine the value of information, is an example of such a model.



A decision support model was also developed for the evaluation of risk management at whole-farm level. This model, consisting of three modules, calculates all costs and income at enterprise level as well as farm level. Risks with regard to crop prices and yield, interest rates and possible hail damage are also fully simulated. Irrigation management, including water and energy use, can therefore be promoted.

Certain fields for further research were identified which could create a set of instruments for the support of irrigation management from micro- to macro level, extending from the farmer to the policy maker. More specific topics for further study, development, improvement and practical implementation were also identified.

This study showed that more attention will also have to be given to the decision maker. Questions like the following arise from an information viewpoint: Is information optimally utilised by decision makers? What management needs exist to implement and carry out a better-information strategy?

Risk management, as an integral part of farm management, ought to be promoted by encouraging managers to view economic variables as probability distributions that ought to be managed. Although the decision support systems that were developed in this study contribute to this, utilisation of such a system will be determined by the relevancy and the value of the information it supplies, as well as by its user friendliness. If the expected value of the information exceeds the cost and effort of acquisition, such a system will contribute to better decision making. Because the system that was developed can supply valuable information for decision making, this system ought to be used to improve risk management.

More information can be obtained from Professor L K Oosthuizen of the Department of Agricultural Economics, University of the Orange Free State, P O Box 339, Bloemfontein, 9300. Copies of the reports may be ordered from the Water Research Commission, P O Box 842, Pretoria 0001.

WRC Reports:
No 347/1/96 Volume I: Development of a Decision Support System for Increasing the Economic Efficiency of Water and Energy Use for Irrigation at Whole Farm Level in Central RSA, Taking Risk Into Account. L K Oosthuizen, J A Meiring, J H F Boles, D J Bosch, P Breytenbach. 1996.

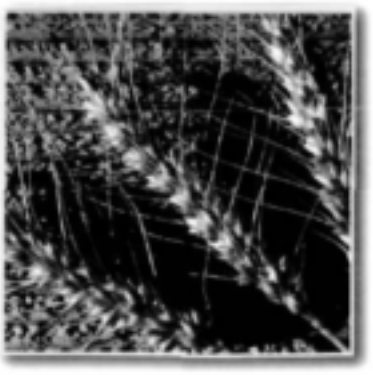
No 347/2/96 Volume II: Increasing Economic Efficiency of Water and Energy Use for Irrigation at Whole Farm Level in the Winterton Area. L K Oosthuizen, J H F Boles, D J Bosch, P Breytenbach. 1996.

No 347/3/96 Volume III: Die Ontwikkeling van 'n Besluitnemingsondersteuningstelsel vir die Ekonomiese Evaluering van Risiko-Bestuur op Plaasvlak en die Toepassing Daarvan in die Halfdroë Gebied Benede die P K le Rouxdam. L K Oosthuizen, J A Meiring. 1996.

A water-balance model for irrigation

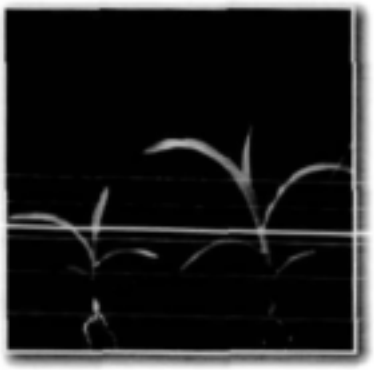
To ensure the most efficient use of irrigation water it is necessary to manage or schedule irrigation in such a way that plants will at no stage be subjected to plant water stress. The daily water requirement of plants is dependent on atmospheric conditions and the foliage cover, while soil-water supply is a function of root distribution and water uptake.

Financed by the Water Research Commission (WRC), soil scientists of the University of the Orange Free State, under the leadership of Professor A T P Bennie, undertook research in 1987 aimed at:



- Measuring the soil-root conductance of water for different soil/crop combinations;
- Finding a root growth model through which rooting density changes at various soil depths during the growth season could be predicted;
- Compiling a simulation model for calculating the lower or dry boundary of plant-available water for different situations; and
- Using the difference between the upper or wet boundary of plant-available water and the water content where plant-water stress appears, for refining irrigation scheduling and planning of irrigation systems.

The soil-water conductance coefficient for a large variety of soil types was combined with crops of wheat, maize, groundnuts and peas in the irrigation areas of Vaalharts, Sandvet (between Bultfontein and Wesselsbron) and Ramah on the Orange River near Luckhoff. It was discovered that soil-water conductance was a function of the silt-plus-clay percentage of the soil.



An effective empirical root-growth model to predict root-density changes was developed and tested. A regression model for calculating the field water capacity of various soil types according to their silt-plus-clay content was derived. A general water retention equation was compiled and critical leaf xylem potentials for identifying serious plant-water stress were noted. All this information was used to develop a model for calculating the profile-available water capacity of specific soil/crop-type combinations under different circumstances and in the course of the growth season.

Regarding irrigation management and scheduling, a system was devised whereby total crop-water requirement could be calculated. Graphs showing specific daily crop-water consumption at specific yield targets were derived for various crop types, and formulae were derived for calculating irrigation-water demand taking into account the profile-available water capacity and seasonal requirements.

Different ways for administering irrigation water were demonstrated and tested in practice. It was shown that scheduling of irrigation according to the water-balance method throughout the growth season was successful, simple and easy to manage. So also were the procedures for calculating plant-available water withdrawal over the whole growth season for specific soil/crop-type combinations. To facilitate application of these results in practice, all the calculation procedures were included in a computer program known as the irrigation water management program or (**BEWAB**).

The report contains much useful information for easing decisions regarding the design of irrigation systems for specific soil/crop combinations. A simple and cheap water-balance method for scheduling irrigation yielded good results, which could be successfully applied in the irrigation areas of Central and Western Free State, Northern Cape and Western Transvaal. This approach is also applicable in other irrigation areas but different coefficients may be necessary in different climatic regions.

More information can be obtained from Professor A T P Bennie, Department of Soil Science, UOFS, P O Box 339, Bloemfontein 9300. Copies of the report can be obtained from the WRC, P O Box 824, Pretoria 0001.

WRC Report No 144/1/88: 'n Waterbalansmodel vir Besproeiing Gebaseer op Profielwatervoorsienings-tempo en Gewasbehoeftes. A T P Bennie, M J Coetzee, R van Antwerpen, L D van Rensburg, R du T Burger. 1988.

Soil water balance model to facilitate irrigation scheduling

Direct measurement of how much water certain crops need is not always feasible on a large scale. Certain models and procedures have been developed to estimate this, but because of the specialist knowledge needed to run the models, this approach has been out of reach of most irrigators. Researchers of the Department of Plant Production and Soil Science at the University of Pretoria, have now developed, calibrated and validated an easy-to-use computer program, **SWB** (Soil Water Balance) to assist irrigation farmers and specialists with irrigation scheduling. The project was funded by the Water Research Commission (WRC) and carried out under the leadership of Professor John Annandale.

Packaging the model in an extremely user-friendly format eliminates the need for the user to have a detailed understanding of soil-plant-atmosphere dynamics, and the accuracy of the mechanistic and therefore universally valid approach increases the value of the program.

Interest in scheduling irrigations using crop-growth computer models has grown since personal computers have become accessible to crop producers. Existing models have their drawbacks in that they are either crop-specific or do not simulate daily crop-water use; that they are simple to use for planning purposes but do not allow real-time scheduling; or that they are aptly suitable for research purposes but, because of the large amount of input information they need, generally not applicable in practice and not user-friendly.

The Soil Water Balance (SWB) model is a mechanistic, real-time, generic crop, soil-water balance irrigation-scheduling model. It is based on the improved generic-crop version of the NEW Soil Water Balance (NEWSWB) model developed by Campbell and Diaz at Washington State University in 1988. SWB gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data. It thus largely overcomes the problems of other models for irrigation scheduling. However, since SWB is a generic crop-growth model, parameters specific to each crop had to be determined.

The following objectives were identified for this project:

- To determine parameters for specific crops which are commonly irrigated in South Africa, and include them in the SWB database
- To identify further SWB development needs in order to meet user requirements
- To automate acquisition of input weather data from automatic weather stations in order to facilitate and make scheduling more convenient
- To evaluate SWB using independent data sets obtained from S A researchers and organisations

- To develop a user-friendly Windows 95 interface for easy technology transfer
- To compile a comprehensive user manual as well as a comprehensive user-help facility
- To identify further research and model development needs which are not satisfied in this project

Three approaches were followed to calibrate and validate SWB in the real-world system using independent data sets. First, an extensive literature survey was carried out followed by personal contact with South African researchers and organisations. This was followed by field trials aimed at collecting data for determining specific crop-growth parameters. Thirdly, an alternative model was devised for determining the soil water balance for crops for which no local data sets were available and field trials were not possible. This model was based on the FAO crop-factor approach, and was developed to include more crops in the SWB database.

Difficulties encountered ranged from incomplete and unreliable data sets to certain collaborators being reluctant to make data available.

The results of field trials at Roodeplaat and Hatfield were used to calibrate SWB. Weather, soil and growth analysis data were used to determine specific crop-growth parameters for six winter vegetables and 19 varieties of summer vegetables. The trials at Hatfield were used to determine FAO basal crop coefficients and growth periods for first- and second-leaf peach trees.

The SWB program was improved and refined, and finalised as SWB (Version 1.0), available for use with Windows 95 on an IBM-PC or compatible computer. The program requires a minimum of 16 Mb RAM and is supplied as executable code on 3.5-inch disks or CD, including a comprehensive user's guide and technical manual.

The program includes a number of special features of importance to the main target group of farmers, irrigation officers and consultants. Several commercial farmers and irrigation officers are already using SWB for real-time irrigation scheduling. Small-scale commercial farmers are also potential users, as well as small-scale subsistence farmers, provided they are advised by irrigation officers.

Further research needs concern the introduction of specific crop-growth parameters for cotton and some important tree crops. Different cultivars for crops already existing in the SWB database could also be included.

Copies of the SWB program are available from Professor John G Annandale, Department of Plant Production and Soil Science, University of Pretoria, Hatfield 0002 (e-mail: annan@scientia.up.ac.za), at R500 for the CD plus users' guide and technical manual. Copies of this report can be obtained from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Report No 753/1/99: Facilitating Irrigation Scheduling by means of the Soil Water Balance Model. J G Annandale, N Benadé, N Z Jovanovic, J M Steyn, N du Sautoy. 1999

Designing and managing gravity irrigation systems

Gravity or surface irrigation entails the use of soil to distribute water over a certain area. The hydraulic behaviour of water on an irrigation border is governed by the universal principles of the conservation of mass and energy. The design of a surface irrigation system involves the calculation and optimisation of complex equations. These equations relate natural resources, such as soil (with variable infiltration parameters and a natural slope) and parameters, which can be manipulated (slope, border lengths, resistance to flow, flow rate and irrigation times) to hydraulics. The Department of Agricultural Engineering of the University of Pretoria was commissioned by the Water Research Commission (WRC) in 1989 to develop a computer program for the design of gravity irrigation systems. Mr Gert Kruger of Rehab Consultation did the research and developed the **OPTIVLOED 2.2** computer program.

The project necessitated the evaluation of existing local and international design procedures, collecting relevant South African data, experimental research, analysis of relevant design criteria, compiling a hydraulic design model, computerising the design procedure and evaluating the results. The results of the research were documented in four volumes, and a computer program entitled OPTIVLOED 2.2 was developed.

Volume 1 of the report presents a summary of the relevant hydraulic theory and results of the research. It also serves as a user guide for the computer program. *Volume 2* details the critical evaluation of existing design procedures with reference to South African conditions. *Volume 3* documents the verification of hydrodynamic models in South Africa on the basis of experimental data. *Volume 4* analyses design tendencies, and describes the model development, computerisation and testing of the OPTIVLOED design procedure.

The computer program was programmed in an object-orientated mode to allow free movement from one aspect of the design towards the other. C++ was used for the programming. Graphic interaction was created by graphically representing design calculations on the computer screen. The designer is able to see how modifications of

design options will affect the system performance. Once the designer is satisfied with his choice, he will proceed to calculate the details of the final design. The design program is bilingual (Afrikaans and English) and can easily be translated into any other language. The design procedure is universal, scientifically sound and user-friendly. OPTIVLOED 2.2 focuses the design and eliminates the need for elaborate simulations during the design. It has potential for worldwide application.

Six OPTIVLOED 2.2 design courses in South Africa were already funded by the WRC. The computer program offers excellent training material for various disciplines (from farmers to extension staff to engineers). The training involves the determination of input parameters, simulation (SIRMOD program) and design (OPTIVLOED).

More information, and the computer program OPTIVLOED 2.2, can be obtained from Mr G H J Kruger, Rehab Consultation, P O Box 5219, Klerksdorp 2573. Copies of the four research reports on this project are available from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Report No 290/1/98
Volume 1: Die Ontwikkeling en Rekenarisering van 'n Geskikte Vloedbesproeiing - Ontwerpprosedure: Samevattende Verslag. G H J Kruger. 1998.

Volume 2: Kritiese Evaluering van Vloedbesproeiing - Ontwerpprosedures.

Volume 3: Bevestiging van Hidrodinamiese Modelle en Kenmerkende Eienskappe Geldig vir Vloedbesproeiing in Suid-Afrika.

Volume 4: Ontwikkeling en Rekenarisering van 'n Toepaslike Ontwerpprosedure vir Vloedbesproeiing.

Computer program to simulate water flow in irrigation canals

The Water Research Commission (WRC) provided financial support for a number of research projects concerning the optimal management of irrigation systems. In one of these projects, the Rand Afrikaans University (RAU) developed a computer program **PROCAN**, that simulates unsteady flow of water in any canal or river; a second RAU project was a water administration system, WAS, that handles all water requests by farmers and is currently running on all major irrigation schemes throughout South Africa.

The RAU research team under the leadership of Dr Nico Benadé integrated these results and developed a computerised system for minimising management-related distribution losses in irrigation canals. The resultant system consists of a simulation model, monitoring stations and a water office database. Their ultimate aim was to create a management system that could be used on all major irrigation schemes in South Africa to optimise irrigation water management and minimise water losses.

The researchers identified and integrated a suitable crop-irrigation scheduling program, SWB, into the water administration system developed by the RAU. They collected climate, soil and crop data at the Loskop irrigation scheme for testing the scheduling program, and compared the volumes of water requested by farmers with the actual amount of water needed for all crops on the irrigation scheme. The program was implemented in the Loskop scheme.

The optimisation system consists of an unsteady-flow simulation model, PROCAN, a water administration system, WAS, and a soil water-balance model, SWB. SWB, the new irrigation-scheduling program developed during this latest research project, is an upgraded version of NEWSWB, which was written by Professor Gaylon Campbell of Washington State University.

PROCAN can be used for calculating lag times, evaporation and seepage losses, hydrographs, and for evaluating different water-distribution scenarios, training canal operators, designing new canals and analysing existing canals.

WAS has been developed into a fully computerised water administration system that can be used for calculating water balance statements, calculating and printing water reports, and calculating water releases into all canals taking lag times and water losses into account. It can also print distribution sheets, water bailiff instructions and water releases.

PROCAN and WAS have been implemented partially or fully on various irrigation schemes throughout South Africa. The water administration system is used at Loskop, Sandvet, Hartbeespoort, Pongola, Riet River, Vaalharts, Olifants River, Kalkfontein and Mooi River irrigation schemes. PROCAN has been successfully calibrated on the first 45 km of the left bank canal at the Loskop irrigation scheme.

The irrigation-scheduling model, SWB (from soil water balance), can be used on a single farm, a group of farms or all farms on an irrigation scheme. The advantage of calculating the water required by all the crops on an irrigation scheme is that the water requested by the farmers can be compared to the actual crop-water requirements. Should there be a large difference between the water required and the water requested, steps can be taken to improve irrigation management on a specific irrigation scheme.

Although the SWB program was successfully integrated into the WAS, its usability is hampered by a lack of crop parameters for a range of different crops. A follow-up research project rectified this shortcoming and refined the model into an even more useful tool for irrigators, advisors, researchers and managers.

More information can be obtained from Dr N Benade, p/a NB Systems, P O Box 15102, Sinoville, 0129, tel: (012) 548 1005, e-mail: ncob@mweb.co.za. Copies of the reports can be obtained from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Reports

No 513/1/97: The Development of a Computerised Management System for Irrigation Schemes. N Benade, J Annandale, Ms H van Zyl. 1997.

No 367/1/93: Die Ontwikkeling van 'n Gerekenariseerde Waterverdelingstelsel vir die Optimale Bestuur van Besproeiingskemastelsels. N Benade. 1993.

No 176/1/92: Die Optimalisering van die Bedryf van Besproeiingskemastelsels. N Benade, R J Engelbrecht, G W Annandale. 1992.

Rainfed
or Dryland Agriculture

Soil water management program for rainfed agriculture

Researchers of the University of the Orange Free State have developed an easy-to-use computer program to assist crop farmers in better managing rainwater resources, and to facilitate decision-making. **SWAMP** (Soil Water Management Program) can be run by farmers themselves to obtain optimum yields from specific fields on their farms.

With financial support by the Water Research Commission (WRC) since 1975, the research, led by Professor A T P Bennie, initially focused on soil compaction problems under irrigation. However, it soon became evident that increasing food production should be based on sustainable dryland agricultural systems, emphasising the capture and efficient use of rainfall, rather than relying on surface water supplies, which are being progressively needed for a burgeoning population, and expanding industries.

Of all the rain that falls in South Africa, 74% is being used for dryland agriculture and forestry. Dryland crop production uses 12% of this rainwater, as compared to 2% used by irrigation. A small improvement in rain-use efficiency in dryland crop production can obviate the necessity for future irrigation development.

Research has provided technologies that allow greater production with less risk, with the same rainfall. These technologies provide means to improve and manage the retention of precipitation in the soil and thus reduce the risk of crops running out of water during the growing season. During droughts the crop water demand exceeds the rainfall, and the larger the amount of rainwater that can be stored in the soil, the lower the risk of crop damage becomes. Accurate balancing of the stored soil water with the expected crop water deficit requires a sound knowledge of the soil water supply and the quantification of each of its components.

A number of soil water-based computer models are already in use in the country, and can supply farmers and agriculturalists with the general information for decision support. This research by the UOFS focused on the need for a practical computer program that can be run by farmers or agricultural advisers themselves, even for specific fields on a farm. Procedures were developed to estimate the evaporation of water from the soil surface, water uptake by crops and water loss by drainage below the deepest roots.

Applying these procedures requires input information that is readily available, like soil depth, texture, rainfall, an estimation of soil wetness and target or actual crop yield. The procedures can be used to estimate the amount of rain stored in the soil, from harvesting the previous crop to planting of the present crop. This information can be used in conjunction with an input of

the expected precipitation to estimate the obtainable yield. It can also aid the farmer in making a decision, based on the economic viability and risk involved, whether to plant or not. The procedures can also be used to estimate the amount of unused plant-available water in the soil at the end of a growing season.

Values estimated by using the procedures were compared with values measured in farmers' fields, and were found to be of acceptable accuracy.

The separate estimation procedures for each of the components of the soil water balance have now been linked in this single computer program. In it, available technology based on 22 years of research results obtained by agricultural scientists at the UOFS Department of Soil Science during six research projects, and practical expertise on agricultural water management is placed into the hands of dryland and irrigated crop producers.

Future research needed to improve the accuracy of the program will focus on improving procedures for estimating run-off.

The SWAMP computer package can be ordered from the Head, Department of Soil Science, UOFS, P O Box 339, Bloemfontein, 9300. Copies of the report can be obtained from the WRC, P O Box 824, Pretoria 0001.

WRC Report No TT 102/98: Gebruik van Rekenaarmodelle vir Landboukundige Waterbestuur op Ekotoopvlak. A T P Bennie, M G Strydom, H S Viey. 1998.

Storage and utilisation of rainwater in semi-arid regions

Soil scientists of the University of the Orange Free State studied rainwater storage in and loss from the root zones of both natural grazing and crop-producing lands, and the effects on this of various cultivation methods. Economic implications were compared and management guidelines compiled for optimal farming practices in dryland areas.

This study between 1989 and 1993 has been the most comprehensive project to quantify the soil-water balance in a semi-arid climatic region ever undertaken in South Africa. It was financed by the Water Research Commission and led by Professor A T P Bennie.

Regarding the impact of different soil utilisation and cultivation practices on rainwater storage and the soil-water balance, three practices were studied. These were:

- Conventional cultivation which leaves a clean, uncovered surface;
- Stubble mulching, which leaves the maximum amount of plant residue on the surface to enhance water infiltration and decrease surface evaporation; and
- No-tillage where the surface is disturbed only during the planting process, and chemical weed control is practised.

Production of different crops were also studied to ascertain how effectively soil-stored rainwater and rain is utilised in the growing season. These included wheat (winter crop mainly growing on stored water); annuals such as maize, sorghum and sunflower (growing in the rainy season); rotational fallow cropping (which effectively increases the water storage period from 5 to 10-12 months); and a system with a management option, where a crop is planted when the plant-available root-zone water content exceeds 120 mm. The studies were undertaken in four areas, namely Bloemfontein, Petrusburg, Hoopstad and Tweespruit.

During the rain-storing period average runoff ranged between 6 and 13%, depending on precipitation. Contrary to expectation, runoff was higher with no-tillage. It could be decreased by disturbing the soil surface. Where there was no shallow water table, surface evaporation was between 62 and 70% of the rainfall. At Hoopstad where a shallow water table was present, 92% of the rainwater evaporated during the storage season.

Deep percolation occurred mainly during seasons of above-average rainfall and ranged between 8 and 15%. At Petrusburg with a deep sandy soil and no percolation-limiting clay layer, deep-percolation levels of up to 36% were measured. At Tweespruit with more clayey soils, percolation was decreased to less than 8% and generally to less than 2% of the rainfall.

The percentage of rainwater stored in the soil profile during the storage season, i.e. the rainwater-storage efficiency, increased with increased dryness of the soil at harvesting and ranged from 15 to 30%. Stubble mulching and no-tillage had no positive effect on the rain storage efficiency. The amount of plant residue on the surface, mostly less than 50% cover, brought no decrease in evaporation and runoff.

During the growth season climax veld showed the least amount of runoff namely 3% of annual rainfall. Runoff increased to 10 to 12% with soil cultivation. In the winter-growth season deep percolation was reversed, and water moved upwards into the root zone. In summer-growth seasons with increased rainfall, deep percolation was as much as 16% of rainfall at Petrusburg, although an average deep-percolation value of 1 to 2% of rainfall was more realistic for veld. Crop production promoted repletion of soil-water resources.

The contribution of pre-planting stored water to the total crop-water use during the growth season averaged at 37% for wheat, 12% for summer crops and 28% for rotational crops. Depending on the amount and distribution of rain, the soil dried out between 60 and 100%.

Stubble-mulch cultivation and no-tillage of more sandy soils, especially of wheat and sorghum, resulted in lower yields than with conventional cultivation - possibly because of root diseases or phytotoxicity. Increasing availability of profile-available water at planting time resulted in increased yields.

Using statistics regarding production costs for the different forms of cultivation, rainfall could be converted effectively to production, both in mass and in monetary value. The figures obtained made it possible to calculate the cost of runoff, evaporation and deep percolation. This indicated rotational cultivation

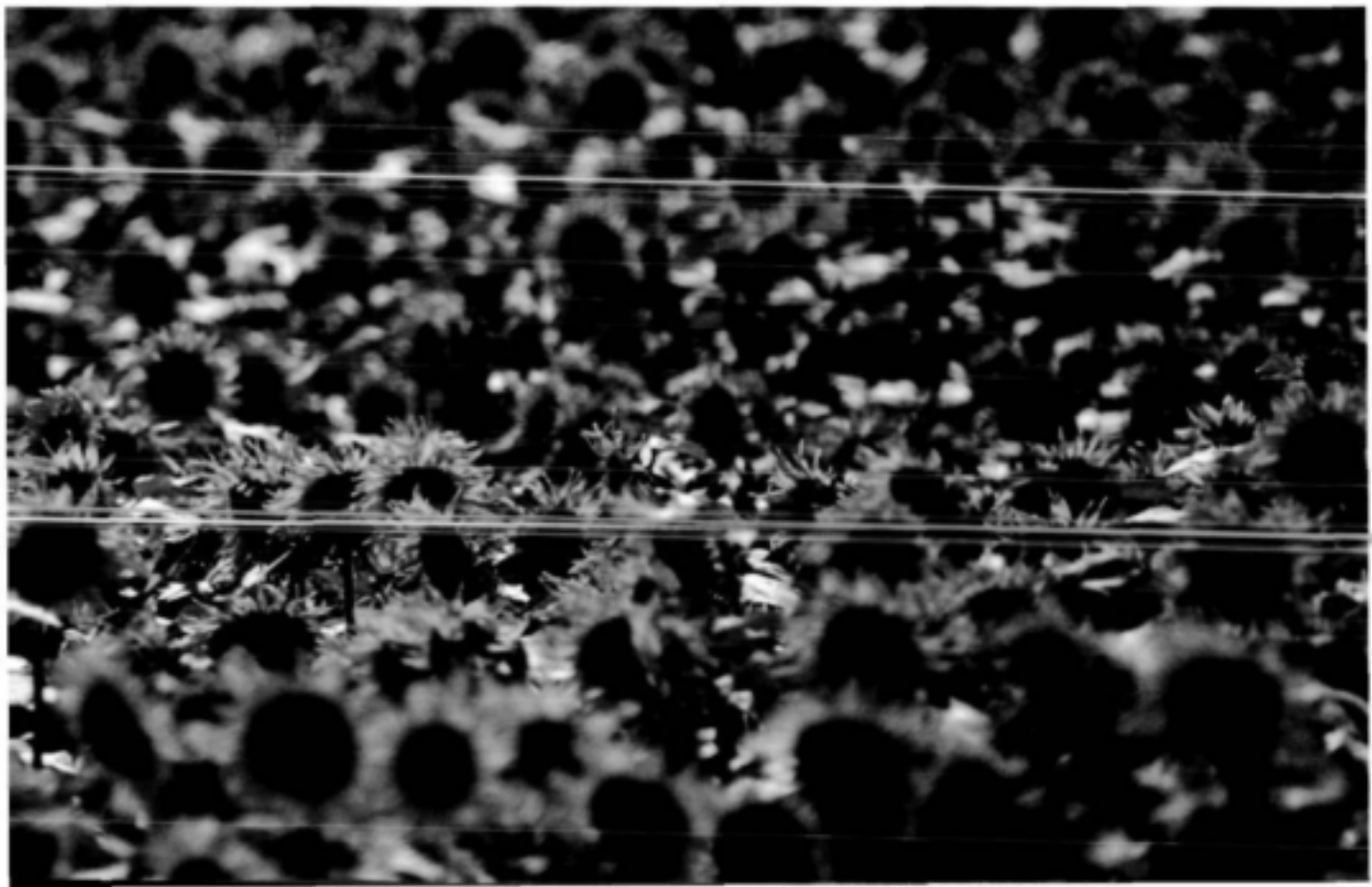
undertaken in the conventional manner, to be the most sustainable and profitable system. The high cost of chemical weed control in conservation tillage made it unsuitable for recommendation under low-yielding conditions. Converting veld to cultivated grazing doubled the Rain Utilisation Efficiency, and when grazing was converted to crop production this was again increased three or fourfold.

Management guidelines for optimal water storage and use for dryland production in semi-arid areas would be specific to each climate, soil type, plant and type of surface disturbance. A computer program for facilitating decision-taking and advice, was deemed necessary. Means of quantifying the different components of the soil-water balance were necessary for compiling trustworthy management guidelines. It was also possible to develop ways by which deep percolation, soil-surface evaporation and surface runoff could be calculated from easily measured variables.

Certain recommendations were made regarding further research. Some of the results obtained during this investigation should, for example, be included in simulation models, which could then be applied with greater accuracy for forecasting production within various soil, climate and soil-type scenarios.

More information can be obtained from the project leader, Professor A T P Bennie, at the Department of Soil Science, UOFS, P O Box 339, Bloemfontein 9300. Copies of the report can be obtained from the WRC, P O Box 824, Pretoria 0001.

WRC Report No 227/1/94: Opgaring en Benutting van Reënwater in Grond vir die Stabilisering van Plantproduksie in Halfdroë Gebiede. A T P Bennie, J E Hoffman, M J Coetzee. H S Frey. 1994.



Livestock

Efficient management of water for livestock

Financial support from the Water Research Commission allowed scientists of the Department of Animal and Wildlife Sciences of the University of Pretoria to investigate the quality of water used for livestock production, with the emphasis on subterranean water, and to develop a comprehensive water quality guideline index system (WQGIS) for farmers.

Professor Norman Casey and Dr James Meyer set out to identify the types of livestock production systems and their common water sources, the variables of relevance in these water sources and their effect on livestock. Obviously this project necessitated collecting a vast amount of data regarding livestock production practices, analysis of source water, biological experimentation, and regional water quality investigations. Computer simulation modelling and decision support systems appeared to be the most plausible realistic methods for assessing the consequences of alternative water management strategies.

Their report was published in three volumes, the first detailing the motivation for and design of the index system, and modelling the system and the software program needed. The second volume presents the main results obtained. These two volumes are supplemented by an Appendix, which provides some of the detail results of the biological experimentation and water quality investigations in specific areas of South Africa, needed for developing the system.

The ultimate aim was to develop a user-friendly computerised guideline system for watering livestock. Professor Casey and Dr Meyer produced a software program, which conducts site-specific risk assessments for water quality. The program, termed CIRRA, an acronym for Constituent Ingestion Rate Risk Assessment, provides calculation results and solution options on an ingestion rate basis. Assessments are category-specific, for example, dairy cows producing a Fat-Corrected Milk Yield of 60 ℓ/day, to cater for specific production levels.

The system provides information according to which the risk regarding the use of a given water source for a given livestock production system and environment can be assessed. The objective was to guide a wide range of users - from water quality managers of complex aquatic systems to veterinarians and private on-farm users of the system - in such a manner that they can

assess the potential value and hazards of water sources, thus enabling optimal utilisation.

Successful livestock production is dependent on the provision of water with a specific chemical composition. A water quality guideline recommends what that chemical composition should be, not just to prevent adverse effects from occurring, but also to achieve optimal water utilisation.

Livestock obtain their water by drinking, ingesting water-containing feeds and by forming water during metabolism in their bodies. They continually lose water due to renal, digestive, and production (e.g. lactation) functions and perspiration. The extent of these forms of water intake and loss differ between livestock and over livestock production systems, and these differences play a major role in determining the optimal chemical composition of a water source used in livestock production.

Certain chemicals and other constituents of subterranean water are termed 'potentially hazardous'. Their effects upon livestock depend on the type and condition of the animals, the quantity ingested and the duration of exposure to water and other sources containing the toxins. CIRRA has application in achieving more efficient management of available water sources for livestock in general by indicating the 'best fit' for different categories of livestock. This will enable the correct allocation of water sources and obviate or decrease the effect of toxicity problems. This applies also to problems of water palatability caused by chemicals and other factors.

Management of water sources along the guidelines set by CIRRA will also solve or lessen the more mechanical problems of clogging, corrosion, encrustation, scaling and sediment.

The CIRRA software program makes allowance for inputting variables encountered by moving stock between different camps with different boreholes and watering points, pasture and soil type; providing different licks or supplemental feeding; seasonal variations in water quality constituent (WQC) levels in water sources etc. This flexibility was not possible with the previously used static tabulated guidelines.

CIRRA provides a user-friendly tool whereby a water source with multiple users and different water quality requirements can be managed. Most importantly, it can be applied to different livestock types, production systems and conditions on a site-specific basis. It also addresses WQCs that are not normally encountered in the natural aquatic environment, but which may be problematic in situations involving industrial pollution or chemical spills. CIRRA furthermore guides the user to find solutions to water with problematic constituents by indicating possible manipulations to system factors which may alleviate adverse effects, including water, animal, environmental and nutritional factors. The incorporation of new research findings is valuable in that it allows for risk assessments to be based on the latest information available.

Volume 2 of the report provides the main information on some of the biological experimentation and water quality investigations conducted in specific areas in South Africa. The first three chapters describe work done on the effects of nitrate, selenium and fluoride on Dohne Merino sheep. Then follow chapters on palatability trials and area water quality studies in the Delftzyl area, the Ganyesa district, Vryburg and Kuruman in the North Western Province, and in the Kruger National Park. The last three chapters discuss the influence of different chemicals in water for layer production, and investigations of the quality of water used in poultry production systems.

Volume 3, the appendix, details the results of hundreds of experiments and investigations regarding the toxic ranges of 24 different chemical elements, conducted on a variety of animals, including dairy cattle, beef cattle, sheep, goats, horses and pigs.

Recent versions of CIRRA cater for wildlife user groups, provide information on recent advances in trace mineral balances, and allow for a data-capturing guide to be created, which enables farmers to collect the required information for risk assessments.

The CIRRA software and more information may be obtained from Professor N H Casey, Department of Animal and Wildlife Sciences, University of Pretoria. Copies of the reports are obtainable from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Reports Nos 644/1/98 (Volume 1); 644/2/98 (Volume 2) and 644/3/98 (Volume 3): An Investigation into the Quality of the Water for Livestock Production with the Emphasis on Subterranean Water and the Development of a Water Quality Guideline Index System. N H Casey, J A Meyer, C B Coetzee. 1998.

Toxic and palatability effects in animals attributable to water quality

The validity of the guidelines presently in use in Southern Africa in assessing the quality of water for livestock production has been questioned. International guideline variables and the levels for specific variables differ and highlight the need for each country to have own relevant guidelines. The guidelines in use in South Africa are based largely on international guidelines and have few locally established variable guidelines.

Researchers of the Department of Animal and Wildlife Sciences at the University of Pretoria received financial support from the Water Research Commission (WRC) to investigate this matter and make recommendations.

Professor Norman Casey and Dr James Meyer reviewed literature dealing with water quality for livestock, and then studied the quality of subterranean water in Southern Africa by reviewing a total of 2 293 data sets of borehole water samples from the NW and NE Transvaal, and from the NW Cape.

Through biological trials on sheep, beef and dairy cattle, broilers and layers, they investigated the effect of the water quality variables deemed to be of major importance to livestock production, based on the incidence of potential toxicity assessed according to international guidelines. These are fluoride (F), total dissolved solids (TDS), chloride (Cl), and sulphate (SO_4). Then followed research concerning primarily the effects of these salts on the palatability of water and water intake.

High-risk areas were identified and selected farms were visited. On the basis of the data reviewed and interviews conducted, research emphasis was placed on F and the palatability effects of primarily Cl, SO_4 and TDS. Similar results were obtained from a review of data from the Atomic Energy Corporation database and recent data (1990-1994) from the Department of Water Affairs and Forestry. Nitrate (NO_3) was added to the list of water-quality variables with high research priority.

The effects of five different levels of F in the drinking water (< 1 mg/ℓ, 6 mg/ℓ, 10 mg/ℓ, 14 mg/ℓ and 20 mg/ℓ) on the health and growth to market weight of South African Mutton Merino wethers were investigated. No significant treatment effects were observed on growth or health. Thyroid gland weight was significantly affected by the treatment in some of the groups with a rise in thyroid gland weight with increasing levels of F in the drinking water. It was concluded, although no clinical symptoms or histopathological lesions were found, that F had a significant physiological impact on the sheep (hypothyroidism), and fluorosis would have developed with time. It was further concluded that an ingestion of 96 mg F/sheep/d of F (25 kg live weight) and 122 mg F/sheep/d of F (42 kg live weight), could be recommended for SAMM wethers for growth to market weight without any adverse effects on growth or health occurring. A similar finding was concluded in a second trial with a level of 15 mg/ℓ F in the drinking water not resulting in any significant effect on health or growth of SAMM wethers to market weight.

Fluoride levels of up to 20 mg/ℓ in the drinking water or at an ingestion rate of up to 3,206 mg F/bird/day, had no negative effects on production characteristics of Ross broilers.

No significant differences between NaF treatments regarding all major production characteristics were found in Silver Grey Hy-line layers at F levels of up to 20 mg/ℓ or an ingestion rate of up to 4,453 mg F/day/bird over a 74-week period.

Similar findings to those made with SAMM wethers were made with Bonsmara steers exposed to NaF in the drinking water to a level of 20 mg/ℓ F, with a resultant ingestion of 350 mg F/steer/day during the initial growth phase, and an ingestion of 600 mg F/steer/day during the final growth phase to market weight.

The effect of Cl and SO_4 on the palatability of water was investigated at varying TDS levels and ratios of Cl:TDS and SO_4:TDS. It was found that both variables had a significant adverse effect on the palatability of the water, judged by a decrease in the water intake for both variables and a decrease in the feed intake for the Cl variable. Sulphate appeared to have a negative effect on palatability at a lower level than Cl. No significant treatment effects were found on growth to market weight or health (clinical observations, and kidney and liver histopathology).

A 'zone of preference' in terms of water intake was identified in Friesland steers exposed to various Cl:TDS:SO_4 treatments in the drinking water. The response indicated that water intake may possibly be predicted by establishing the location of a 'zone of preference', which aids in assessing the relative importance of water quality variables in terms of toxicological, palatability and adaptation factors. All these factors are important in assessing the effect, and thus acceptance of a water source.

Saline water was found to significantly alter the bone [F] in SAMM wethers, compared to fresh water, with a significant negative correlation between salinity and bone [F] being found. A TDS concentration of 3000 - 6000 mg/ℓ appeared to have a beneficial effect on hot carcass weight in Bonsmara steers exposed to F in the drinking water.

A need for an index system to assess the suitability of water for livestock production was identified, as the present system does not fulfil this role satisfactorily. The index system should be based on the assessment of water intake for (i) toxic variables - to determine the levels of ingestion of the variable concerned, and (ii) palatability variables - to assess the impact on the variables on water requirement and feed intake. These will then be combined to form a water quality index (WQI).

More information can be obtained from Professor N H Casey, Department of Animal and Wildlife Sciences, University of Pretoria. Copies of the report are available from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Report No 301/1/96: An investigation into the quality of water for animal production. N H Casey, J A Meyer, C Coetzee, W A van Niekerk. 1996.

weather

Atlas of agrohydrology and climatology of South Africa

Scientists of the School of Bioresources Engineering and Environmental Hydrology at the University of Natal in Pietermaritzburg compiled a *South African Atlas of Agrohydrology and -Climatology*, which is of incalculable value to agriculture, forestry and horticulture in Southern Africa. Researched and published with financial support by the Water Research Commission (WRC) the Atlas consists of more than 200 colour maps graphically depicting a comprehensive volume of information on agrohydrology and agroclimatology.

Agrohydrology seeks to evaluate the influence of available water on the agricultural potential and on agricultural sustainability, with the objective of promoting a high efficiency of water use, maximising infiltration of rain and irrigation water into the soil and minimising runoff and attendant soil losses.

Agroclimatology, on the other hand, refers to the influence of weather and climate on intelligent planning of land use, selection and production of crops, managing soil moisture budgets and optimising agricultural practices for maximum economic returns.

This Atlas supersedes the publication *Agrohydrology and -Climatology of Natal* published by the WRC in 1983, which was immediately accepted as a popular reference work as well as text at several tertiary institutions. It was widely used by water resource and agricultural planners, and by consultants and farmers alike. The present Atlas represents the University of Natal's expanded research covering South Africa's nine provinces as well as Lesotho and Swaziland, so that it applies to the contiguous geographical entity referred to as Southern Africa.

The objectives of this Atlas are to map, at regional level, climatic parameters that are important in agrohydrology and agroclimatology, and to then apply this information to resource planning, primarily in the fields of water and agriculture. The Atlas is intended as a functional users' document to provide the 'big picture' in Southern Africa, but in sufficient detail to be useful in regional decision-making.

In adopting a regional approach, one of the methodologies used has been to relate climatic parameters which are measured at relatively few irregular point locations in the study area (e.g. temperature, potential evaporation), to known physiographic variables such as altitude, latitude, longitude, distance from the ocean or topographic exposure, and then to apply these relationships to mapping at points where no measurements are made. However, the Atlas presents more than maps only; also included is text on concepts and background regarding the parameters mapped, plus statistical analyses and also scientifically related information on methods used or verifications attained.

While the Atlas has a multitude of uses, it should, however, not be used to obtain what may be perceived to be 'exact' parameter values at very specific locations of interest or at farm level. The reason why one should guard against this is that, while sometimes considerable spatial detail may be presented on a map, the values at a specific point were initially derived either by regression analysis or by other simulation models (some simple, others more complex), and this has resulted in a smoothing of local effects and a dampening of outlier values. Values at a specific point should thus be viewed in relative rather than absolute terms.

Layout of the Atlas

The Atlas comprises 18 sections of varying lengths and at varying levels of detail, viz.

1. Background information
2. Physical environment
3. Solar radiation
4. Precipitation
5. Temperature
6. Heat units
7. Frost
8. Positive chill units
9. Relative humidity
10. Potential evaporation
11. Soils
12. Agricultural production potential
13. Pasture yields
14. Agricultural and horticultural crop yields
15. Timber production
16. Natural hazards
17. Irrigation requirements
18. Water resources

Support services

Support services are available to users of this Atlas with specialised requests (e.g. separate maps, enlargements or more detailed statistics). A time-based levy will be charged to service requests.

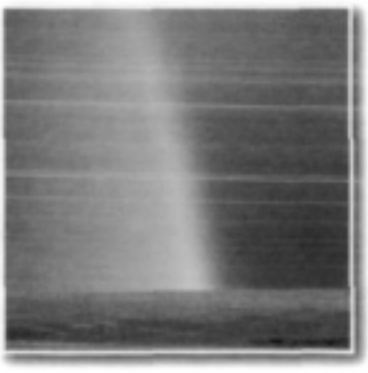
Special requests should be addressed to Professor R E Schulze (Attention: Atlas), School of Bioresources Engineering and Environmental Hydrology, University of Natal, Private Bag X01, 3209 Scottsville, fax: (033) 260-5818, E-mail: schulze@agua.ccwr.ac.za. Copies of the South African Atlas of Agrohydrology and -Climatology may be obtained from the Water Research Commission, P O Box 824, Pretoria 0001 at a cost of R190.

WRC Report No TT82/96: South African Atlas of Agrohydrology and -Climatology. R E Schulze with M Maharaj, S D Lynch, B J Howe, and B Melvil-Thomson. 1997.

Mapping rainfall over Southern Africa

For many years the basic source of information on average annual rainfall in Southern Africa was the 1:250 000 Mean Annual Precipitation (MAP) map series compiled and drawn by the Hydrological Research Division of the Department of Water Affairs in 1965, from data obtained from the South African Weather Bureau. Since then, rainfall figures for more than 20 more years have been collected and more sophisticated computer capabilities have vastly improved analysis techniques.

The Water Research Commission provided financial support for the farming, engineering and hydrological fraternities of Southern Africa to revise the MAP maps in a project initiated in 1982. The project, led by Professor Roland Schulze of the Department of Agricultural Engineering at the University of Natal in Pietermaritzburg, now the School of Bioresources Engineering and Environmental Hydrology, had the following objectives:



- Re-evaluating the distribution of mean annual and mean monthly rainfall over Southern Africa;
- Investigating rainfall variability over the area and other statistics;
- Automated mapping of these statistics; and
- Re-evaluating the regions of homogeneous rainfall distribution.

MAP is an index, which is used to characterise the overall climate and moisture status of a catchment. It has a major influence on soil conditions and the drainage characteristics of the soils, and is a dominant factor influencing type and condition of vegetation. It was used, for example, by Dr W V Pitman as a basis for regionalising Namibia into homogeneous meteorological zones. He also related the frequency of severe storms and the amount of rainfall per storm to Mean Annual Precipitation.

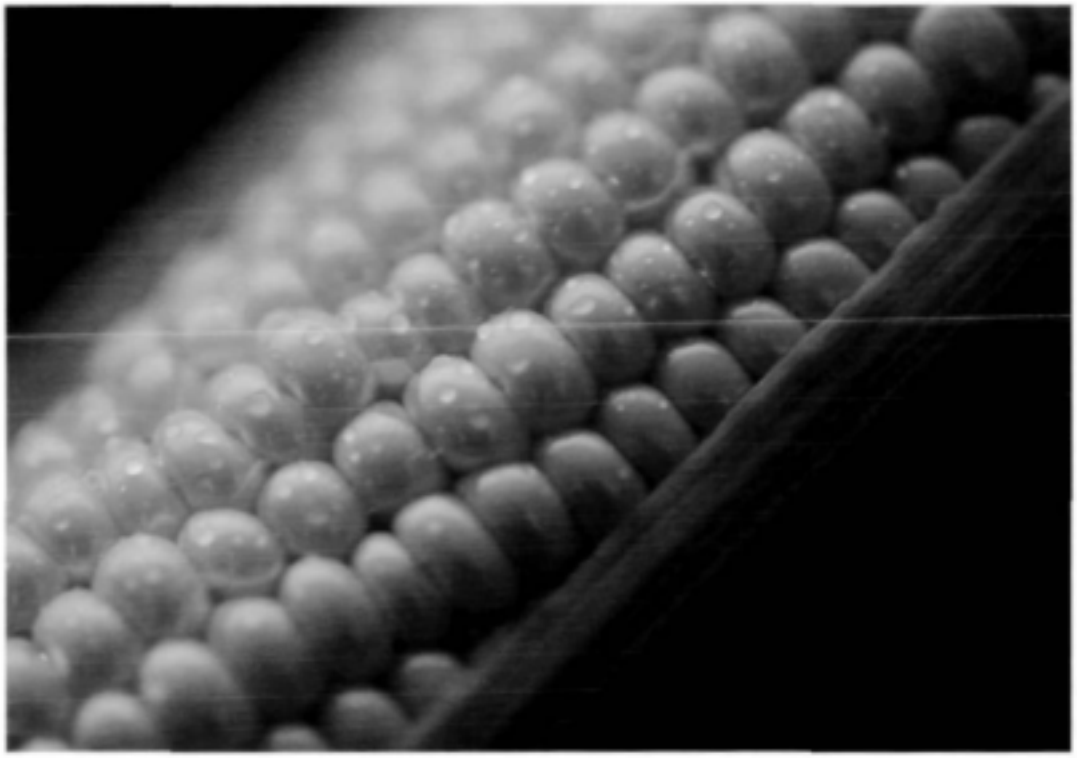
Since then many agricultural scientists have utilised MAP information in projects such as estimating mean annual runoff, depth-duration-frequency relationships for point rainfall, the relationship between rainfall, runoff and streamflow in South Africa, or determining the cumulative distribution of point rainfall rate.

In the field of agrohydrology, Rupert Jones as long ago as the early 1980s, expressed *Eragrostis curvula* yield as a function, among others, of MAP. In the same year Gavin Brockett used MAP and other variables to obtain a function for kikuyu yield, and Professor Schulze could relate MAP, among other variables, to map average first-burning dates of veld in Kwazulu/Natal. Optimum growing areas for pineapples, the first planting dates for maize in Kwazulu/Natal, and optimum growth criteria for various timber species were all related to MAP by various researchers.

It must be obvious that Mean Annual Precipitation statistics are vital to many agricultural activities, and that updating of the MAP information was timeous and necessary.

The task of mapping time- and place-related statistics regarding rainfall requires extensive data sets. Creation, collation, checking and managing these data formed a large part of the project. Daily or monthly rainfall records from over 9 000 stations made up the precipitation data set.

Since physiography plays an important role in influencing the spatial distribution of long-term average rainfall in many areas, a comprehensive set of primary and generated physiographic data was also created. The generated physiographic data were indices of continentality, exposure, distance to a mountain barrier and surface roughness. These data are prerequisites to performing spatial analyses of MAP in areas that have a complex terrain and a sparse raingauge network.



The data were assembled onto a grid of one minute of a degree. The size of this data set necessitated computerising most of the functions of checking, manipulation and management. However, patient and careful human scrutiny was also required.

Finally, 70 isohyetal maps of MAP were prepared at a scale of 1:250 000. These maps provided an efficient and effective means of communicating important and frequently applied information to a wide range of users. Digital images of all these maps were created and retained on computer tape, and are available on request.

These maps of precipitation statistics, combined with the programmes for interpolation and contouring, the monthly data file and the grid of altitude points, provide a powerful and new information base to the water research and development community of Southern Africa.

So important is the mapping of rainfall that the WRC has just recently (March 2000) commenced a follow-up research project under the leadership of Professor Schulze and project management of his colleague Steven Lynch, to revise the rainfall map of the late 1980s. This revision will make use of longer rainfall data sets and even more sophisticated computerised mapping techniques.

More information on the maps of the 1980s and the new project can be obtained from either Professor R E Schulze or Mr S D Lynch, both at the School of Bioresources Engineering and Environmental Hydrology, University of Natal in Pietermaritzburg, Private Bag X01, 3209 Scottsville.

WRC Report No109/1/89: Mapping Mean Annual and Other Rainfall Statistics over Southern Africa. M C Dent, S D Lynch, R E Schulze. 1987.

water RESOURCES

Measuring evaporation above vegetated surfaces

Three factors, which will affect future progress and development of South Africa, are population growth, AIDS and limited water resources. In particular, agriculture by the year 2010, will have to make do with less water at a much higher price. One of the most important factors affecting water supply from a catchment is the evaporation from the climax grassland community and also from forests established on agricultural and natural (especially wetland) communities. In spite of the importance of evaporation in different communities, very little research has been done in southern Africa on the processes and measurement techniques of evaporation.

If we know what the evaporation is and also have soil information and weather information from an automatic weather station, it is possible to take decisions on when to irrigate and how much water to apply. Timeous application of water is the key to the efficient use of water in agriculture.

The Water Research Commission (WRC) financed a research team under the leadership of Professor Mike Savage of the University of Natal, in co-operation with the CSIR, to undertake research in this field. Their project set out

- To investigate various methods for measuring evaporation and to compare results for different sites, seasons and weather conditions;
- To study the effect of some management practices (e.g. burning and residue placement) on evaporation;
- To compare Bowen ratio estimates of evaporation for a grassland and a riparian zone community;
- To investigate the effect of fire on evaporation in grassland and wetland communities; and
- To quantify surface roughness, turbulence and advection (wind influence) etc.

Because of roughness of the terrain, some techniques also necessitated assessing the stability of the atmosphere.

Prior to this study the Bowen ratio method for measuring evaporation had not been used in South Africa. The team thoroughly investigated this technique and got to know its strengths and limitations. They gained experience in the use of many other micrometeorological measurement methods, and obtained valuable data, for example, data that enabled the stability of the atmosphere to be assessed, and published their findings in international journals.

The sensors used in the eddy correlation methods were investigated in the laboratory in order to identify the factors limiting their accurate measurements. This method and other techniques were also used in the field above a variety of surfaces - bare soil, maize, grassland and vines, and findings compared with those of the

Bowen ratio technique, lysimetric (weighing) measurements and other methods.

In the course of the work the scientists developed a variety of methods for calibrating and improving the instruments and techniques used in measuring evaporation, and pinpointed topics which merit future research.

The report devotes a large section to a discussion and evaluation of the Bowen ratio and eddy correlation techniques, and concludes that the Bowen ratio energy balance method is suitable for the long-term monitoring of total evaporation of a grassland surface.

In irrigated agriculture, information on total evaporation is important in selecting cropping strategies, designing irrigation systems and irrigation scheduling. Methods for evaporation measurement include soil-based, plant-based and aerodynamic techniques. The latter have many advantages over the other techniques, and form the main topic of this research.

More information on this research can be obtained from Professor M J Savage, School of Applied Environmental Sciences, University of Natal, Private Bag X01, Scottsville 3209.
e-mail: savage@agron.unp.ac.za.
Copies of the report may be obtained from the Water Research Commission, P O Box 824, Pretoria 0001.

WRC Report No 349/1/97: Evaporation Measurement above Vegetated Surfaces Using Micrometeorological Techniques. M J Savage, C S Everson, S R Metelerkamp. 1997.

Water balance in a grassland catchment

Because of rising demands for water from all sectors of society, there is a need to maintain optimum water yields from South African catchments. Grassland catchment areas are also under pressure for more grazing and afforestation, and this may result in reducing the presently available catchment water yields.

The Water Research Commission (WRC) supplied the funding for a research project in this field by scientists of the CSIR's Division of Water, Environment & Forestry Technology, under the leadership of Dr Colin Everson. The project included accurate estimations of the catchment area water budget, and became the first long-term investigation in South Africa in which all the components of the catchment water balance were measured simultaneously. Evaporation, streamflow, rainfall, groundwater storage and soil water were monitored continuously over a five-year period in the catchment study site. The unique data set makes a significant contribution to our understanding of the hydrological processes that operate in montane grassland catchments.

The research team measured total evaporation using the Bowen ratio energy balance technique and compared this to evaporation estimated from annual precipitation and streamflow data. Results showed that approximately 54% of the annual rainfall was evaporated back into the atmosphere. Evaporation from wet areas was about 33% higher still, indicating that evaporation models may underestimate water losses from catchments with extensive riparian zones.

The results of the study indicated that the Penman-Monteith equation was suitable for describing the effect of environmental variables on evaporation. Soil water was modelled in four dimensions and showed the complex distribution of volumetric soil water within the hillslope. The ability to extrapolate soil moisture on a hillslope in time and space provides a powerful tool for landscape management. Soil water is a critical variable in the modelling of infiltration, flux and redistribution of water in catchments. Accurate measurement of soil water is therefore an important factor in estimating water budgets.

Changes in the soil water storage of one catchment were measured over four years and used to model the temporal and spatial distribution of soil water on a hillslope. Soil moisture changes in the grassland catchment of this study varied significantly with season. In the dry season there was a gradient of increasing moisture content downslope from the ridge. This indicated that the stream was fed by moisture moving slowly downstream under conditions of unsaturated

flow. The lower part of the slope therefore produced runoff early in the storm period while infiltration was still occurring on the upper section of the hillslope transect. The saturated area of the riparian zone increased or decreased in size depending on rainfall amount and antecedent wetness of the soil. This zone therefore produced a quick release of water during storms.

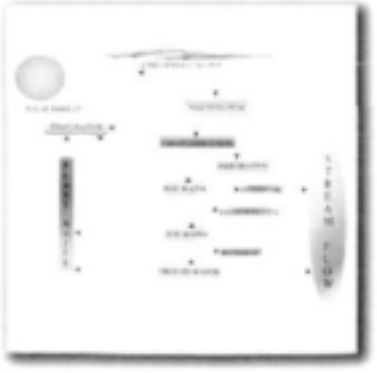
Subsurface stormflow was a major component of total stormflow from these grassland catchments. Part of the baseflow from the catchment originated from the deep coarse-textured soils. During the dry-winter period baseflow was sustained by the slow drainage of the unsaturated soil at the upper part of the hillslope. The high water levels in the saturated zone were maintained by subsurface flow from the upslope parts of the catchment.

The results of this study indicated that unsaturated subsurface flow of water in the soil is an important component of the hydrology of these catchments. Therefore lumped type models are unlikely to accurately determine the complex moisture conditions found on the hillslope of this study. Models that account for the spatial distribution of soil moisture within a catchment are likely to be the most accurate.

The data collected in this study were used to test two hydrological models, TOPOG and ACRU. The study has shown that practical difficulties around the use of TOPOG will limit its implementation, while ACRU generally predicted streamflow well, except in wet years. One of its limitations is its inability to account for subsurface soil-water flow in a catchment. Refinements may be necessary to reduce the 15% under-estimation of streamflow.

More information can be obtained from Dr C S Everson, Division of Water, Environment & Forestry Technology, CSIR, c/o Department of Applied and Environmental Sciences, University of Natal, Private Bag X01, Pietermaritzburg 3209. Copies of this report are available from the Water Research Commission, P O Box 824, Pretoria, 0001.

WRC Report No 493/1/98: Monitoring and Modelling Components of the Water Balance in a Grassland Catchment in the Summer Rainfall Area of South Africa C S Everson, G L Molefe, T M Everson. 1998.



Further Report

Summaries

Weather

Development of an objective statistical system to forecast summer rainfall over Southern Africa
(Report No 672/1/97)
MR Jury, HM Mulenga, SJ Mason, A Brandao
Department of Oceanography, University of CapeTown. 1997.

Previous research had shown seasonal rainfall forecasts to be both feasible and beneficial for managing water resources, planning crop production and minimising rain-related risks. This project was undertaken to obtain greater objectivity in forecasting by identifying atmospheric and oceanic precursor patterns which anticipate rainfall; to formulate reliable predictors; to develop algorithms; and to analyse dynamic interactions underlying seasonal rainfall. Multivariate linear regression models were developed, the number of predictors restricted to four or five out of an initial 100 candidates. The models were validated and found to possess acceptable skill.

A methodology for developing regional climate change scenarios from general circulation models
(Report No 594/1/97)
BC Hewitson
Department of Environmental and Geographical Science, University of Cape Town. 1997.

The inability to translate global-scale predictions regarding the influence of global warming on precipitation into regional-scale predictions has limited attempts to assess climate-change impacts on South Africa's water resources. The aims of this project were to validate global circulation model (GCM) simulations on South African precipitation and temperature patterns, to develop new methodology for deriving cross-scale relationships and to develop preliminary estimates of regional climate changes suitable as input in hydrological and agricultural models. Once a suitable downscaling procedure was developed, preliminary scenarios of expected temperature and rainfall changes for different parts of South Africa under double the present-day CO_2 conditions could be generated.

Development of a real-time, non-conventional rainfall mapping system
(Report No 438/1/95)
J van Heerden, MM Truter, CJ de W Rautenbach
Department of Civil Engineering (Chair of Meteorology), University of Pretoria. 1995.

A system was developed for the real-time mapping of daily rainfall using Meteosat data, calibrated on the basis of data obtained with radar and from rain-gauge networks. A procedure was designed whereby daily rainfall rates could be assigned successfully to clouds depicted in Meteosat imagery. The main features of this procedure are to classify pixel groups recognised as raining clouds into different types of rain-producing cloud types; to calculate cloud depths in terms of temperature differences between cloud bases and cloud tops; and to use a predetermined relationship for each cloud type to calculate appropriate rainfall rates from corresponding cloud depths. Maps depicting satellite-derived daily rainfall compared well with maps based on measured rainfall for non-coastal regions. Further research is needed regarding coastal regions.

South African summer rainfall variability and its association with the marine environment
(Report No 278/1/94)
BMR Pathack, MR Jury, FA Shillington
Department of Oceanography, University of Cape Town. 1994.

Predictions of rainfall anomalies would have enormous benefits for water resources management and other socio-economic activities. This project set out to provide an objective statistical basis for such predictions on monthly to seasonal time scales. Rainfall fluctuations were analysed in association with fluctuations of sea surface temperature (SST) and other appropriate meteorological variables in a belt around the globe between 20°N and 40°S. Key ocean areas in which SST was strongly associated with subsequent summer rainfall over South Africa were identified. The research revealed a range of indicators with potential for use in an empirical model for predicting summer rainfall anomalies.

Interpolation of the daily rainfall model.
(Report No 305/1/94)
L McNeill, A Brandao, W Zucchini
Department of Mathematical Statistics, University of Cape Town, 1994.

The main objective of the project was to provide, through interpolation, estimates of the parameters at sites throughout South Africa for which little or no rainfall data were available. Parameter values could be interpolated on a regular grid of one minute of a degree covering 500 000 sites over Southern Africa at a resolution of about 1,5 km. This model can be used to generate daily rainfall sequences and to deduce a wide range of rainfall characteristics at any location in Southern Africa.

Research on the climatic dependence of evaporation coefficients
(Report No 280/1/94)
WH van Zyl, JM de Jager
Department of Agrometeorology, University of the OFS. 1994.

This project aimed at identifying the relationship between climatic variables and variables in crop factors. Traditionally, establishing a specific set of crop factors at any one location was time-consuming, spanning a number of seasons. Extrapolation of these factors to other locations was also very difficult. The project team isolated the influences of various climatic variables such as radiation, wind and humidity on variation in crop factors and expressed these relationships in mathematical terms. Given the climate at any location, they can now determine applicable crop factors with confidence. Sound irrigation scheduling, of which crop factors are a core component, can therefore be implemented swiftly and with confidence at such locations.

The generation of a spatially distributed daily rainfall database for various weather modification scenarios
(Report No 373/1/92)
AW Seed
Hydrological Research Institute Department of Water Affairs and Forestry. 1992.

A realistic state of the art set of natural and modified area rainfall series applicable in the Bethlehem-Nelspruit region was needed as a foundation for rainfall modification impact studies. This project developed the necessary models and data sets to generate such series, using available records of daily rainfall and data on the mean radar-estimated effects of seeding on individual convective cloud complexes. The increase in mean annual rainfall observed during the PAWS experiment (1984/85 to 1986/87) was estimated at 7,3% for daylight hours seeding. The effect of weather modification on a particular day showed great variability. A fast rainfall interpolation algorithm was developed together with a database management system, capable of managing 6 000 rain maps within a single base.

Research on a weather service for scheduling the irrigation of winter wheat in the Orange Free State region
(Report No 117/1/87)
JM de Jager, WH van Zyl, BE Kelbe
University of the O F S. 1987.

This project demonstrated the feasibility of providing an effective irrigation-scheduling service on an irrigation scheme such as Vaalharts. Meteorological data from an automatic weather station in the Vaalharts area were obtained daily in Bloemfontein and processed through the PUTU-9 irrigation-scheduling model for wheat. Logistics of communicating information and advice to farmers were developed and tested. The ability of PUTU-9 to assess the degree of crop-water stress on a continuous basis proved to be of considerable value for working out irrigation scheduling strategies for coping successfully with water restrictions which were in force at the time. The PUTU-9 model itself, developed under a previous research contract, was further tested and refined.

Programme for atmospheric water supply. Phase 1, 1983-1986.
Volume 1: Executive summary.
Volume 2: Natural clouds and rain in Nelspruit.
Volume 3: Experimental seeding of Nelspruit clouds.
Volume 4: Instruments, techniques and studies.
(Report Nos 133/1/88, 133/2/88, 133/3/88 133/4/88)

Programme for atmospheric water supply Phase 2, 1987 - 1989
Vol. 1: Executive summary
Vol. 2: Aircraft and radar measurements and cloud seeding experiments
Vol. 3: Radar data interpretation, cloud modelling and statistical considerations
Reports 133/5/90, 133/6/90, 133/7/90
Company for Research on Atmospheric Water Supply, and Department of Environment Affairs (Weather Bureau). 1993

Rain clouds are potentially the most easily and economically exploitable high-quality water source. Research on the potential of rainfall augmentation through cloud seeding has centred around Nelspruit, Carolina and Bethlehem, since 1983. Initially dry ice crystals were sown in the clouds, and afterwards hydroscopic salt particles were introduced by means of pyrotechnic flares into updraughts at the bases of clouds. This report describes the significant results obtained in a single season in 1991/92 during a random seeding experiment. Progress was made in understanding some of the physical mechanisms involved in the cloud responses to hygroscopic seeding. This progress was based on cloud physical calculations taking into account aircraft-observed sizes and numbers of naturally-occurring cloud condensation nuclei, of flare-produced dry salt particles and of cloud particles in treated and non-treated clouds. The calculations, carried out by collaborators at the National Center for Atmospheric Research in the USA, confirm that cloud liquid water, initially occurring in the form of minute cloud droplets, is much more rapidly and completely converted into precipitation-size drops in treated than in untreated clouds. Follow-up research was aimed at verifying the 1991/92 results, at assessing total enhancement of areal rainfall (as opposed to isolated storm rainfall) over a specified target area and confirming runoff, water yield, agricultural production and forestry responses to seeding.

Water Resources

Development of flood-damage functions and a computer program to determine the advantages of flood and flood damage-control measures (In Afrikaans: Die ontwikkeling van vloedskade-funksies en 'n rekenaarprogram om die voordele van vloedbeheer- en vloedskadebeheermaatreëls te bepaal. Deel 1: Samevattende verslag. Deel 2: Besproeiingsgebied. Deel 3: Stedelike gebied)
(Report Nos 490/1/96, 490/2/96, 490/3/96)
MF Viljoen, LA du Plessis, HJ Booysen
Department of Agricultural Economics, University of the OFS. 1996.

Computer programs were needed for estimating the damage wreaked by floods, which occur on average every two years in South Africa. The programs are aimed at integrating the hydrological information on floods with the topographical properties of the flood-plain, as well as with the land uses within the flood-plain and the flood-damage functions of the various land uses (the relationships indicating the damage done to a specific land use, for example, for various flood-water depths). Studies were conducted in urban (Vereeniging and Upington) municipal areas, and an irrigation area (upstream and downstream of Upington). Appropriate computer programs were developed and their application demonstrated. It was, for example, shown that the models could be used to estimate the average annual damage; and that that they could be applied to determine the benefits of flood control measures in irrigation and urban areas.

Potential impacts of rainfall stimulation on water resources and forestry in the Nelspruit-Bethlehem target zone.
(Report No 439/1/94)
GJ Howard, AHM Görgens
Ninham Shand Cape Inc. 1994.

Research has provided strong evidence that increases in convective storm rainfall can be brought about by appropriate cloud-seeding. This project examined possible impacts of an operational cloud-seeding programme on water resources and forestry in parts of the Eastern Transvaal highveld and adjacent escarpment region. The ACRU model was configured and verified for 13 catchments in the region. For a mean annual rainfall increase by augmentation of 7%, the model predicted increases of 20 to 48% for catchment runoff, 14 to 42% for reservoir yield and 16 to 30% for timber yield.

Rainfed/Dryland agriculture

The feasibility of stochastically modelling the spatial and temporal distribution of rainfields
(Report No 550/1/98)
GGS Pegram, AW Seed
Department of Civil Engineering, University of Natal. 1998.

Water resource engineers often require information of how rainfall associated with storm and prolonged rain events is distributed in space and time. The limited and declining number of rain gauges in the national network cannot satisfy this need. Radar rainfall-measurement technology has the potential but cannot fulfil the need because of its restricted availability. The alternative was to investigate the modelling of simultaneous spatial and temporal behaviour of rainfields to enable the space-time occurrence of rainfall to be simulated realistically for training and design purposes. The development of a rain-day model based on sequential occurrences of dry, scattered and rain days, for simulating the distribution of daily rainfall amounts over a large area was continued. Special attention was given to accurate representation of seasonal variations over the year. Also, the modelling of spatial distribution of rainfall at given times slices was investigated to enable the variability and clustering nature of the rainfall process as observed by radar to be replicated.

Modelling the water balance on benchmark ecotopes
(Report No 506/1/97)
M Hensley, JJ Anderson, JJ Botha, PP van Staden, A Singels, M Prinsloo, A du Toit
Institute for Soil, Climate and Water, Agricultural Research Council. 1997.

The soil-water balance is an important component of crop growth and hydrological models. Confidence in these models, which are potentially powerful tools for planning and management, would be greatly enhanced if they could be made to perform credibly over the wide range of typical soil, climate and land management conditions encountered in South Africa. There had been no previous attempts to systematically obtain representative data sets for typical land units (ecotopes) representing specific crop-soil-climate combinations. In testing different models using the benchmark data sets, certain strengths and weaknesses in their ability to simulate both water balances and crop yields were revealed. The sources of many of the weaknesses were identified for future improvement.

The determination of the relationship between transpiration rate and declining available water for *Eucalyptus grandis*
(Report No 441/1/97)
PJ Daye, AG Poulter, S Soko, D Maphanga
Division of Water, Environment and Forestry Technology, CSIR. 1997.

In attempting to answer questions regarding soil-water content, transpiration rates and water stress in *Eucalyptus*, elaborate measures were taken to induce plantation water stress by preventing rain from recharging soil-water. Although the soil dried out to a depth of at least 8 m, deep drilling revealed live tree roots at 28 m below the surface. Thus, accessibility of deep soil water to trees was preventing development of material water stress even after more than a year of withholding water. Under such conditions new plantations may continue to use water at near-potential rates for several years after establishment, until all accessible stored water has been depleted.

Storage and utilisation of rainwater in soil for the stabilisation of plant production in semi-arid regions. (In Afrikaans: Opgaring en benutting van reënwater in grond vir die stabilisering van plantproduksie in halfdroë gebiede)
(Report No 227/1/94)
ATP Bennie, JE Hoffman, MJ Coetzee
Department of Soil Science, University of the O F S. 1995.

Because little information was available on the impact of various soil-cultivation and land-use practices on rainwater storage in the soil and its subsequent use, it was necessary to investigate the most efficient land-use and soil-water management practices to ensure most effective use of the water. Water-use efficiency was calculated in terms of above-ground biomass, gross income and net income. With these results known the costs of water losses due to runoff, evaporation or deep percolation could be quantified in the same manner. The research indicated that rotational cropping, with conventional tillage was the most sustainable and economic. Conservation tillage could not be recommended due to the high cost of chemical weed control and lower yield. When pastures were established in place of veld the rain-use efficiency doubled, and when veld was converted and cultivated for crop production, rain-use efficiency was increased three- to fourfold.

Drought-tolerant and water-efficient fodder shrubs (DTFS): Their role as a "drought-insurance" in the agricultural development of arid and semi-arid zones in Southern Africa.
(Report No KV65/94)
HN le Houérou
Consultant. 1995.

Drought-tolerant fodder shrubs (DTFSs) are cultivated on approximately 10 million ha of the world's arid and semi-arid areas as an agricultural development aid - and on approximately 800 000 ha in South Africa. The species most frequently planted locally are saltbush, green cactus, blue cactus and agave. These plants thrive on a relatively wide range of soils and are salt-tolerant so that they can be cultivated under irrigation with water of a high salt content, rendering animal production possible in areas where natural vegetation is not always reliable. The report evaluates the cultivation of these DTFSs with regard to soil, climatic and water requirements, their water utilisation efficiency, their establishment and management as feed crops, the economic aspects of DTFS cultivation, and the danger of their becoming invader plants.

Evapotranspiration and water use studies in wheat and soybeans with the help of the weighing lysimeter technique
(Report No H2/1/87)
WS Meyer, DM Oosterhuis, PR Berliner, GC Green, AJ van der Merwe
Soil and Irrigation Research Institute, Department of Agriculture and Water Supply. 1987.

The project aimed at generating a better understanding of processes in the soil-plant-atmospheric continuum, which are important in determining the water and irrigation requirements of crops. Objectives were to improve understanding of the process of water movement through the soil-plant-atmosphere system; the onset and early detection of water stress in plants; and the effect of different degrees of stress on crop growth and development and how this affects subsequent water use, growth, development and yield. Two crops, namely wheat and soybeans were grown in rotation and studied. The project yielded new techniques and insights and demonstrated that better understanding of water relationships in the soil-plant-atmospheric continuum can lead to the achievement of high water use efficiencies in irrigation.

Irrigation

Response of potato genotypes to different irrigation water regimes
(Report No 389/1/96)
MJ Steyn, HF du Plessis, P Fourie
Roodeplaat Vegetable and Ornamental Plant Institute, Agricultural Research Council. 1996.

The effects of soil-water regimes on 14 potato genotypes were investigated during four autumn and three spring plantings. The influence of different treatments on tuber yield and size distribution, internal quality, root development and water use was studied. Photosynthetic rate and stomatal resistance were evaluated as screening methods for drought tolerance in potatoes. It was found that the influence of water stress on tuber yield and size was seasonal: yield and size distribution was adversely affected in spring plantings when stress was aggravated by high evaporative demand and high temperatures. In spring the ranking of genotypes according to total yield changed for the different water regimes, indicating differences in adaptability to water stress. For the autumn plantings yield rankings did not change but water stress shifted size distribution downwards in all genotypes. Tuber density and chip colour was influenced by water regimes only in autumn, with best quality obtained from the most stressed treatments for all genotypes. Changes in the magnitudes of stomatal resistance and photosynthetic rate with increasing water stress were good indicators of drought tolerance. Drought had no effects on root development.

Effect of pre-programmed deficit irrigation on plant growth (In Afrikaans: Reaksie van gewasse op voorafgeprogrammeerde tekortbesproeiing)
(Report No 423/1/97)
ATP Bennie, LD van Rensburg, MG Strydom, CC du Preez
Department of Soil Science, University of the Orange Free State. 1997.

The aim of this project was to extend the capabilities of BEWAB, a computer program which can be used for irrigation planning and management at farm level, and to test and refine where necessary, its capacity to provide correct recommendations for conditions of controlled water stress. The best soil-water management option for controlled deficit irrigation included depletion of all available soil water by the end of the season. Longer (two-weekly) intervals between irrigations proved to be more effective for deficit irrigation and helped to combat non-productive loss of water by evaporation from the soil surface. Well-planned deficit irrigation resulted in crops adapting to the drier conditions; plants are shorter and leaves smaller, with reduced transpiration rates.

The influence of different water and nitrogen levels on crop growth, water use yield, and the validation of crop models
(Report No 307/1/95)
S Walker, TP Fyfield, JPA McDonald
Institute for Soil, Climate and Water, Agricultural Research Council. 1995.

Crop growth and irrigation-scheduling models are powerful aids for irrigation planning and management. This project aimed at identifying the weaknesses of such models and improving them. Valuable comprehensive data sets were acquired. These comprised growth and physiological measurements relating to wheat crop growth and development for a wide range of water- and nitrogen-supply conditions over a period of four seasons. Other products of this research were guidelines and precautions relating to the use of measuring equipment, and the development of useful measuring techniques.

Long-term salt balance of the Vaalharts irrigation scheme
(Report No 420/1/96)
CE Herold, AK Bailey
Stewart Scott (CE) Inc.1996.

A study of the Harts River in 1987 showed that little of the salt contained in the Vaalharts irrigation water left the area via surface return flows. To determine the validity of these findings and discover what happens to the salt, a hydro-salinity model was compiled to simulate the long-term behaviour of the system. It was confirmed that Vaalharts is operating as a salt sink and has already accumulated two thirds of the total dissolved salt load of the irrigation water since the late 1930s.

Transfer of research results on the irrigation of vegetable crops into practice (In Afrikaans: Die fasilitering van tegnologie-oordrag deur verbeterde besproeilingsriglyne vir groente en 'n meganistiese gewasmodelleringsbenadering)
(Report No 476/1/96)
JG Annandale, AJ van der Westhuizen, FC Olivier
Department of Plant Production and Soil Science, University of Pretoria. 1996.

Investigations into irrigation of vegetable crops in the Loskop irrigation area showed reluctance to apply sound irrigation-scheduling techniques because of uncertainties regarding cost and benefits. The research was extended to demonstrate the applicability of scientific irrigation scheduling at farm level, and to reduce the costs and increase the benefits of this practice. It was found that the most successful instruments for transferring advanced irrigation management technology into practice were crop simulation models operated by advisers and consultants. Development of a universally applicable, user-friendly, generic, mechanistic crop-simulation model with the necessary adjustments of soil and crop parameters was initiated.

Saptact 1.0 - A computer program for qualitative evaluation of irrigation farming
(Report No 382/1/96)
CT Crosby
Murray, Biesenbach and Badenhorst Inc. 1994.

The objective was to assess ways and means of incorporating qualitative research techniques in a practical system for acquiring, analysing and presenting data and information relevant to the viability of irrigation farming. Utilisation and presentation of information gathered were achieved through the development of a computer program PFACT (South African Procedure for assessing farming FACtors). The project clearly showed that there is a place for qualitative research in agriculture and engineering with special reference to irrigation. It also emphasised the potential role of the individual farmer in contributing to the design of new technology and development programmes. The increasing attention being given to small-scale farmers who operate in circumstances unfamiliar to many specialists has revealed that farmers' perceptions are as important as 'facts' available to the specialist. The project revealed specific relevant perceptions in farmers which should be taken note of in developing proposals, and indicated the low priority that most farmers place on irrigation management, as well as the almost complete dearth of effective irrigation extension.

The response of citrus seedlings to soil compaction and variations in soil water potential in the upper range of plant-available water
(Report No 261/1/96)
SS Mkhize, FMG Vanassche, MC Laker
Department of Plant Production and Soil Science, University of Pretoria. 1995.

The use of micro-irrigation systems tends to keep the soil too wet, leading to oxygen deficiencies in the root zone, which result in degeneration of the plants and aggravation of root diseases. The main objective of this project was to improve irrigation management under high-frequency micro-irrigation. In order to alleviate problems experienced by citrus growers, two citrus root-stocks were selected for the experiments in the project. The two plant parameters most affected by high bulk density soil under high soil-water potentials, were the size of the root system and root hydraulic conductivity. The project was concluded with an irrigation scheduling trial at an established citrus estate. Implementation of recommendations by the research team resulted in significant savings in irrigation water and pumping costs, an increase in yield and an improvement in the quality of the yield.

Small-scale irrigation in South Africa
(Report No 578/1/94)
M de Lange
MMB Inc. 1993.

An appropriate irrigation system has to enable the farmer to optimise the natural resources. In addition, the physical characteristics of the irrigation system have to be such that the farmer is capable of using it, and that its performance is acceptable from a water usage point of view. Financial considerations will provide the incentive and motivation for these farmers to switch over gradually to commercial irrigation farming. The need is therefore for relatively inexpensive, less complicated irrigation systems. This 2-two-year project aimed on the one hand at evaluating existing irrigation techniques and equipment with a view to their use by subsistence and emergent farmers, and on the other hand establishing design approaches and criteria with a view to effective planning and application of irrigation under developing conditions.

An evaluation of the four-electrode electro-magnetic induction techniques of soil salinity measurement
(Report No 269/1/94)
AL Batchelor, WE Scott, A Wood
Department of Agronomy, University of Natal. 1994.

Salinisation of irrigation land is experienced to a greater or lesser degree at virtually all irrigation schemes in South Africa. World-wide, it is one of the major factors which impedes the sustainable use of irrigation land. Determination of the extent of the problem and trends over time is hampered by the time-consuming nature of sampling and the cost of laboratory analyses required by traditional surveys of soil-salinisation. The suitability of instruments and techniques developed overseas for the accelerated measurement of soil-salinisation was evaluated during this project. Relationships were established between instrument readings and traditional laboratory determinations for a wide range of soils, and were tried in practice. Good correlation was achieved between the accelerated and the traditional methods of measurement. The accelerated methods are, however, considerably less expensive.

Research on maximising irrigation projects efficiency in different soil-climate-irrigation situations
(Report No 226/1/94)
R Mottram, JM de Jager
Department of Agrometeorology, University of the OFS. 1993.

The main aim of the project was to implement and test irrigation-scheduling methodologies under practical farm situations. The results prove conclusively that scientific irrigation scheduling not only results in greater water-use efficiency, but is also amenable to practical, day-to-day farm operations. In situations where farmers had sufficient water, the scheduling procedures maximised yield without necessarily increasing total water use. In water-deficient situations the scheduling programme was able to indicate water requirements at critical growth stages, so minimising yield decrease. The experiments also showed that successful transfer of new technology, such as irrigation scheduling, requires intensive co-operation between researcher and the farming community.

Water-use efficiency of certain irrigated temperate pasture species (In Afrikaans: Waterverbruik en waterverbruiks-doeltreffendheid van gematigde aangeplante weidings onder besproeiing)
(Report No 257/1/94)
RE Steynberg, PC Nel, NFG Rethman
Department of Plant Production, University of Pretoria. 1994.

The main aim was to determine the water consumption and water-use efficiency of different pasture species, and to establish irrigation standards for the species. A field test was conducted under a rain shelter to accurately determine water consumption for 10 pasture species. It was concluded that a single set of irrigation criteria for pasture species was inadequate for efficient irrigation management and water utilisation. The species were found to have considerably deeper root systems than had generally been accepted. The rooting depth of 300 mm which had in the past been used for planning purposes can be increased for all species. The rooting depths of the various species showed definite variations.

Development of criteria for sprinkler irrigation systems to combat surface sealing of soils (In Afrikaans: Aanpassing van oorhoofse besproeiingstelsels by die infiltreerbaarheid van gronde)
(Report No 208/1/92)
AA Bloem, MC Laker, LF la Grange
Department of Pedology, Potchefstroom University for CHE and Department of Agricultural Engineering, University of Pretoria. 1992.

Against the background of problems caused by crust formation, or sealing under sprinkler irrigation, the project aimed to quantify the factors influencing infiltration ability as well as soil-water dynamics; to establish an irrigation simulator and infiltrometer; and to make recommendations on the adaptation of sprinkler irrigation systems for more effective water utilisation under conditions of crust formation. An irrigation simulator which can produce a spectrum of drops of a uniform size at different energy levels was developed by the Department of Agricultural Engineering. It eliminates a number of the shortcomings of other simulators. The Department of Pedology compiled an index which included drop size, application rate, drop speed and infiltration ability, and which correlated well with erosion. The final infiltration ability of 67 South African soils was determined at four energy levels and correlated with the physical-chemical properties of the soils. Using these results, predictions can be made of the final infiltration ability and the maximum allowable irrigation energy flow of a soil based on its properties.

The quantification and limitation of water losses associated with centre-pivot irrigation systems. (In Afrikaans: Identifisering, kwantifisering en beperking van waterverliese onder spilpuntbesproeiingstelsels)
(Report No 153/1/91)
C van der Ryst
Department of Agricultural Engineering and the Department of Agronomy, University of the OFS. 1991.

Because of problems experienced with using the conventional uniformity index in the case of centre pivot systems, a new approach, known as the emitter index, was defined and tested. This index was shown to be feasible in practice when the correct design approach was used. The project also showed that, in order to limit wind and evaporation losses, drop sizes under centre pivot systems must be of the order of 1 to 3 mm in diameter. A mathematical relationship between evaporation losses, wind speed, vapour-pressure deficit and the depth of application was established, based on project observations. A set of recommendations on the design, construction and management of centre-pivot irrigation systems was formulated.

Low pressure flow control mechanism for flood irrigation
(Report No 207/1/91)
JH Eckard, AD Brink, G Vorter
Department of Agricultural Engineering, University of Pretoria. 1991.

The objective was to develop a simple flow-control mechanism by means of which flow for flood-irrigation purposes could be maintained within approximately 10% of a pre-selected value. The outcome was an immersed spout which is held under the water surface by means of a float. The spout is connected to the dam outlet by means of a sturdy pipe and flexible coupling. By changing the spout size and/or its depth under the water surface, the delivery rate can be varied to the required value to suit particular circumstances. General use of the mechanism can make a significant contribution to the standard of flood irrigation in South Africa.

The economic evaluation of alternative irrigation-scheduling strategies for wheat in the irrigated area of the Orange Free State (In Afrikaans: Ekonomiese evaluering van alternatiewe besproeiingskeduleringstrategieë vir koring in die Vrystaatstreek)
(Report No 218/1/91)
LK Oosthuizen
Department of Agricultural Economics, University of the OFS. 1991.

The project indicated clearly that size, static head and delivery rate of a centre pivot system are the

major factors affecting the economic viability of the system. The research also showed that irrigation scheduling practices resulted in a saving of water and also increased the net income of the farmers.

Correction factors for evaporimeter coefficients used for scheduling irrigation of wheat
(Report No 151/1/89)
WH van Zyl, JM de Jager, CJ Maree
University of the O F S. 1989

Results of this project proved conclusively that the use of a single crop evaporation coefficient per crop per season was not correct. This report introduces a new concept, namely atmospheric evaporation demand (AED). This description of upper-limit evaporation eliminates much of the confusion which existed in the past as to whether to use maximum, potential, basal or reference evaporation to express upper-limit evaporation. The Penman-Monteith equation, weather data from an automatic weather station and a canopy surface conductance value of 0,06 m s^{-1} can be used to estimate reference evaporation accurately. This estimate, together with the crop evaporation coefficient defined in this report must now be regarded as the most accurate method of calculating AED. This approach greatly facilitates and improves the scheduling of irrigation.

Studies on irrigation management based on PAWC and soil-water monitoring
(Report No 166/1/89)
FMG Vanassche, MC Laker
University of Fort Hare. 1989.

The project studied plant-available water capacities (PAWC) for wheat, durum wheat and maize crops, and the effect of soil-water stress at various growth stages on the yield of these crops. It was found that moderate stress, defined as the extraction of 100% of PAWC, did not reduce the yields of either maize or wheat, but had a marked detrimental effect on durum wheat yield. Pre-dawn leaf-water potential (PLWP) was proved to be a reliable parameter for the identification of first material stress (FMS) in both immature and mature plants. A standardised procedure for PLWP measurements, described in the report, proved very reliable and yielded highly reproducible results, offering a reliable technique for PAWC determinations for a crop at any growth stage. The study also proved that deficit irrigation can be applied successfully during peak demand periods without reducing yields or irrigation water-use efficiencies. In fact, deficit irrigation generally gave higher irrigation-water efficiencies than full irrigation, proving the validity of the PAWC concept for irrigation scheduling.

Crop-water requirements, deficits and water yield for irrigation planning in southern Africa
(Report No 118/1/88)
MC Dent, RE Schulze, GR Argus
University of Natal. 1988.

The project set out to provide the irrigation planner with the means, firstly, of helping to decide on the need to irrigate a given crop in a specific environment and, secondly, of assessing the irrigation requirements of the crop at various levels of risk. Clearly the large number of possible combinations of crop, soil and climate peculiar to a planting location and date, made the potentially unmanageable bulk of a complete set of guidelines something to be avoided. Solutions were found to the problem of reducing bulk, while retaining the essential detailed information provided by a comprehensive analysis. Analyses were carried out for each of 712 homogenous climate zones throughout southern Africa, especially delimitated for this purpose. This spatial detail and resolution constituted a considerable improvement, compared to that achieved in previous presentations of estimated irrigation requirements of crops in South Africa.

Physical-chemical properties of soils bordering the Mooi river after long periods of irrigation (In Afrikaans: Fisies-chemiese eienskappe van gronde langs die Mooirivier wat oor 'n lang termyn besproei is)
(Report No 135/1/88)
DJ Nel
Potchefstroom University for C H E. 1988

Owing to the distribution of soils in the area under investigation, a meaningful comparison of the extent to which different soils, which had been irrigated for different periods, had degenerated, was not successful. It was found, for instance, that certain soils on the flood plain which had been irrigated for almost 75 years, are not found in the higher-lying areas. The latter have been irrigated for 20 years. Another aspect which was investigated is the influence of magnesium in the soil and water of the area on the chemical and physical condition of the soil. Several aspects concerning the influence of magnesium on *inter alia* clay mineralogy, ion exchange and the release of electrolytes were studied intensively. The results of these studies have contributed to a better understanding of the swelling and dispersive characteristics of soils.

Proceedings of the South African Irrigation Symposium
(Report No TT 71/95)
The SA Irrigation Institute, SA Society of Crop Production, SA Institute of Agricultural Engineers, Soil Science Society of SA, Agricultural Economic Association of Southern Africa, Water Research Commission. 1991.

This report constitutes the Proceedings of the Second National Irrigation Symposium held in 1991 in Durban. It contains the opening address by Dr Al van Niekerk MP, Minister of Agriculture, and the keynote address: Spotlight on irrigation development in the RSA: the past, present and future, by JJ Bruwer and PS van Heerden. These are followed by papers on various subjects in the following fields:

- International Perspectives on Irrigation
- Soil and Water
- Crop-water Relationships
- Engineering and Design
- Irrigation Planning
- Irrigation Management
- Economics of Irrigation
- Information and Technology Transfer

Livestock

Biological and chemical control of blackflies (Diptera: *Simuliidae*) in the Orange River
(Report No 343/1/95)
RW Palmer
Onderstepoort Veterinary Institute, Agricultural Research Council. 1994.

This project was undertaken in response to complaints from farmers whose stock was being affected by the biting of pest blackflies. The efficacy of the larvicide *Bacillus thuringiensis* var *israelensis* (Bti) and of the organophosphate temephos was investigated. It was found that Bti was better suited for use in clear water, and temephos for turbid water. Temephos was found to "carry" about 3 times farther than Bti. Development rates of *S chutteri* range from 7 days in mid-summer to 37 days in mid-winter. The recommended time intervals between treatments consequently ranged from 6 to 32 days. Dosage indicated that Bti has a wide margin of safety, other than temephos. It was concluded that good control of blackfly may be obtained with minimal impact on the non-target fauna, provided recommended dosages of temephos are not exceeded. Overdosing should be strictly avoided.

Principles of integrated control of Blackflies (Diptera: Simuliidae) in South Africa
(Report No 650/1/97)
RW Palmer
Onderstepoort Veterinary Institute, Agricultural Research Council. 1998.

Natural flow variations in water resources are removed by increased flow control and management, and this stimulates development of blackflies (*Simulium* spp). The microbial larvicide *Bacillus thuringiensis* var *israelensis* and an organophosphate larvicide were effective but costly. This project set out to investigate ways to increase the efficiency of using these methods to control blackflies by studying the relationship between population dynamics and variations in the ecosystem. It was found that outbreaks were related to temperature and that they could be predicted by monitoring the larval and adult numbers. Decisions to spray are based on SSnumbers, combined with factors such as river flow and temperature. Observations indicated that *Microcystis* blooms might be toxic to larvae, that the bivalve *Corbicula fluminalis* might limit numbers as they compete for the same food source, and the alga *Cladophora glomerata* provided habitat for predators. All this information was brought together in a model, which assists in the decisions of when to apply larvicide.

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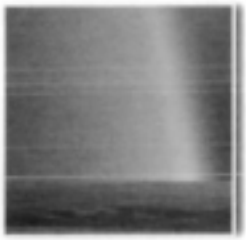

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(Part 1: Text. Part 2: Appendices)
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