1993

Annual Report

Water Research Commission

Mission statement

To contribute effectively to the best possible quality of life for the people of South Africa, by promoting water research and the application of research findings.

Therefore, the WRC endeavours dynamically and purposefully to:

- *Promote co-ordination, communication and co-operation in the field of water research*
- *Establish water research needs and priorities*
- *Fund water research on a priority basis*
- *Promote effective transfer of information and technology.*

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1993

Annual Report

Water Research Commission

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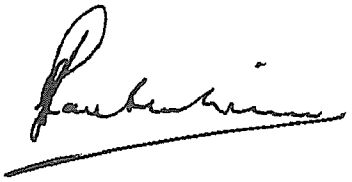
WATER RESEARCH COMMISSION
PO BOX 824
PRETORIA
0001
31 MARCH 1994

Dear Mr Van Wyk

We take pleasure in submitting to you, herewith, the report of the Water Research Commission for the period 1 January to 31 December 1993.

The balance sheet and statement of revenue and expenditure for the financial year to 31 December 1992, as certified by the Auditor General, as well as a receipts and payments account for the year ended 31 December 1993 and a budget for 1994, are furnished under ***Financial Statements*** *of this report.*

Yours respectfully



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Contents

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(Water sources; urban water reticulation; water and sanitation for developing communities; water utilisation for agricultural and ecological purposes)

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Dr HM Saayman
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Dr PCM Reid
Mr AG Reynders

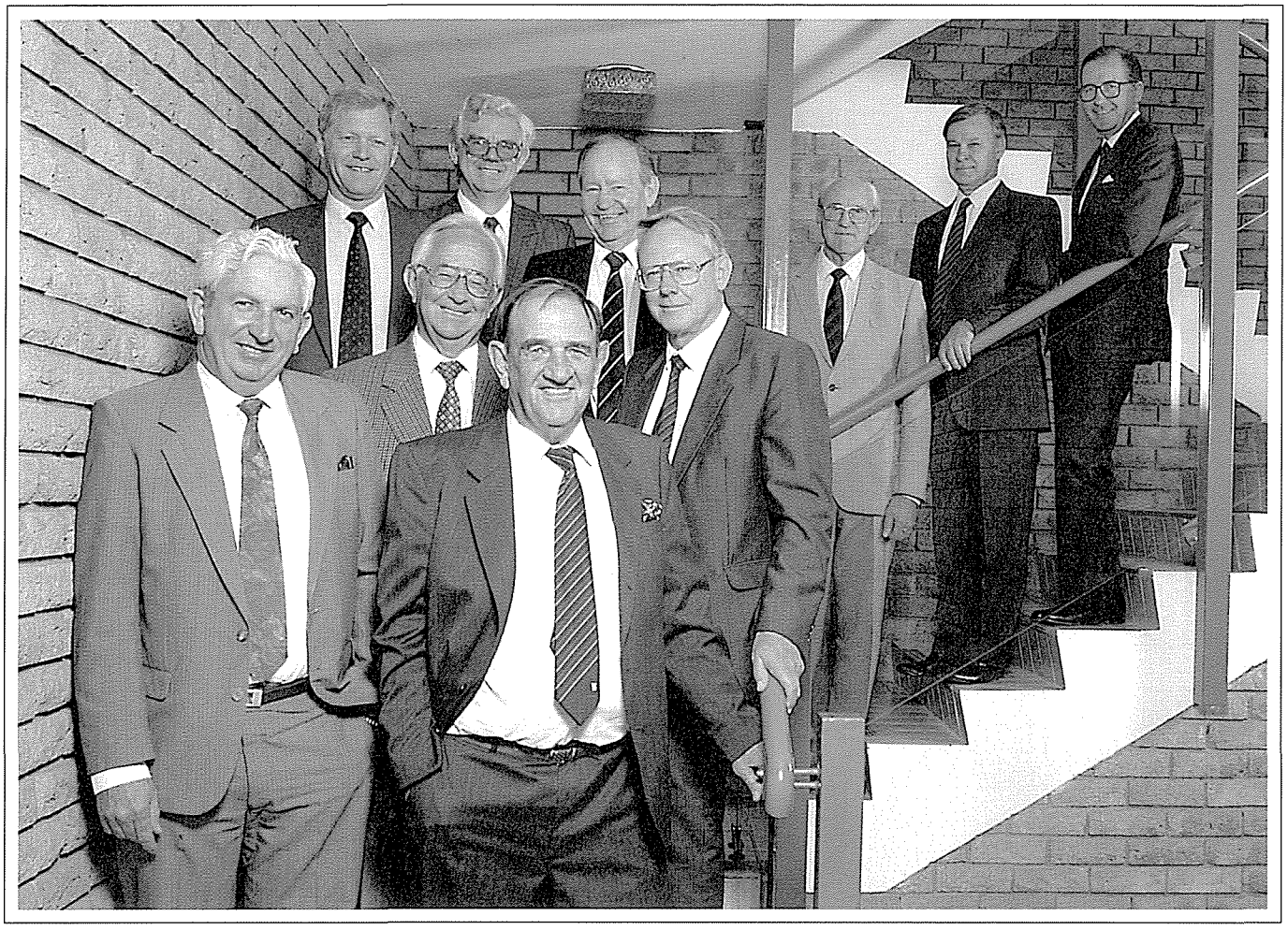
Administrative

Director: Administration

Mr PM van der Schyff

Members of the Water Research Commission

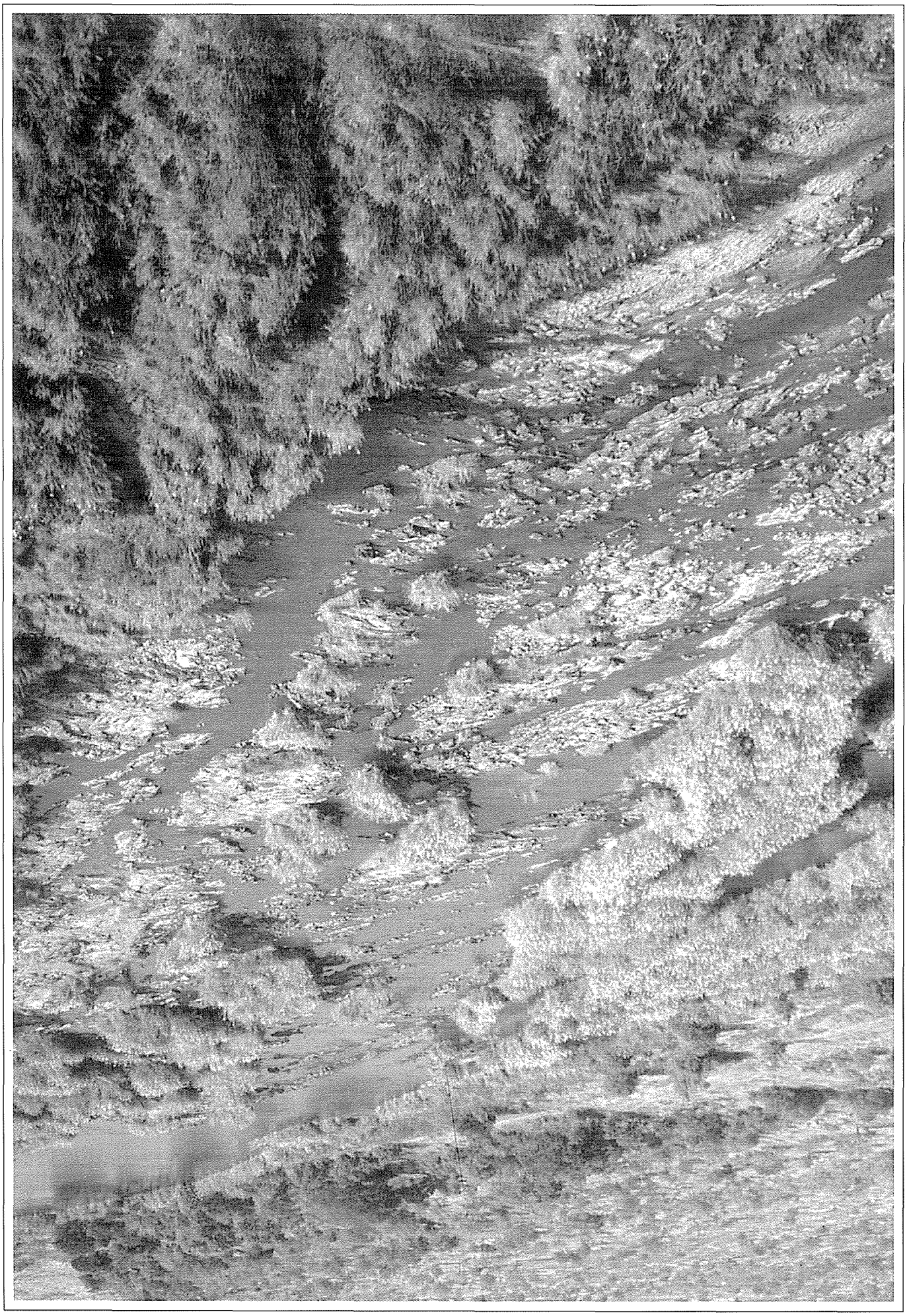
as on 31 December 1993



Front row
Mr AJ Clayton (Co-opted member) - City Engineer: Cape Town
Mr AJ Raubenheimer (DMS) (Chairman) - Former Minister of Water Affairs

Middle row
Mr DW Steyn - Former Minister of Economic Affairs and Technology
Mr M Erasmus - Director-General: Department of Water Affairs and Forestry

Back row
Mr VJ Bath - Chief Executive: Rand Water
Prof T Erasmus - Vice-Principal: University of Pretoria
Dr WL van Wyk - Former Deputy Director-General: Department of Mineral and Energy Affairs
Mr DH Marx - Chairman: Magalies Water
Mr PE Odendaal - Executive Director: Water Research Commission
Prof PD Tyson - Vice-Principal: University of the Witwatersrand



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The year under review

The multidisciplinary approach to water research is evidenced by the variety of research areas supported by the Water Research Commission (WRC). The research fields and allocation of funds to the various areas for 1993 are reflected in the accompanying bar chart.

The WRC does not itself undertake research, but enters into agreements with other organisations to carry out the research. In the following table the research sectors responsible for the research are listed, as well as the extent of their involvement:

Research Sector	*Number of times involved*	*%*
Universities	*138*	*51*
CSIR	*53*	*20*
Consulting engineers	*27*	*10*
Government departments	*2*	*1*
Local authorities	*7*	*3*
Water boards	*11*	*4*
Private companies	*10*	*4*
Other organisations	*20*	*7*
Total	***268***	***100***

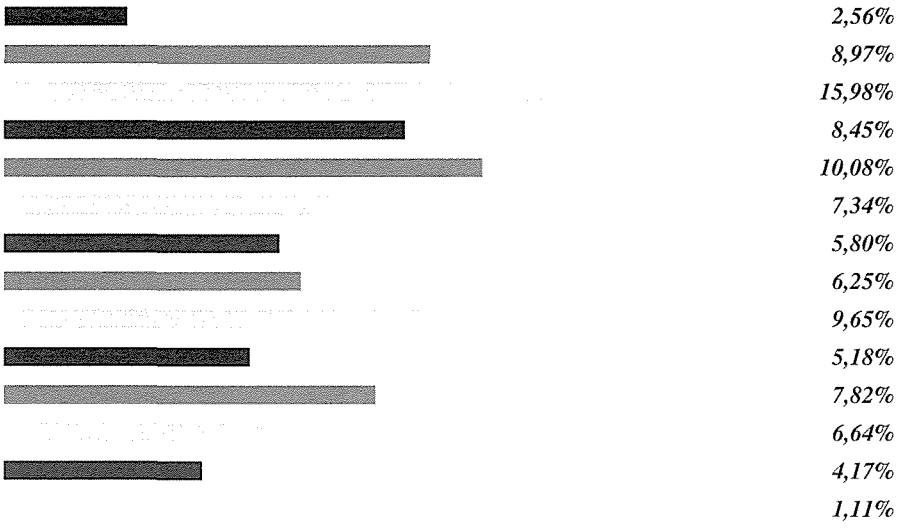
From the figures it is evident that universities are involved in 51% of the total number of contracts. The number of times that organisations are involved, namely 268, exceeds the number of projects supported, for the reason that more than one organisation is, in certain cases, involved in the execution of a project. In 1993 the WRC financially supported 248 projects at a budgeted amount of R39 107 062.

In addition to the direct funding of contractual projects, the WRC also supports 2 research support services financially:

- The South African Water Information Centre (SAWIC)
- The Computing Centre for Water Research (CCWR).

While the activities pertaining to the past year will be reported on in the various chapters, certain highlights will be singled out in this chapter.

Allocation of funds (%) to the various areas during 1993



Urban sanitation evaluation

The provision of water and sanitation services to the rapidly expanding urban areas in South Africa is a great challenge facing the country. Unfortunately our understanding of the options available for doing this is limited. In order to assist in improving this understanding, the WRC is funding a range of related projects. An important project in this category, completed during the year, was **Technical, Socio-economic and Environmental Evaluation of Sanitation for Developing Urban Areas in South Africa** (Project No 385).

The project, carried out by the Palmer Development Group, in association with the Water Research Group at the University of Cape Town, was structured in 3 phases:

Phase I:

A review of international practice in the field of sanitation, and a review of the current situation with sanitation in South Africa (including the TBVC states). This included for each region in the country, a survey of urban areas to determine who has access to adequate sanitation, what types of system are being used, and how sanitation systems are funded and managed. Questionnaires and interviews were used as tools to collate the information.

Phase II:

Various key issues in the implementation of sanitation projects were identified and studied in a series of case studies. The most used sanitation systems were also evaluated in terms of their cost, acceptance by communities, ease of construction and operation, and environmental impact.

The provision of water and sanitation services to the rapidly expanding urban areas in South Africa is a great challenge facing the country

Phase III:

The key findings of Phases I and II were summarised in a report and presented to professionals and other interested parties in the sanitation and water sectors at a series of 6 workshops around the country. On the basis of the work completed and inputs received during the workshops, a draft set of guidelines for the implementation of sanitation projects was developed and key areas for action in the sanitation sector identified.

Sanitation fact-finding mission to Zambia

Very little experience exists locally regarding the long-term functional performance of many of the sanitation systems being installed today. During the early 1960s, a number of so-called self-topping aqua privy schemes had been installed in Zambia, and as these represent possibly the longest existing system of this type in the world, a mission, initiated and led by the WRC, visited Lusaka, Mazabuka, Kafue and Kabwe (Broken Hill).

It was found that while some systems had totally collapsed and were in total disrepair, other similar systems were still functioning perfectly. Simple and seemingly insignificant maintenance tasks being carried out timeously, appeared to have made the difference between success and failure.

Considerable experience was gained during the visit and the pitfalls to be avoided, clearly identified.

WRC scholarships for post-graduate training in water-related sciences

In 1993 the WRC decided to award 2 scholarships annually for the purpose of stimulating post-graduate training in water-related sciences. The scholarships will be awarded for a period of 2 years subject to certain conditions. The WRC every year will identify a specific field of water activity experiencing a need for trained manpower. For the relevant year the scholarships will be available for study in the field of activity identified.

The reason for this involvement was that research organisations often experienced problems in finding researchers with a suitable background to participate in WRC projects. Pointing out such research areas and promoting post-graduate training, will eventually benefit the research effort. At the same time a contribution will be made towards developing specialised areas of expertise.

Water ecosystems was the first field of activity identified, and the first recipients of the WRC scholarships for study during 1994 and 1995 are:

- Ms MC Uys for study at Rhodes University
- Mr S Pillay for study at the University of Zululand.

Workshop on technology transfer

Technology transfer (TT), i.e. the implementation of successful research results, is of primary importance to the WRC. For this reason the WRC has heavily stressed this facet of its research support over the years. Much experience has been gained and it has become clear that TT is a complex process and that there is no magic formula for success. One principle that has come strongly to the fore is the important role which is often played by the researcher himself in the process.

In order to evaluate the TT strategies which have been taken by the

WRC to date - successes and failures - the WRC arranged a workshop in December which was attended by a selection of research leaders (mainly from universities). The objectives of the session were to develop, by critically examining the past, proposals for improving TT strategies; to impress upon the research community that TT is necessary; and to expose researchers from various disciplines and problem areas to TT approaches in other disciplines and problem areas.

Future direction of the South African Water Information Centre (SAWIC)

A workshop on the future direction to be taken by SAWIC was held in June. Some 21 participants took part in the proceedings. Presentations ranged from **The Role of Research Support Services in the Mission of the WRC** and **The Role of Bibliographic Information in the Water Research Environment**, to **Emerging Technologies in the Information Field**.

A number of major issues were identified by the participants as requiring further investigation. These will be taken up by task groups, the results of which will help shape the future of the Centre. The main conclusion reached by the workshop was that SAWIC is essential to the activities of the South African water community and that its continuation into the future should be strongly supported.

Co-ordination of mining-related water research

The impact of mining activities on the water environment is mostly diffuse by nature and difficult to control. The authorities therefore only fairly recently started paying attention to regulating the problem. Joint initiatives are now being taken by the industry and the authorities to quantify the impact and to combat its effect on the environment.

The WRC has substantially increased its funding of mining-related research

This situation has created a need to co-ordinate mining-related research separately from other research fields. The WRC therefore established a Co-ordinating Committee comprising representatives of the mining industry, interested authorities, specialist researchers and the WRC. Research objectives were identified during the first meeting held in October, and thereafter prioritised during a workshop held in November. The priorities agreed on are as follows, in order of priority:

- Development of new technology to combat water pollution due to mining activities
- Determination of water consumption by mining
- Determination of the impact of mining on water quality
- Evaluation of economic, socio-political and regulatory issues which affect water sources
- Definition of the best available technology not entailing excessive cost (BATNEEC).

Research on mining pollution expanded

In recognition of the mining industry's endeavours to curb the impact of its gold and coal mining activities on the water environment, and to reduce its consumption of fresh water, the WRC has lately increased its research funding in this area.

To enable the mining industry to comply with the Department of Water Affairs' policy of receiving-water quality objectives, various relevant research projects have been launched by the WRC. These include research on the development of an integrated and generic water quality simulation model for open-cast coal mining water circuits and the prediction of pollution levels from coarse sulphide rock materials. Moreover, as the industry comprises a large number of independent mines experiencing different water management problems, a survey of the current water management and treatment procedures in the SA gold and coal mining industries has been initiated to establish the BATNEEC. Design aspects of covers for the rehabilitation of open-cast mines and waste dumps are also being addressed.

The rapid assessment of in-stream water quality

A technique for the rapid assessment of in-stream water quality was developed and refined by the CSIR's Division for Water Technology. The technique makes use of the invertebrate fauna in a stream and is now ready to be applied on a country-wide basis.

A special workshop was arranged to familiarise prospective users with the technique. It is important that users share the same understanding of the technique, to ensure comparable results between different users. It also provided an opportunity to access the best available information, in order to effect modifications which would facilitate the application of the technique.

Biological testing of water quality

In addition to heavy metals which may be released into the water environment, there are also an increasing number of xenobiotic compounds which are potential pollutants. The number of compounds to be tested for, and the cost per analysis, make it impossible to determine water quality by chemical means alone, and biological tests are therefore increasingly being used.

The WRC supports a number of projects aimed at the development and evaluation of such biological tests. During the course of the research it became apparent that there was a need for a suitable forum where people, active in the field of biological testing, could establish contact and discuss their work. The forum would also serve a co-ordinating function in this new field. The concept was tested at a special workshop, which resulted in the establishment of an Interest Group which would meet in open forum, e.g. at the conferences of appropriate scientific societies.

The Water Research Group of the University of Cape Town has developed a hypothesis which explains the cause of bulking sludges at nutrient removal activated sludge plants

Sludge bulking in nutrient removal plants

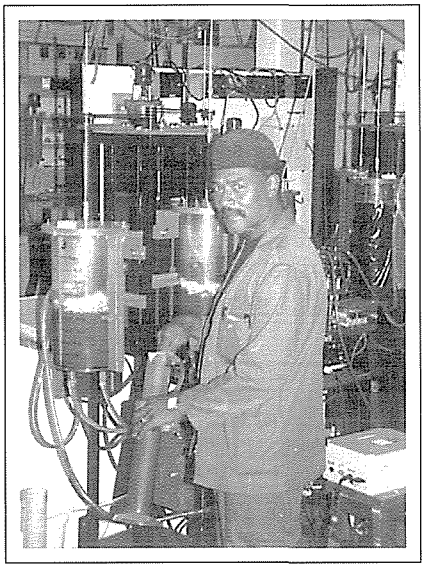
In a series of projects sponsored by the WRC, the Water Research Group, University of Cape Town, developed a hypothesis which explains the cause of bulking sludges at nutrient removal activated sludge plants. If confirmed, this should lead to practical strategies for bulking control with considerable beneficial impact on the quality of effluent produced and the cost and ease of plant operation.

This hypothesis is based on the theory that the floc-forming bacteria denitrify from NO_X to N, while the filamentous bacteria only denitrify from NO_3 to NO_2. The less oxidised forms of NO_X, particularly NO, inhibit cell metabolism. It is the inhibitory effect of the accumulated intermediate denitrification compounds within the cells of the floc-formers, which gives the filamentous bacteria the competitive edge in nutrient removal activated sludge plants.

A new WRC funded project was initiated during 1993 to investigate the hypothesis and to develop appropriate bulking control strategies.

Algal toxins

It has been known since the 1880s that blooms of cyanobacteria (blue-green algae) can produce potentially lethal toxins. However, research on toxic algae had not been considered very important in the past, as the occurrence of toxic algae was generally perceived to be a rare event. However, with increasing enrichment of the water environment, there is now a renewed interest in algal toxins. Experts now hold the view that when a bloom of blue-green algae occurs, one must assume it to be toxic, unless proven otherwise.



Mr T Lakay (Water Research Group, UCT) in front of the experimental unit in which the hypothesis on the causes of sludge bulking is being verified

Dr MJ Pieterse (WRC) with Prof GA Codd (University of Dundee, Scotland) and Dr B Rae (Umgeni Water) at the Algal Toxin Workshop held in Durban

Against this background the WRC entered into an agreement with Umgeni Water and the CSIR's Division of Water Technology, to assess the seriousness of the problem in South Africa, to develop sensitive detection methods for these toxins, to estimate the survival of toxins in water after destruction or decomposition of algae, and to plan and design for remedial action.

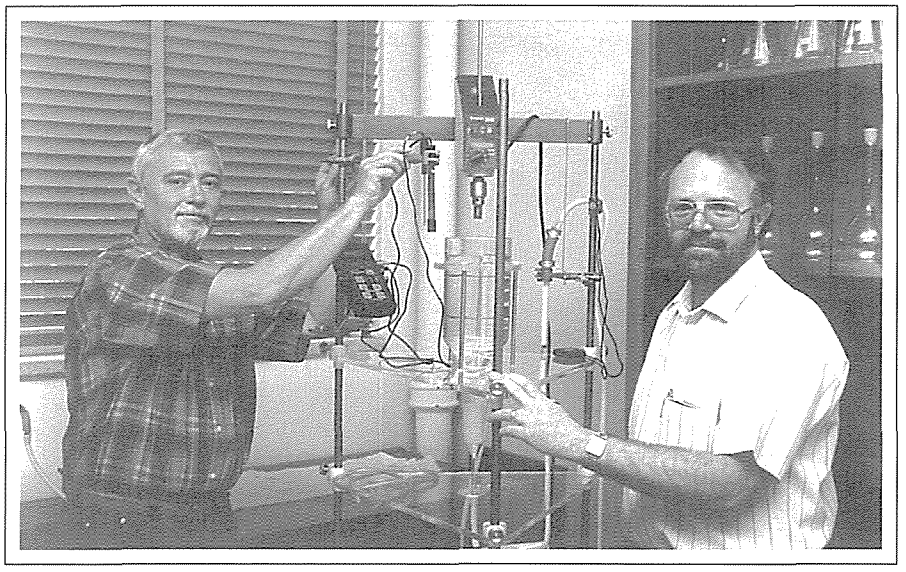
As a further initiative, a workshop on algal toxins was held in Durban during May 1993, under the auspices of the WRC and Umgeni Water. The objectives were to address the magnitude of the problem in South Africa; to evaluate present and previous research; and to look at research needs and priorities, taking due cognizance of overseas work. Prof G A Codd, Head of the Department of Biological Sciences, University of Dundee, Scotland, participated in the workshop as guest speaker.

Algae in drinking water: Overseas co-operation

Co-operative research has been brought about between the well-known German research group of the *Wahnbachtal Sperrenverband* near Bonn, and the Department of Botany and Genetics of the University of the OFS (UOFS) which is being supported by the WRC for research on the removal of algae from drinking water. This co-operative research was officially launched with the first study visit of one of the German scientists, Mr Helmut Schell. Mr Schell and Prof AJH Pieterse of the UOFS collaborated for a period of 3 weeks on the finer aspects of algae removal in drinking-water treatment. This was a follow-up visit on Prof Pieterse's 3-week visit to Wahnbachtal in 1992. During that visit the German team benefited greatly from the considerable fund of knowledge accumulated by Prof Pieterse and his team.

Co-operative research has been brought about between the well-known German research group of the Wahnbachtal Sperrenverband *near Bonn, and the Department of Botany and Genetics of the University of the OFS*

Continued collaboration will take the form of a further visit to the UOFS by a German algologist, Dr J Clasen, followed by a visit to Germany by Prof Pieterse.



Mr H Schell of the Wahnbachtal Sperrenverband *near Bonn (left) and Prof AJH Pieterse (UOFS) (right) next to the test apparatus used for drinking-water treatment tests in Germany and South Africa*

Design guide for dissolved air flotation

A South African guide for the design of dissolved air flotation (DAF) water treatment processes has recently been published by the WRC. The guide was compiled by the consulting engineering firms GFJ Inc. and Bergman and Partners.

The guide covers both potable water treatment and thickening of sewage sludges, and was based on a country-wide survey and available international literature. Recently, this design guide was accepted by the Scientific and Technical Research Programme of the International Association on Water Quality (IAWQ) as a role model for an international version. This design guide will fill a pressing need since, internationally, there is currently very little detailed design information available on DAF.

Novel method for phosphate removal

A demonstration of the "Catphate" process for the removal of dissolved orthophosphates from sewage effluents was arranged at the Daspoort Water Treatment Works, Pretoria, during August 1993.

The process, originated by WUST Consultants uses scrap iron shavings in a rotating vessel to transform dissolved orthophosphate into precipitated ferric phosphate, which may then be removed by conventional filtration. The process was evaluated by the CSIR's Division of Water Technology over a period of several years. Consistent removal of low levels of phosphates was achieved over prolonged periods, covering both winter and summer climatic conditions.

Membrane technology: Master Plan for Research and Development (R&D)

During recent years it became obvious that there was an urgent need to co-ordinate and rationalise membrane research and development in the water field.

In order to address this need, the WRC conducted a 2-day workshop during June 1993, to develop a strategic plan for membrane research in South Africa. The overall aim of this plan is to establish research needs and priorities for the optimal development and exploitation of synthetic membranes in the water field. The areas of application were limited to potable water and industrial and municipal waste water.

Representatives from 12 major role-playing organisations attended the workshop, where a general vision of the future for membrane R&D emerged and a mission statement was generated. This was followed by a strategic analysis of the current membrane R&D situation in the country. A small working group will finalise the Master Plan.

During recent years it became obvious that there was an urgent need to co-ordinate and rationalise membrane research and development in the water field

Application of membrane technology

The treatment of brackish water to potable water standards along the Cape west coast, has been successfully achieved by a local membrane manufacturer, Membratek (Pty) Ltd.

At present, several villages and small, isolated communities are totally dependent for their drinking water on the application of tubular reverse osmosis (RO) technology, developed for the WRC by the Institute for Polymer Science (IPS), University of Stellenbosch. A mobile desalination plant presently serves 3 small communities, whilst a further 3 fixed units are operating in the Bitterfontein area.

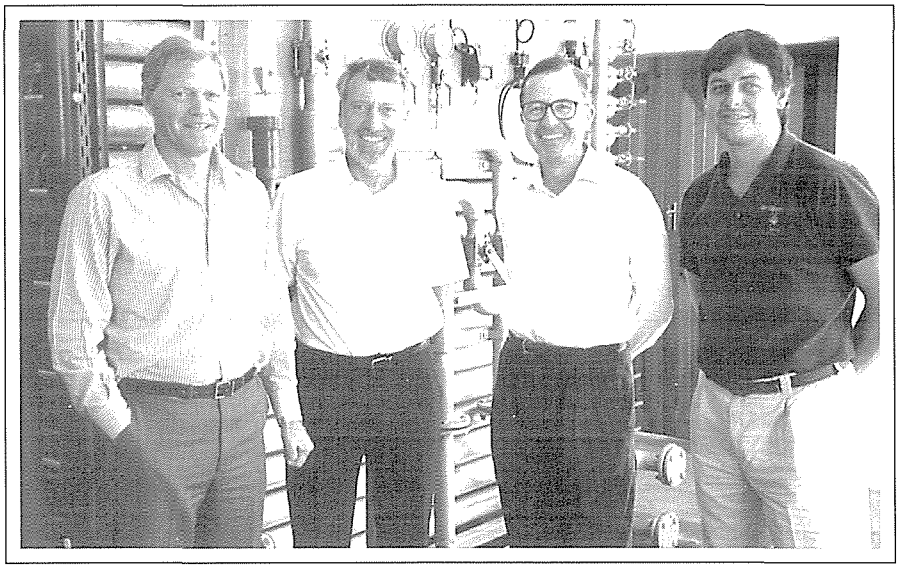
Membratek also accepted for application, the latest capillary membrane technology, developed by the IPS with extensive WRC funding.

Guide for the marine disposal of effluents through pipelines

Several South African coastal communities currently discharge their domestic and industrial effluents into the sea. Population and attendant industrial growth, the often limited space available for conventional sewage treatment facilities and the inherent economic advantages, render the marine disposal option increasingly attractive to other coastal agencies.

Marine disposal systems must be designed to ensure that, even under the most adverse oceanographic conditions, the resultant chemical, biological, bacteriological and physical impacts do not adversely affect the marine environment or its designated end uses. To this end, the *Guide for the Marine Disposal of Effluents through Pipelines* was compiled and incorporates inputs from the CSIR, the Departments of Water Affairs and Forestry and Constitutional Development and Planning, the Sea Fisheries Research Institute and other experts in the field.

The Guide is not a design manual, but the technical information provided will benefit those considering the marine disposal option and those engaged in the planning, design and operation of outfall sewers.



A visit by WRC members to Bitterfontein potable water desalination plant on 16 November 1993. In front of the reverse osmosis unit are, from left: Mr V Bath (Rand Water), Dr R Sanderson (University of Stellenbosch), Prof P Tyson (Wits University) and Mr D Nel (Membratek)

Guidelines for water and effluent management in industry

The need for guidelines to assist industry in reducing its water intake and managing its waste-water disposal as effectively as possible, is of national concern in South Africa, in view of the country's water scarcity and the growing deterioration in the quality of available water supplies. To establish norms for water and waste-water management the WRC, in collaboration with the Department of Water Affairs, contracted a firm of consulting engineers, SRK (CE) Inc. to undertake a National Industrial Water and Waste-water Survey (NATSURV) of all classes of industry.

As an outflow of NATSURV, 14 different guides were published, each of which focusing on water and waste-water management in a different industrial category. The final 2 guides in the series have now been published: NATSURV 13 deals with the *Textile Industry,* and NATSURV 14 with the *Wine Industry.*

A Guide to Water and Waste-water Management in the Poultry Abattoir Industry has also been released by the WRC. This guide is based on a separate investigation, also carried out by SRK. A surprising fact which emerged from the research, was the great variation in water consumption by different poultry abattoirs, in spite of the fact that all have to comply with the same meat hygiene regulations. The report deals with several simple techniques that can be used to reduce the pollutant load and hence the cost of treatment.

Water metering

During the year the WRC collaborated with Kent Measurement in 3 workshops on fluid flow measurement, in order to transfer the state-of-the-art to representatives from various sectors of the water industry. The workshops were held in Cape Town, Durban and Johannesburg and were conducted by Dr Richard Furness, Business Director of ABB Kent-Taylor, based in the UK. The workshops were well attended, in spite of a very short lead time - in Johannesburg the attendance was almost 150.

Dr Furness, *inter alia*, presented his views on developments over the next 20 years. He predicted that non-contact measuring is likely to become more prominent and that the water meter, as known today, will most likely disappear.

The concept of a water resources development game was introduced to highlight some of the ecological problems faced when water resources are developed

Revised design runoff manual

Techniques developed by the USA Department of Agriculture's Soil Conservation Service (SCS) for the estimation of design flood volume and peak discharge from small catchments (<30 km^2) were adapted in 1979 for use in Southern Africa, by the Agricultural Catchment Research Unit (ACRU) of the University of Natal. Based on extensive research and improved data bases, an updated version of the SCS design manuals was produced in 1987. By 1991 when more than 1 000 copies of these manuals had already been distributed, it was decided that a computerised update was necessary. This work was also undertaken by ACRU.

The updated manual consists of an 80-page user manual and a user-friendly software package for PC/DOS environments. The latest South African soil classification system has been incorporated. The manual includes several worked examples and should prove extremely useful for a wide variety of practitioners.

Australian experts advise on ecohydrology and low-flow hydrology

During February, Prof Tom McMahon, a hydrologist, and Dr Brian Finlayson, a geomorphologist - both from the University of Melbourne, Australia - visited South Africa and participated in a seminar on ecohydrology and a workshop on low-flow hydrology.

During the seminar the concept of a water resources development game was introduced to highlight some of the ecological problems faced when water resources are developed. The approach was useful to bridge some of the gaps between hydrologists, water engineers and aquatic ecologists and certainly warrants follow-up in a typical South African context.

The workshop resulted in some important recommendations. It was generally agreed that continuous daily hydrographs are needed to characterise South African rivers, although correlations with traditional monthly flows remain important. Prof McMahon, in particular, has considerable experience with low-flow hydrology in Australia and made valuable inputs to the South African work.

Master Plan for research on hydrometeorology

The strategic research plan of the Co-ordinating Committee for Research on Hydrometeorology (CCRH) was tabled and accepted by the WRC in May. It was revised and updated in October.

According to the plan, the overall goal of hydrometeorological research is to acquire an adequate understanding of the ways in which atmospheric and related processes influence the amount and variability of the national water supply, so that water management procedures can be improved and the potential for augmentation assessed. Of the 4 primary goals contributing towards the overall goal, the two which currently command the most attention are (a) to develop an ade-

quate understanding of spatial and temporal characteristics of precipitation and other potential atmospheric sources of water for Southern Africa; and (b) to develop weather and climate forecasting tools needed for better management and more effective utilisation of Southern Africa's water resources. Good progress with respect to (a) over recent years has resulted in a gradual shift in emphasis from (a) to (b).

Weather modification: Planning of an areal rainfall enhancement experiment

During 1993, the WRC took the decision to immediately initiate the planning of an areal rainfall experiment. This will possibly be the final phase of the WRC's support for weather modification research. The decision is based on positive research findings and the need to demonstrate the practical relevance and usefulness of the research in the water resources context. It is expected that, in the time required to plan the area experiment, continued good progress in research on the modification of individual convective storms would provide the final justification for implementation of the planned experiment.

Areal rainfall data, needed to enable the use of distributed hydrological models for runoff and flood forecasting, cannot be satisfactorily estimated from point (rain-gauge) measurements

To stand any chance of success the experiment, which will be the first serious attempt in South Africa to increase rainfall in an area, will have to gain the general acceptance of the community. Experience has shown that there are often differences and conflicting interests in a community which first have to be resolved. Furthermore, as the major objective of the technology to be tested is to harvest more water on the ground for the benefit of water resources, agriculture and forestry, without detriment to the environment, the experiment will also have to enjoy the support and involvement of all interested and affected parties. Representatives of communities and all affected sectors will, from the beginning, be drawn into the planning process, one of the aims of which will be to objectively select the most appropriate experimental area.

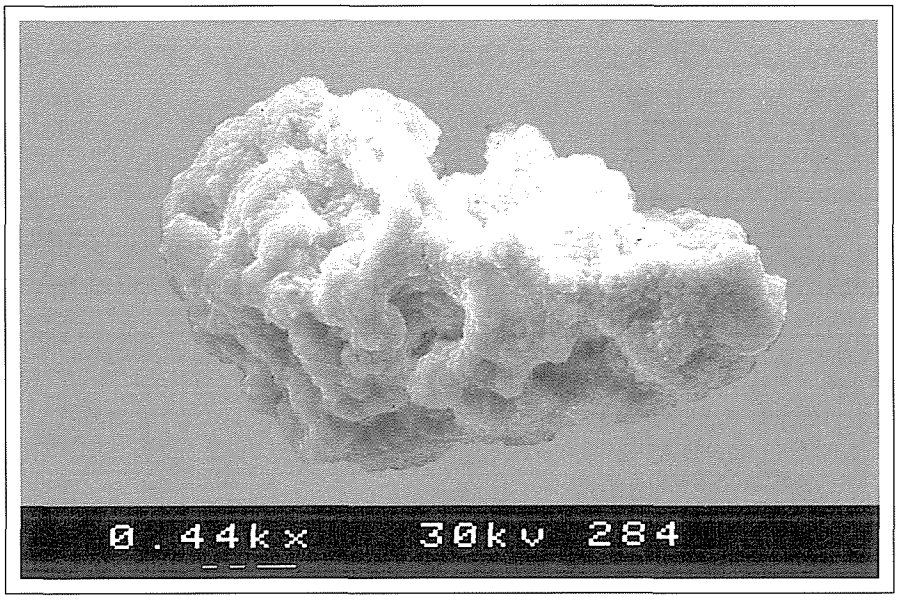
A series of planning workshops which will involve a planning team and all major role-players has already commenced.

New hydrometeorological radar research facility for South Africa

Weather radar presents the only viable means of studying many of the convective cloud processes responsible for the major portion of South Africa's summer rainfall, and also of directly measuring spatially distributed (areal) rainfall. Areal rainfall data, needed to enable the use of distributed hydrological models for runoff and flood forecasting, especially in small and medium-sized catchments, cannot be satisfactorily estimated from point (rain-gauge) measurements. In order to do so, the rain-gauge density would have to be unrealistically large.

The beneficial use of radar in South Africa for applications such as these, has thus far been hampered by the lack of a suitable radar facility for research and training. To fill this gap, the WRC decided to purchase a dual wavelength (10 cm and 3 cm), mobile radar of Russian manufacture. This research radar will initially be installed at Bethlehem. It will be integrated into the Weather Bureau's precipitation research programme, but will also be at the disposal of researchers at the Department of Water Affairs and Forestry, the University of Pretoria and any other organisation which undertakes appropriate research. A management committee will assist the WRC in ensuring that the facility is used optimally.

The contract for the purchase of the radar was signed in October during a visit to South Africa by senior representatives of the Russian manufacturers.



Electron microscope photograph of a KCl particle released from a burning hygroscopic cloud-seeding flare

"Africa needs Groundwater" *convention*

The **Africa needs Groundwater** convention was held in Johannesburg, September 1993. Over 200 delegates from 10 African countries and from Europe, Australia and the USA attended the convention, which focused on groundwater issues of particular relevance to the African Continent. Twelve papers reporting on WRC-funded research were presented, attracting considerable interest from the delegates.

The convention paved the way for closer ties with the International Association of Hydrologists and resulted in a proposal for the formation of a Hydrogeological Association of Africa. These initiatives will ensure the transfer of technology in the field of hydrogeology between South Africa and the rest of Africa and will be of considerable benefit to local groundwater researchers and practitioners.

Protection of groundwater resources

In December 1992, the National Rivers Authority (NRA) in the UK published the landmark document *Policy and Practice for the Protection of Groundwater*. Dr Andrew Skinner of the NRA, one of the principal authors of the document, recently visited South Africa at the invitation of the Groundwater Division of the Geological Society. Apart from delivering the opening address at the **Africa needs Groundwater** convention, Dr Skinner participated in a number of discussion groups on the topic of preparing a groundwater protection policy and strategy for South Africa.

The WRC has launched a number of research projects, and is actively pursuing new initiatives, to support the development of such a protection strategy. The role of public education and participation in such a process is deemed to be crucial to success. Mr Andrew Stone of the American Groundwater Trust provided guidance on the involvement of the public in the process, at 2 workshops held in January this year. The workshops concluded that the most effective way of protecting groundwater in South Africa, is to encourage its use.

The role of public education and participation is deemed to be crucial to success in protecting groundwater

Hydrogeological mapping

Mr Gerry Jacobson, principal researcher of the Australian Geological Survey Organisation and co-author of the *National Hydrogeological Map of Australia*, recently visited South Africa as a guest of the WRC. During his visit he participated in both the national and regional mapping programmes, meeting with a number of local researchers in the field.

Australia has made great advances in the use of geographical information systems and automated cartography in the compilation of hydrogeological maps. As such, their approach serves as a "model" for the South African map series.

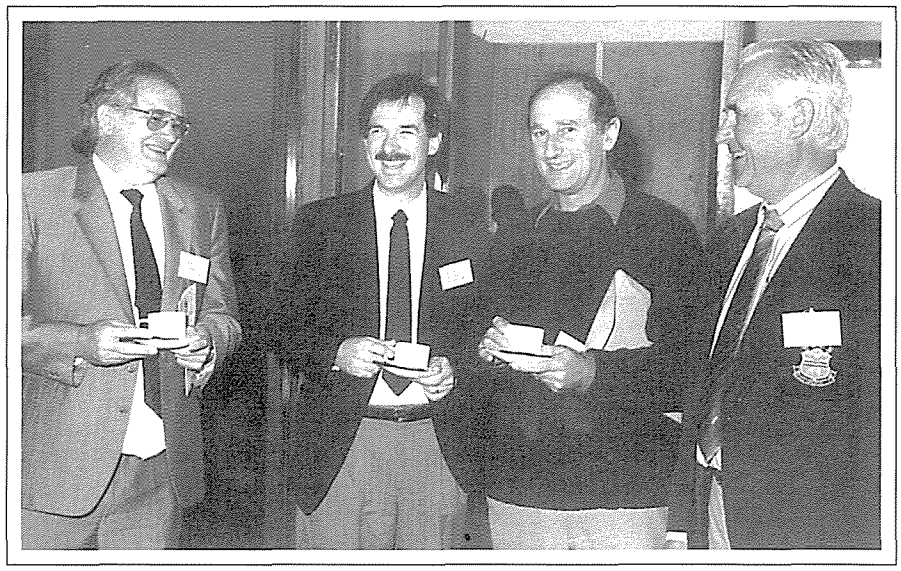
Mr Jacobson's visit was very timely in that the projects on the preparation of the national and pilot regional-scale maps, which are being funded by the WRC, are drawing to a close. His input was consequently focused on these and his strong support of local approaches provided considerable encouragement to South African map compilers.

Computer programs for a flood-warning system

As was reported in 1992 the WRC entered into an agreement with a consortium of consulting engineers known as flood consultants, for the development of a flood advisory service. Arising from this, the WRC entered into an agreement with the Department of Civil Engineering at the University of Pretoria in 1993 for the further development of computer programs for a flood-warning system.

The programs are designed to be part of a permanent flood-warning system and are not suitable for use on an *ad hoc* basis solely in the event of flood situations.

Publication of and training in the



Seen at the **Africa needs Groundwater** *convention were, from left: Prof FDI Hodgson (UOFS), Mr AG Reynders (WRC), Mr G Jacobson (Australian Geological Survey Organisation) and Prof JOG Kirchner (UOFS)*

use of the programs will represent a rounding-off phase. Should flood situations arise in the mean time, the programs have been made available to the following organisations for testing:

- Johannesburg Civic Protection Organisation
- Umgeni Water
- Bloemfontein office of the Department of Water Affairs and Forestry.

Smallholder irrigation

Available resources for smallholder irrigation development, such as capital, land and especially water, are limited. South Africa cannot afford to make these resources available without confidence in long-term success and self sufficiency in the development of such resources. In order to investigate the potential role of a participative approach in smallholder irrigation development, a workshop was held which included *inter alia* visits to smallholder developments in KaNgwane in the Eastern Transvaal.

Available resources for smallholder irrigation development, such as capital, land and especially water, are limited

The workshop was organised and funded by the Development Bank of Southern Africa, the South African Sugar Association and the WRC. It was attended by developers, consultants, managers, researchers, farmers and a number of overseas experts. One of these, Dr Jean-Claude Legoupil (then Regional Representative of the International Irrigation Management Institute for West-Africa) attended the workshop as consultant to the WRC. He has considerable experience of irrigation development projects in North and West Africa.

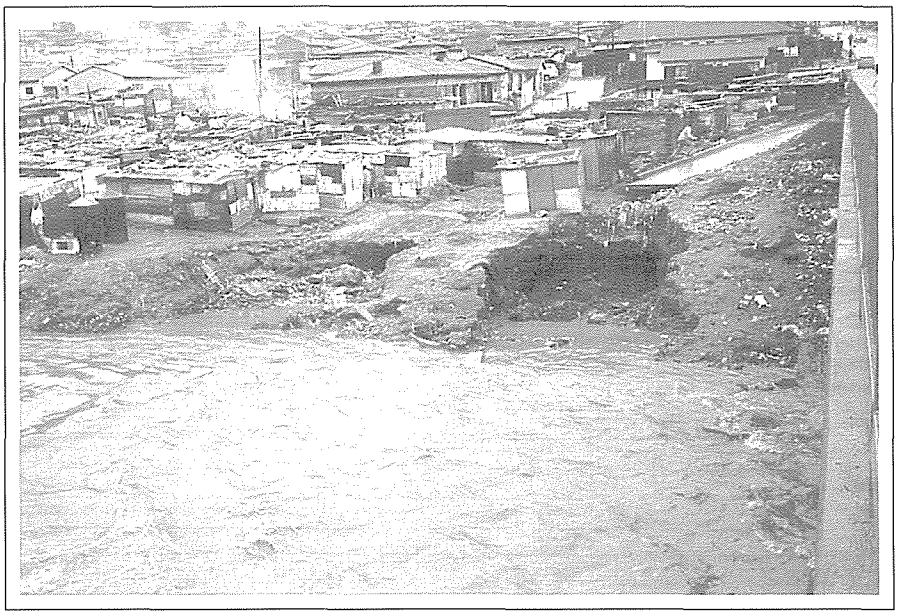
The main purpose of the workshop was to confirm experience elsewhere about the validity of, and justification for, a participative approach in the development and management of irrigation projects - an approach little applied in South Africa in the past. It was also envisaged that guidelines (based purely on South African experience) would then be jointly formulated on how to implement this approach for irrigation project planning, implementation and management.

By and large the workshop endorsed the participative approach, formulated guidelines and emphasised the importance of community/individual participation.

Manual for irrigation planning in developing areas

The Working Group on Agricultural Resources and Soil Utilisation of the Secretariat of the Economic Community of Southern Africa (SECOSAF) awarded a high priority to the planning of irrigation development in developing areas. A multi-disciplinary task group consequently compiled a document titled *A Manual for Irrigation Planning in Developing Areas* which ought largely to meet the requirements of planners.

Parallel to the above need the master plan for irrigation research of the WRC's Co-ordinating Committee for Irrigation Research also identified "refining of planning methods for the optimisation of irrigation development" as of the highest priority. Against this background the WRC in collaboration with SECOSAF and the Development Bank of Southern Africa, funded the publication of the above manual. The WRC views this contribution as an input to technology transfer which will benefit developing agriculture.



A minor flood in the Jukskei River at Alexandra Township, Johannesburg, 6 October 1993, after 85 mm of rain had fallen over a period of 6 days

Reduction of irrigation return flow

Measures to improve the efficiency of irrigation normally also result in a reduction in drainage losses. Consequently improved irrigation efficiency will also combat the salinisation of rivers which is associated with irrigation.

The Breë River, being one of South Africa's severely salinised rivers, became the subject of an evaluation of the design and operation of irrigation systems along the river with a view to controlling potential drainage losses. The firm MBB Inc. undertook the evaluation. The standard of irrigation design appeared to be high and should enable farmers to irrigate in a manner such as to contain drainage losses. With only a few exceptions, however, over-irrigation was observed in general with concomitant high drainage losses and low water utilisation efficiency.

The least drainage occurred in the cases of drip irrigation, followed by micro- and sprinkler irrigation. Subsequent conversations with participating farmers brought to light the fact that in general a low level of theoretical knowledge exists concerning irrigation scheduling and that irrigation largely takes place in accordance with own experience. A follow-up project is envisaged to ascertain to what extent incentives and other measures can enhance irrigation efficiency.

Irrigation management services

The WRC has contributed substantially over many years to research into soil-plant-atmosphere-water relationships and irrigation scheduling. The research findings have over many years been effectively synthesised in the form of crop growth models. However, these developments have been slow to benefit the majority of irrigators as the challenge of packaging this information into an easily grasped technology, has proved a daunting task.

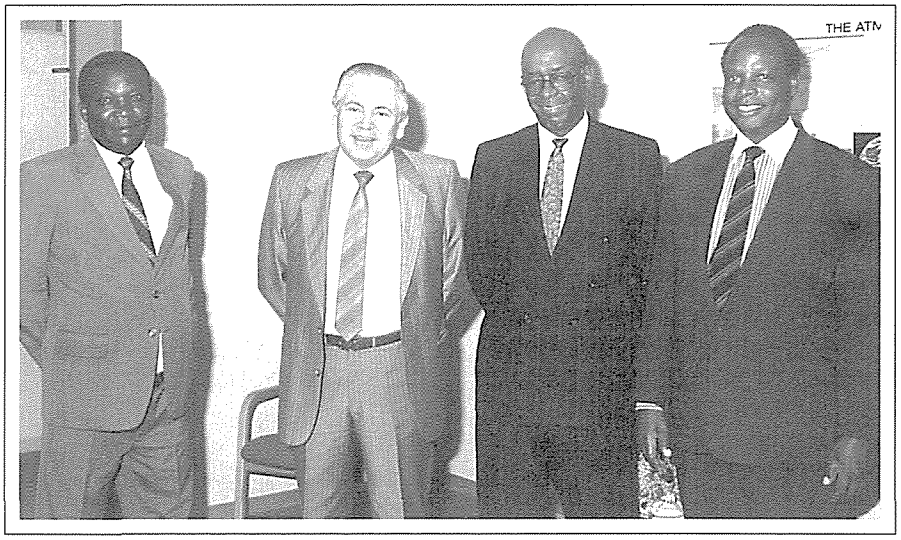
Over-irrigation is observed in general with concomitant high drainage losses and low water utilisation efficiency

Research is now concentrating on optimising the use of PC modelling and automatic weather stations in promoting effective irrigation. Individual farmers, irrigation boards, advisers and potential consultants and researchers are collaborating in this research. The objective is to establish how beneficial the technology is in terms of increased efficiency, how acceptable it is to users, and how viable commercial irrigation management services based on the technology might be. Such services should enable subscribing farmers to share fully in the benefits of advances in irrigation technology.

Liaison with irrigation authorities in Kenya

During 1992 the WRC made contact with the National Irrigation Board (NIB) of Kenya with a view to investigating irrigation practices in that country, especially with respect to the management, use and design of irrigation systems. Subsequent to this contact Messrs B Bargoria (General Manager of the NIB), S Gitonga (Deputy General Manager of the NIB) and W Njoroge (Deputy Permanent Secretary of the Kenyan Department of Rural Water Supply) in 1993 visited the WRC and a number of local organisations concerned with irrigation for developing communities.

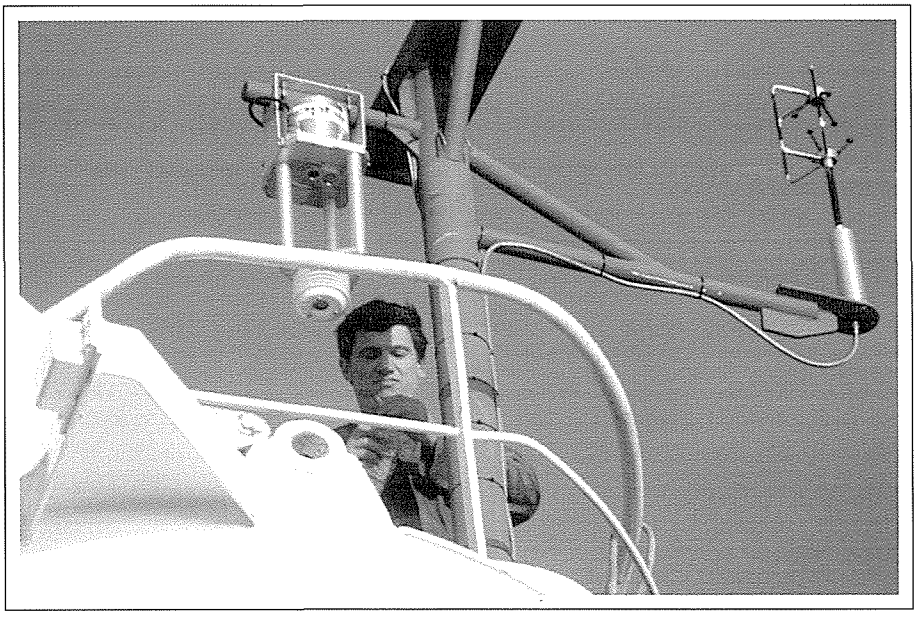
The conclusion arrived at after this visit was that in view of the experience gained in Kenya on irrigation under developing conditions, taken in conjunction with local irrigation research financed by the WRC, opportunities existed for mutual co-operation between the irrigation set-up of Kenya and that of South Africa. By expanding the current liaison, mutual inputs are sure to be to the advantage of irrigation in the African context.



A number of Kenyan irrigation officials recently paid South Africa an exploratory visit as guests of the WRC. From left: Mr W Njoroge (Kenyan Department of Rural Water Supply), Mr DS van der Merwe (WRC) and Messrs S Gitonga and B Bargoria (National Irrigation Board, Kenya)

2

Hydrometeorology



Highly sophisticated instrumentation being installed on the research vessel SA Agulhas *by Dr Mathieu Rouault of the University of Cape Town in order to study the effect of the ocean on the overlying atmosphere and ultimately on Southern Africa's weather.*
(Photo: Prof JRE Lutjeharms, University of Cape Town)

Rainfall deficits over the past year have once again impacted seriously on water resources and served to underline Southern Africa's sensitivity, in this regard, to climatic variability. Developing an adequate understanding of this variability at various temporal and spatial scales, thereby enabling better management of water resources, is a major goal of the hydrometeorological research supported by the WRC.

At the historical time scale, research at the South African Museum continues to contribute to a better understanding of the variations in the rainfall climate over the past 2 000 years, with greater resolution being sought in the most recent part of this period. The research depends on joint interpretation of data extracted from both modern wood samples and archaeological charcoal deposits. Data are obtained using dendrochronological, wood anatomical and stable isotope analytical techniques.

The period of climatological record during the present century permits recent climatic variability to be examined in considerably greater detail. Stochastic daily climate models have been developed which reflect this variability. Provided that climate is not subject to any significant systematic change in the short term, such models are useful for deriving probabilities associated with a wide range of climatic scenarios. The latest development, at the University of Cape Town, is the derivation of interpolated values of the 16 parameters of the Zucchini-Adamson daily rainfall model for 500 000 grid points at a spacing of 1 min of a degree latitude and longitude over South Africa. These parameters encapsulate, in great detail, most of the information which might be required concerning the rainfall climate at each grid point.

While previous research has revealed much about temporal variability of rainfall at a point and also about spatial variability or distribution of longer term (e.g. mean annual or mean monthly rainfall), knowledge about the spatial distribution of short-term rainfall amounts (e.g. at the daily or event scales) is still seriously lacking. Such knowledge is an urgent requirement of, *inter alia*, hydrologists needing to apply distributed modelling for predicting runoff or flooding events. The major limitation in this regard has been one of inadequate measurement of spatial rainfall. This limitation is being addressed in joint research by the University of Pretoria, the Weather Bureau and the Department of Water Affairs and Forestry which aims to integrate satellite and radar data with data from existing, usually sparse, rain-gauge networks. A start has also been made with the stochastic modelling of spatially distributed daily rainfields at the University of Natal.

Explaining, rather than merely characterising, climatic variability is a research challenge which must be addressed vigorously if the vision of being able to predict future climatic or rainfall patterns for South Africa is to be realised. WRC-supported research into causes of monthly and seasonal variability is being undertaken at the Universities of Pretoria and Cape Town, complementing research being done independently at the University

of the Witwatersrand and the Weather Bureau. Both global and regional mechanisms and precursors (e.g. El Niño) responsible for climate variability are being investigated. Early fruits of this research have been tentative seasonal rainfall forecasts. These have shown considerable promise but can undoubtedly be refined with further research.

The hydrometeorology projects supported by the WRC focus largely on high priority research areas identified in the strategic research plan of the Co-ordinating Committee for Research on Hydrometeorology. This plan was tabled formally for the first time in 1993 and will be revised annually.

During 1993 the WRC supported 11 hydrometeorological projects of which 2 were completed and 1 commenced.

Completed projects

Reconstruction of the climatic history of the last 2 000 years in the summer rainfall regions of Southern Africa (No 222) South African Museum, Cape Town

Knowledge of the historical rainfall variability is necessary to place more recent rainfall variations into the correct perspective and assist in the rational management of national water resources. This project used changes, over time, in wood anatomical characteristics of selected tree species to infer changes in growing conditions. Dated charcoal from archaeological deposits provided the information on historical variations in frequency and dimensions of xylem vessels, whereas modern-day variations in these xylem characteristics along a rainfall gradient provided the relationships needed to infer rainfall conditions from vessel dimensions. Species which proved most useful for climatic reconstruction using this technique were *Protea roupelliae, Protea caffra* and *Combretum apiculatum*. Rainfall appeared to have been high at the start of the 2 000 year period, low at 800 AD, and to have increased sharply to a high value in 1 700 to 1 800 AD before declining to its present lowest level.

Cost: R215 000

Term: 1988-1992

Relationships between lightning and precipitation (No 279) Division of Earth, Marine and Atmospheric Science and Technology, CSIR

In order to develop a better understanding of the processes of precipitation development in convective clouds, cloud physicists have recognised the need to clarify the role of electrical phenomena in such processes. South African expertise and technology for detecting and mapping the origins of lightning flashes in storms created a unique opportunity for increasing knowledge concerning relationships between lightning and precipitation. Studies revealed that the height of origin of lightning in storms in the PWV area was strongly bimodal, with sharp peaks at 5,3 and 9,2 km above sea level. Moreover, the 20 dBZ radar reflectivity surface which approximates the region of separation between those parts of the cloud which contain precipitation-size particles and those which do not, is the source of most lightning flashes. It would therefore appear that the 20 dBZ contour coincides approximately with the surface of greatest electrical charge and that this charge resides mainly in the smaller cloud particles which co-exist with the larger precipitation particles near the 20 dBZ contour.

Cost: R300 000

Term: 1989-1992

New project

Development of models to stochastically generate spatially distributed daily rainfields (No 550) Department of Civil Engineering, University of Natal.

All currently available rainfall information is based on rain-gauge (point) measurements which have been shown to be a poor representation of areal or spatially distributed rainfall. However, catchment runoff and agricultural production respond to areal rainfall and ideally therefore, areal rainfall data are required as inputs to distributed models. A promising start to the problem of modelling spatially distributed rainfields has already been made but these efforts need to be extended to address questions concerning both seasonal variation in parameters and validation of models. The aims of this one-year project are to develop a daily model of spatially distributed rainfall which accurately reflects seasonal rainfall patterns and to investigate methods of stochastically generating rainfields that fit a random set of point measurements.

Research projects

Completed

- **222** Reconstruction of the climatic history of the last 2 000 years in the summer rainfall regions of Southern Africa (South African Museum, Cape Town)
- **279** Relationships between lightning and precipitation (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)

Current

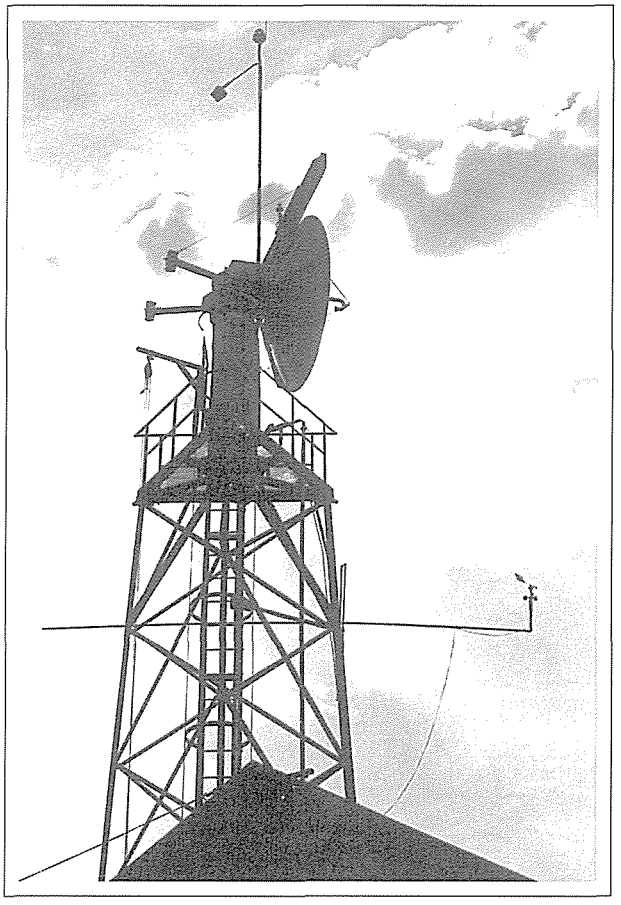
- **278** Prediction of South African summer rainfall variability from ocean surface temperatures (University of Cape Town - Department of Oceanography)
- **305** Interpolation and mapping of daily rainfall model parameters for South Africa (University of Cape Town - Department of Mathematical Statistics)
- **306** Techniques for seasonal and long-term rainfall forecasting in South Africa (University of Pretoria - Department of Civil Engineering (Chair of Meteorology))
- **349** Evaporation measurements above vegetated surfaces using micro-meteorological techniques (University of Natal - Department of Agronomy)
- **374** The southern Agulhas Current and its influence on the weather and climate of Southern Africa (University of Cape Town - Department of Oceanography)
- **436** Mechanisms of short-term rainfall variability (University of Cape Town - Department of Oceanography)
- **437** Assessment of the potential for using stable carbon isotope ratios of wood charcoal as a climate indicator (South African Museum, Cape Town)
- **438** Development of a real-time, non-conventional rainfall mapping system (University of Pretoria - Department of Civil Engineering (Chair of Meteorology))

New

- **550** Development of models to stochastically generate spatially distributed daily rainfields (University of Natal - Department of Civil Engineering)

3

Rainfall stimulation



Of all unconventional water resources which may be considered as a means of augmenting South Africa's water supplies, cloud water, which is also of high quality, is potentially the most easily and economically exploitable. Research on the potential of enhancing rainfall through the seeding of summer convective clouds has gone through several intensive phases since 1983. This research has been supported by the WRC and the Weather Bureau, and activities have centred around Nelspruit and Carolina in the Eastern Transvaal and Bethlehem in the Orange Free State.

Prior to 1991, promising results were obtained during experimentation with dry-ice seeding of convective clouds. Such seeding aims at enhancing precipitation development by initiating large numbers of ice crystals in the super-cooled region of the cloud where the ice particles then start to grow rapidly at the expense of the super-cooled cloud droplets. Despite these promising results, however, there was also strong evidence, based on several seasons of observation, that a more appropriate and effective means of increasing precipitation in local convective clouds would be to initiate early coalescence growth of cloud droplets in the warm region near the base of the cloud. Consequently, investigations from 1991 onwards have concentrated on hygroscopic seeding using aircraft-mounted pyrotechnic flares as a means of introducing salt particles into updraughts at the base of the cloud.

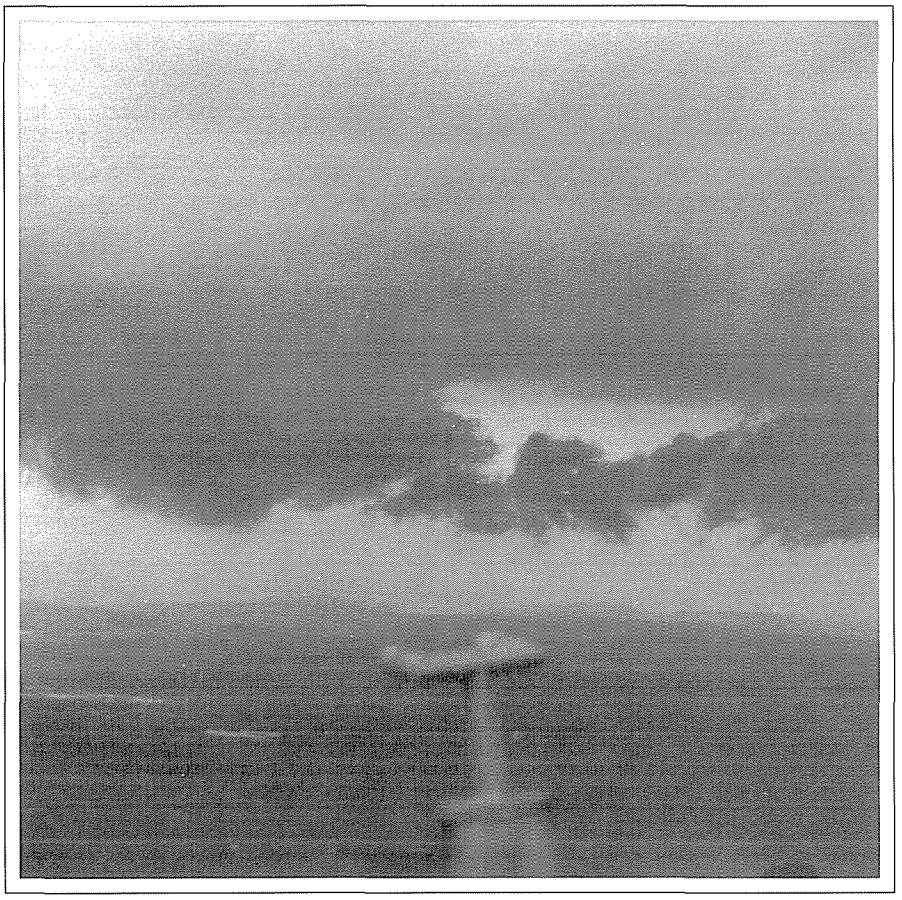
A randomised seeding experiment conducted over a single season (1991/92) yielded results showing significant increases in precipitation in treated clouds from approximately 25 min after seeding. These results and others indicative of the research progress made up to the end of 1992 have been fully documented in WRC Report No 133/8/93. For several reasons, it was not possible to carry out a necessary repetition of the randomised experiment in 1992/93. Nevertheless, during this season, 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.

The promising results to date, together with financial considerations, have prompted the WRC to aim at the winding-up of the present research phase after one or, at most, two more seasons. This present phase comprises the necessary repetition of the 1991/92 randomised seeding experiment and further cloud physical investigations needed for a more complete verification of hypotheses concerning the mechanisms whereby hydroscopic seeding enhances precipitation. A further objective of the WRC, dependent on the confirmation of initially promising results, is to enter into the final phase of rainfall stimulation research at the first opportunity. This final phase will consist of a formal experiment aimed at, firstly, assessing the degree of enhancement of areal rainfall (as opposed to isolated storm rainfall) over a specified target area and, secondly, at confirming runoff, water yield, agricultural production and forestry responses to seeding, estimated during the course of prior desk-top studies.

The planning of the area experiment has already been set in motion. All likely research participants as well as parties who might be affected are being involved in the planning process, during which the optimum target area will also be selected.

In recent times much effort has gone into informing communities about all aspects of rainfall stimulation research and in exploring ways whereby communities can monitor research activities and serve as an external source of response information. In this way it is hoped to dispel unfounded suspicions and pave the way for the remaining research and ultimately, implementation of a potentially valuable technology.



Updraught region of a cumulus cloud where hygroscopic seeding takes place

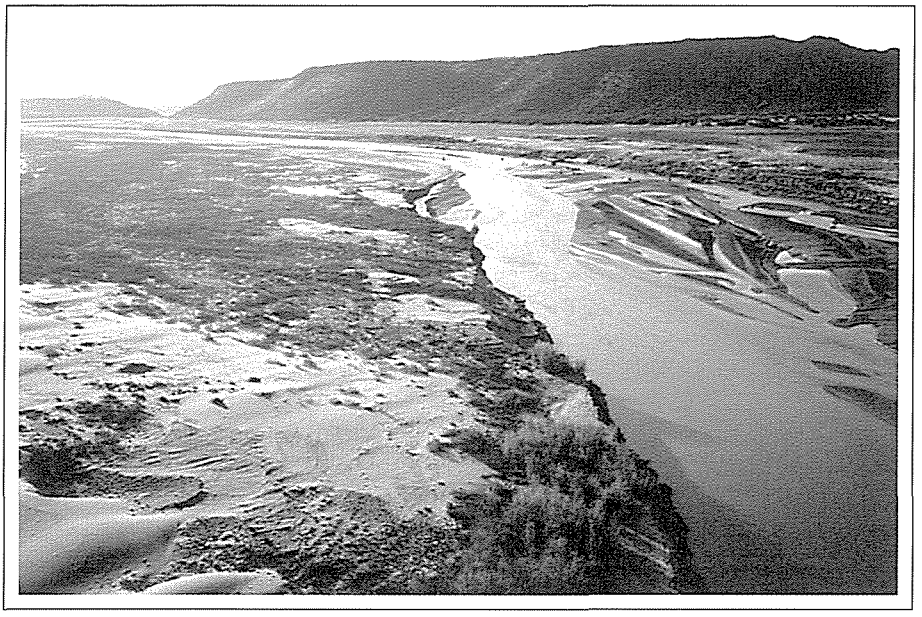
Research projects

Current

- **133** National precipitation research programme with a view to rainfall enhancement (Company for Research on Atmospheric Water Supply and Department of Environment Affairs (Weather Bureau), subcontracting CloudQuest (Pty) Ltd and Unisa)
- **439** Potential impacts of rainfall augmentation on water resources and forestry in the Nelspruit-Bethlehem target zone (Ninham Shand (Cape) Inc.)

4

Surface hydrology



The role of modern hydrological research is gradually shifting away from problem-solving towards providing scientifically correct information, allowing informed decisions to be made in hydraulic engineering and water management.

As a precondition for research on surface hydrology a certain amount of surface water is expected to be visible most of the time. Hydrology of dry regions is probably dominated by groundwater recharge, occasional floods and land degradation. The interaction of surface and groundwater is also limited in these areas. Water management in such areas is totally governed by risk assessments and extreme variability requiring long data sets that can be obtained from routine data collection networks.

It is no wonder, therefore, that hydrological research is most prominent in those regions where surface water is seen to be a permanent feature of the landscape. These regions are source areas and it is necessary to understand them well. It is also becoming clear that through rainfall stimulation it is relatively easier to create more surface water in these areas where the non-linear relationship between rainfall and runoff can be exploited advantageously. The hydrology of the Eastern Transvaal escarpment and the Drakensberg is consequently of great importance.

However, in the beginning of the year a workshop on low-flow hydrology again focused strongly on an increasingly serious problem. Even in naturally well-endowed regions the streams and wetlands are frequently drying up or are running low. The need to quantify expected transmission losses in our large rivers has again been confirmed. In discussions with aquatic ecologists it is now becoming clear that daily flow data are the hydrological signals to work with if ecologically sound management of resources is the objective. This is an important quantum leap in hydrology and water management. It not only means more stringent requirements on data processing and modelling capabilities, but also that rainfall measurements have to become of an acceptable standard.

On the water management side the competition for scarce water resources is reaching critical proportions in some areas. A decision support framework embedded in national and regional scenario-based policy decisions could prove to be one of the indispensable tools in future integrated catchment management. Considerable progress has been made in analysing the possible application of economic principles in water management.

During 1993 the WRC supported 25 projects related to surface hydrology of which 7 commenced during the year and 2 were completed.

Workshop on low-flow hydrology

In February Prof TA McMahon and Dr B Finlayson of the University of Melbourne, two Australian experts in the field of hydrology and ecohydrology, visited South Africa.

This opportunity was used to hold a workshop on low-flow hydrology. Among the participants were many prominent hydrologists, water ecologists and water resource managers of the country. The workshop highlighted several key issues: flow regimes in riverine ecosystems; waste load allocation in seasonal rivers; dependency

of rural and developing communities on low flows; and legal requirements to manage surface- and groundwater as one resource.

During the workshop several research needs were identified and it is expected that this workshop will be followed by similar ones in the future.

Completed projects

Effects of urbanisation on catchment water balance

(No 183) Water Systems Research Group, University of the Witwatersrand

Previous research into urban hydrology had shown that urban development affects runoff and thus the water balance in catchments. Consequently more intense flood runoff was anticipated, resulting in less residual water to maintain the ecological balance within the catchment.

Results of this research indicate that stormwater runoff for the developed portion of catchments was increased by a factor of up to four over that from an undeveloped catchment. This is mainly attributed to impervious surfaces such as roads and roofs, and the consequent decrease in infiltration. Garden watering, using imported municipal water, and the unquantifiable outflow of groundwater were complicating factors. The results highlight the need to amend the Town Planning Regulations to incorporate flood retention on private gardens and the use of dual draining systems to enable floods to be stored on roads or preferably on parks and purpose-made infiltration strips.

Cost: R1 250 000

Term: 1986-1992

Quantitative structuring of national water planning objectives for use in decision support systems in South Africa

(No 296) Department of Mathematical Statistics, University of Cape Town

This project summarises the results of research carried out over the past few years, aimed at providing a justifiable basis for systematically incorporating multiple goals and perspectives into water management in South Africa, particularly where these goals include less tangible issues (such as the environment). A procedure has been developed which incorporates concepts of scenario planning and multiple criteria decision-making (MCDM), and which emphasises the participation of many interest groups in the planning process, consistently with the principles of integrated environmental management. Although more research is needed in order to refine the procedure, it has been successfully tested in experimental workshops with different groups concerned with the Sabie-Sand River catchment area, and decision support software is already available for supporting implementation of the procedures.

Cost: R362 800

Term: 1990-1992

New projects

Classification and hydrological modelling of low flows in Southern Africa *(No 494) Institute for Water Research, Rhodes University*

From an ecological, hydrological and water resource management point of view it is becoming increasingly important to understand the impacts of land-use change on streamflow and specifically to be able to predict changes in flow regimes.

Rivers are not only used to supply water but are often used for the disposal of sewage and waste water. The assimilative capacity of rivers becomes most critical during periods of low flow which may be extended by afforestation, construction of dams, abstractions, etc. The aims of this 3-year study are to use existing hydrological data to characterise low-flow regimes within Southern Africa and to assess and possibly improve existing rainfall-runoff models to specifically simulate low-flow regimes.

Palaeoflood hydrological analysis for selected South African rivers *(No 509) Geological Survey*

Floods have always posed a threat to man in terms of loss of life and damage to property. This situation is exacerbated by a perception that floods have a random pattern of occurrence with seemingly little hope of predicting their magnitude and spatial and temporal occurrence.

The current practice in selecting design floods requires the use of annual maximum flood-peak records which in South Africa are on average 20 to 30 years in length. A further problem with the use of these flood records is that most of the flow gauging records are not calibrated for larger flood events.

Palaeoflood hydrology (PFH) is the study of past or ancient flow events which occurred prior to direct measurement by modern hydrological procedures. In view of the potential value of PFH as an applied research tool, this 2-year research project is addressing the following objectives:

- To evaluate whether PFH can supply reliable maximum peak-flood estimates for South African rivers with the aim of placing an upper limit to the peak maximum flood for each river under investigation
- To refine the present peak-flood estimates as calculated using the statistical, deterministic and empirical approaches as applied by the hydrologist, and in particular, to test the validity of the probable maximum flood and regional maximum flood figures against PFH data.

Evaluation of river losses from the Orange River downstream of PK le Roux Dam *(No 510) BKS Inc.*

The flow in the lower Orange River is highly regulated and controlled by releases from the PK le Roux Dam to provide water for both power generation and the needs of various downstream users. The water released from the dam is subject to considerable evaporation (often in excess of 3 000 mm) in addition to other conveyance losses.

In a recent hydrological analysis of the Orange River undertaken by BKS Inc. for the Department of Water Affairs and Forestry, it was estimated that river losses in the order of 800 million m^3/a occur between PK le Roux Dam and the Orange River mouth. The possible losses through riparian vegetation and seepage from the river (which were not taken into account when estimating the losses) may increase this figure.

Until recently, the Orange River was regarded as a water resource with considerable surplus capacity for further utilisation. Recent investigations, however, have indicated that the resources are limited and any further developments must be carefully considered, particularly in view of the imminent implementation of Phase 1 of the Lesotho Highlands Water Project. It is, therefore, of paramount importance that the losses be examined in detail and quantified with confidence, to narrow down the large variation in the initial estimates.

This 1-year project will formulate a set of practical guidelines that can also be used to estimate losses from other rivers where such losses are significant in the overall water balance.

Hydrological implications of afforestation in the North-Eastern Cape *(No 511) Division of Forest Science and Technology, CSIR*

A forestry operation, approximately 80 000 ha in extent, is being established in the NE Cape. Concern has been expressed in a number of circles about the effects of afforestation on both the water quality and yield from the catchments being afforested. The WRC shares the view of Mondi (Ltd) and the Department of Water Affairs and Forestry that the new afforestation in the NE Cape presents a unique opportunity to initiate a comprehensive monitoring and research programme.

This 3-year research project is designed to provide practical information to policy makers (the Department of Water Affairs and Forestry and the Department of Agriculture), as well as to forest managers, on management options for increasing both water yield and water quality from the forestry estate. It will provide a baseline situation analysis from which further monitoring and research can be launched.

Development of procedures for decision support in water resources management *(No 512) Department of Statistical Sciences, University of Cape Town*

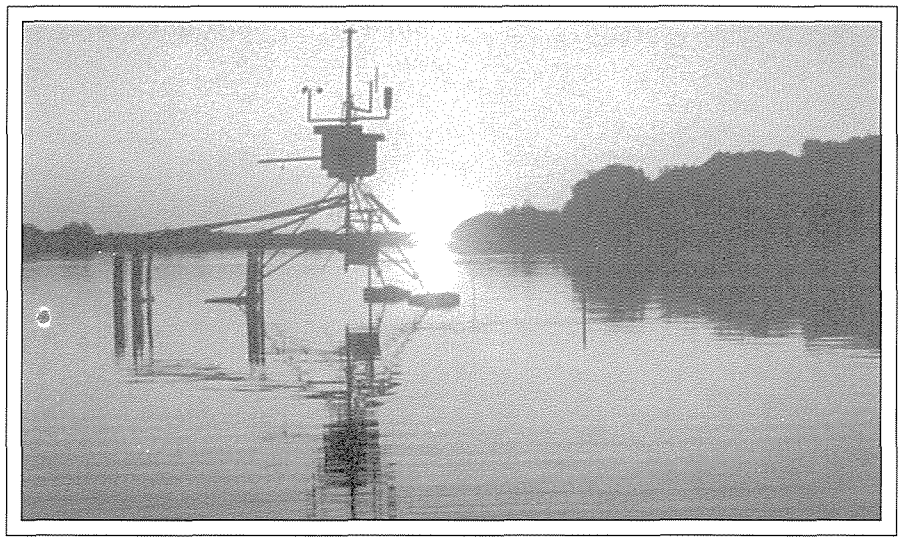
The previous project executed by this research team (No 296: **Quantitative structuring of national water planning objectives for use in decision support systems in South Africa**) has established certain basic decision analytical principles, for the incorporation of the qualitative goals of society into systematic water resource planning. It is anticipated that by the end of 1993 these principles will have been validated in the context of long-term water development plans for a region. This research has provided evidence that society's value judgements regarding the qualitative criteria can in fact be captured in a systematic and comparable manner. However, the research during 1990/92 raised many further questions which need to be resolved before the principles can be incorporated into useful and credible decision support systems (DSS).

Consequently the overall objective of this 3-year project is to develop the operational framework in which the decision analytical tools for the treatment of less well quantified objectives (as determined during the 1990-92 project) can be implemented in water resources management in South Africa.

Case study of stormwater pollution control in a representative valley *(No 518) Wates, Meiring and Barnard Inc.*

Formal, semi-formal and informal urban developments which are springing up around virtually all of our major towns and cities are creating problems of unprecedented pollution, through inadequate, or a total lack of, facilities for sanitation and refuse collection and sometimes unacceptable social habitats.

During the course of this 1-year



Bowen ratio apparatus in the Orange River: Attention to detailed hydrological processes

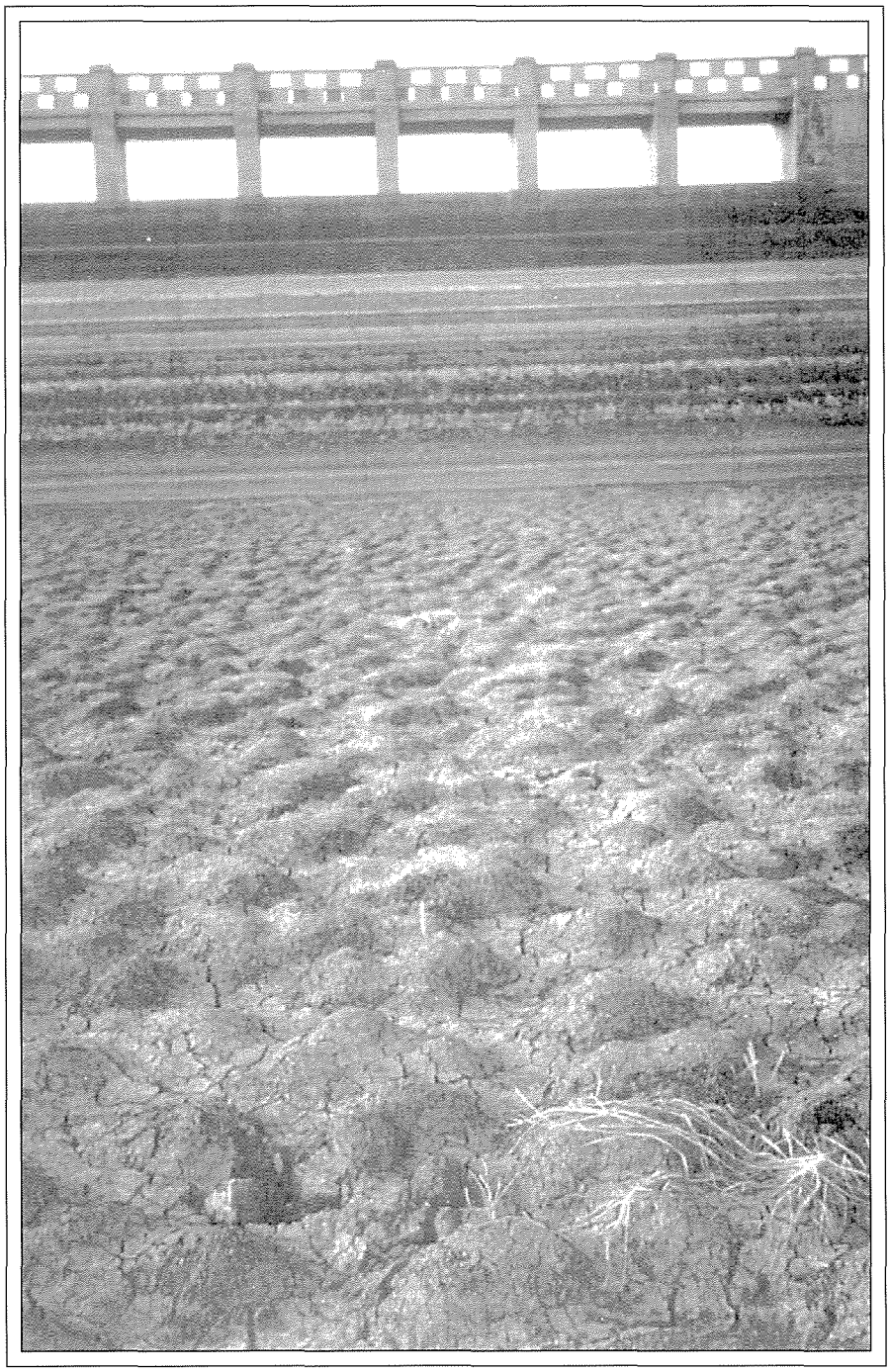
project qualitative information will be gathered from a specific valley and the effectiveness of pollution control measures will be evaluated.

The site selected to carry out the research programme is the Hennops Valley, upstream of and including the Verwoerdburg downtown lake. The reason for selecting this valley is that a wide assortment of pollution sources is found there, such as the Olifantsfontein Sewage Works, a quarry, Tembisa and Ivory Park townships, semi-formal and squatter areas in the Rietspruit and Natalspruit catchments as well as various agricultural and industrial activities. Extended reed-beds also occur in the catchment and the effect of these on the pollution load will also be observed. It is therefore a representative drainage system.

Similar situations have been identified elsewhere and it is the purpose of this study to evaluate cost-effective measures to rectify these situations. There are 2 approaches to this problem:

- Firstly, the quantitative approach, requiring detailed studies over long periods for the solution to the problem
- Secondly, the qualitative approach which identifies the worst cases and solves these, thereby eliminating 80% of the pollution for 20% of the cost.

The research will lead to guidelines for local authorities for the control of storm-water pollution which may include most of the points raised above.



The Van Ryneveld Pass Dam (31 million m³) in the Graaff-Reinet area contains 40% sediment

Control of dam siltation in South Africa *(No 580) BKS Inc.*

In spite of attempts to solve the problem of dam siltation pro-actively in South Africa, the sediment production rates are still high and vary between 37 and 740 $m^3/km^2.a$. This results in an annual decrease in the storage capacity of dams of between 0,2% and 0,9% (with a mean for the country as a whole of 0,52%) and the deterioration of dam basin characteristics e.g. the ratio of the water surface to the storage capacity.

The aim of this research project, which will be executed over a period of 30 months, is to evaluate the following techniques to control dam siltation in South Africa:

- Throughflow of incoming sediments during high-flow conditions
- Flushing of dam basins by water-level drawdown
- Diverting incoming flow with high sediment loads
- Off-channel storage
- Density current
- Removal of sediment by means of pipe systems
- Dredging of precipitated sediment.

Practical and cost-effective guidelines for the operation of dams are therefore envisaged.

Research projects

Completed

- **183** Effects of urbanisation on catchment water balance (University of the Witwatersrand - Department of Civil Engineering, Water Systems Research Group)
- **296** Quantitative structuring of national water planning objectives for use in decision support systems in South Africa (University of Cape Town - Department of Mathematical Statistics)

Current

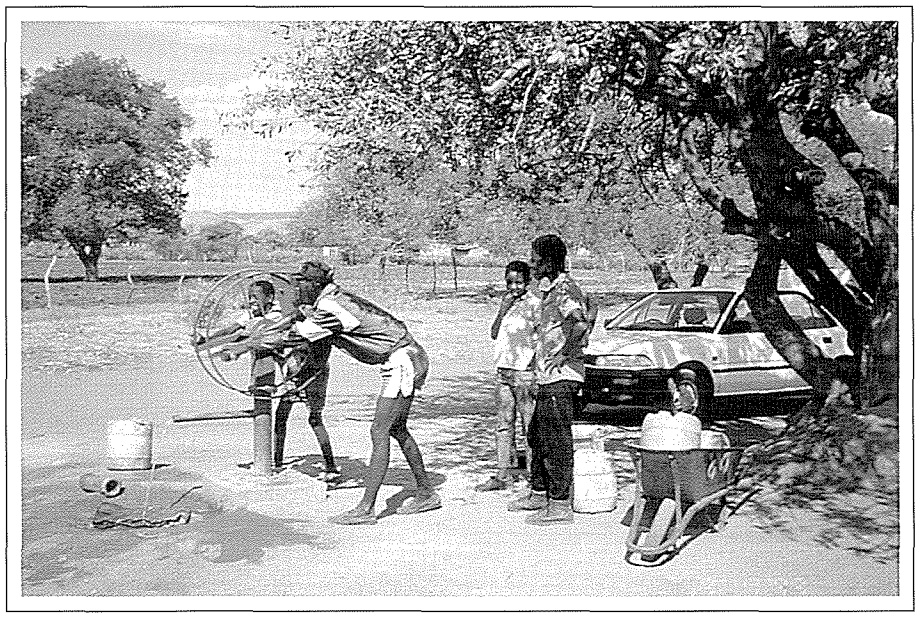
- **235** Hydrological modelling studies in the Eastern Cape (Rhodes University - Department of Geography)
- **270** Hydrological systems model development (University of Natal - Department of Agricultural Engineering)
- **298** Surface water resources of South Africa 1990 (Consortium of consulting engineers)
- **299** Adaption and calibration of an urban runoff quality model (CSIR - Division of Water Technology)
- **300** Utilisation of geographical information systems (GIS) and integrated environmental management (IEM) in the planning and management of water resources within river catchments (University of Pretoria - Department of Landscape Architecture)
- **317** Urban catchment monitoring (Welkom City Council and SRK (CE) Inc.)
- **319** Monitoring the effect of catchment development on urban runoff and water balance (University of the Witwatersrand - Department of Civil Engineering, Water Systems Research Group)
- **375** Development of a distributed hydrological modelling system to assist with water quantity and quality management in the Mgeni catchment, Phase II (University of Natal - Department of Agricultural Engineering)
- **415** Application of resource economics to water management decision making in South Africa (University of Natal - Institute of Natural Resources)
- **424** Development of an urban component for the ACRU model (University of Durban-Westville - Department of Geography)
- **425** Development of an integrated catchment management system for the Crocodile River catchment (CSIR - Division of Forest Science and Technology)
- **442** Development of improved flow gauging structures for South African rivers (Sigma Beta Consulting Engineers)
- **444** Development of rigorous engineering methodology for designing vegetative erosion protection systems (SRK (CE) Inc.)
- **490** Development of flood damage functions and a computer program to determine the advantages of flood and flood damage control measures (University of the Orange Free State - Department of Agricultural Economics)
- **492** Effect of the agricultural environment on water resources (University of Natal - Department of Agricultural Engineering)
- **493** Development and testing of a water balance model for a grassland catchment in the summer rainfall area of South Africa (CSIR - Division of Forest Science and Technology)

New

- **494** Classification and hydrological modelling of low flows in Southern Africa (Rhodes University - Institute for Water Research)
- **509** Palaeoflood hydrological analysis for selected South African rivers (Geological Survey)
- **510** Evaluation of river losses from the Orange River downstream of PK le Roux Dam (BKS Inc.)
- **511** Hydrological implications of afforestation in the North-Eastern Cape (CSIR - Division of Forest Science and Technology)
- **512** Development of procedures for decision support in water resources management (University of Cape Town - Department of Statistical Sciences)
- **518** Case study of stormwater pollution control in a representative valley (Wates, Meiring and Barnard Inc.)
- **580** The control of dam siltation in South Africa (BKS Inc.)

5

Groundwater



World-wide, groundwater serves as a major source of urban water supply, both for domestic and industrial purposes, normally requiring only minimal treatment. It is as a supply for rural communities and irrigated agriculture, however, that groundwater comes into its own, providing a source of cheap, clean water at the point of need. In South Africa, where it is estimated that some 12 million people are without access to safe drinking water supplies, it is particularly important that groundwater be viewed as a means of rapidly addressing this great need in the short term.

As groundwater quality is affected by virtually every activity of society, it stands to reason that much can be gained by alerting people to its susceptibility to pollution and, better still, involving the general public in programmes to protect groundwater. With this in mind, two workshops were held on the topic **Public Education and Participation in Groundwater Protection** in January this year to assist in the development of a proactive aquifer protection strategy. Mr Andrew Stone of the American Groundwater Trust, presented keynote addresses on these occasions.

Dr Andrew Skinner's participation in the **Africa needs Groundwater** convention in September provided those interested in the field of groundwater protection policy with a further opportunity to consider the complexities of this topic. Dr Skinner, of the National Rivers Authority (NRA) in the UK, was involved in the compilation of the recently published landmark document *Policy and Practice for the Protection of Groundwater* (in England and Wales). He provided valuable guidance on an integrated approach to groundwater protection, involving both source (borehole, wellfield) and resource (aquifer) protection.

The Hydrogeological Mapping Programme has experienced continued growth this year with the initiation of a "pilot" regional-scale hydrogeological map. In addition to this, the Department of Water Affairs and Forestry has launched an ambitious mapping programme whereby they hope to complete the hydrogeological mapping of South Africa at a regional scale over the next 5 years. This programme has raised awareness of groundwater and will result in the tools to manage this valuable resource on a sustainable basis in the future.

During 1993 the WRC supported 28 projects related to groundwater of which 8 commenced during the year and 6 were completed.

Completed projects

Evaluation and development of geophysical techniques for characterising the extent and degree of groundwater pollution *(No 267) Divisions of Earth, Marine and Atmospheric Science and Technology, and Water Technology, CSIR.*

Geophysical techniques are used world-wide as an aid in the detection and monitoring of groundwater and soil contamination. Most of these techniques have been refined and are applied in areas of primary aquifers comprising unconsolidated sediments. This project consequently investigated the usefulness of these techniques in the hard rock aquifers common to South Africa for the delineation of pollution plumes at waste sites.

During the course of the project the importance of understanding the

structural geological setting of aquifers, in particular around waste disposal sites, was realised. A set of guidelines for the use of geophysical techniques for mapping and monitoring contamination has been prepared. The researchers strongly recommend that detailed geophysical surveys should be carried out as part of the geohydrological investigation prior to the establishment of a new waste site, and continued after site closure to monitor the movement of the pollution plume.

Cost: R437 300

Term: 1989-1991

Integration of remote sensing, digital image processing and geographical information systems technologies for regional-scale groundwater resources assessment in South Africa

(No 310) SRK (CE) Inc.

The high costs and time required to collect hydrogeological data over a large area during an assessment of the groundwater resources potential of a region has often resulted in an uneven distribution of data and an insufficient data base with which to make assessments with any degree of confidence.

The type of data most commonly used in regional groundwater investigations, such as geology, soils, relief, vegetation type and density, and drainage, although very expensive to collect in the field, can be obtained rapidly and at a fraction of the cost of ground surveys through the use of satellite imagery.

Digital image processing allows one to extract valuable data from satellite imagery and other digital data sets. This project has demonstrated the value of combining these technologies in a geographic information system environment for the preparation of a groundwater resources potential map of the Magalakwena River Basin.

This approach will make an important contribution to the regional hydrogeological mapping programme.

Cost: R251 000

Term: 1990-1992

Preliminary investigation of the nitrate content of groundwater and limitation of the nitrate input *(No 368) Division of Water Technology, CSIR*

Increasing nitrate levels in groundwater are a matter of concern worldwide as a result of their effect on human and animal health, especially the acute health effects on small children when regularly drinking water with a nitrate content of more than 10 mg/*l* (as nitrogen). From available information in the National Groundwater Data Bank, which was processed as part of this project, it seems that this level is being exceeded in 27% of the sources. Some of these high nitrate values are of natural origin, while others are the result of human activities, e.g. pit latrines, cattle-kraals, fertiliser application, sewage sludge disposal, on-site sanitation, etc. This preliminary investigation needs to be followed up to quantify the situation better and to identify measures to curb the problem.

Costs: R70 000

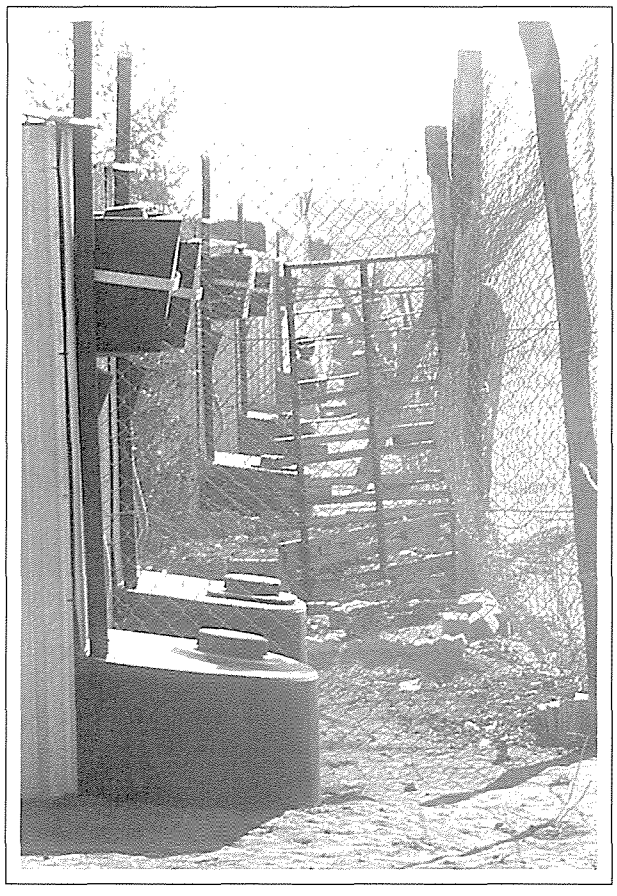
Term: 1991-1992

Assessment of health aspects of the impact of domestic and industrial waste disposal activities on groundwater resources

(No 371) Division of Water Technology, CSIR

The transmission of hazardous chemical substances and infectious diseases through contaminated drinking water is a frequent and well-documented occurrence. Any disease caused by drinking contaminated water can be transmitted through groundwater if the disease-causing agent reaches the water source in infective doses to cause the specific illness. Some contaminants are more likely than others to be present in groundwater with the result that some water-borne diseases occur more frequently. This literature review was aimed at gaining knowledge about the impact of domestic and industrial waste disposal practices on groundwater supplies and the associated health implications.

Based on international experience, the researchers believe that the few documented cases of groundwater contamination in South Africa should



Impact of low-cost sanitation systems on groundwater quality is being investigated

not be seen as an indicator that similar problems do not exist in this country.

This review provides a sound basis for more detailed investigations of the health aspects related to contamination of groundwater resources from domestic and industrial waste disposal in South Africa.

Cost: R48 000

Term: 1991-1992

Development of a strategy to monitor groundwater quality on a national scale (No 482)

Division of Water Technology, CSIR

A one-year project aimed at identifying practical strategies to monitor groundwater quality on a national scale was recently completed by the CSIR. The study was literature-based and thus used international experiences to identify suitable strategies. The report recommends that empirical and hierarchical approaches be adopted so that a national network can be established relatively quickly at low cost. Further, the groundwater network should be linked to other hydrological monitoring networks in order to ensure the efficient use of available resources and to reduce duplication of effort. One of the tools developed as an aid in identifying priority monitoring areas is the national groundwater vulnerability map. The results of the study are presently being put to use in the design and implementation of a pilot-scale groundwater quality monitoring network.

Cost: R150 000

Term: 1992-1993

Identification and verification of polluted areas in the dolomitic aquifer of the PWV-area

(No 500) Atomic Energy Corporation of South Africa

The dolomitic aquifers of the PWV area are one of the most important sources of groundwater in South Africa. They have been investigated and developed to provide emergency water supplies in times of drought. It is therefore imperative that this vulnerable resource be protected from pollution arising from mining, industrial and urban development, and agricultural activities.

Water samples taken before 1987 by the Department of Water Affairs and Forestry indicated that elevated levels of pollutants are present at certain localities within the dolomites. Although the aim of this project was to resample the identified boreholes showing elevated levels of pollutants, such as sulphates and nitrates, it was found that many of these boreholes had been destroyed as a result of mushrooming informal settlements.

Sampling of additional holes has, however, provided valuable data on the extent, as well as identifying possible sources, of the pollution problem.

Cost: R70 000

Term: 1992-1993

New projects

Groundwater abstraction in the Port Elizabeth municipal area (No 515) SRK (CE) Inc. and the Municipality of Port Elizabeth

This joint 2-year project is in progress to determine the distribution of boreholes and volumes of groundwater abstracted from the Table Mountain Group sandstone aquifer in the Port Elizabeth municipal area.

The results will be used to formulate suitable guidelines for the control of groundwater development and protection of the aquifer in terms of groundwater quality and volumes of water abstracted. The potential for saline water intrusion to the aquifer is being investigated. The research is also aimed at determining:

- Spatial and seasonal variations in groundwater abstraction and groundwater chemistry
- Potential for groundwater contamination through surface disposal of effluents and the application of fertilisers
- Impacts of groundwater abstraction on municipal consumption.

Application of seismic tomography and ground-penetrating radar for the detection of fractures and the determination of hydraulic properties of fractured rock aquifers (No 516)

Division of Earth, Marine and Atmospheric Science and Technology, CSIR

It has been estimated that more than 90% of South Africa's groundwater occurs in fractured rock aquifers. In order to locate these water-bearing zones, and to exploit them in a manner that will assure their long-term integrity, a thorough understanding of the location, physical nature and orientation of these fractures is required. Fractures, when present in an aquifer system, also influence the flow of groundwater. Geophysical fracture characterisation techniques based on seismic anisotropy and related shear-wave splitting as well as radar have been under investigation for a number of years to address this problem. Recently, armed with new theoretical concepts and hardware developments, significant progress has been made in fracture characterisation.

The main aim of this 3-year project is to investigate the physical nature of hardrock aquifers using seismic borehole tomography and ground-penetrating radar techniques.

Production of the Pietersburg 1:500 000 hydrogeological map sheet 2326 (No 517) Water Systems Management and the Department of Water Affairs and Forestry

The increasing importance of groundwater in South Africa, particularly as a source of supply of domestic water for remote rural communities, small urban settlements, and for farm-scale irrigation development, has created an urgent need for summarised and mapped hydrogeological information country-wide in a synoptic and visual form, at all planning levels. The recent development of a fully operational and dynamic National Groundwater Data Base at the Department of Water Affairs and Forestry, the advancements made in geographic information system technologies and

the design of effective linkages between various data bases and other information systems have created the opportunities of meeting this need in the near future.

Considerable progress has been made over the past 3 years with regard to the planning of a hydrogeological mapping programme for South Africa. This 1-year project is aimed at producing a pilot map together with an explanatory document to serve as a "blueprint" for the entire 1:500 000 series, comprising some 23 sheets.

Distribution of fluoride-rich groundwater in the Eastern and Mogwase regions of Bophuthatswana: Influence of bedrock and soils, and constraints on utilisable drinking-water supplies *(No 526) Department of Geology, University of Cape Town*

Fluoride is one of a few potentially toxic trace elements whose primary path into the human body is via drinking water. *Ad hoc* sampling of groundwater which provides the drinking-water supply of approximately 95% of villages in Bophuthatswana has shown that fluoride concentrations in some parts of the country grossly exceed water quality guidelines. Fluorosis, a severely debilitating illness resulting from excessive consumption of fluoride, is clearly manifested in many villages. This 3-year study is designed to provide a comprehensive picture of the extent and underlying causes of fluoridisation of the groundwaters of Bophuthatswana, and the intervening areas of the Transvaal, and the distribution of potentialy harmful groundwater liable to promote fluorosis when used as a drinking-water supply.

Review of approaches and methodologies for determining recharge and leachate generation rates at waste disposal sites *(No 564) Division of Water Technology, CSIR*

The CSIR is currently undertaking a literature review of methods used to determine groundwater recharge and to predict leachate generation rates at waste disposal sites. When dealing with drier or water-deficient areas, the 2 approaches apparently yield contradicting results. The 1-year project will evaluate local and internationally used approaches in order to assess the apparent problem in greater detail. From this, the state of current knowledge and practice can be appraised and further research needs defined.

Hydrogeological, isotopic and hydrochemical assessment of the response of a fractured multi-layered aquifer to long-term abstraction *(No 565)*
Schonland Research Centre, University of the Witwatersrand

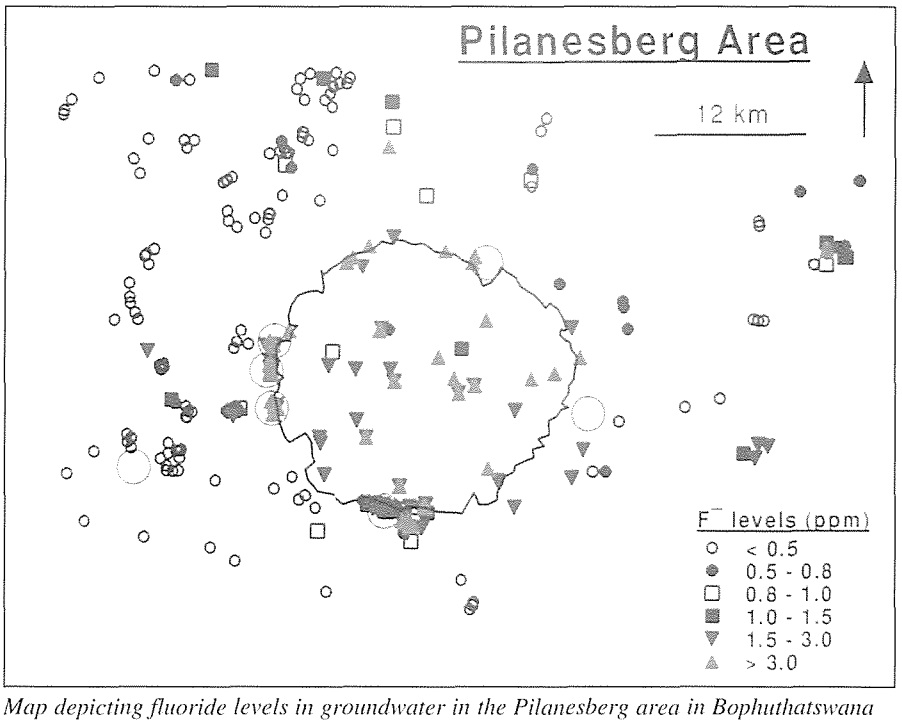
A fractured sandstone aquifer in the Northern Kalahari has been used for groundwater abstraction since 1967. Excellent records of drawdowns and volumes pumped have been maintained. This vast wealth of data is being used to evaluate the response of a fractured rock aquifer to long-term abstraction. The same aquifer can be found in NW South Africa and Zimbabwe. Through an understanding of the behaviour of one part of the aquifer, the management of future groundwater schemes may be enhanced.

The objectives of this 1-year project are:

- To establish a GIS compatible data base and interpret 22 years of monitoring data
- To establish the extent and characteristics of the aquifers in the study area with reference to the Karoo sequence
- To develop a preliminary mathematical model for assessing the response of a fractured and multi-layered aquifer to long-term abstraction with specific attention being paid to the analysis and evaluation of test pumping results
- To assess recharge to the fractured aquifer using historical and new isotopic analyses, hydrochemistry and water level monitoring data.

Conversion of the software packages TRICON and BAYES from personal computers to machines using the UNIX operating system *(No 566)*
Institute for Groundwater Studies, University of the OFS

The software packages TRICON and BAYES emanated from a WRC project entitled **A comparative study of two- and three-dimensional ground-**



Map depicting fluoride levels in groundwater in the Pilanesberg area in Bophuthatswana

water models. They were originally developed for IBM-compatible personal computers, using the DOS operating system, with the following objectives in mind:

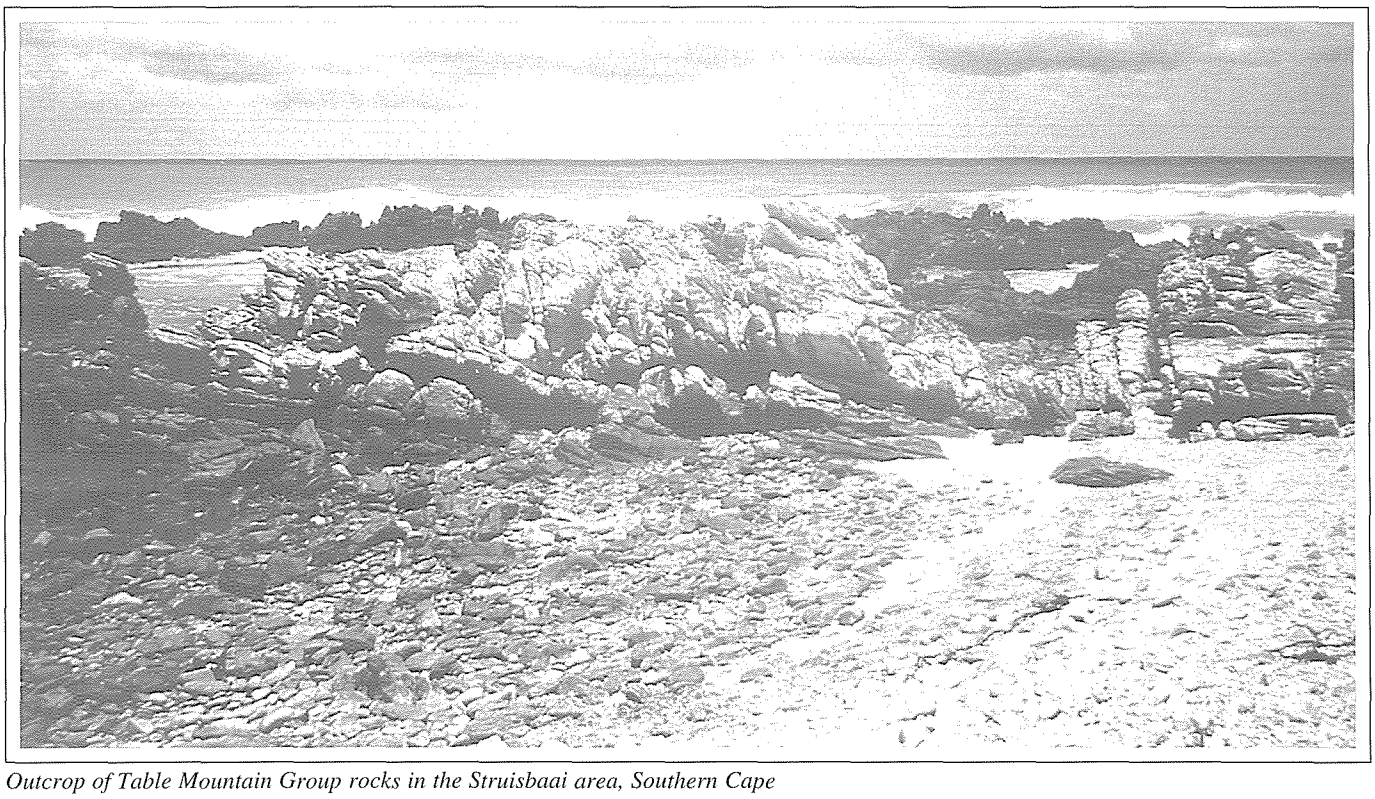
- To draw accurate and aesthetically acceptable contour maps of a regionalised variable, i.e. a variable that varies in space
- To estimate values of a regionalised variable, and its associated error, at points where no measurements are available.

The restriction to IBM-compatible machines unfortunately limited their practical application considerably. Both packages are, therefore, being converted during this 1-year project to machines that use the UNIX operating system which will allow later incorporation into a GIS package, also under development by the Institute for Groundwater Studies.

Investigation of the contaminant attenuation capacity of the soil/aquifer system with special emphasis on the vadose zone *(No 572) Division of Water Technology, CSIR, and the Department of Soil and Agricultural Water Science, University of Stellenbosch*

During infiltration through soils and transport in aquifers many contaminants are naturally attenuated, but not all subsurface environments are equally effective in this respect. The unsaturated zone provides the first line of natural defence against groundwater pollution. This is not only because of its strategic position between the land surface and the groundwater table, but also because it provides a favourable environment for pollution attenuation or elimination. Attenuation may occur as a result of processes such as adsorption, retardation, physical filtration, precipitation, biological and radioactive decay.

During the course of this 4-year study, the contaminant attenuation capacity characteristics of various soils, aquifers and the subsurface environment as a whole for specific contaminants will be determined. The results are expected to provide planners, policy makers and pollution control authorities with a useful tool with which to assess groundwater pollution risks.



Outcrop of Table Mountain Group rocks in the Struisbaai area, Southern Cape

Research projects

Completed

- **267** Evaluation and development of geophysical techniques for characterising the extent and degree of groundwater pollution (CSIR - Division of Earth, Marine and Atmospheric Science and Technology, and Division of Water Technology)
- **310** Integration of remote sensing, digital image processing and geographical information systems technologies for regional-scale groundwater resources assessment in South Africa (SRK (CE) Inc.)
- **368** Preliminary investigation of the nitrate content of groundwater and limitation of the nitrate input (CSIR - Division of Water Technology)
- **371** Assessment of health aspects of the impact of domestic and industrial waste disposal activities on groundwater resources (CSIR - Division of Water Technology)
- **482** Development of a strategy to monitor groundwater quality on a national scale (CSIR - Division of Water Technology)
- **500** Identification and verification of polluted areas in the dolomitic aquifer of the PWV area (Atomic Energy Corporation of South Africa Ltd)

Current

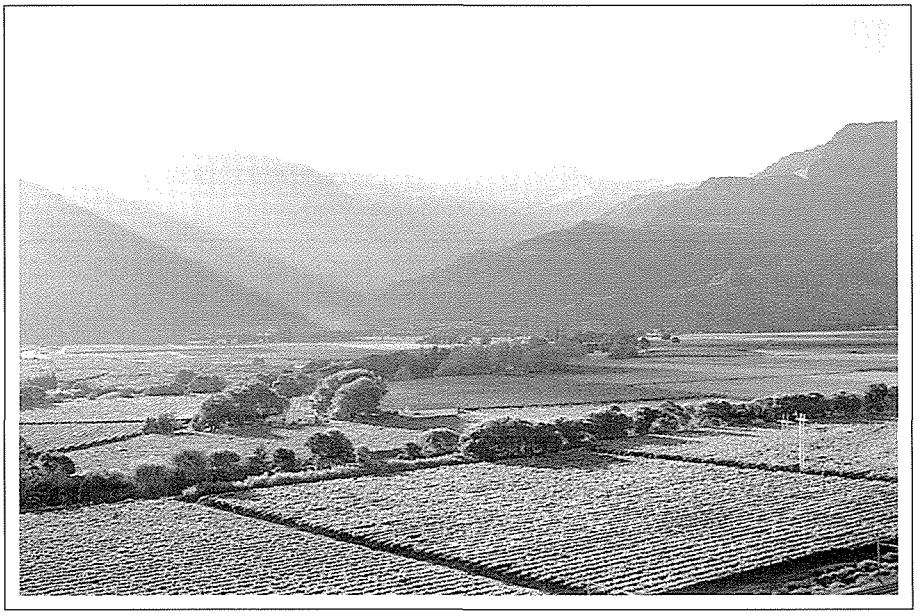
- **221** Geohydrological investigation and evaluation of the Zululand coastal aquifer (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **273** Investigation of the potential use of NOAA satellite remotely sensed data for identification of regional-scale fracture zones for groundwater supply purposes in Southern Africa (SRK (CE) Inc.)
- **291** Regional investigation into groundwater quality deterioration in the Olifants River catchment above the Loskop Dam, with specialised investigations in the Witbank Dam subcatchment (University of the Orange Free State - Institute for Groundwater Studies)
- **311** Development and evaluation of geohydrological and isotope hydrological methodologies for the identification of areas potentially suitable for waste disposal (University of the Witwatersrand - Schonland Research Centre, and Atomic Energy Corporation of South Africa Ltd)
- **352** Development of a method for the selection of suitable landfill sites, and of guidelines for sanitary landfill in municipal areas (CSIR - Division of Water Technology)
- **353** Preparation of a manual on quantitative estimation of groundwater recharge and aquifer storativity (Department of Water Affairs and Forestry)
- **377** Use of geographic information systems and other computer-aided drafting facilities for the production of geohydrological maps (University of the Orange Free State - Institute for Groundwater Studies)
- **378** Development of techniques for risk analysis and groundwater management of Southern African aquifers (University of the Orange Free State - Institute for Groundwater Studies and CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **481** Geochemistry and isotopes for resource evaluation in the fractured rock aquifers of the Table Mountain Group (CSIR - Division of Water Technology)
- **483** Compilation of a hydrogeological map of South Africa (JR Vegter Esq. and Department of Water Affairs and Forestry)
- **484** Integrated multidisciplinary geodynamic/geophysical approach to groundwater exploration around the South African coastline (Atomic Energy Corporation of South Africa Ltd)
- **485** Development of a systematic method for evaluating site suitability for waste disposal based on geohydrological criteria (CSIR - Division of Water Technology)
- **486** Catchment water quality deterioration as a result of water-level recovery in abandoned gold mines on the eastern and central Witwatersrand (University of the Orange Free State - Institute for Groundwater Studies)
- **487** Analysis and interpretation of aquifer tests in secondary aquifers (University of the OFS - Institute for Groundwater Studies)

New

- **515** Groundwater abstraction in the Port Elizabeth municipal area (SRK (CE) Inc. and the Municipality of Port Elizabeth)
- **516** Application of seismic tomography and ground-penetrating radar for the detection of fractures and the determination of hydraulic properties of fractured rock aquifers (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **517** Production of the Pietersburg 1:500 000 hydrogeological map sheet 2326 (Water Systems Management and the Department of Water Affairs and Forestry - Directorate of Geohydrology)
- **526** Distribution of fluoride-rich groundwater in the Eastern and Mogwase regions of Bophuthatswana: Influence of bedrock and soils and constraints on utilisable drinking-water supplies (University of Cape Town - Department of Geology)
- **564** Review of approaches and methodologies for determining recharge and leachate generation rates at waste disposal sites (CSIR - Division of Water Technology)
- **565** Hydrogeological, isotopic and hydrochemical assessment of the response of a fractured multi-layered aquifer to long-term abstraction (University of the Witwatersrand - Schonland Research Centre)
- **566** Conversion of the software packages TRICON and BAYES from personal computers to machines using the UNIX operating system (University of the Orange Free State - Institute for Groundwater Studies)
- **572** Investigation of the contaminant attenuation capacity of the soil/aquifer system with special emphasis on the vadose zone (CSIR - Division of Water Technology and the University of Stellenbosch - Department of Soil and Agricultural Water Science)

6

Agricultural water utilisation



Agricultural development, more especially irrigation development, results in changes in ecosystems. The degree of change will depend on the relevant circumstances. Viable irrigation calls for meaningful planning, implementation and management. If these are lacking, not only is irrigation as such detrimentally affected, but also the two major natural resources in this regard, viz. soil and water.

Damage to these resources can take a number of forms viz. waterlogging, salinisation, nutrient losses, pollution and erosion. The vast majority of WRC projects related to agricultural utilisation, launched in the past, were therefore aimed at either eliminating the mentioned deleterious effects or at least largely minimising them. In the recent past other variables have also been taken into account and projects on increased economic water-use efficiency at global farming level, as well as on the interdependent factors determining the viability of irrigation farming were launched.

Investigation of the actual and potential impact of irrigation on ecosystems and of possible habitat losses is, however, a facet which has in the past been restricted virtually exclusively to salinisation research. In view of the resolutions of the United Nations Conference on Environment and Development (held in 1992 in Rio de Janeiro), it is, however, clear that more prominence will have to be given in future to environment-related irrigation research, under conditions of developing agriculture as well.

From the above it is clear that the interdisciplinary nature of research on agricultural water use is an aspect which is fundamentally different from other fields of water research. This interdisciplinary nature needs to be accepted and encouraged, as it is only then that research programmes in which the following broad objectives are being pursued, will be initiated and carried out in such a manner that the end result meets the demands of acceptability and applicability:

- Data collection and processing with a view to planning, projections and therefore management
- Improved performance of the current commercial irrigation systems, for developed as well as for developing agriculture
- Given the necessary information, improved management of irrigation systems
- Establishment of environmentally friendly irrigation practices
- Effective information and technology transfer in the agricultural water industry.

These objectives once again confirm the priorities set out in the Master Plan for Agricultural Water Research.

During 1993 the WRC funded 32 agriculturally related research projects. Of these 5 projects were completed during the year while 6 new research agreements were concluded.

Workshop on the field water balance in the modelling of cropping systems

The ability to address components of the field water balance accurately is a key to the successful application of models in irrigated and dryland agriculture and in agrohydrology. With models being regarded as the encapsulation of useful knowledge and in increasing demand for research and management purposes, this workshop provided an opportunity for a stock-taking exercise regarding the central element of these models, i.e. the field water balance.

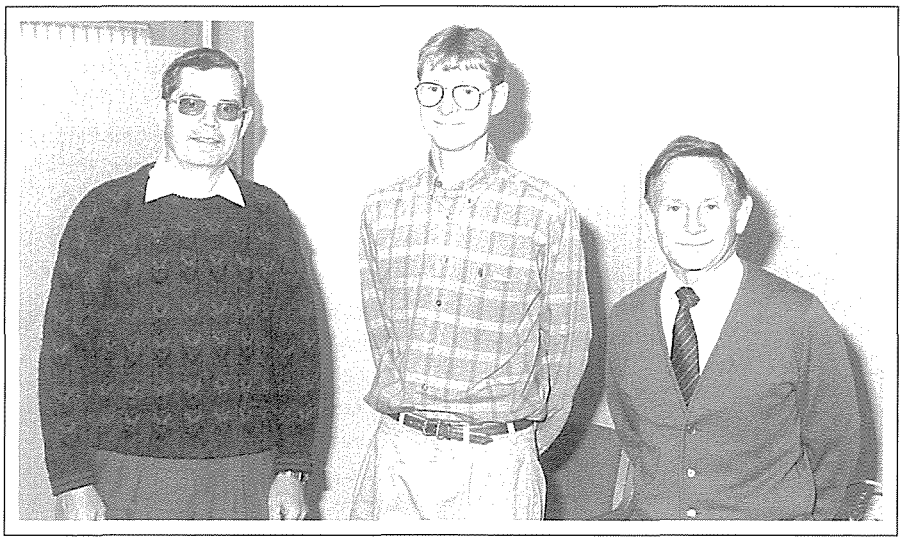
The group involved in the workshop had the advantage of the inputs of Prof Gaylon Campbell of the Department of Soil Physics and Environmental Sciences, Washington State University, which included an introductory overview of almost all topics dealt with. Topics addressed during the workshop were *inter alia* variation in modelling approaches; objective assessment of model performance; field validation of models and identification of model limitations. It is anticipated that this workshop will contribute significantly to the development and application of these models in South Africa.

Membership of the International Commission on Irrigation and Drainage (ICID)

The ICID was established in 1950 with the broad objective of raising the technical standards of irrigation and drainage projects, flood control systems, as well as the improvement of the operation and maintenance of these projects and systems. It, therefore, endeavours to stimulate and promote the development and application of the sciences and techniques of engineering, agriculture, economics, ecology and social science in managing water and land resources for irrigation and drainage.

Presently the ICID is the only international organisation which concentrates exclusively on irrigation and drainage. Up to December 1992 South Africa had not been a member of this organisation, but in 1992 South Africa's application for membership as from 1 January 1993, was approved. In the initiatives to obtain full membership for South Africa, the WRC, the Departments of Water Affairs and Forestry and of Agriculture, the Agricultural Research Council and the SA Irrigation Institute, played important roles.

From an irrigation point of view, South Africa is in certain respects unique in the world. Consequently the local experience and expertise puts South Africa in a position to make significant contributions to the aims of the ICID. At the same time South African membership provides a platform for regular liaison between local irrigation scientists/ engineers/technologists and their counterparts in other parts of the world.



A successful workshop on modelling the soil water balance of agricultural and hydrological systems was attended inter alia *by (from left) Prof GS Campbell (Washington State University), Dr J Annandale (University of Pretoria) and Dr GC Green (WRC)*

Completed projects

Maximising irrigation project efficiency in different soil-climate-irrigation situations

(No 226) Department of Agrometeorology, University of the OFS

This project's major aim was to implement and test irrigation scheduling methodologies under practical farm situations.

The results of the research 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.

During the experimental period it was gratifying to note the generally high level of interest of the farming community involved. The experiments also showed, however, that successful transfer of new technology, such as irrigation scheduling, requires intensive co-operation between researcher and the farming community.

Cost: *R974 000*

Term: *1988-1993*

Estimation and evaluation of moisture stress in crops by means of remote control aerial surveillance *(No 229) Department of Soil Science, University of the North*

The aim of this project was to develop the use of remote-controlled aircraft as low-cost remote sensing platforms for the detection of crop water stress.

The project team built and tested a wide range of remote-controlled aircraft that varied in sophistication from the simplest glider type to a highly sophisticated long-range type aircraft. This was done in order to ensure that the widest possible range of conditions, as regards landing and take-off conditions, would be accommodated. Similarly, on-board instrumentation varied in sophistication, with the top end having colour video imagery relayed directly from the aircraft to a ground station and also being computer compatible.

The project proved that the remote-controlled platforms and instrumentation could identify crop water stress quickly, accurately and cheaply. The methodology could also be applied in identifying crop disease and nutrient imbalances.

Cost: *R360 300*

Term: *1988-1993*

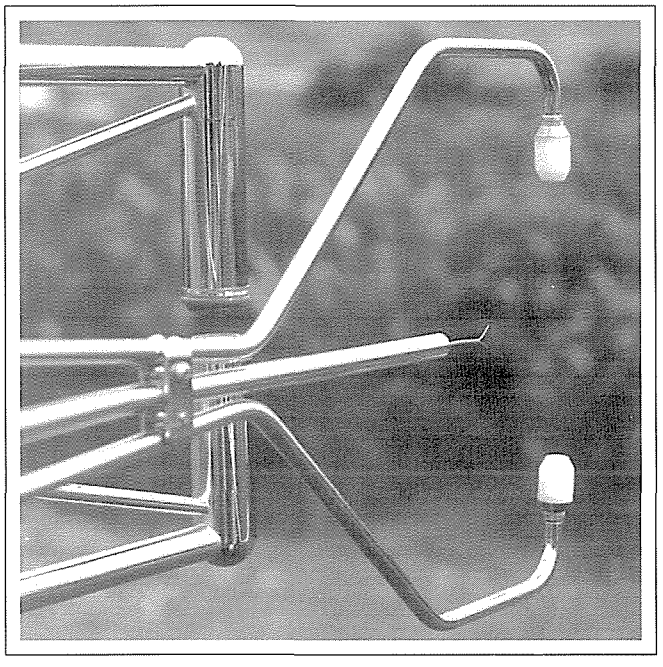
Relationship between climate and crop factors *(No 260) Department of Agrometeorology, University of the OFS*

This project aimed at identifying the relationship between climatic variables and variation in crop factors. Traditionally the establishment of a specific set of crop factors at any one location, was a time-consuming process and spanned a number of seasons. Extrapolation of these factors to other locations was also very difficult.

The research team was able to isolate the influences of the various climatic variables, such as radiation, wind and humidity on variation in crop factors, and to express these relationships in mathematical terms. Given the climate at any location, the research team is able to determine applicable crop factors, at the new location, with a great degree of confidence. Sound irrigation scheduling strategies, of which crop factors are a core component, can therefore be implemented swiftly and with confidence at such locations.

Cost: *R241 000*

Term: *1989-1993*



Eddy correlation apparatus which measures the transfer of heat and the water vapour above a crop through the high frequency measurement of fluctuations in temperature, humidity and vertical wind speed (Photo: Prof MJ Savage, University of Natal)

Development of a consolidated computer software package for the management of an irrigation scheme *(No 367) Energy Laboratory, Rand Afrikaans University*

This project sought to integrate two existing simulation packages into a single irrigation project management package. These two individual packages, developed by the same laboratory, firstly simulated water flow in canals and secondly put in place an administrative office base.

The consolidated software package now makes it possible to calculate irrigation water releases into a canal system, based on water orders, and at the same time debit each user individually for water consumed. The packages have been successfully tested on the Loskop Irrigation Scheme and implemented on various other similar schemes.

Cost: R49 000

Term: 1991-1992

Decision-making procedures for determination of crop water requirements *(No 379) MBB Inc.*

The primary objective of this pilot project was to assess the feasibility of establishing a PC-based decision support system for the estimation of crop water requirements under irrigation. The intention was that the procedures should:

- Be suitable for use by practitioners with limited computer experience and training
- Be in line with current international practice
- Incorporate both interpreted research results and the practical experience of specialists.

An implied secondary objective was to incorporate in the procedure the results of WRC supported research projects dealing directly, or indirectly, with crop water requirements.

A PC-based program, SAPWAT (Southern African Procedure for estimating irrigation WATer requirements) is the main product of this pilot project. SAPWAT is a comput-

erised procedure for estimating crop irrigation requirements, and, in common with similar procedures, is an aid to estimation, and not a calibrated simulation model. Each element of the procedure is an improvement on what is currently available, even in the accepted FAO procedures. It is a synthesis of international trends and local research incorporating information and models such as ZONEFINDER, ACRU, PAWC, PBMWAT and BEWAB developed by the Universities of Natal, Fort Hare and the Orange Free State.

Following the recommendation that SAPWAT be developed to the stage where it is accepted as the standard procedure for estimating irrigation requirements of crops in Southern Africa, the WRC entered into a further agreement with the same research team. The follow-up project is to commence in 1994.

Cost: R237 000

Term: 1991-1992

New projects

Effect of pre-programmed deficit irrigation on crop reaction *(No 423) Department of Soil Science, University of the OFS*

In a previous WRC-funded irrigation project, a water balance scheduling model (BEWAB), was developed with the main objective of managing soil-induced crop water stress in such a manner as to ensure the maximum effective use of irrigation water at farm level. This management technique has proved to function well under total irrigation.

It is already known that the occurrence and duration of crop water stress depend on environmental conditions, soil water retention ability and content, as well as the growth stage during which the stress occurs. Various results have indicated that the application of continuously rationed water to grain crops does not cause additional reduction in yield. This would indicate that a plant physiological mechanism exists whereby plants can adapt to deficit irrigation. Too little information is, however, available to offer a proper explanation for the adaptation phenomena of crops under sub-optimal water supply conditions. The purpose of this 4-year investigation is to launch field experiments, using different crops, to determine the effect of pre-planned rationed water application on the development and production of crops.

Improved estimation of plant and soil evaporation from cropped lands *(No 507) Department of Agrometeorology, University of the OFS*

The partitioning of total crop evaporation into the transpiration (effective use) component and the soil evaporation (wastage) component is one of the weakest links in current crop growth and hydrological models. Such models are in increasing demand for planning and managing irrigation and for contributing information on the hydrology of agricultural lands. Recent evidence suggests that soil evaporation is a larger and more variable contributor to inefficient crop water use than previously realised. In order to use available models for optimising water use efficiency in various crop production systems, their ability to correctly partition total crop evaporation into plant and soil components will have to be improved. The main aim of this 2-year research project is to bring about such an improvement.

Modelling the water balance on bench-mark ecotopes *(No 508) Institute for Soil, Climate and Water, Agricultural Research Council*

In recent years much effort by researchers in the fields of irrigation, dryland crop water use and surface hydrology has gone into the development and adaptation of simulation models to be used for water management within these fields. However, these models, which are in increasing demand for decision support purposes, still have weaknesses.

In South Africa model validation, especially with regard to the all-important water budgeting components, has been largely opportunistic. The main reason for this deficiency is that the acquisition of representative data sets is extremely costly and laborious. It has therefore become necessary to undertake a well-planned data acquisition and model evaluation programme which will reduce this deficiency.

This 3-year research project aims to identify 8 benchmark situations, in each of which a comprehensive data set of lasting value will be obtained, expressly for the purpose of evaluating and refining water budgeting model routines typical of those used in the models to which reference has been made.

Development of a computerised management system for irrigation projects *(No 513) Energy Laboratory, Rand Afrikaans University*

For a number of years the WRC funded 2 projects, both completed at the end of 1992, that related directly to the computerised management of water in irrigation projects. The one project, at RAU, aimed at an optimisation system for minimising distribution losses in irrigation canal systems. The second project, at UOFS, aimed at maximising on-farm irrigation efficiency.

The optimisation system currently consists of an administrative data base, a flow simulation model and concomitant instrumentation. The system has been implemented (partially or fully) on various irrigation projects throughout South Africa. Models used to maximise on-farm irrigation efficiency have been implemented, with marked success, on a number of farms in the Bergville-Winterton area, Taung and in Aliwal-North.

The major aim of this 2-year project is to integrate the canal simulation/administrative data base model with the on-farm irrigation scheduling models. A total package will be made available to the managers of irrigation projects that will assist them in ensuring the most efficient use of water in their projects.

Evaluation of irrigation techniques used by subsistence and emergent farmers *(No 578) MMB Inc.*

Irrigation systems for subsistence and emergent farmers have to comply with the relevant economic criteria, humanitarian objectives and human capabilities. Financial considerations will provide the incentive and motivation for these farmers to switch over gradually to commercial irrigation farming.

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. The need is therefore for relatively inexpensive, less complicated, irrigation systems.

On the one hand this 2-year project aims 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.

Computerised weather-based irrigation water management system *(No 581) Department of Agrometeorology, University of the OFS*

The Department of Agrometeorology is in the closing stages of a research contract during which several methodologies aimed at maximising irrigation scheme efficiency in different soil-climate-irrigation situations have been developed. Some of these methodologies, which depend largely on real-time weather data, will enhance efficiency of individual irrigators while others will promote efficiency at the decision-making level relating to water allocation and distribution on the scheme.

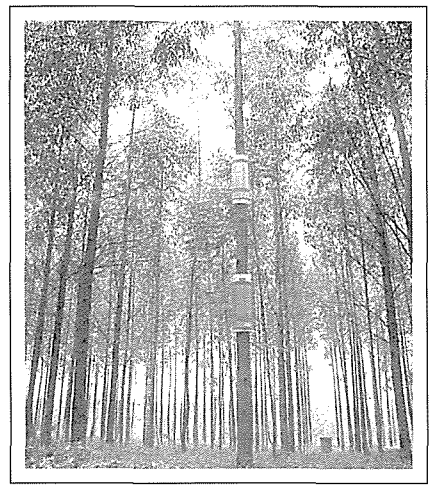
This 3-year project is a logical extension of the past research. Methodologies developed have to be scaled up and integrated into a comprehensive irrigation water management system ultimately to be operated, as a service, either by the University, and/or the government extension service to irrigation managers countrywide. There is a growing realisation that a service of this nature is the most feasible way of enabling the majority of irrigators to share fully in the benefits of recent technological advances in the management of irrigation.

Research projects

Completed

- **226** Maximising irrigation project efficiency in different soil-climate-irrigation situations (University of the Orange Free State - Department of Agrometeorology)
- **229** Estimation and evaluation of moisture stress in crops by means of remote control aerial surveillance (University of the North - Department of Soil Science)
- **260** Relationship between climate and crop factors (University of the Orange Free State - Department of Agrometeorology)
- **367** Development of a consolidated computer software package for the management of an irrigation scheme (Rand Afrikaans University - Energy Laboratory)
- **379** Decision-making procedures for determination of crop water requirements (MBB Inc.)

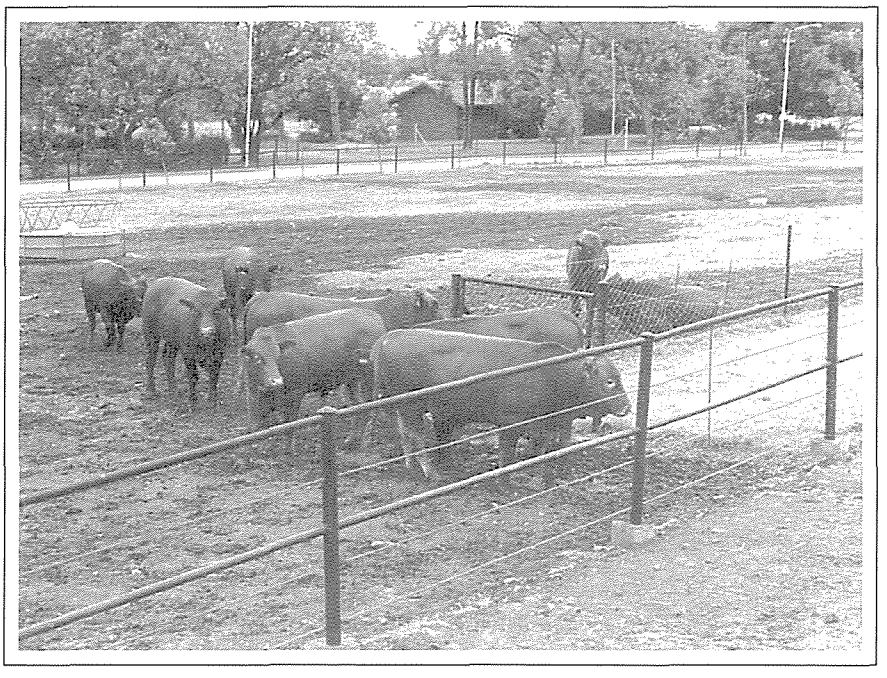
A community garden at Shawela in Gazankulu. Irrigation is by means of short furrows and water from the reservoir. Each participant cultivates a 45 x 5 m (225 m^2) lot and markets the produce locally



Monitoring the sap flow (transpiration rate) of eucalyptus trees using a stem steady state energy balancing technique (Photo: Prof MJ Savage, University of Natal)

Current

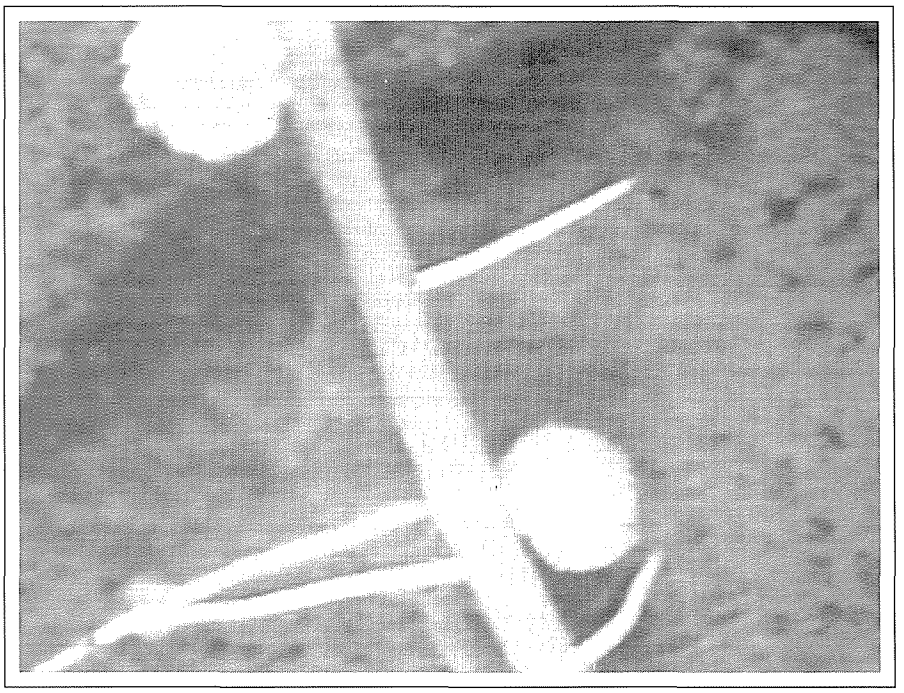
- **227** Storage and utilisation of rain water in the soil for the stabilisation of plant production in semi-arid areas (University of the OFS - Department of Soil Science)
- **228** Factors affecting the water-use efficiency of irrigated crops with special reference to the physiological responses of these crops (University of the OFS - Department of Agronomy and Hortology)
- **257** Water-use efficiency of certain irrigated temperate pasture species (University of Pretoria - Department of Plant Production)
- **261** Soil/plant/water relations in the upper reaches of plant available soil water (University of Pretoria - Department of Soil Science)
- **262** Moisture sensors to facilitate water management (University of Stellenbosch - Institute of Polymer Science)
- **290** Flood and furrow irrigation: A critical evaluation of design procedures and the computerisation of the most suitable approaches (University of Pretoria - Department of Agricultural Engineering)
- **301** Investigation into the quality of water for animal production (University of Pretoria - Department of Animal and Wildlife Science)
- **303** Use of saline water for irrigation purposes and an assessment of salt tolerance criteria of crops (University of Stellenbosch - Department of Soil and Agricultural Water Science)
- **307** Influence of different water-nitrogen regimes on crop canopy development, water flow resistance and crop yield, with a view to improvement of irrigation models (Agricultural Research Council - Soil, Climate and Water Institute)
- **343** Development of an effective and environmentally safe larviciding programme for the control of the blackfly, *Simulium chutteri*, along the Orange River (Agricultural Research Council - Onderstepoort Veterinary Institute)
- **347** Global farm approach to enhancing the economic efficiency of water and energy use for irrigation in the central RSA (University of the OFS - Department of Agricultural Economics)
- **348** Root development and water usage of commercial timber species (University of Natal - Department of Agronomy)
- **372** Assessing the impacts of varying rainfall conditions on vegetation dynamics, production and certain hydrological properties of natural grassland, using a system modelling approach (Potchefstroom University for CHE - Department of Plant and Soil Sciences)
- **382** Evaluation of the interdependent factors which determine the viability of irrigation farming (MBB Inc.)
- **389** Scheduling irrigation of tuber crops with specific reference to potatoes (Agricultural Research Council - Vegetable and Ornamental Plant Institute)
- **417** Optimal water utilisation by turf (Potchefstroom University for CHE - Department of Plant and Soil Sciences)
- **440** Identification of irrigated land in an intensively cultivated agricultural area in the South-Western Cape by means of satellite remote sensing (University of Stellenbosch - Institute for Cartographic Analysis)
- **441** Determination of the relationship between transpiration rate and declining available soil water for *Eucalyptus grandis* (CSIR - Division of Forest Science and Technology)
- **476** Transfer of research results on the irrigation of vegetable crops into practice (University of Pretoria - Department of Plant Production)
- **479** Molecular approach to drought tolerance (Agricultural Research Council - Institute for Plant Biotechnology)
- **499** Effect of exchangeable sodium percentage and clay mineralogy on the infiltration capacity of soils already sealed due to cyclic irrigation (Potchefstroom University for CHE - Department of Plant and Soil Sciences)



Bonsmaras used in the fluoride growth trial at University of Pretoria experimental farm

New

- **423** Effect of pre-programmed deficit irrigation on crop reaction (University of the OFS - Department of Soil Science)
- **507** Improved estimation of plant and soil evaporation from cropped lands (University of the OFS - Department of Agrometeorology)
- **508** Modelling the water balance on benchmark ecotopes (Agricultural Research Council - Institute for Soil, Climate and Water)
- **513** Development of a computerised management system for irrigation projects (Rand Afrikaans University - Energy Laboratory)
- **578** Evaluation of irrigation techniques used by subsistence and emergent farmers (MMB Inc.)
- **581** Computerised weather based irrigation water management system (University of the OFS - Department of Agrometeorology)



A soybean root (1 mm dia. with branches and nodules) as seen by the minirhisotron video camera (48 d after planting and at 35 cm depth)

The new helicopter of the Department of Agriculture preparing for blackfly control along the Orange River. The river between Hopetown and Augrabies Falls was treated 5 times between July and September 1993

7

Water pollution

In spite of the fact that experts have long been warning that pollution renders our water sources less suitable or even wholly unsuitable for an intended purpose this realisation is now also starting to dawn on the broad population. It is therefore increasingly being accepted that in a water-deficient country such as South Africa, not only is it important to develop water sources, but that the quality of these sources should be maintained. In actual fact, certain experts already regard the provision of water of an acceptable quality as a greater long-term challenge than merely supplying water in sufficient quantities. In order to meet the challenges in this regard, a two-pronged strategy is being adopted with regard to the research: on the one hand research is aimed at eliminating pollution as far as possible, while on the other hand determining which levels of pollution would be acceptable to consumers. The WRC already funds high-priority research projects in both categories. As the Department of Water Affairs and Forestry succeeds increasingly in managing the various factors determining water quality in an integrated fashion, the relative importance of diffuse pollution is becoming increasingly apparent. These aspects, as well as others, are therefore also being reflected in changing research needs and in new research priorities.

In this chapter the emphasis is on **Salinisation, Eutrophication** and **Water Quality Studies**.

Salinisation continues to be one of the most problematic consequences of water pollution in South Africa. It is caused by the addition of a variety of salts to the water environment which is almost inevitably the result of, among others, the increasing use and reuse of water necessitated by development. As the salt content of water increases, it becomes less suitable for most users, incurring additional costs. In 1993 the WRC financed 11 salinisation projects of which 2 commenced during the year and 3 were completed.

Eutrophication is the enrichment of the water environment with plant nutrients and the ensuing excessive growth of algae and water plants. Serious problems concerning water purification and deterioration of the water environment are still being experienced as a result. During the year the WRC financed 7 eutrophication projects of which one commenced during the year and one was completed.

The gradual deterioration of water quality and the increasing awareness of water quality as a factor determining the utilisation potential of water, led to the identification of a number of research needs. The WRC currently finances 13 projects relating to **Water Quality Studies** of which 4 commenced during the year and 3 were completed.

Completed projects

Abilities of several solute and water transport models to predict the quantity and quality of water leaving the root zone

(No 196) Department of Soil and Agricultural Water Science, University of Stellenbosch

Although sophisticated mathematical models are available to describe the physical and hydrochemical processes occurring in the root zone of soils, the difference between reality and the ideal situation which they simulate often prevents the full potential of the

models from being realised. The abilities of such models which have varying degrees of process description sophistication, were evaluated against field data, as part of the project. Based on these evaluations guidance is provided to researchers and other potential users with regard to the selection of mathematical models which can be used to predict the quantity and composition of water draining through the root zone of irrigated soil. In this way a contribution is made to the responsible application of the type of model used.

Cost: R317 200

Term: 1986-1990

Phosphate export models for catchments *(No 197) Division for Water Technology, CSIR*

This project was aimed at providing the tools to predict phosphate export from catchments experiencing changing phosphate loads from point and non-point sources. Water quality management requires predictions of the effects catchment changes will have on reservoir eutrophication under conditions of both good and poor data availability. To cater for both situations two distinct types of models were developed to predict P-export from non-point sources, viz. a deterministic model coupled to hydrology, and a stochastic model based on measurements of P-concentrations. The products of this project facilitate improved predictions of P-export, both for catchments with sufficient data on land-use characteristics, as well as for catchments with few land-use data, but with phosphate concentration measurements.

Cost: R266 036

Term: 1988-1991

Design and use of irrigation systems in the Breë River with a view to the control of potential drainage losses *(No 256) MBB Inc.*

Measures taken to improve irrigation efficiency largely correspond to those leading to a reduction in drainage losses, thereby combating the salinisation of rivers associated with irrigation. The investigation proved the standard of irrigation design in the Breë River to be high, thus enabling farmers to irrigate in such a manner that drainage losses are reduced. However, with only a few exceptions, over-irrigation with concomitant high drainage losses was generally observed and low levels of water-use efficiency were calculated. The least drainage was calculated for drip irrigation, followed by micro- and sprinkler irrigation. Subsequent discussions with participating farmers indicated a low level of theoretical knowledge regarding irrigation scheduling and that they largely irrigate from own experience.

Cost: R559 000

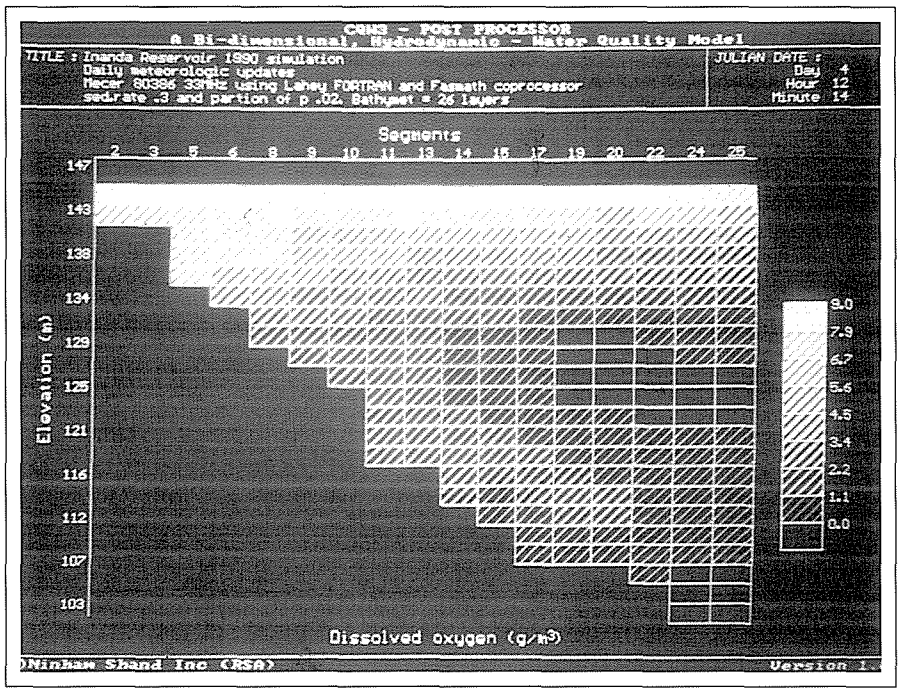
Term: 1988-1991

Applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa *(No 304) Ninham Shand Inc. and the Department of Civil Engineering, University of Cape Town*

This project aimed to evaluate existing mathematical models for their ability to predict stratification and related processes for South African impoundments, adapt them as required and demonstrate their application value. Modelling data bases were assembled for Hartbeespoort Dam, Inanda Dam, Roodeplaat Dam and Vaal Barrage. Four hydrodynamic reservoir models (DYRESM, MINLAKE, CE-QUAL-W2 and WASP4) were selected for the investigations. It was found necessary to develop supporting software to enhance both the input and output side of models, with a strong accent on computer screen graphics. The technical feasibility of destratification by air bubble plume action was demonstrated for Roodeplaat Dam and the two-dimensional nature of the translation of the low-salinity release through the Vaal Barrage was successfully simulated. Additional applications will be demonstrated as part of an extension of the project to the end of 1994.

Cost: R277 274

Term: 1990-1992



Two-dimensional representation of model-predicted water quality changes in the Inanda Dam

Assessment of the feasibility and impact of alternative water pollution control options on TDS concentrations in the Vaal Barrage and Middle Vaal

(No 326) SRK (CE) Inc.

The 2-year study reviewed the relative contributions from major sectors to the salinity loads in the Vaal Barrage and Middle Vaal catchment areas. Data from industrial premises, mines, power stations and municipal sewage works were assembled, collated and analysed to provide an integral view of point-source salinisation of the Vaal River. The combined point sources discharge 298 Ml/d of effluent, containing 568 t of TDS, to the Vaal River.

Of the various pollution control options, blending still seems the most attractive interim means of controlling TDS levels; this is because it is relatively inexpensive and is also applicable to non-point sources. Centralised effluent treatment can be considered when adequate areal grouping of similar industry types is realised in future.

Cost: R600 000

Term: 1990-1991

Establishing revised water quality criteria for the South African coastal zone *(No 401)*

Division of Earth, Marine and Atmospheric Science and Technology, CSIR

Use of the *Water Quality Criteria for the South African Coastal Zone* (WQCSA), which were formulated in 1984, revealed certain shortcomings, especially regarding human health aspects. To enable incorporation of interim local and international developments in the field, the CSIR was commissioned to convene a user-representative workshop to update the existing WQCSA.

The revised version, entitled *Water Quality Guidelines for the SA Coastal Zone* (WQGSA), addresses aesthetics, chemical and physical variables, nutrients, toxic organic and inorganic compounds, microbiological variables and radioactivity. Its application will not only enable deep-sea outfall design, but also acceptable development and maintenance of the coastal zone.

WQGSA will be incorporated into the Department of Water Affairs and Forestry's envisaged publication series of various water-related quality guidelines.

Cost: R65 000

Term: 1991-1992

Soil buffering of rain-water salinity in the Vaal Dam catchment *(No 414) Department of Agronomy, University of Natal*

Indications are that the sulphur dioxide levels, due to combustion, in the Eastern Transvaal highveld air are equivalent to ten times the annual salt load entering the Vaal Dam. If only 10% of the sulphur dioxide dissolved as sulphates in rain should fall in the catchment area, it will in the long term cause the salt content of the Vaal Dam to double. One of the uncertainties in this regard is the degree to which these salts can be retained by the soil. This investigation indicated that although certain soils in the catchment area have the ability to absorb large quantities of salts, these in total cannot retain significant amounts. On the other hand the present sulphate content of the soil is already at such levels as to make it virtually impossible to distinguish it from additionally added sulphate in rain.

Cost: R142 200

Term: 1991-1993

New projects

Pilot study to investigate alternative management options to enhance the use of saline water for irrigation purposes

(No 522) Department of Soil and Agricultural Hydrology, University of Stellenbosch

Salt concentration is one of the major variables which determines the quality of water for irrigation purposes. The Department of Water Affairs and Forestry attempts to manage water quality in such a way that it complies with the demands of among others, irrigators. In order to verify these requirements for wine-grapes under local conditions, the WRC already funds research to determine how yields are affected when irrigating with water of varying salt concentrations. For this purpose irrigation practices generally found in the area, are employed. It is, however, known that the effect of high salt concentrations in irrigation water can be reduced by management measures at farm level, e.g. high-frequency and subsurface drip irrigation. During this pilot study over 30 months the effectiveness of such alternative management measures will be investigated.

Lower Vet River water quality situation analysis with particular reference to the OFS goldfields *(No 523) Stewart Scott Ing.*

As part of a previous WRC-funded investigation in the OFS Goldfields a good deal of water quality related information was gathered which should form the background for the drawing-up of a water quality management plan for the area. The gap between the information gathered during this investigation and the needs of a management plan can be best bridged by an analysis of the water quality situation in the greater catchment area. As such a situation analysis will assist in the practical application of research results, the WRC supports this 1-year project.

Developing a rule model for the design of stream water quality monitoring strategies in the forestry industry *(No 524)*

Division of Forest Technology, CSIR

The need for information on the impact of different forestry practices on water quality, is expected to increase as a result of the greater emphasis that the Department of Water Affairs and Forestry is placing on water pollution originating from diffuse sources. A data base with information on water quality under a wide range of flow conditions for a

variety of different forest treatments was assembled over a period of 17 years by the former South African Forestry Research Institute. This data base is expected to yield valuable information about the potential for water quality degradation posed by different forestry treatments. It will be used as part of this 1-year study to derive a rule-based model or set of guidelines for the forestry industry. The rule model will be used in determining the most cost-effective methods for water quality monitoring for both short- and long-term goals.

Development of a dynamic model for the growth and bloom of algae in the Vaal River *(No 536) Department of Applied Mathematics, University of the OFS*

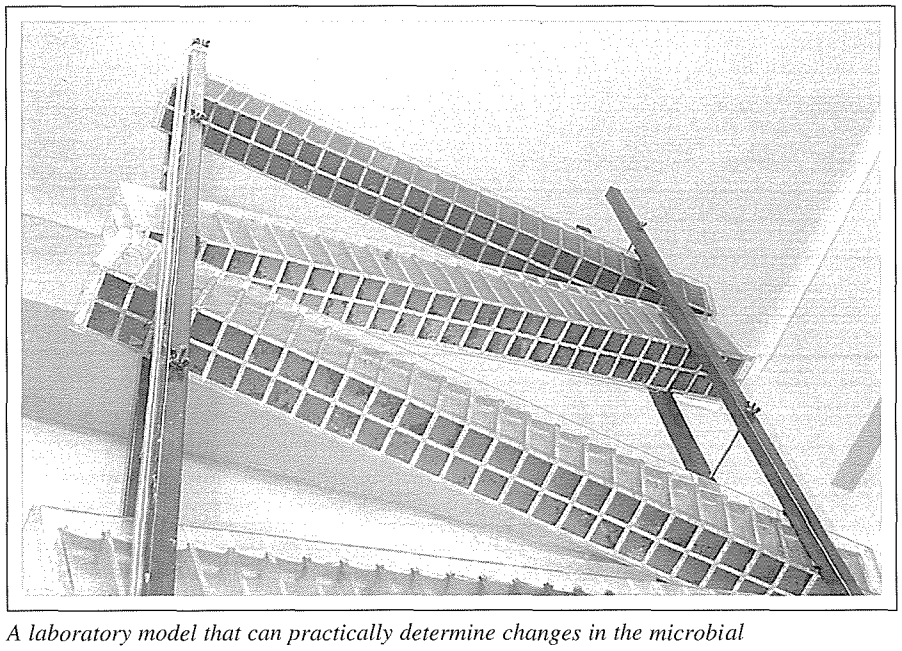
The runoff to the Vaal River of domestic and industrial waste products rich in plant nutrients leads to a eutrophic condition and therefore favourable conditions for algal bloom. These algae cause aesthetic problems for all river users, increase the purification costs of drinking water and create considerable problems for the organisations having to provide drinking water from the river, *inter alia* due to the unpleasant odours and tastes of this water. From a managerial point of view it is therefore desirable to have an efficient mathematical model with which reliable predictions can be made of the occurrence, nature and extent of algal blooms, in order that suitable countermeasures may be taken timeously. The purpose of this 3-year project is to develop such a management model, based on a promising model already developed by the University.

Potential for the use of economic instruments to protect the quality of water resources in South Africa *(No 574) Economic Project Evaluation (Pty) Ltd*

It is generally accepted that the traditional legislative, or command-and-control, approach to controlling water quality faces many difficulties. This approach can experience daunting administrative problems and is often difficult and costly to apply. It can, furthermore, be inequitable, and may also have dubious incentive effects. It is anticipated that an economic approach to water quality control may offer significant benefits by way of enhanced effectiveness and reduced cost. This, however, needs to be confirmed in practice. This 2-year project will use the upper Olifants River basin to compare the two approaches and assess the practicality of employing economic measures to protect water quality in South Africa. It will also assess the benefits that could ensue from adopting an economic approach to water quality management.

Development of a laboratory river model to determine the environmental impacts of key xenobiotic compounds *(No 583) International Centre for Waste Technology, University of Natal and Umgeni Water*

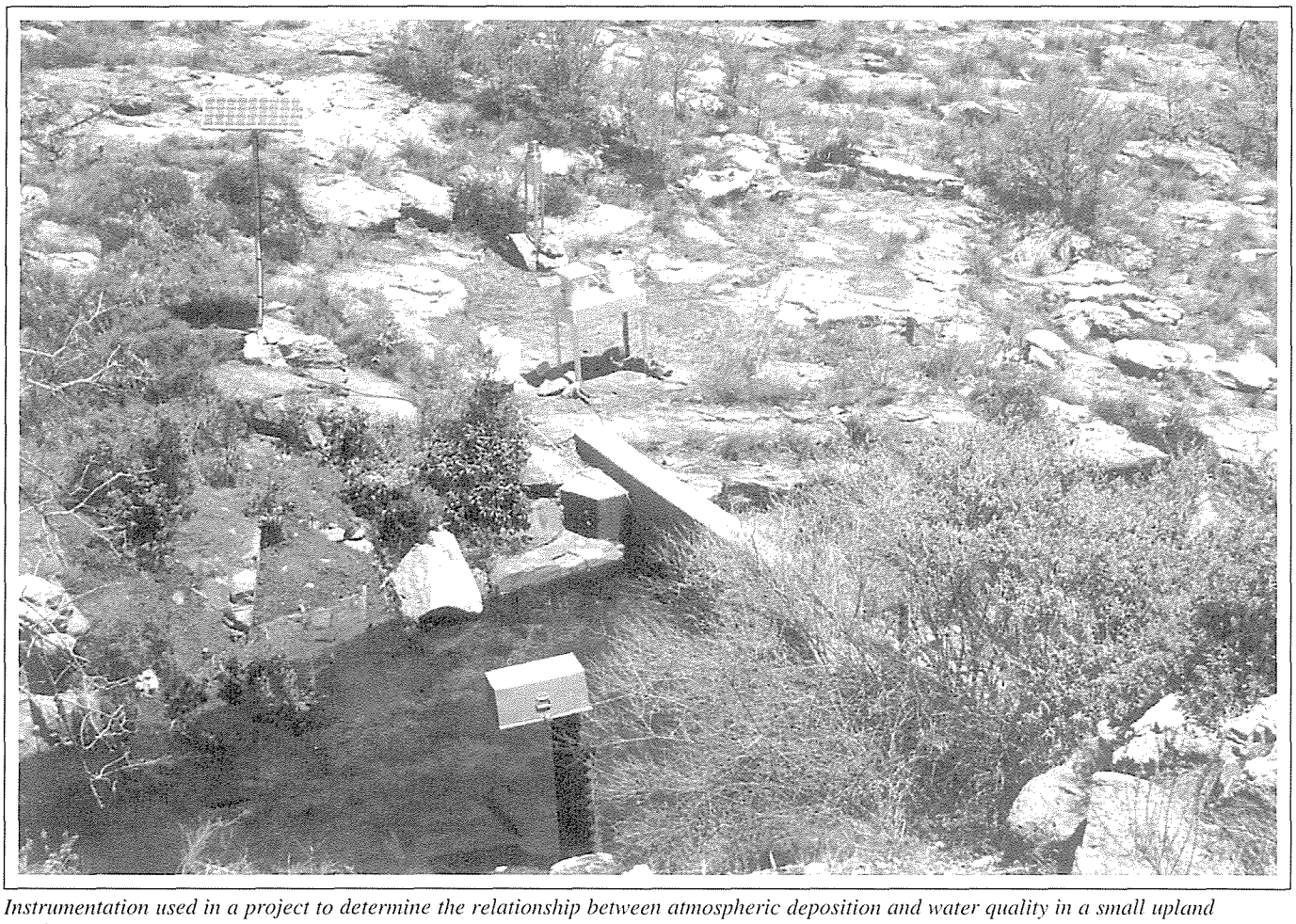
Man-made molecules already comprise in excess of 20% of the 4 million chemicals present in the biosphere. Although some of these are toxic, the environmental impact potential of the majority has yet to be determined and this situation keeps on deteriorating. As effluents consist of a mixture of various substances, it is even more difficult to assess their potential impact. This 3-year project makes use of the fact that the microbiological population is one of the foundations on which higher life forms depend and build on to get an indication of the impact of foreign substances on the environment. For this purpose a physical laboratory model will be developed imitating microbiological processes in a river and determining the effect of man-made compounds of key interest on these processes. The large numbers in which microbes occur make it easier to arrive at statistically significant and justifiable conclusions.



A laboratory model that can practically determine changes in the microbial population in a river

Demonstrating the potential of geographical information systems technology in hydro-salinity modelling by using the DISA model *(No 588) Institute for Geographical Information, University of Stellenbosch*

Most hydrological models require geographically based input data. Before the advent of geographical information systems (GIS) most of the required data were labour-intensively measured and calculated from existing maps. Due to the time-consuming nature of the process the potential of the hydrological models could often not be fully realised. Currently the potential of GIS technology is still not properly realised in hydrological modelling, one of the reasons being that it is necessary to bring together the skills of divergent disciplines for this. The aim of this 18-month project is to demonstrate the potential of GIS technology by integrating a GIS model with the DISA model (a daily irrigation and salinisation analysis systems model).



Instrumentation used in a project to determine the relationship between atmospheric deposition and water quality in a small upland catchment

Research projects

Completed

- **196** Abilities of several solute and water transport models to predict the quantity and quality of water leaving the root zone (University of Stellenbosch - Department of Soil and Agricultural Water Science)
- **197** Phosphate export models for catchments (CSIR - Division of Water Technology)
- **256** Design and use of irrigation systems in the Breë River with a view to the control of potential drainage losses (MBB Inc.)
- **304** Applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa (Ninham Shand Inc. and the University of Cape Town - Department of Civil Engineering)
- **326** Assessment of the feasibility and impact of alternative water pollution control options on TDS concentrations in the Vaal Barrage and Middle Vaal (SRK (CE) Inc.)
- **401** Revised water quality criteria for the South African coastal zone (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **414** Soil buffering of rain-water salinity in the Vaal Dam catchment (University of Natal - Department of Agronomy)

Current

- **195** Hydrosalinity studies in the Eastern Cape (Rhodes University - Institute for Water Research)
- **266** Extension of the management-orientated models for eutrophication control (CSIR - Division of Water Technology)
- **269** Four-electrode electrical conductivity and electromagnetic induction techniques of soil salinity measurement for use under South African conditions (University of Natal - Department of Agronomy)
- **312** Occurrence and accumulation of selected heavy metals in freshwater ecosystems affected by mine and industrial polluted effluents (Rand Afrikaans University - Department of Zoology)
- **313** Concentration ratios of selected radionuclides in aquatic ecosystems affected by mine drainage effluents (Rand Afrikaans University - Department of Zoology)
- **344** Contribution of groundwater to the salt load of the Breë River using natural isotopes and chemical tracers (University of the Orange Free State - Institute for Groundwater Studies)
- **359** Phytoplankton blooms in the Vaal River and the environmental variables responsible for their development and decline (University of the Orange Free State - Department of Botany)
- **364** Field dilution studies on large offshore pipelines (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **369** Completion of research relating to the DISA model - A daily irrigation and salinity analysis system model (Ninham Shand (Cape) Inc.)
- **380** Investigation techniques for the determination of microbial aspects of water quality of South African rivers (CSIR - Division of Water Technology and Rand Water)
- **404** Manual for waste load allocations in South Africa (CSIR - Environmental Services)
- **405** Situation analysis of water quality in the Buffalo River, Eastern Cape, with special emphasis on the impact of low-cost high-density urban development on water quality (CSIR - Division of Water Technology)
- **411** Coastal pollution: Pathogenic microorganisms (University of Pretoria - Department of Medical Virology)
- **419** Water quality and quantity assessments in catchments with changing land uses in the Umzinto coastal area (SA Sugar Association Experiment Station)
- **420** Long-term salt balance of the Vaalharts irrigation scheme (Stewart Scott Inc.)
- **421** Relationship between atmospheric deposition and water quality in a small upland catchment (CSIR - Division of Water Technology)
- **443** Compilation of guidelines for the use of peroxone and other oxidants in the treatment of eutrophic water (CSIR - Division of Water Technology)
- **447** Optimising diffuser design for offshore pipelines - Laboratory experiments (CSIR - Division of Earth, Marine and Atmospheric Science and Technology)
- **465** Detergent phosphorus in South Africa: Impact on eutrophication with specific reference to the Umgeni catchment (University of Natal - Department of Chemical Engineering and Umgeni Water)
- **498** Collection and evaluation of runoff water quality data from a disused feedlot in Natal (CSIR - Division of Water Technology)

New

- **522** Pilot study to investigate alternative management options to enhance the use of saline water for irrigation purposes (University of Stellenbosch - Department of Soil and Agricultural Hydrology)
- **523** Lower Vet River water quality situation analysis with particular reference to the OFS gold-fields (Stewart Scott Ing.)
- **524** Development of a rule model for the design of stream water quality monitoring strategies in the forestry industry (CSIR - Division of Forestry Science)
- **536** Development of a dynamic model for the growth and bloom of algae in the Vaal River (University of the OFS - Department of Applied Science)
- **574** Potential for the use of economic instruments to protect the quality of water resources in South Africa (Economic Project Evaluation (Pty) Ltd)
- **583** Development of a laboratory river model to determine the environmental impacts of key xenobiotic compounds (University of Natal - International Centre for Waste Technology, and Umgeni Water)
- **588** Demonstrating the potential of geographical information systems technology in hydrosalinity modelling by using the DISA model (University of Stellenbosch - Institute for Geographical Information)

8

Municipal effluents

The Co-ordinating Committee for Sanitation reviewed the research plan for sanitation during 1993, but no major changes were made. For the first time this Committee was able to review a list of current research projects in the field from the WRC-funded project register.

The number and complexity of organic chemicals available to, and therefore subject to release by industry, is so great that the time and cost of analysing for each is prohibitive. The use of standard organisms to test for the presence of toxic compounds is a cost-effective method for assaying water quality, and the first few standard tests have recently been specified by the Environmental Protection Agency in the USA as part of the battery of tests for monitoring water quality. In recognition of the bioassay being a cost-effective way of testing for toxicity in water and effluents which is suitable for use by the Department of Water Affairs and Forestry, the WRC is currently funding projects in this field, the first of which are due to be completed during 1994.

Internationally, the technologies of bioaugmentation, bioremediation and biostimulation are increasingly proving to be economic methods for the rehabilitation of sites polluted by industrial waste or spillage. This rehabilitation of sites using biological organisms is seen as a future growth industry world-wide. In recognition of South Africa's need for this type of technology, the WRC is funding projects in this area which aim to address specific problems known to occur in South Africa.

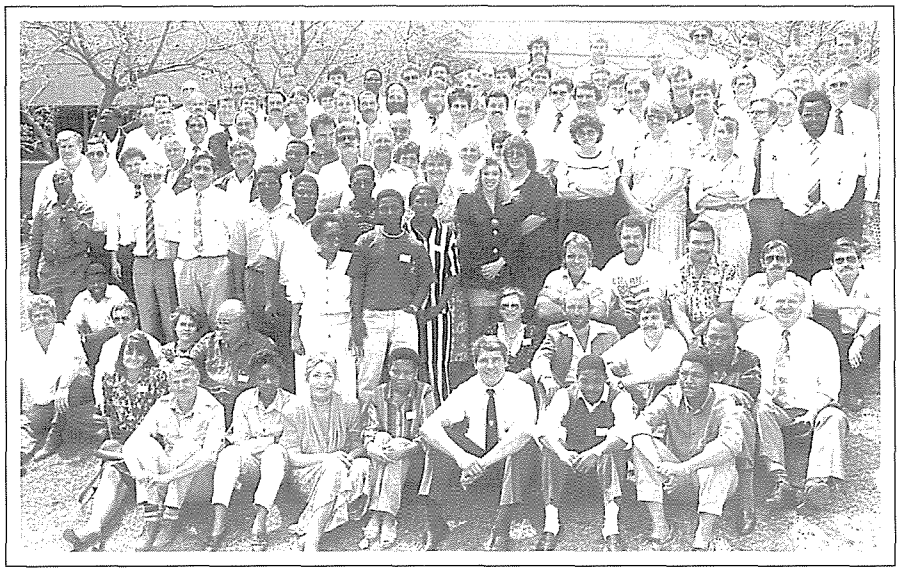
The WRC has continued to support the initiative of transferring the technology of waste-water treatment to the works personnel. The development of competency-based training for water-care personnel is progressing well, and has almost reached the point where the first courses can be developed. In addition to this, a number of one-day workshops were funded at venues throughout the country to instruct works personnel on the use of the *Operating Guide for the Anaerobic Digestion of Waste-water Sludge* published during 1992.

In this field which encompasses **Sewage Treatment, Sewage Sludge Treatment and Disposal** and **Wetlands**, the WRC supported 22 projects during 1993, of which 6 commenced during the year, 14 are current and 2 were completed.

Completed projects

Biological phosphate removal mechanisms in the activated sludge process *(No 314) Department of Microbiology and Plant Pathology, University of Pretoria*

An understanding of the metabolic mechanisms responsible for the accumulation of excess phosphate by bacterial cells in the activated sludge process would enable the management of the phosphorus removal process to be refined. Application of the refined process would enable the industry to consistently achieve a higher quality of effluent. With this in mind, the researchers classified all the strains of *Acinetobacter* (the bacteria responsible for most of the P-removal) and investigated possible connections between the presence of enzymes and the ability to remove P. A finding



Dr WR Ross photographed together with works personnel attending his one-day workshop on the use of the "Operating Guide for the Anaerobic Digestion of Waste-water Sludge" *in Pretoria*

emerging from this project was that *Acinetobacter* is not the only bacterium responsible for phosphorus removal in P-removal activated sludge systems.

Cost: R153 000

Term: 1990-1993

Comprehensive study of an iron-phosphate removal system

(No 430) Division of Water Technology, CSIR

The main aim of the study was to optimise conditions for the continuous removal of phosphates from sewage effluents in a contactor filled with iron filings. The effects of pH, temperature, presence of other ions and heavy metals in solution and the retention time in the contactor were investigated.

It was shown that phosphate levels could be reduced from about 6 mg P/*l* to less than 1 mg P/*l*. The optimal pH range was 6,8 to 8,2 and a temperature range of between 10°C and 28°C had no detrimental effect on the process.

Heavy metals, such as chrome, copper and nickel, as well as calcium and magnesium ions, had no significant effect on phosphate removal. As expected, the longer the retention time of the effluent in the contactor, the higher the level of phosphate removal proved to be.

Cost: R89 600

Term: 1993

New projects

Causes and control of A/A filament bulking in nutrient removal activated sludge systems *(No 542) Department of Civil Engineering, University of Cape Town*

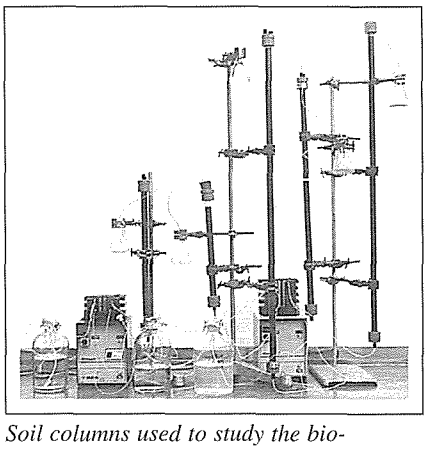
Sludge bulking is a persistent problem in nutrient removal activated sludge plants, causing poor solid/liquid separation through poor sludge settleability. The prevention of sludge bulking would enable existing plants to treat more effluent, thereby saving the industry a substantial sum of money. Other methods aimed at specific control of bulking sludges have been unsuccessful, but during this 3-year project the researchers will investigate the hypothesis that the intermediate products of denitrification are responsible for inhibiting the growth of the floc-forming bacteria, thereby giving the filamentous bacteria the competitive advantage.

Bioremediation technology for the treatment of contaminated seepage water and soil in South Africa *(No 543) Division of Water Technology, CSIR*

Sites contaminated by organic pollutants are widespread in South Africa, although the extent of the problem has not been fully assessed. During this 2-year project the researchers will make a preliminary assessment of the extent of the problem, and then address certain specific organics. A protocol will be developed for assessing the efficiency of specific bacteria for the bioremediation of specific substances. The project team will investigate the bioremediation of a number of refractory chemicals using defined procedures, and the economics of the technology, and will make recommendations for the application of the technology to contaminated sites.

Study of activated sludge microbial population dynamics for the optimisation of biological phosphorus removal *(No 554) Department of Microbiology and Plant Pathology, University of Pretoria*

Previous studies of the process of enhanced biological phosphorus removal (EBPR) have focused on the process rather than the species of bacteria involved. During this project the researchers will investigate two main aspects of the process which address the role of individual species. The first is to what extent EBPR depends on community structure in the activa-



Soil columns used to study the bioremediation of soils in the laboratory

ted sludge, and the second is what role do genera other than *Acinetobacter* play in the uptake and storage of excess phosphorus.

This 3-year project aims to isolate and determine the efficiency of organisms other than *Acinetobacter* which can take up and store excess phosphate and to establish the role of species diversity in the activated sludge community structure in phosphorus removal.

Limitation of convection currents in clarifiers *(No 555)*

Department of Chemical Engineering, University of Pretoria

In the purification of drinking water and sewage the gravity separation of floc plays a decisive rôle. Unfortunately the temperature of the water in a clarifier is virtually never in equilibrium with that of the environment. The resultant heat exchange gives rise to convection currents in the clarifier which affect gravity separation detrimentally. If convection currents could be brought under control, not only could smaller clarifiers be built, but water of a better quality could also be produced.

In order to possibly utilise the potential benefits mentioned, the 1-year project aims to quantify the occurrence of convection currents at a sewage works and at an industrial effluent treatment works, as well as to conduct laboratory studies to evaluate the impact of various anti-convection mechanisms.

Refinement of design parameters for sludge thickening by dissolved air flotation *(No 556)*

Energy Laboratory, Rand Afrikaans University

During a plant survey of flotation units conducted at the request of the WRC, the thickening plants for activated sludge showed a wide variation with respect to certain critical design parameters. At the same time it is a fact that dissolved air flotation is considered by certain users to be an unsatisfactory method of sludge thickening, while others find the process to be highly satisfactory. The major deficiency in the survey just completed, was that such statements can virtually never be supported by reliable analytical data.

The aim of this 2-year project, therefore, is to attempt to ascertain the optimum values of certain major design variables, with the aid of the critical evaluation of full-scale thickening plants and supporting laboratory tests. The extent to which pilot-scale results can be applied directly for the design and optimisation of full-scale plants will be determined.

Development of a cross-flow microfiltration unit to improve the performance of anaerobic digesters at waste-water treatment works *(No 560)* *Department of Chemical Engineering, University of Natal*

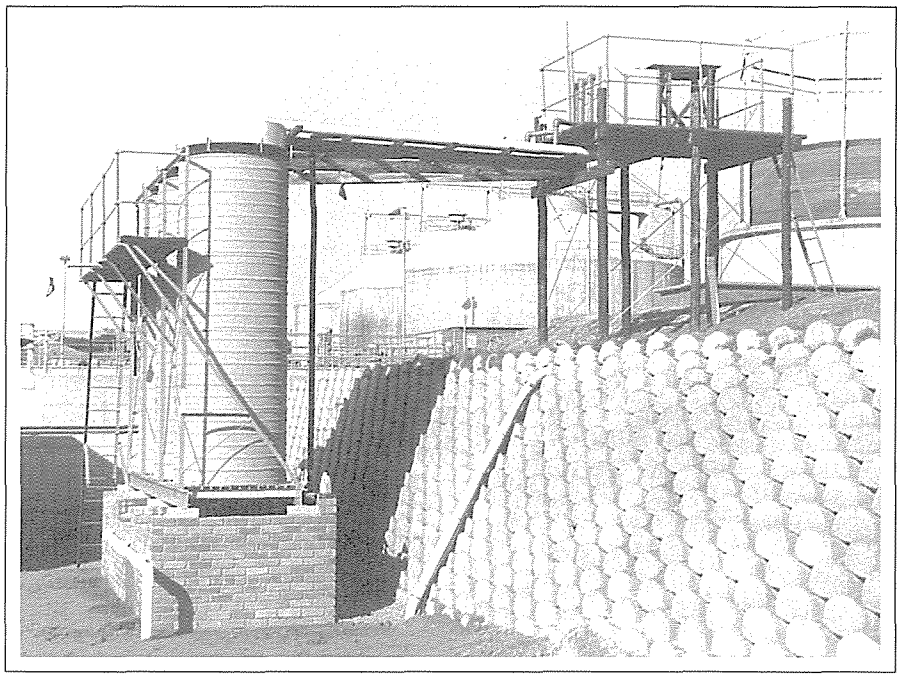
The use of a suitable filtration unit to recycle biomass effectively decouples the solids and liquid residence times within an anaerobic digester. Such decoupling enables the volumetric throughput of a digester to be substantially increased without impairing biomass digestion. As a result, existing works are able to cope with small increases in flow and to delay the construction of additional digesters, which would otherwise be necessary. Moreover, downstream processes also benefit because of the reduced volumetric loading to the sludge dewatering equipment.

The aim of this 3-year project is to develop and demonstrate the ability of the woven-tube cross-flow microfiltration unit to improve the performance of anaerobic digesters. The study will be conducted at the Durban Corporation's Northern Waste-water Treatment Works.

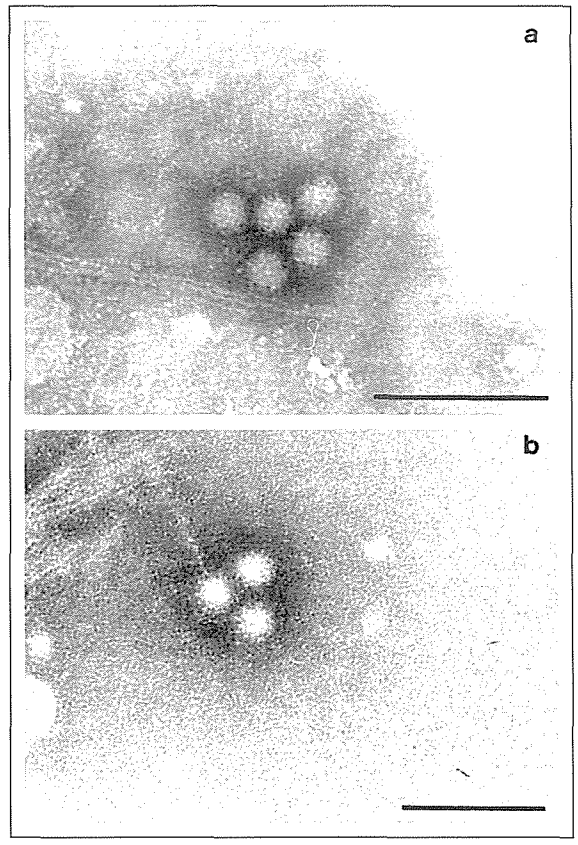
High-rate recirculation and solids contact optimisation of biological filtration plants

(No 569) Wates, Meiring and Barnard Inc.

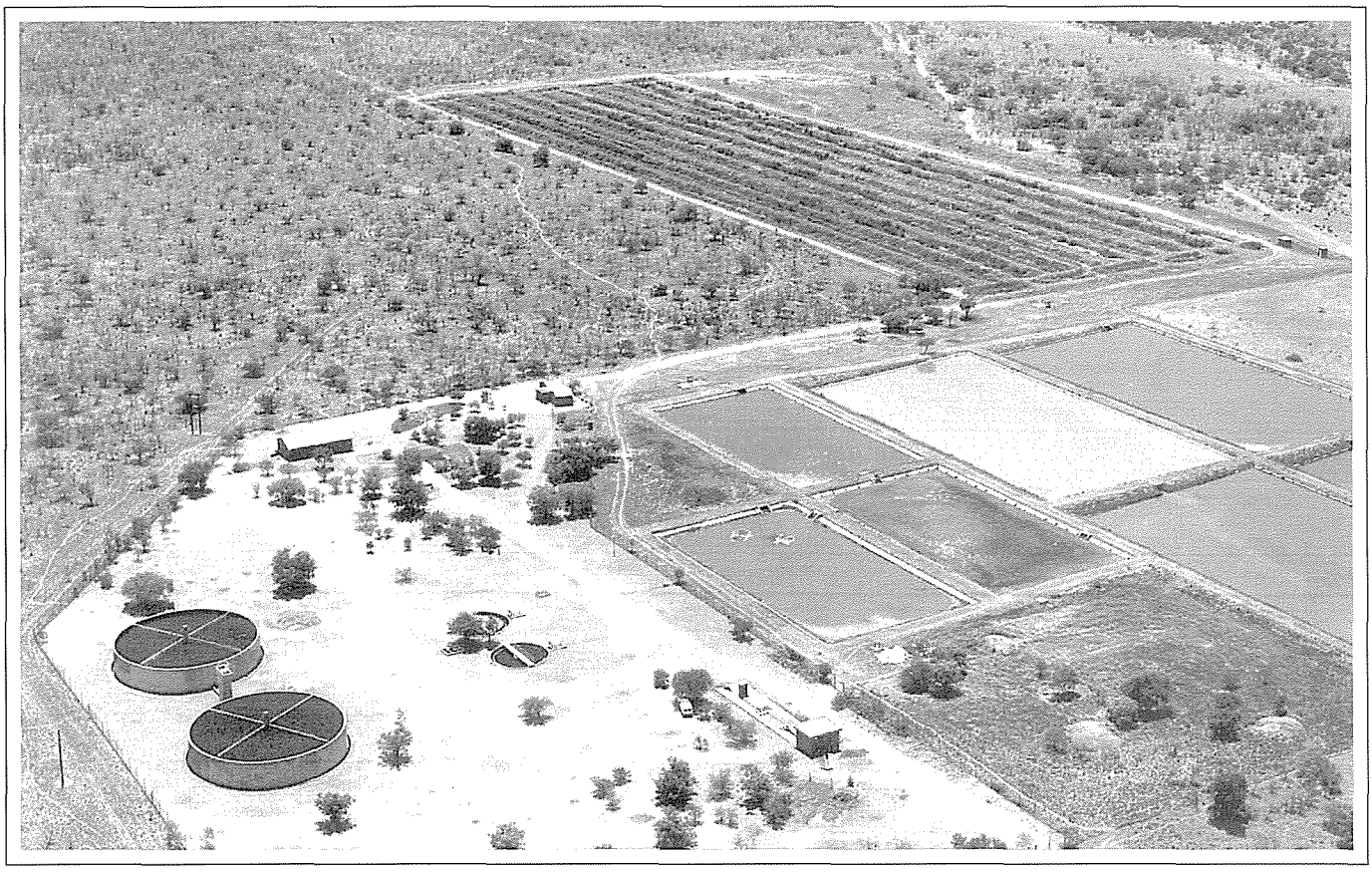
Biofiltration has been the workhorse of the South African waste-water treatment industry for decades, but its inflexibility and the large volumes of media required to achieve acceptable effluent quality make this process less desirable. However, many biofilter plants are operational in the country, and so South Africa needs technologies to upgrade these plants cost-effectively. The aims of this 2-year project are to develop operational and design criteria for two modifications of the conventional biofiltration process, the first of which is the high-rate recirculation directly around the biofilter, and the second is optimisation of the biofiltration solids contact, a process which can remove some phosphorus when managed properly.



Pilot plant for high-rate recirculation of secondary effluent through a biofilter



The first electron-microscope photos of "small round viruses" in South Africa:
(a) without antibodies; and
(b) with antibodies which cause virus clumping. This facilitates observations and typing
(Rod = 100 mm)
(Photos: Dr MB Taylor, UP)



Aerial view of Lethlabile Waste-water Treatment Works near Brits, Transvaal, where the PETRO process has been successfully applied

Research projects

Completed

- **314** Biological phosphate removal mechanisms in the activated sludge process (University of Pretoria - Department of Microbiology and Plant Pathology)
- **430** Comprehensive study of an iron-phosphate removal system (CSIR - Division of Water Technology)

Current

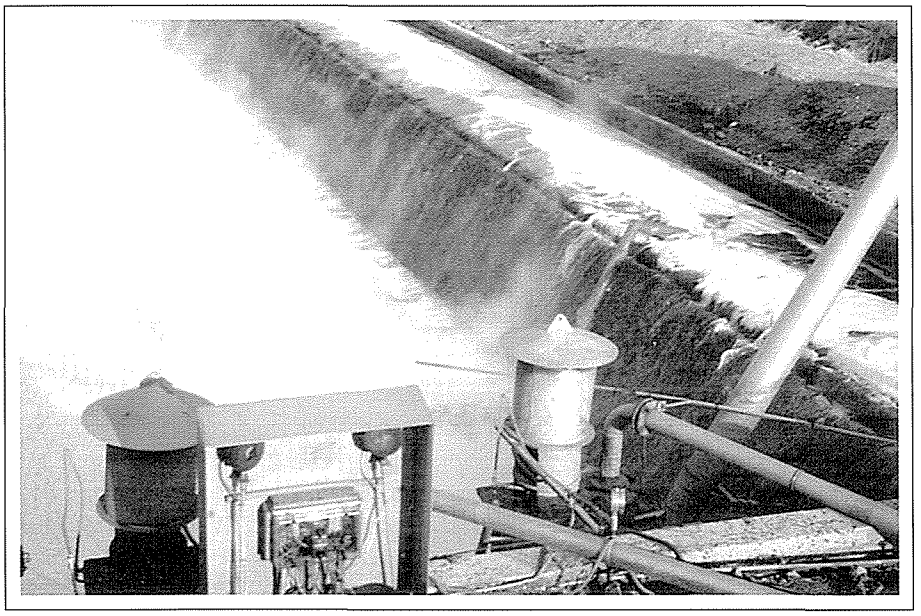
- **232** Preparation of engineering design guidelines for artificial wetlands for waste-water treatment (CSIR - Division of Water Technology and Stewart Scott Inc.)
- **248** Chemical augmentation of biological phosphate removal (City Council of Johannesburg)
- **286** Development and evaluation of specific control methods for ameliorating low A/A bulking (University of Cape Town - Department of Civil Engineering)
- **316** Aspects of sewage sludge treatment and disposal (City Council of Johannesburg)
- **328** Full-scale study of chemical sludge bulking control (University of Pretoria - Department of Chemical Engineering)
- **356** Consolidation of activated sludge research (University of Cape Town - Department of Civil Engineering)
- **366** Full-scale pilot plant studies on phosphate crystallisation in biological systems (CSIR - Division of Water Technology and City Council of Pretoria)
- **391** Co-disposal of sewage sludge and refuse (City Council of Cape Town)
- **416** Application and performance of full-scale constructed wetlands for waste-water treatment in South Africa (SRK Inc.)
- **427** Development of electro-osmotic sludge dewatering technology (CSIR - Division of Water Technology)
- **429** Bio-augmentation technology for waste-water treatment in South Africa (CSIR - Division of Water Technology)
- **462** Activated fixed and suspended cultures for nitrification (University of Pretoria - Department of Chemical Engineering)
- **491** Pond enhanced trickling filter operation (PETRO) (Wates, Meiring and Barnard Inc. and CSIR - Division of Water Technology)
- **496** Human viruses in diffuse effluents and related water environments (University of Pretoria - Department of Medical Virology)

New

- **542** Causes and control of A/A filament bulking in nutrient removal activated sludge systems (University of Cape Town - Department of Civil Engineering)
- **543** Bioremediation technology for the treatment of contaminated seepage water and soil in South Africa (CSIR - Division of Water Technology)
- **554** Study of activated sludge microbial population dynamics for the optimisation of biological phosphorus removal (University of Pretoria - Department of Microbiology and Plant Pathology
- **555** Limitation of convection currents in clarifiers (University of Pretoria - Department of Chemical Engineering)
- **556** Refinement of design parameters for sludge thickening by dissolved air flotation (Rand Afrikaans University - Energy Laboratory)
- **560** Development of a cross-flow microfiltration unit to improve the performance of anaerobic digesters at waste-water treatment works (University of Natal - Department of Chemical Engineering, Pollution Research Group)
- **569** High-rate recirculation and solids contact optimisation of biological filtration plants (Wates, Meiring and Barnard Inc.)

9

Industrial effluents



In 1973 overseas consultants, by reason of their extensive experience regarding the environmental problems caused by industrial effluents, identified research needs and developed guidelines according to which research in this field ought to be undertaken. Research priorities were also determined and the WRC has financed a number of projects in the industrial field over the years.

The serious drought of 1983, with the concomitant water restrictions, challenged industries anew and guidelines focusing on water conservation had to be adapted especially. One of the consequences was the well-known NATSURV project. The project comprised a national survey of industrial water and waste water. The aim of this investigation was firstly to develop a data base which could be used for water intake and pollution loads readily attained by industry. Secondly, an attempt was made to establish the areas requiring research to assist industry in improving its water and waste-water management at minimum cost or even to its own advantage.

Fourteen industry-directed guides resulted from the NATSURV project. During the year the last two of these guides were published, viz. *Water and Waste-water Management in the Textile Industry* and *Water and Waste-water Management in the Wine Industry*.

The 38 research projects supported during the year in this category deal with water and waste-water management in a wide range of industries which include the sugar; pulp and paper; meat; wool; sorghum beer; steel; dairy; hides and skins; and fruit and vegetable industries. Projects aimed at power station water economy are also dealt with in this chapter.

Of the 38 projects 3 were completed during the year and 6 commenced.

Completed projects

Degradation of mortar linings and concrete by micro-organisms in industrial water systems *(No 398) Engineering Investigations Division, Eskom*

This study evaluated the effects of micro-organisms and the concentration of aggressive chemical species on the mortar linings and concrete used to protect mild steel pipework.

Active microbially induced corrosion occurred in the test rigs as demonstrated by the metal loss determined on the mild steel samples. The evaluation showed no deleterious effects on the concrete and mortar samples under the test conditions, while uniform microbial attachment was identified on all the material evaluated.

The addition of a biodispersant to the non-sterile rig resulted in a significant reduction in the numbers of attached bacteria.

Mortar linings and concrete were therefore considered to be suitable

alternative materials for the corrosion protection of industrial water systems with similar water chemistry to that used in this investigation.

Cost: R100 000

Term: 1991-1993

Interaction between the boundary layer and Kendal Power Station natural-draught dry-cooling tower *(No 452) Division of Earth, Marine and Atmospheric Science and Technology, CSIR, and Eskom*

Earlier work at Grootvlei Power Station revealed a significant interaction between the cooling towers and the stable boundary layer. In the light of the importance of dry-cooling, and its susceptibility to environmental temperature fields, it is important to establish the effect of scale-up on the performance of natural-draught dry-cooling towers. The earlier study was, therefore, repeated at Kendal Power Station where the cooling towers each serve 660 MW generators.

The results obtained indicate that the existing inter-tower spacing is probably insufficient to prevent interaction between adjacent cooling towers under calm wind conditions and during prevailing winds from certain quadrants. Tower interaction disturbs the stable boundary layer causing air warmer than that of the undisturbed boundary layer to enter an adjacent cooling tower and could, therefore, impair its efficiency.

Cost: R200 000

Term: 1992

Laboratory-scale treatment of acetic acid effluents by the anaerobic digestion/ultrafiltration (ADUF) process *(No 459) Membratek (Pty) Ltd*

The possibility of treating sugar producers' acetic acid effluent by means of the ADUF process, was investigated using a laboratory set-up.

The results of the preliminary study indicated that although the effluent was readily biodegradable, high load rates could not be obtained. Two causes were thought to have an inhibitory effect on microbial action. Firstly, the effluent contained furfural which is known for its bactericidal properties, and secondly the effluent suffered severe nutrient deficiencies, even though phosphate and nitrogen were added on a regular basis. Nevertheless, the flux values of the ultrafiltration unit could be maintained at 20 to 30 $l/m^2.h$ and fouling was never serious enough to cause decreased throughput.

Cost: R39 800

Term: 1992

New projects

Technology transfer of aquatic chemical speciation modelling

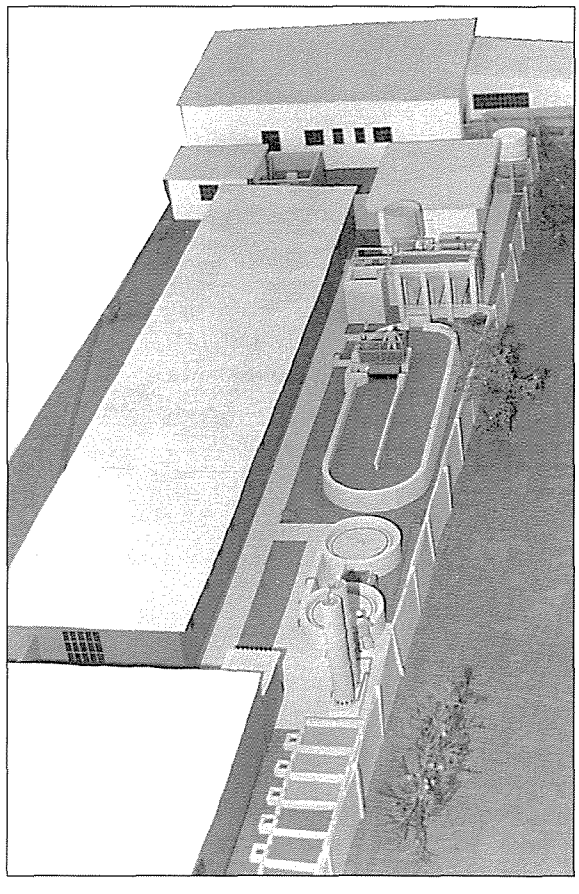
(No 530) Department of Chemical Engineering, University of Natal

An in-depth knowledge of the chemical composition of a water system and its interaction with its surroundings is essential for the understanding of phenomena as diverse as bioavailability and nutrient cycling, biotoxicity, scaling and corrosion, groundwater quality, leachate attenuation, water and effluent treatment, chemical dosing and desalination.

The United States Environmental Protection Agency (USEPA) has funded the development of a PC-based general geochemical speciation program, called MINTEQA2, which can be used to calculate the equilibrium composition of solutions or natural aquatic systems. The aim of the 2-year project is to promote the local use of the chemical speciation program MINTEQA2 - acting as a link between the USEPA and South African users.

Extractive purification of industrial effluents *(No 533) Department of Chemical Engineering, Potchefstroom University for CHE*

The plating industry generates large quantities of heavily contaminated effluents containing a variety of metal cations, organic acids and other organic derivatives. Such effluents are difficult to treat, even with existing precipitative techniques. Consequently the effluents either have to be disposed of in costly evaporation ponds, thereby merely transferring the ecological problem, or have to be treated



A model of the proposed tannery waste-water treatment pilot plant to be constructed at LIRI, Grahamstown, Eastern Cape, for the extension of Project 457

destructively, resulting in further and worse ecopollution.

There is therefore a need for real purification of plating effluents. The techniques to be investigated in the course of this 1-year project, will be restricted to the so-called liquid-membrane extraction systems. Selective chemical precipitation is a strong support technique planned for complementary application.

Use of filamentous micro-organisms for the purification of industrial effluents *(No 535)*

Department of Chemical Engineering, University of Pretoria

The University of Pretoria has been engaged for the past 10 years in purposefully cultivating filamentous micro-organisms to purify effluents, while at the same time producing single-cell protein. From this research has now emerged the fact that, due to the specific chemical composition of the effluents, each effluent has its own specific micro-organism yielding the best result. In this regard it was found that the fungus *Geotrichum* yielded the best results for petroleum effluent, while *Aspergillus* shows promise for the treatment of paper effluent.

As considerable experience and expertise have been gained in the culture of *Geotrichum* and *Aspergillus*, this 2-year project aims to expand this expertise to make the treatment of paper and sugar effluents with fungi a practical reality.

Development and demonstration of effluent treatment systems appropriate to the needs of the red meat abattoir industry *(No 546)*

SRK (CE) Inc.

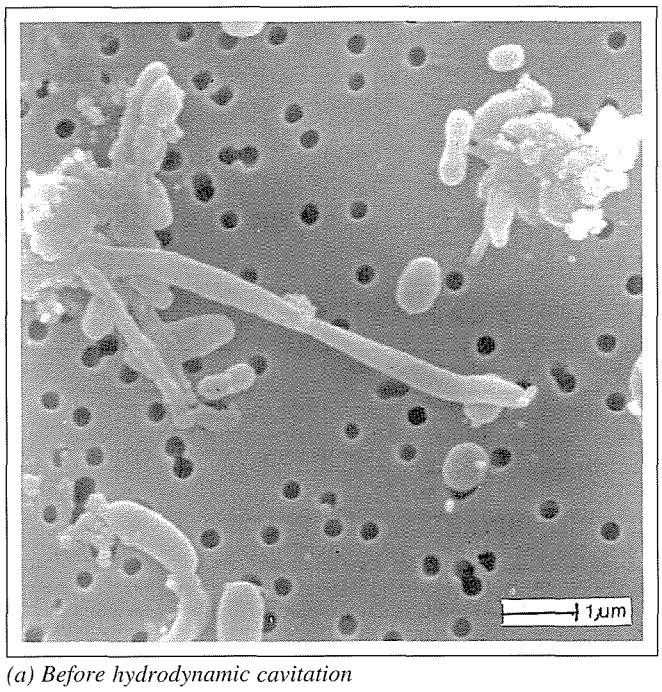
The red meat abattoir industry is represented by some 300 abattoirs in the Republic of South Africa. These abattoirs exert a significant influence on national water resources in that they are water-intensive operations using at least 7 million m^3/a and impose heavy loads on treatment works and receiving waters, discharging about 6 million m^3/a of effluent.

Over the period 1983 to 1986 the WRC supported investigative work aimed at establishing water and effluent management guidelines for the red meat abattoir industry. A number of treatment technologies were evaluated including screening, sedimentation, dissolved air flotation and membrane systems.

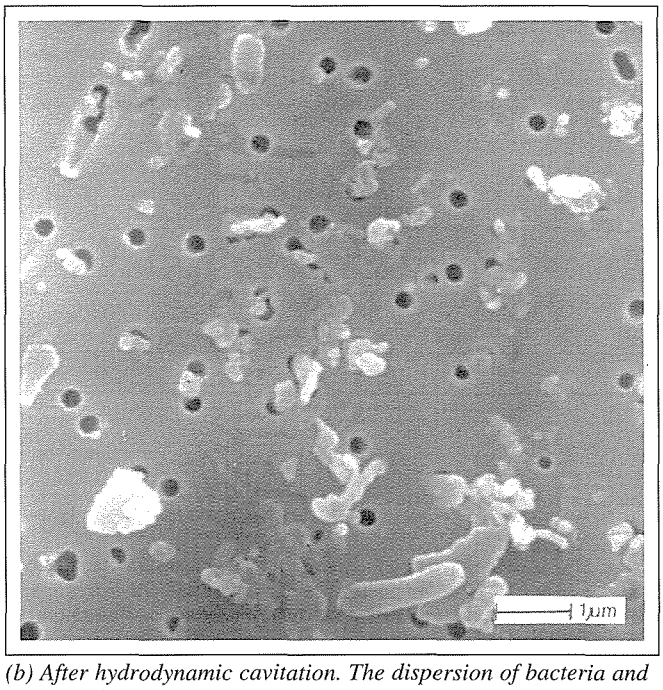
There is a strong feeling within the abattoir industry that the time is now appropriate to evaluate the effluent treatment needs of abattoirs of all sizes and situations. The work envisaged during this 2-year project would include:

- Auditing water-use and effluent production across a spectrum of different abattoir operations
- Reviewing and confirming water reuse opportunities in abattoirs
- Updating the industry's knowledge on effluent treatment technologies available
- Developing these treatment technologies into the context of cost-effective systems.

A scanning electron micrograph of filtered raw water obtained from Wiggins Water Treatment Plant in Durban (scale is shown at bottom of micrographs):



(a) Before hydrodynamic cavitation



(b) After hydrodynamic cavitation. The dispersion of bacteria and algae is shown clearly

Evaluation of the potential quantity of methane gas from 85 anaerobic household digesters *(No 551) BE La Trobe*

The Grahamstown municipality has installed 85 individual anaerobic digesters at its new site and service area of the Coloured township as an alternative sewage treatment system. Permission has been obtained from the City Council to collect the digester emitted gases by inter-connecting all the digester vent pipes. It will thus be possible to monitor gas formation, its quality and quantity, at a central collection point. If sufficient, the biogas could be utilised to provide energy for communal hot water or a cooking facility.

If this 2-year project provides positive results, it could be of great benefit to the local inhabitants of the site and services areas throughout South Africa. Although the research on the production and capture of methane gas from large anaerobic digesters and sewage works is well documented, the collection of methane gas from digesters serving individual facilities, as a sanitation facility, needs further study.

Evaluation of immobilised semi-conductor particles for the photo-catalytic oxidation of organic pollutants in industrial and municipal waste water

(No 552) Department of Chemistry, University of Stellenbosch

The purification of polluted water has become a priority as far as the conservation of the environment is concerned. Considerable progress has already been made with various technologies to deal with this problem. Biological degradation is an important technique but is restricted by the slow rate at which certain compounds break down. Other compounds are immune to biological degradation. New developments have, in the mean time, taken place and oxidants can now be generated photochemically in solution.

The aim of this 2-year project is to develop a system at laboratory scale in which immobilised semi-conductor particles will be used to oxidise pollutants in runoff photo-catalytically by means of commercial lamps and/or sunlight.

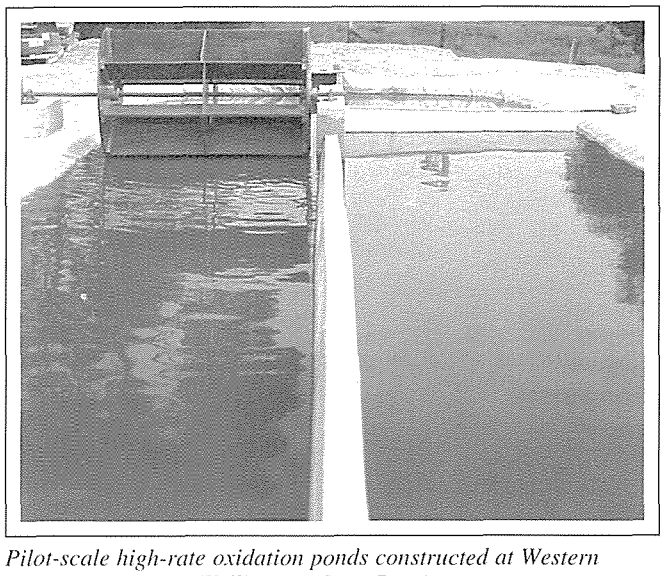
Should the above investigations be concluded successfully, the systems can be scaled up to pilot-plant scale and eventually to commercial scale. It is foreseen that a portable system could be developed for application wherever crisis pollution may arise.

Application of capillary membranes in the biotechnological treatment of industrial effluents *(No 553) Institute of Polymer Science, University of Stellenbosch*

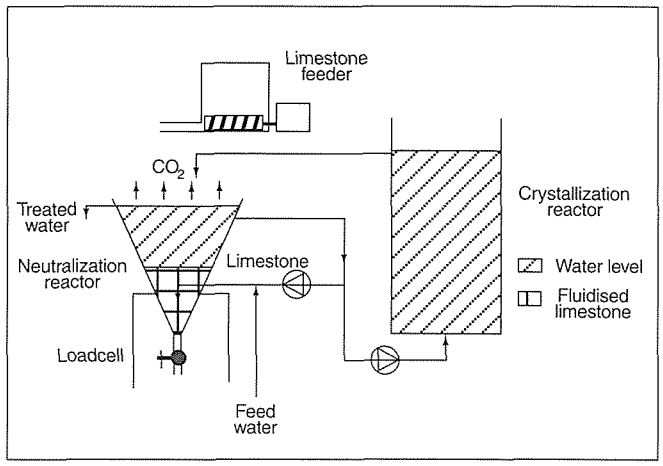
Pressure-driven membrane separation is a relatively new unit process initially developed for the purpose of water desalination. As the various unit processes have become established in the course of time, membrane separators have also been used more often in applications other than the traditional removal of salt or colour from drinking water.

The pressure-driven membrane processes in particular, can profitably be used in conjunction with other unit processes for the treatment of industrial effluents. The effective separation and reclamation of biomass or its products in the biotechnological treatment of effluents represent a problem and delay the establishment of this technology.

The aim of this 2-year project is specifically to investigate the use of capillary membranes in the biotechnological treatment of industrial effluents. The research will centre on two biological treatment processes.



Pilot-scale high-rate oxidation ponds constructed at Western Tanning Company, Wellington, Cape Province



Flow diagram of cone-shaped fluidised bed reactor and crystallisation reactor for the neutralisation of water containing high concentrations of sulphuric acid with calcium carbonate

Research projects

Completed

- **398** Degradation of mortar linings and concrete by micro-organisms in industrial water systems (Eskom - Engineering Investigations Division)
- **452** Interaction between the boundary layer and Kendal Power Station natural-draught dry-cooling tower (CSIR - Division of Earth, Marine and Atmospheric Science and Technology and Eskom)
- **459** Laboratory-scale treatment of acetic acid effluents by the anaerobic digestion/ ultrafiltration (ADUF) process (Membratek (Pty) Ltd)

Current

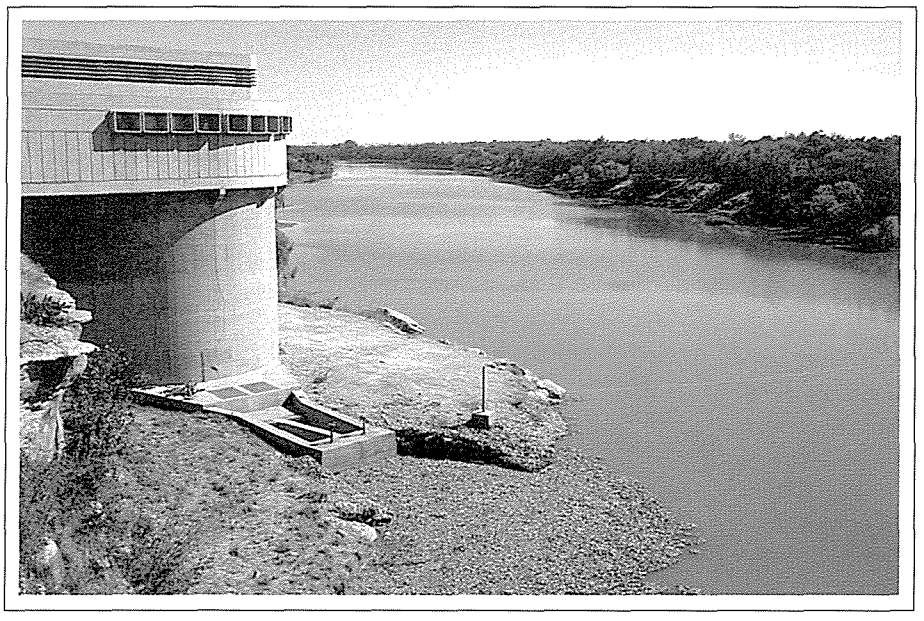
- **161** Treatment of wool scouring effluents (University of Natal - Department of Chemical Engineering, SRK (CE) Inc. and Gubb and Inggs (Pty) Ltd)
- **239** Transfer of waste-water management technology to the meat processing industry (SRK (CE) Inc. and South African Abattoir Corporation)
- **241** Dewatering of compressible filter cakes (University of Natal - Department of Chemical Engineering)
- **263** Biological treatment of industrial water with the simultaneous production of single cell protein (University of Pretoria - Department of Chemical Engineering)
- **285** Evaluation of various factors affecting dry-wet cooling (Eskom and University of Stellenbosch - Bureau of Mechanical Engineering)
- **308** Recovery of water and chemicals from ion-exchange regeneration effluents (University of Natal - Department of Chemical Engineering)
- **309** Phase diagrams of complex precipitants (University of Natal - Department of Chemical Engineering)
- **315** Utilisation of the fungus *Geotrichum* in waste water (University of Pretoria - Department of Chemical Engineering)
- **318** Optimisation of biofouling control programmes (University of Pretoria - Department of Microbiology)
- **322** Study on a mine-water reclamation test plant (Chamber of Mines Research Organisation)
- **331** Improved oxygen transfer for high biosludge concentrations (University of Pretoria - Department of Chemical Engineering)
- **333** Removal of suspended solids from pulp and paper effluents by employing a combined sedimentation, flotation and sand filtration process (CSIR - Division of Water Technology)
- **342** Improvement in water usage control and waste-water treatment in the sorghum beer industry (University of Pretoria - Department of Chemical Engineering)
- **355** Neutralisation of water containing high concentrations of sulphuric acid with calcium carbonate (CSIR - Division of Water Technology)
- **357** Microbiological transformations of metal contaminated effluents (University of Durban-Westville - Department of Microbiology)
- **365** Evaluation and improvement of the anaerobic digestion/ultrafiltration (ADUF) effluent treatment process (CSIR - Division of Water Technology)
- **388** Evaluation of various methods for the forming of free radicals for the oxidation of molecules in industrial effluents and potable water (University of Natal - Department of Chemical Engineering, Pollution Research Group)
- **393** Use of algae to bioassay for toxic substances in water (University of the Orange Free State - Department of Botany)
- **408** Fats and oils in effluents (University of Pretoria - Department of Chemical Engineering, Division of Water Utilisation Engineering)
- **409** Phenols in the steel industry waste water: Origin, prevention and removal (University of Pretoria - Department of Chemical Engineering, Division of Water Utilisation Engineering)
- **410** Biological approach to the removal of organics from saline effluents (Rhodes University - Department of Biochemistry and Microbiology)
- **453** Development of procedures to assess whole effluent toxicity (CSIR - Division of Water Technology)
- **455** Anaerobic digestion of dairy factory effluents (Irene Animal Production Institute, Agricultural Research Unit)
- **456** Regional treatment of textile and industrial effluents (University of Natal - Department of Chemical Engineering)
- **457** Monitoring and optimisation study of high-rate biofiltration, aerobic biological treatment processes for tannery and fellmongery waste water (LIRI Technologies)
- **458** Development of an expert systems approach to water management in the fruit and vegetable processing industry (SRK (CE) Inc.)
- **464** Use of yeast biomass and yeast products to accumulate toxic and valuable heavy metals from waste water (Rhodes University - Department of Biochemistry and Microbiology)
- **478** Saving of water with air-cooled heat exchangers (University of Stellenbosch - Department of Mechanical Engineering and Eskom)
- **495** Biotechnological approach to the removal of organics from saline effluents (Rhodes University - Department of Biochemistry and Microbiology)

New

- **530** Technology transfer of aquatic chemical speciation modelling (University of Natal - Department of Chemical Engineering, Pollution Research Group)
- **533** Extractive purification of industrial effluent (Potchefstroom University for CHO - Department of Chemical Engineering)
- **535** Use of filamentous micro-organisms for the purification of industrial effluents (University of Pretoria - Department of Chemical Engineering, Division of Water Utilisation Engineering)
- **546** Development and demonstration of effluent treatment systems appropriate to the needs of the red meat abattoir industry (SRK (CE) Inc.)
- **551** Evaluation of the potential quantity of methane gas from 85 anaerobic household digesters (BE La Trobe)
- **552** Evaluation of immobilised semi-conductor particles for the photo-catalytic oxidation of organic pollutants in industrial and municipal waste water (University of Stellenbosch - Department of Chemistry)
- **553** Application of capillary membranes in the biotechnological treatment of industrial effluents (University of Stellenbosch - Institute of Polymer Science)

10

Drinking water



The water consumer is becoming more and more critical regarding both the quality and cost of the drinking water which reaches him. Coupled to this, the increasing threat of pollution makes certain demands on the one hand, while on the other hand, there is an increased tendency by regulating authorities world-wide to lay down ever more stringent quality criteria for drinking water.

The drinking water supplied is firstly judged by means of the consumer's own senses which normally include: smell, taste, temperature, colour and turbidity. Because the water consumer is unable to judge the other quality criteria, such as microbiological quality, and inorganic and organic quality, he is in this respect dependent on the water supplier and the organisations which are in control of the quality. In order to ensure the desired quality levels under increasingly demanding circumstances, the water supplier requires the necessary technology to ensure that the treated water complies with the guidelines.

In the above regard the WRC supports various research programmes and projects pertaining to drinking water in the following main research areas, i.e. **Water Treatment and Reclamation, Drinking-Water Quality and Health Aspects** and **Urban and Rural Water Supply**.

Water treatment and reclamation

As recommended in the WRC Strategic Plan for Research on Potable Water Treatment, the accent in drinking-water research has shifted toward research on the "Cost-effective Provision of Water to the Unserved Communities" (More information on this is also given in **Chapter 13** of this report). However, the majority of the South African population is still being supplied from conventional water treatment and distribution systems. Therefore, taking into account the worsening pollution of surface water sources and the increasing quality awareness of both the consumer and supplier of potable water, further research on the bulk treatment and supply of potable water is becoming even more important than in the past.

The current research thrusts in this field revolve around the following:

- Oxidation and disinfection processes in the treatment of, especially, eutrophic water
- Understanding and modelling the role of algae in cost-effective water treatment
- Improving our understanding of, and drawing up of guidelines for, the treatment of various typical South African raw water sources.

Drinking-water quality and health aspects

The Co-ordinating Committee for Health-related Water Quality held its 5th meeting this year and, *inter alia*, made certain refinements to its strategic research plan and list of research projects. Three research projects in this category were completed and 4 projects commenced. One of the new projects concerns algal toxins - a subject which is receiving world-wide attention these days.

Urban and rural water supply

Workshops on fluid flow measurement

The WRC and Kent Measurement of Johannesburg, jointly organised a series of 3 workshops which were run by Dr Richard Furness, an expert in fluid flow measurement from the UK. Dr Furness is currently business director at ABB Kent-Taylor, UK. He has been involved with flow measurement for more than 20 years and has been actively involved with the drafting of a number of BS specifications. He is also chairman of the ISO Committee on turbine and positive displacement meters.

During the past decade, flow measurement has undergone many new developments. There are currently more than 100 different ways to measure flow. The aim of the above-mentioned workshops was to equip practitioners with an understanding of aspects such as meter behaviour, meter design, installation considerations, calibration methods, and criteria for the selection of equipment. This technical seminar covered the practical aspects of fluid flow measurement.

By all accounts, the visit by Dr Furness was an outstanding success with some 250 persons attending the 3 workshops, held in Cape Town, Johannesburg and Durban. The largest attendance of 145 was in Johannesburg. A notable feature of the attendance at each venue was the large number of attendants from consulting engineering firms.

Completed projects

Bacteriophages as water quality indicators *(No 321) Department of Medical Virology, University of Pretoria*

In research on indicator systems which are more reliable for human viruses than faecal bacteria, the indicator features of bacteriophages (phages) are currently being investigated (phages are viruses which infect bacteria). The main objective of the research was to investigate the possibility of using certain groups of phages as indicators of water quality, particularly with regard to human viruses. One of the results is that techniques for the detection of *B. fragilis* phages, which are more complicated than those of commonly used coliphages, have been established and optimised. Evidence has been presented that phages fulfil the fundamental requirements of indicators for faecal pathogens, notably human viruses. Indicator features of phages disclosed by this and other studies warrant further research regarding their application in practice for water quality assessment and also for the detection of low numbers of phages in large volumes of water.

Cost: R203 400

Term: 1990-1992

Development of guidelines for the design and application of dissolved air flotation/filtration processes *(No 332) GFJ Inc. and BS Bergman and Partners*

A South African design guide for dissolved air flotation (DAF) has been published as a technology transfer document for both local and overseas distribution.

Since South Africa was one of the pioneering countries regarding the research on, and design of, DAF processes for potable water production, it was considered fitting to produce a practical, user-friendly design guide to augment the scant design information generally available in textbooks on this process.

The guide covers both potable water treatment and thickening of sewage sludges, and was compiled from a country-wide plant survey, incorporating the available international literature.

Cost: R75 000

Term: 1990-1991

Mutagenicity of drinking water produced with conventional treatment methods of surface water sources *(No 360) Rand Water*

The main objective of the project was to investigate the occurrence of mutagens (compounds which can increase the frequency of mutation in die DNA molecule and which in certain instances can lead to carcinogenesis) and the impact of the treatment process on them. No mutagenicity was detected in the raw water or in the water after the various treatment stages, except after breakpoint chlorination. The mutagens can be removed using activated carbon(GAC). No mutagenicity was detected in cases where the water was treated with chlorine dioxide or chloramine. Although there were indications of mutagenicity under certain circumstances, these were, however, in such negligible concentrations as to have no health implications.

Cost: R150 000

Term: 1991-1992

Determination of exposure to chemical residues in South African food and water intake *(No 399) Department of Community Health, University of Cape Town*

A knowledge of the quantities of different types of liquids and foods consumed by an individual is necessary to ascertain the relative importance of various dietary pathways in the consumption of pesticide residues. This information is also important for the rational setting of standards for contaminants.

Dietary surveys were carried out in Cape Town during the period 1983 to 1990 on 5 000 persons. The method used was the 24-hour recall. The data were analysed using the South African food composition tables of the Medical Research Council.

Food intake tables for individual food items as well as food groups are given.

Cost: R34 000

Term: 1991-1992

Magnetite as flocculant in water purification processes

(No 473) Department of Chemical and Environmental Engineering, University of Pretoria

Large quantities of magnetite are produced annually as a by-product by various mines in South Africa and only a small quantity is commercially utilised.

Various aspects of the water purification ability of magnetite, as reported in the literature, were verified for the South African conditions. It was demonstrated that the magnetite removes organic colour in particular, as well as turbidity, phosphates, geosmin and COD. The efficiency of removal increases when the pH of the water drops.

It was recommended that the following possible applications exist in the South African water purification industry, for which the magnetite process presents an economically competitive alternative to other purification processes:

- Drinking-water sources high in colour, and low in turbidity, alkalinity and pH
- Industrial effluents having high colour, especially of organic origin, and low pH
- Acid mine water.

Pilot-scale studies will, however, be necessary to establish these possibilities in practice.

Cost: R20 000

Term: 1992

New projects

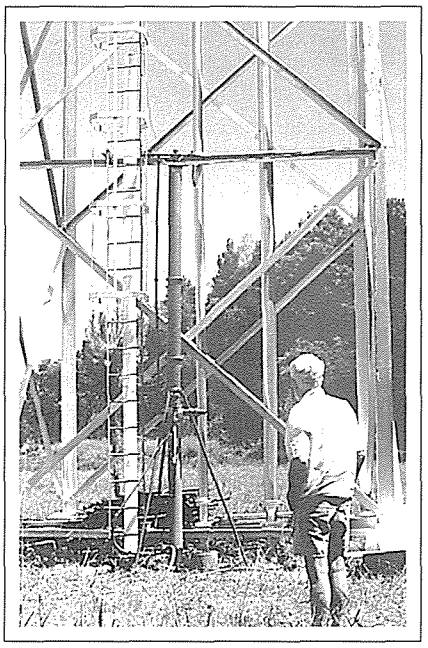
Ozonation in the production of potable water from polluted surface water *(No 446) Rand Water and the Department of Chemical Engineering, University of Pretoria*

The primary objective of this 3-year project is to determine the impact of ozonation on coagulation, flocculation and filtration with respect to the removal of inorganic and organic suspended material, with specific reference to the activated silica and lime process. The removal of undesirable dissolved substances and the formation of by-products will be investigated as part of the project.

The Vaal River catchment is one of the catchments in which intensive industrial activity and high-density population give rise to salinisation of the raw water and eutrophication-related water purification problems. The use of ozone, before and during the purification process, has the potential to optimise certain processes. If this optimisation results in the expected cost savings with respect to chemicals, it will be to the advantage of Rand Water and its consumers.

Guidelines for the treatment of Eastern and Southern Cape coloured water *(No 534) Division of Water Technology, CSIR*

In the southern coastal regions of South Africa organically coloured surface waters are used as primary source of drinking-water supply. Treatment of the coloured waters is still to a large degree empirical.



Colour removal by means of the direct-series filter at a forestry station in the SE Cape Province

Problems encountered with the treatment of coloured waters include among others the following:

- Inefficient stabilisation of the water, leading to corrosion of the distribution networks
- Poor colour removal due to insufficient dosing of coagulants when the quality of the raw water changes
- High aluminium residue in the final water due to overdosing
- Problems with the handling of large volumes of lime sludge.

The aim of this 2-year project therefore is to determine the limits of the effectiveness of the various unit processes, in order to establish guidelines for the design of future works or for the upgrading of existing works.

Guidelines to coagulation and flocculation for South African waters *(No 537) Pavel Polasek and Associates*

In a previous report (Report No 217/1/89) submitted to the WRC it was found that effective coagulation and flocculation were still two of the main problem areas in drinking-water treatment in South Africa. Surveys showed that many water treatment plant coagulation and flocculation systems were incorrectly and inadequately designed for the type of water that was treated.

Upgrading the systems for chemical dosing and floc formation, and eliminating outdated designs and arrangements, would lead to improved product water quality, greater permissible hydraulic loadings and cost savings because of smaller-sized plants and reduced consumption of chemicals.

The aim of this 2-year project is thus to provide a manual for the design of more efficient chemical dosing plants and coagulation-flocculation systems for purifying most of the typical South African waters.

Investigation of inorganic materials derived from water purification processes for ceramic applications *(No 538) Division of Materials Science and Technology, CSIR*

Sludges and silts produced by waterworks create disposal problems world-wide. Finding a use for such materials could possibly eliminate or reduce these disposal problems, by preventing the spoiling of land or fouling of waterways, reducing disposal costs, and creating possibilities of financial return from the sale of products, such as inexpensive bricks, blocks and tiles for low-cost housing.

Waterworks sludges have been identified as a source of raw material for the production of bricks and tiles. The aims of this 1-year project are to do a preliminary technical and economic feasibility study of waterworks sludges for the production of bricks, blocks, tiles, or any other alternative traditional ceramic applications.

Evaluation of the use of bacteriophages as indicators for water quality *(No 540) Department of Medical Virology, University of Pretoria*

The overall objective of this research is to further evaluate and develop in practice the use of bacteriophages (viruses using bacteria as hosts) as indicators of water quality. The behaviour of selected bacteriophages and groups of them will be studied relative to other indicators and human viruses in water treatment process environments, in order to make up for deficiencies when using bacteriophages as indicators. Special attention will be paid to the numbers in which bacteriophages occur in waste water and polluted water environments, as well as to their survival. In order to be able to significantly address these matters more sensitive methods for the detection of bacteriophages need to be developed. This 3-year project follows on an earlier research project on bacteriophages as indicator organisms, which was also carried out by the University of Pretoria.

Bio-degradable organic compounds and microbial regrowth in drinking water *(No 541) Rand Water*

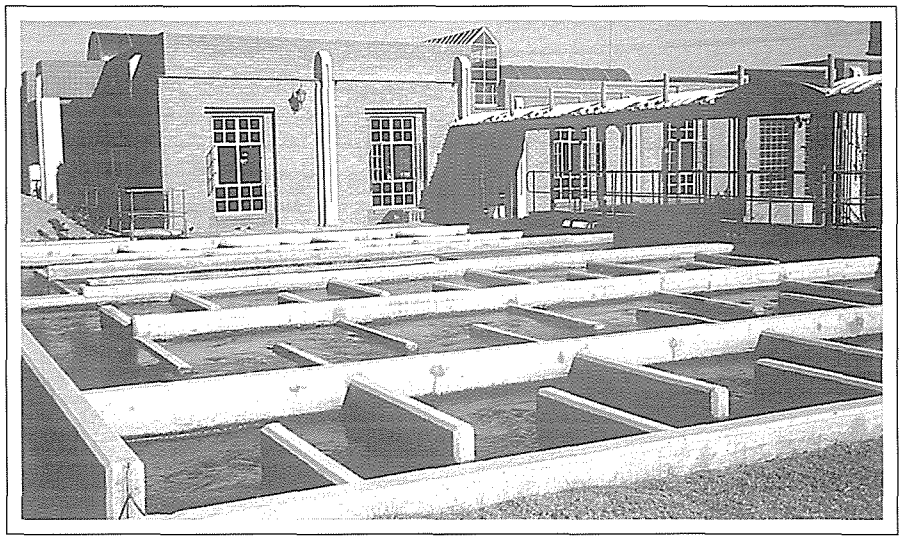
In spite of the disinfection of drinking water micro-organisms can still collect in distribution systems. This microbial aftergrowth can include a variety of micro-organisms which not only pose health implications, but also cause undesirable odours and tastes.

The presence of dissolved biodegradable or assimilable organic material in raw and treated water is probably the main reason for the occurrence of microbial aftergrowth in water distribution systems. In the project which will be carried out over a 3-year period, the most suitable method for the determination of dissolved biodegradable material will be investigated first of all. Furthermore, various water treatment processes with regard to the removal of biodegradable material will be evaluated. An investigation will also be carried out on the minimum concentration of biodegradable or assimilable material for the growth of certain bacteria.

Algal toxins in drinking-water supplies *(No 549) Umgeni Water and the Division of Water Technology, CSIR*

Algae in water can cause many problems: they can for example interfere with treatment processes, cause aesthetic, taste and odour problems and they can be a health hazard by producing toxins. There is currently a renewed interest in algal toxins and their potential health implication, also for human beings.

The overall aim of the 3-year project is to obtain a more complete picture of the occurrence of algal toxins in South African water supplies. The key issue is the development of one or more sensitive assays to detect the presence of the toxins. With a more extensive data base on the occurrence and actual concentration of toxins in water supplies, it will be possible to rationally assess the seriousness of the problem in the RSA; to estimate the survival of toxins in water after destruction or decomposition of algal blooms; and to plan and design for the most suitable and cost-effective remedial actions.



Combined flotation/filtration plant for the treatment of eutrophic surface water at Rietvlei, Pretoria

Optimal operation of combined flotation/filtration of eutrophic surface water *(No 557) Energy Laboratory, Rand Afrikaans University*

In spite of the considerable progress made in the recent past with the refining of practical design guidelines for the flotation of eutrophic water, there are doubtful areas especially with regard to the coagulation options and flocculation requirements. This is clearly indicated in the literature study and plant survey of dissolved air flotation recently completed at the instance of the WRC.

The aim of this 2-year research project is to optimise the following parameters for the combined flotation/filtration of a typically eutrophic surface water by means of bench-scale and full-scale plant tests:

- Optimum flocculation conditions in terms of energy input, as well as time, inclusive of the choice and dose of main coagulant, and the choice, dose and position of support coagulant
- Monitoring of filtrate in terms of residual coagulant
- Optimal chemical dosing of filter wash-water with a view to wash-water reclamation.

Algal rupture - further investigation *(No 558) Umgeni Water*

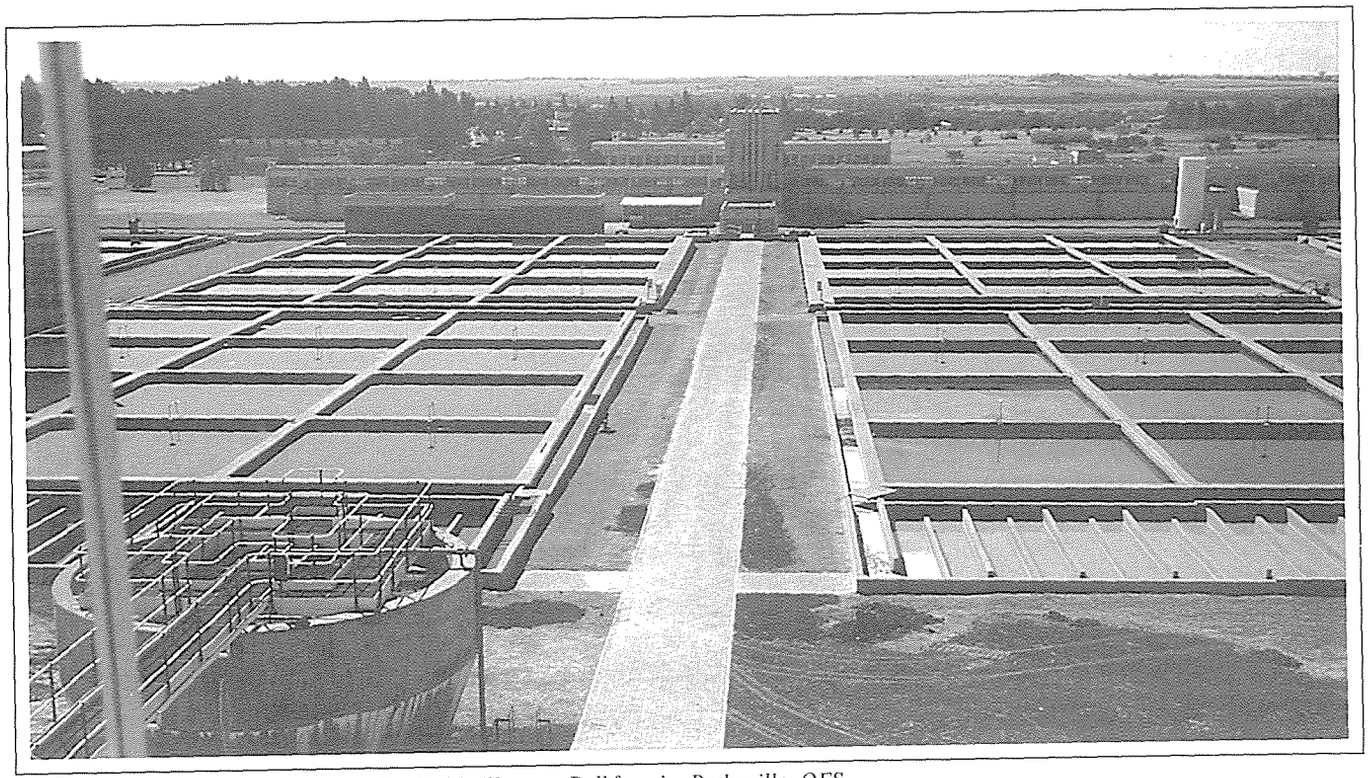
Following upon a preliminary study, this 1-year project aims to investigate the extent of algal rupture taking place in raw water mains due to pressure fluctuations between the point of abstraction and the water treatment plant.

When subjected to large pressure fluctuations, as does occur in water lines laid across hilly terrain, the cell walls of a certain fraction of the algae present in the water will burst and cell contents are released into the water. The released contents contain unwanted trace organics such as geosmin, algal toxins and trihalomethanes, which might lead to increased treatment costs in order to remove these substances. Preliminary studies show that this is indeed the case.

Occurrence and distribution of algal species and related substances in a full-scale water purification plant *(No 567) Department of Botany and Genetics, University of the OFS*

Eutrophication and salinisation in the Vaal River result in large-scale algal blooms and, consequently, in serious ecological, aesthetic and water purification problems. Inadequate information is available on the connections between morphological and physiological characteristics of specific problem-causing phytoplankton species on the one hand, and aspects of water purification processes such as oxidation, flocculation, sedimentation, filtration and flotation on the other hand.

The research will contribute toward understanding of the effects of algal growth on purification processes with the aim to develop techniques to remove algal material more efficiently from the raw water. This 4-year project will follow an interdisciplinary approach by involving engineering and chemically orientated persons in addition to biologists and will also



A full-scale water treatment plant of Goldfields Water at Balkfontein, Bothaville, OFS

involve co-operative research with German scientists from the Wahnbachtal Reservoir Association near Bonn.

Development of an Exxpress unit for the production of potable water and the dewatering of waterworks sludges

(No 568) Umgeni Water

Earlier sludge dewatering work done on a prototype Exxpress unit yielded a large body of knowledge on the mechanisms that determine cake formation, cake recovery and tube blockages. Procedures have been developed to aid the design and operation of the process.

In addition to its application for the dewatering of waterworks sludges, the Exxpress process can provide potable quality water (without the addition of chemicals) at high fluxes and with low energy consumption.

For commercialisation of the process one must be in the position to supply relevant plant-scale advice. In order to do so a full-scale plant must be available for experimental and developmental purposes.

The aim of the 3-year project is to construct a full-scale plant to:

- Develop and demonstrate the Exxpress process for the dewatering of waterworks sludges
- Apply the Exxpress process to the production of potable water from river water.

An atlas of potentially water-related diseases in South Africa *(No 584) Department of Community Health, University of Cape Town*

Few data are readily available on the incidence or prevalence in South Africa of potentially infectious water-related diseases. For the amelioration of these diseases, many of which are rife among the rural and poorer sectors of society, it is important that all available information for South Africa is collated in a systematic form and that gaps in information are identified. The overall aim of this 2-year project is, therefore, to provide a systematic, comprehensive atlas of diseases potentially related to water in South Africa. In this process a thorough computerised bibliography of the chosen diseases would be assembled. Maps of the distribution of the disease in South Africa, and descriptive notes, would be produced. These maps would be at the spatial resolution (in most cases) of magisterial or statistical regions. Maps of mortality for all deaths registered in South Africa would be plotted for each of the diseases listed in the atlas (if appropriate).

Evaluation of water pipe leaks in the Johannesburg municipal area *(No 587) Division of Materials, Science and Technology, CSIR*

The leakage of water from municipal water distribution mains is a problem facing all water authorities worldwide. South Africa is no exception. Losses of 20% or more are not uncommon.

Clearly, this waste of water is unacceptable under the current pressures on South Africa's water resources.

This 2-year project aims to critically examine the reasons for leaks from water pipes in Johannesburg and to classify the causes of leaks. Findings will be compared with other areas, possibly Pretoria. Although corrosion is accepted as being responsible for the bulk of the leaks occurring in water pipes, no detailed systematic evaluation has been undertaken to classify the corrosion mechanisms responsible for failure. This aspect is considered to be critically important if correct remedial measures are to be implemented. Furthermore, the results will indicate where further research should be directed in order to decrease the number of leaks occurring, and this will be applicable to all municipal areas in South Africa.

Research projects

Completed

- **321** Bacteriophages as water quality indicators (University of Pretoria - Department of Medical Virology)
- **332** Guidelines for the design and application of dissolved air flotation/filtration processes (BS Bergman and Partners Inc. and GFJ Inc.)
- **360** Mutagenicity of drinking water produced with conventional treatment methods of surface water sources (Rand Water)
- **399** Determination of exposure to chemical residues in South African food and water intake (University of Cape Town - Department of Community Health)
- **473** Magnetite as flocculant in water purification processes (University of Pretoria - Department of Chemical and Environmental Engineering, Division of Water Utilisation)

Current

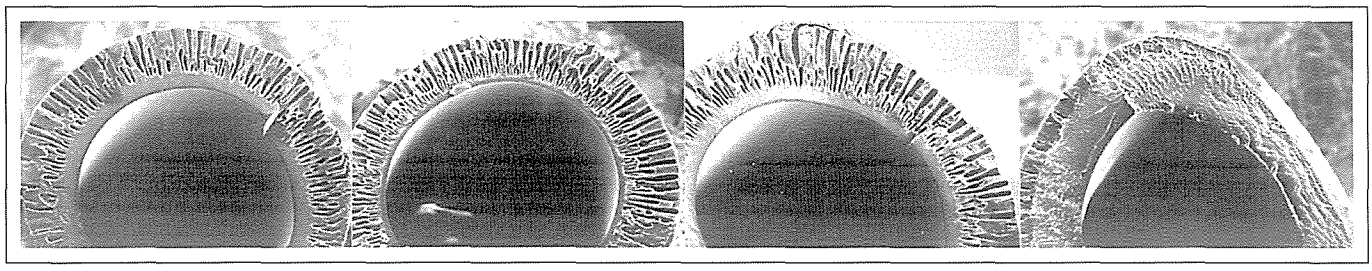
- **254** Effects of varying water quality on the corrosion of different pipe materials in the PWV/Klerksdorp areas (CSIR - Division of Materials Science and Technology)
- **259** Effect of water quality and chemical composition on corrosivity in mild steel pipelines (Rand Water)
- **280** Evaluation of full-scale flotation-filtration and chlorine dioxide plants (OFS Gold Fields Water Board)
- **281** Effect of water quality on the effectiveness of chlorine dioxide in drinking-water treatment (Rand Water)
- **282** Development of a combination of sedimentation, flotation and sand filtration processes for water treatment (SEDIDAFF) (CSIR - Division of Water Technology)
- **354** Evaluation and development of deep-bed filtration for the treatment of South African surface waters (CSIR - Division of Water Technology and Local Government Affairs Council)
- **358** Development of guidelines for toxicity bio-assaying of drinking and environmental waters in South Africa (CSIR - Division of Water Technology)
- **363** Development and evaluation of small-scale potable water treatment equipment (University of Natal - Department of Chemical Engineering and Umgeni Water)
- **381** Corrosion performance of various non-metallic piping materials and coatings in potable water (CSIR - Division of Materials Science and Technology)
- **383** Holistic approach to affordable planning and maintenance of water and sewer systems (Water Management Services)
- **400** Research into domestic meter replacement policy and testing of water meters (CSIR - Division of Building Technology)
- **432** Microbiological corrosion of common piping materials in the PWV area (CSIR - Division of Materials Science and Technology)
- **434** Evaluating the long-term use of polypropylene for hot- and cold-water piping (CSIR - Division of Materials Science and Technology)
- **445** The removal of colour from Cape waters using ozonation and ultrafiltration (Stewart Scott Inc.)
- **448** Improvement of injection nozzles for dissolved air flotation (Rand Afrikaans University - Department of Civil Engineering)
- **449** Evaluation of non-conventional disinfection technologies for small water systems (CSIR - Division of Water Technology)
- **450** Performance criteria for package water treatment plants (Umgeni Water and University of Natal - Department of Chemical Engineering, Pollution Research Group)
- **451** Occurrence of protozoal parasites in South African drinking water (CSIR - Division of Water Technology)
- **469** Studies on microbiological drinking-water quality guidelines (CSIR - Division of Water Technology)
- **470** Application of health risk assessment techniques to microbial monitoring data (CSIR - Division of Water Technology)
- **472** Characterisation of South African media for sand filtration (Rand Afrikaans University - Department of Civil Engineering)
- **488** Optimisation of the Rand Water system (University of the Witwatersrand - Water Systems Research Group)
- **489** Development of procedures for the control of unaccounted-for water in water distribution systems and for the reduction of water loss (De Leuw Cather Inc.)
- **504** Guide for water purification and plant design: Phases 2 and 3 (Dr FA van Duuren)

New

- **446** Ozonation in the production of potable water from polluted surface water (University of Pretoria - Department of Chemical Engineering, Division of Water Utilisation and Rand Water)
- **534** Guidelines for the treatment of Eastern and Southern Cape coloured water (CSIR - Division of Water Technology
- **537** Guidelines to coagulation and flocculation for South African waters (Pavel Polasek Association)
- **538** Investigation of inorganic materials derived from water purification processes for ceramic application (CSIR - Division of Materials Science and Technology)
- **540** Evaluation of the use of bacteriophages as indicators for water quality (University of Pretoria - Department of Medical Virology)
- **541** Bio-degradable organic compounds and microbial regrowth in drinking water (Rand Water)
- **549** Algal toxins in drinking-water supplies (CSIR - Division of Water Technology)
- **557** Optimal operation of combined flotation/filtration of eutrophic surface water (Rand Afrikaans University - Energy Laboratory)
- **558** Algal rupture - Further investigation (Umgeni Water)
- **567** Occurrence and distribution of algal species and related substances in a full-scale water purification plant (University of the OFS - Department of Botany and Genetics)
- **568** Development of an Exxpress unit for the production of potable water and the dewatering of waterworks sludges (Umgeni Water)
- **584** Atlas of potentially water-related disease in South Africa (University of Cape Town - Department of Community Health)
- **587** Evaluation of water pipe leaks in the Johannesburg municipal area (CSIR - Division of Material Science and Technology)

11

Membrane technology



Synthetic membranes are being used all over the world in a growing range of applications. Membranes have become cost-effective industrial products and currently membrane systems are being used in efficient unit processes of considerable technical and commercial importance - particularly in the desalination of brackish water or sea water for potable use, or in the treatment of industrial effluents.

In the field of water purification, membranes are also destined to play an ever-increasing role in future in South Africa. Overseas projections are that there will be an annual growth rate of approximately 5%, for reverse osmosis membranes alone, over the next few years.

In South Africa, however, research funding is on a rapidly declining path and it has, therefore, become imperative that we use our dwindling funds and available scientific manpower to the best advantage in the national interest. To that end the WRC has taken the initiative to develop a strategic plan for membrane research and development in South Africa. The first meeting of the working group responsible for the creation of this strategic plan was held during June 1993 at the WRC. The main aim was to establish research needs and priorities for the optimal development and exploitation of synthetic membranes in the water field in South Africa.

It is hoped to finalise this strategic research plan early in 1994 and to implement the findings during the evaluation of new research proposals in the membrane technology field as early as May 1994.

During the year under review 8 projects were finalised, 6 commenced and 10 were on-going.

Completed projects

Membrane development and fabrication for reverse osmosis and ultrafiltration (No 172)

Institute for Polymer Science, University of Stellenbosch

This investigation was conducted along 2 broad fronts, namely:

- The chemistry of suitable polymers for membrane production and the evaluation of novel membranes
- Engineering development of membrane fabrication equipment for practical application and commercialisation.

The main results were found to be:

- The consistency of membrane performance and membrane adherence to a polyether terphthalate base was improved by changing the membrane-forming polymer, reducing the rate of precipitation and increasing the viscosity of the casting solution
- The composition of casting solutions, for the support membrane, was optimised and suitable flat-sheet, thin-film composite membranes were produced
- The incorporation of primary diamines resulted in effective cross-linking of the membrane structure by the formation of salts, without the use of thermal curing.

Cost: R1 222 410

Term: 1985-1987

Development of fixed and dynamic membrane systems for the treatment of brackish water and effluents (No 219)

Institute for Polymer Science, University of Stellenbosch

The main aim of this study was to effect improvements in cellulose acetate membranes and newly developed ultrafiltration and reverse osmosis membranes.

The main results emanating from this work were:

- Substandard cellulose acetate membranes could be regenerated by novel cross-linking of polymers and deteriorated spiral-wrap membranes could be upgraded
- Polyether sulphone ultrafiltration and nanofiltration membranes were produced with low molecular mass cut-offs and also used as support media for dynamic membranes
- Stable, thin-film composite membranes were developed with improved reverse osmosis performance

- A series of polyacrylic copolymers were synthesised and evaluated as dynamic membranes in typical industrial effluents
- Techniques to produce wet phase-inversion membranes were successfully implemented.

Cost: R1 751 277

Term: 1988-1991

Development of a South African electrodialysis membrane system *(No 395) Division of Water Technology, CSIR*

The main aims of this limited investigation were to:

- Design and construct a laboratory-size prototype electrodialysis (ED) unit from materials available in South Africa
- Evaluate the performance of the ED unit for brackish water desalination
- Evaluate the batch ED system for the treatment of nickel and zinc electroplating rinse waters
- Develop heterogeneous ion-exchange membranes and to determine their characteristics.

The main results obtained were:

- A prototype ED unit could be wholly manufactured from local materials
- The performance of the prototype ED unit compared favourably with that of a commercially available ED unit, for brackish water desalination
- It was possible to treat nickel and zinc electroplating rinse waters effectively with ED for metal and water recovery
- Heterogeneous ion-exchange membranes could be prepared from local resins.

Cost: R89 142

Term: 1991

Evaluation of prototype capillary micro- and ultrafiltration membranes for industrial application *(No 397) Membratek (Pty) Ltd*

This project comprised 2 phases, namely the investigation and modelling of the hydrodynamic characteristics of the capillary system and evaluation of its performance in the laboratory by using real feedwaters.

The prototype capillary modules had characteristics similar to regular 9 mm tubular ultrafiltration units, with the major advantage of lower pressure drop at increased flow velocities.

The major advantages of the capillary modules were found to be the following:

- Capillary modules could operate at higher linear flow velocity for increased turbulence, with resultant higher flux
- The high packing density, together with the low cost of construction, renders this capillary configuration eminently suitable for the clarification of a variety of feedwaters
- Fouling could be controlled by adopting higher than normal flow velocities and standard chemical cleaning methods.

Cost: R25 000

Term: 1991-1992

Modelling of flow through porous membranes *(No 402) Department of Applied Mathematics, University of Stellenbosch*

The design of large-scale membrane systems necessitates, *inter alia*, a thorough understanding of the basic flow phenomena through such porous media. Accordingly, this study aimed to effect analytical modelling of flow through the different pore structures found in synthetic membranes and to establish a computer code to study and predict flow phenomena in complex membrane systems.

A new set of equations for fluid movement through and adjacent to a synthetic membrane were established. These equations may be used in future mathematical and computational research on membrane processes and design of membrane systems. Although this report deals primarily with water seepage through synthetic membranes, the mathematical results are applicable to any Newtonian fluid or porous medium.

Cost: R76 000

Term: 1991-1992

Feasibility study of membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics *(No 431) Department of Chemical Engineering, Potchefstroom University for CHE*

There exists a need in membrane technology to find easily measurable, comparable and reliable parameters for different types of membrane. The project was aimed at obtaining a profile of the permeability or compaction of a membrane, using dynamic, electric measurements.

The main results were as follows:

- A hydrodynamic, characterisable cell was developed for the electrochemical measurements, and the placement of the measuring electrodes was optimised
- The format and suitable material for the manufacture of the electrodes were investigated
- The suitability of the equipment for the electrochemical characterisation of the membranes was investigated
- Finite element analysis was employed to investigate the deformation of the membrane
- Computational fluid mechanics techniques were employed to numerically determine flow distribution, tensions and deformations of a hollow-fibre membrane with success.

Cost: R83 000

Term: 1992

Reaction kinetics in a slurry precipitation and recycle reverse osmosis (SPARRO) seed reactor *(No 461) Division of Mining Technology, CSIR*

Earlier work on the slurry precipitation and recycle reverse osmosis (SPARRO) plant has led to the belief that if the short contact time between the raw water and the seeded slurry before entering the RO modules were increased, it would enable raw water "contaminants" to be captured in the gypsum crystal matrix and prevent them from degrading membrane performance.

This study concluded that membrane degradation does not appear to be due to the foregoing postulate, but rather to a combination of phenomena associated with the increasing concentration of dissolved and suspended solids in the feed to successive rows of membrane modules. Radioactivity may be one such phenomenon. Radionuclides appear to be almost totally rejected by the membranes, even when their overall salt rejection is poor.

Cost: R56 250

Term: 1992

Development of an ultrafiltration pretreatment system for sea-water desalination by reverse osmosis *(No 467) Membratek (Pty) Ltd*

Extensive pretreatment of the raw sea water is required for the successful operation of reverse osmosis plants. The aim of this project was to develop a suitable ultrafiltration system for the pretreatment of sea water, in particular:

- To investigate the requirements of such a system and the optimisation of flow configurations and system design to maximise flux values
- To develop a cost-effective ultrafiltration pretreatment system
- To evaluate the performance of the developed pretreatment system through pilot studies.

Both medium and low molecular mass cut-off membranes were found to be prone to fouling. Physical examination of the foulants indicated that both organic and inorganic materials were present.

Tubular sea-water ultrafiltration modules could be cleaned mechanically with sponge balls, whilst smaller tubular and capillary modules required biochemical cleaning.

Cost: R65 500

Term: 1992

New projects

Membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics *(No 529) Department of Chemical Engineering, Potchefstroom University for CHE*

Membrane technology requires simple, reliable correlative parameters, and for the optimal design of a complete membrane system the following aspects need optimising:

- Containerisation in which and with which the membrane has to be operated
- Dynamic transformation of the membrane
- Effect of such transformation on the permeability, polarisation concentration in the boundary layers and the optimal operational cycle to prevent irreversible plastic compaction
- Determination of flow, pressure and temperature property profiles in the system.

A powerful computational fluid mechanics computer package will be used to investigate mass transfer and flow through porous media. Flow through a membrane can be optimised with the aid of computational fluid mechanics. Electrochemical impedance spectroscopy will also be used to determine the porosity of membranes under dynamic conditions.

The project will last 2 years.

Development of characterising and cleaning techniques to classify organic foulants and to remove them from ultra- and microfiltration membranes by biochemical means *(No 531) Department of Biochemistry, University of Stellenbosch*

The optimal implementation of membrane separation in the treatment of industrial effluents is normally that in which substances with pollution as well as resale value, have to be removed from the effluents. Application of this process, however, often becomes uneconomical due to the sharp drop in flux as a result of membrane fouling.

Tubular membrane systems can be cleaned by mechanical, physical, chemical and biochemical means. The latter approach unfortunately does not receive adequate attention and very seldom forms part of a cleaning protocol.

This 2-year project aims to establish procedures by which organic fouling of ultra- and microfiltration membranes can be classified, as well as to develop and evaluate effective biochemical and physical cleaning methods.

Electrically driven membrane separation processes for the treatment of industrial effluents *(No 532) Division of Water Technology, CSIR*

Electrically driven membrane separation processes, such as electrodialysis (ED) and its variants - electrodialysis reversal (EDR); electro-osmotic pumping ED (EOP-ED); electro-electrodialysis (EED); and bipolar electrodialysis (BED), are proven technologies which are eminently suited to the reclamation of water and chemicals from industrial effluents.

A prototype ED system has been manufactured from locally available materials. Several ED and EDR systems are available for large-scale investigations such as the reclamation of chromium, nickel and water from plating effluents and rinse waters, the

recovery of waste ion-exchange regenerants and the reclamation of acids from pickling baths.

This 1-year investigation will evaluate these electrically driven membrane separation processes for the reclamation of water and chemicals from industrial effluents in full-scale plants.

Synthesis of organic precursors for the development of novel tubular membranes for the treatment of industrial effluents *(No 547) Department of Chemistry, University of Stellenbosch*

The objectives of this 2-year project are as follows:

- Development of methods for the synthesis of specifically substituted aromatic acids, as well as cyclic, aliphatic and aromatic diamines which are not commercially available
- Synthesis of soluble polyamides having high molecular mass which will exhibit high resistance to strong acids and alkalis as well as oxidising agents
- The use of such precursors for the manufacture of new types of tubular membrane.

Only two successful asymmetrical purification membranes are currently available on the world market. One is a cellulose acetate membrane which is robust as well as resistant to chlorine, while the second is a polyamide membrane manufactured only by Separem in Italy. It is a robust membrane resistant to high concentrations of chlorine, acids and alkalis. Membranes, similar to the proven Separem model, will be developed.

Investigation into the upgrading of Orange River water and secondary sewage effluent by means of ultra- and nanofiltration *(No 548) Institute for Polymer Science, University of Stellenbosch*

The research conducted during this 2-year project will aim at ascertaining to what extent low-pressure membrane filtration will be able to play a role in the re-utilisation of existing water sources and the upgrading of water, imported over long distances in order to provide a better quality water to consumers in the Uitenhage district.

Both Orange River and secondary sewage water will be used as feed water, and the membrane filtration tests will be conducted by means of ultra- and nanofiltration membranes.

The investigation will aim to obtain the following information:

- Long-term reliability, integrity and performance of the various membrane types
- Relationship between reclamation, pressure and flow speed on the one hand and product supply and quality on the other hand
- Maximum realisable reclamation
- Membrane fouling tendencies and cleaning techniques.

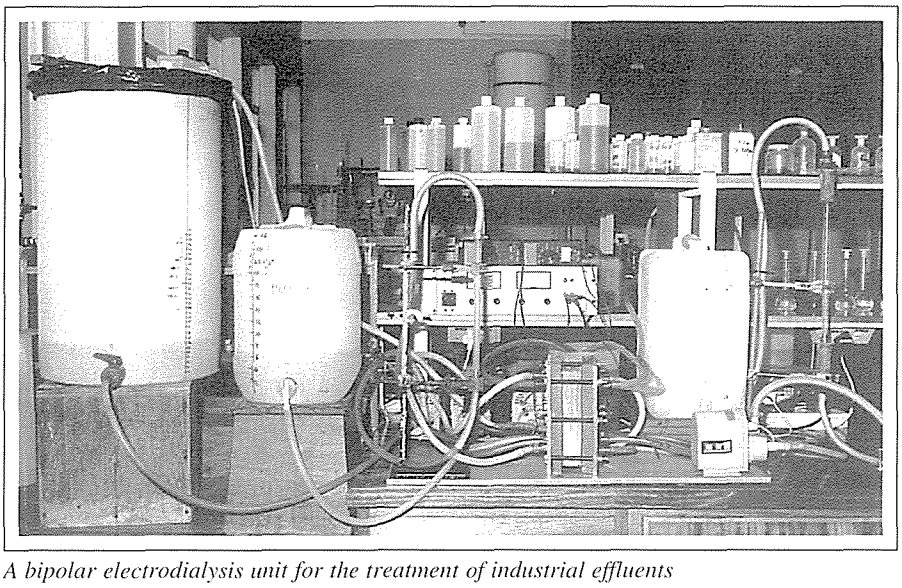
Modelling flow through porous media *(No 585) Department of Applied Mathematics, University of Stellenbosch*

The primary objective of this 2-year project is to further expand the already developed mathematical model for flow through porous membranes to serve as a basis for a variety of water-related research areas regarding water movement through porous membranes.

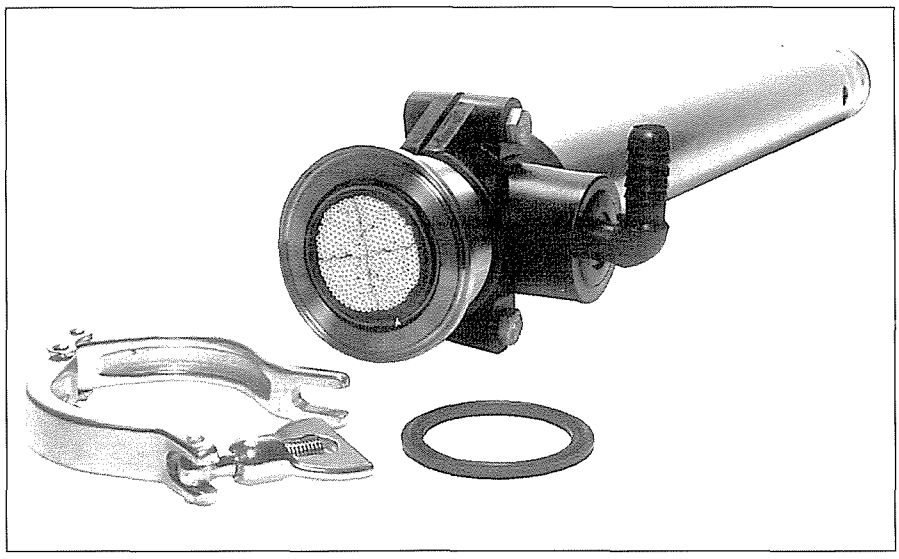
The second and equally important objective is to try and apply existing and new mathematical results in practice and at an interdisciplinary level for various other water research projects in South Africa.

In accordance with the above objectives, analysis and modelling of the following will occur:

- Separation processes where chemicals or suspensions are transported through the liquid medium
- Electrokinetic effects on ion movement in a membrane system
- The impact of macroscopic marginal effects, anisotrophy of the porous structure and membrane technology and pore size distribution on the through-flow.



A bipolar electrodialysis unit for the treatment of industrial effluents



A stainless steel capillary membrane module for the desalination of brackish water or effluents

Research projects

Completed

- **172** Membrane development and fabrication for reverse osmosis and ultrafiltration (University of Stellenbosch - Institute for Polymer Science)
- **219** Development of fixed and dynamic membrane systems for the treatment of brackish water and effluents (University of Stellenbosch - Institute for Polymer Science)
- **395** Development of a South African electrodialysis membrane system (CSIR - Division of Water Technology)
- **397** Evaluation of prototype capillary micro- and ultrafiltration membranes for industrial application (Membratek (Pty) Ltd)
- **402** Modelling of flow through porous membranes (University of Stellenbosch - Department of Applied Mathematics)
- **431** Feasibility study of membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics (Potchefstroom University for CHE - Department of Chemical Engineering)
- **461** Reaction kinetics in a slurry precipitation and recycle reverse osmosis (SPARRO) seed reactor (Chamber of Mines Research Organisation)
- **467** Development of an ultrafiltration pretreatment system for sea-water desalination by reverse osmosis (Membratek (Pty) Ltd)

Current

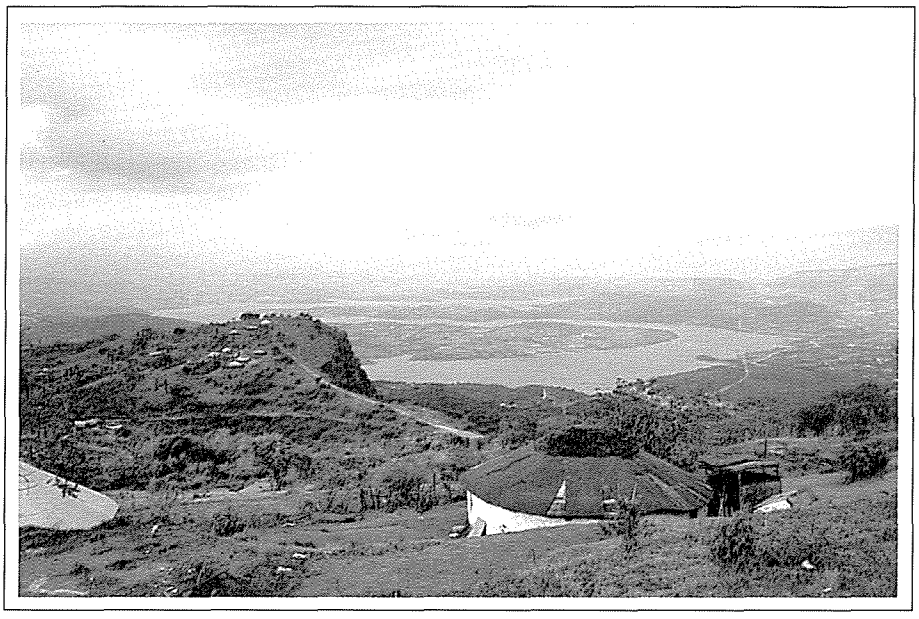
- **201** Treatment of inorganic brines and concentrates (University of Natal - Pollution Research Group)
- **238** Design criteria for crossflow microfiltration (University of Natal - Pollution Research Group)
- **274** Technical support for the application of dynamic membrane plants for the treatment of industrial effluents (University of Natal - Pollution Research Group)
- **275** Evaluation of membrane technology for electroplating effluent treatment (CSIR - Division of Water Technology)
- **325** Modelling of tubular reverse osmosis systems (University of Natal - Pollution Research Group)
- **361** Development of tolerant membranes (University of Stellenbosch - Institute for Polymer Science)
- **362** Industrial application of membranes (University of Stellenbosch - Institute for Polymer Science)
- **387** Development and production of membrane systems (University of Stellenbosch - Institute for Polymer Science)
- **466** Research into fluoro-carbon coating of ion-exchange membrane surfaces to overcome fouling and general scaling (Eskom)
- **468** Feasibility study for the provision of point-source water by enhanced solar distillation (University of Stellenbosch - Institute for Polymer Science)

New

- **529** Membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics (Potchefstroom University for CHE - Department of Chemical Engineering)
- **531** Development of characterising and cleaning techniques to classify foulants and to remove them from ultra- and microfiltration membranes by biochemical means (University of Stellenbosch - Department of Biochemistry)
- **532** Electrically driven membrane separation processes for the treatment of industrial effluents (CSIR - Division of Water Technology)
- **547** Synthesis of organic precursors for the development of novel tubular membranes for the treatment of industrial effluents (University of Stellenbosch - Department of Chemistry)
- **548** Investigation into the upgrading of Orange River water and secondary sewage effluent by means of ultra- and nanofiltration (University of Stellenbosch - Institute for Polymer Science)
- **585** Modelling flow through porous media (University of Stellenbosch - Department of Applied Mathematics)

12

Conservation of aquatic ecosystems



As predicted, 1993 saw the stabilisation of research projects, with only 5 new projects being registered in this field. A subtle shift in emphasis also took place, however, with 2 of these 5 projects concentrating on aspects pertaining to estuarine management. Research on riverine systems nevertheless progressed very well.

The drought in the Eastern Transvaal had devastating effects on the environment of this region. It did, however, provide an opportunity to study the effects of decreasing flow in the Sabie River on the invertebrate and fish life in this river. Subsequent to the relatively good rains during the first quarter of 1993, another unique opportunity presented itself, i.e. studying the invertebrate and fish life in the same river during the recovery phase following the rains. In order to incorporate the recovery phase data into the project reports, it was necessary to extend the duration of these projects.

The Co-ordinating Committee for Water Ecosystems Research met once during the year. The Masterplan/ Guideline for water ecosystems, drawn up in late 1992, was formally accepted by the WRC. Steps were also set in motion to review and update the document *Limnological Criteria for the Management of Water Quality in the Southern Hemisphere* (edited by Hart and Allanson).

Research within the multidisciplinary Kruger National Park Rivers Research Programme received a boost during the year with the appointment, for an initial 1-year period, of Prof C Breen (Institute of Natural Resources - Natal University) as managing director of the Programme. The main task of the director is to consolidate research effort by means of appropriate decision support systems. The systems are currently being developed and a number of workshops were convened in order to assist in this task. These systems should be functional early in 1994.

In this field the WRC supported 23 projects during 1993, of which 5 commenced and 2 were completed.

Completed projects

Assessment of the instream flow requirements of rivers *(No 295) Freshwater Research Unit, University of Cape Town*

The aim of this research was to establish acceptable methods for assessing the instream flow requirements of South African rivers. Efforts would be focused on the understanding of a sophisticated North American methodology, namely instream flow incremental methodology (IFIM).

The baseline result of the research was that the use of IFIM is very suitable for the determination of the instream flow requirements of South African rivers. The methodology is, however, very data-intensive, specifically as regards biological interactions. Such data are scarce in South Africa.

The research team was nevertheless able to formulate guidelines, in conjunction with Australian scientists, for the implementation of simplified methodologies that are less data-intensive and therefore more suited than IFIM to South African data sets.

Due to the nature of IFIM, the project team was able, to a large extent, to promote communication and collaboration between engineers and ecologists.

Cost: R453 000

Term: 1990-1993

Contribution to the estuaries research programme *(No 412)*

Institute of Natural Resources, University of Natal

This study is funded within a special programme of the FRD and is a joint venture between the FRD, the WRC, the Department of Environment Affairs, Portnet and the Natal Provincial Administration. It was shown that freshwater-starved estuarine systems had a negative effect on the zooplankton community. In severe cases of freshwater deprivation species disappearance and consequent community changes took place.

Studies of the estuarine-marine larval exchange patterns for vertebrates and invertebrates have been used as a guide to management of estuaries. Although a common picture is emerging in this regard, substantially more data are required before recommendations can be made.

The WRC has extended its involvement in this programme in the form of a new 3-year project, namely project No 525 (see details below).

Cost: R50 000

Term: 1992

The ideal water ecosystem which is the ultimate objective

New projects

Environmental status of the Orange River mouth as reflected by the fish community

(No 505) Department of Zoology and Entomology, University of the OFS

Water resource development within the Orange River system has already had an effect on the flow of the river at its mouth. The Lesotho Highlands Water Scheme will exacerbate this situation. Due to the fact that the Orange River mouth and estuary are internationally recognised as important sites for both fish spawning and bird breeding it is necessary to critically assess the effect of this further water-resource development on the conservation status of the estuary. The major research aim of this 2-year project is thus to provide a description of the present state of the river mouth as indicated by the fish community. Proposed environmental management requirements will be prepared and further research needs quantified.

Natural and unnatural factors regulating the structure and functioning of estuarine systems *(No 525) Institute for Natural Resources, University of Natal*

This 3-year extension of project No 412 will concentrate on the impact of disturbances in river flow patterns and flooding frequencies on the natural spatial and temporal scales of change within estuarine systems. The results of the study will assist in the formulation of plans and strategies for remedial action in the case of such disturbances. This study is funded within a special programme of the FRD and is a joint venture between the FRD, the WRC, the Department of Environment Affairs, Portnet and the Natal Provincial Administration.

Standard laboratory organisms for water quality studies *(No 545)*

Institute of Water Research, Rhodes University

The receiving water quality objectives approach now adopted by the Department of Water Affairs and Forestry requires that there be a method for assessing the ability of the receiving rivers to absorb the effluent. Existing organisms for bioassaying are all from standing water, while the requirement for South Africa is riverine organisms. During the course of this 3-year project the researchers aim to identify suitable riverine organisms for use in laboratory studies, to develop techniques for maintaining populations of these organisms in the laboratory and to establish protocols for the use of these organisms for bioassaying.

Effects of different magnitude flows on South African riverine ecosystems *(No 576)*

Freshwater Research Unit, University of Cape Town

The continued population increase is leading to rapid development of the country's remaining unexploited water resources. At the same time, there is a growing awareness of, and concern for, the welfare of our natural environment as a sustainable resource. Planners and water managers are increasingly seeking guidance on how to develop water resources with minimum impact on aquatic ecosystems. In the planning of new water resource developments - almost all of which involve rivers in some form - a new important question now routinely asked by the planners and developers concerns the quantity of water needed by the river itself for ecosystem maintenance.

The overall aim of this 3-year project is thus to increase our ability to advise water resource managers/ developers as regards instream requirements of rivers by:

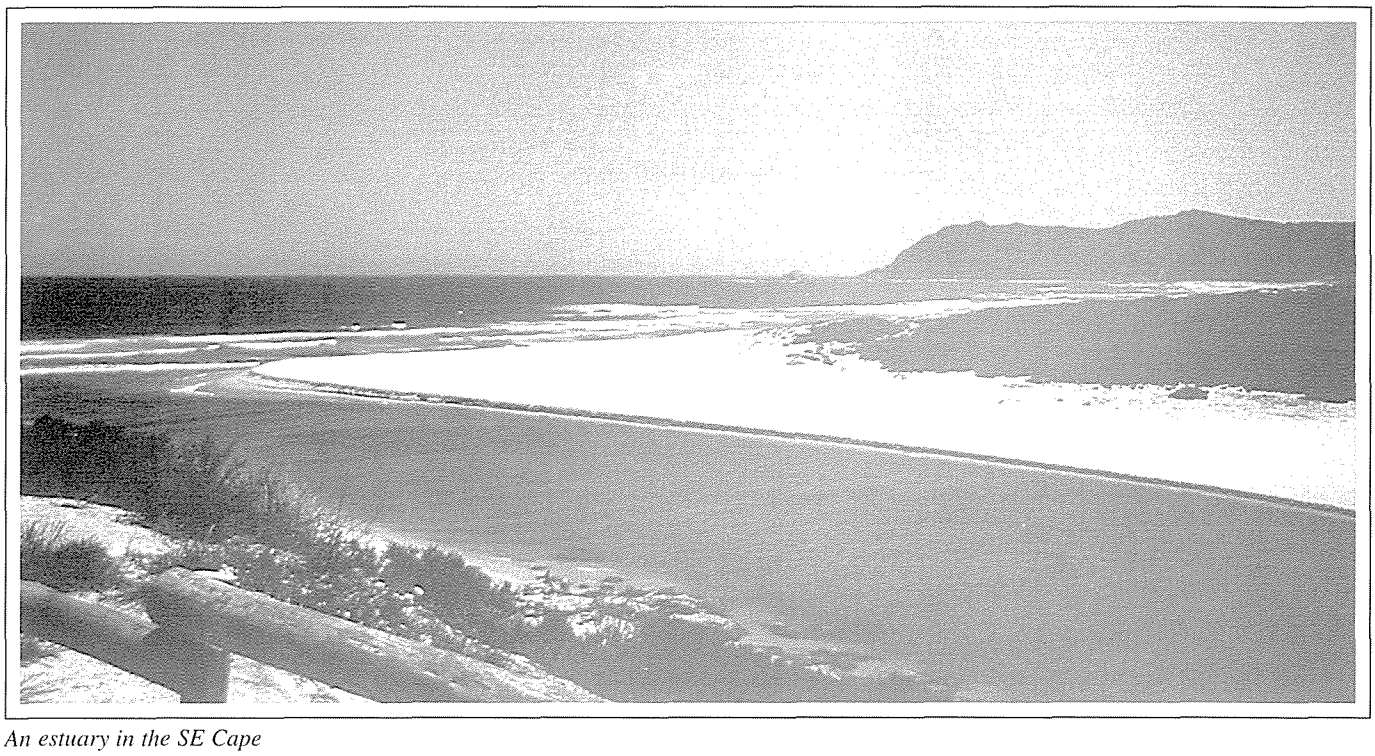
- Increasing the understanding of the effects of different magnitudes of flow on riverine biotas, through focused research on South African rivers
- Continuing the development of scientifically acceptable methodologies for assessing the water quantity requirements of rivers.

Decision support system for the integrated management and conservation of estuaries

(No 577) Institute of Natural Resources, University of Natal

Estuarine systems are favoured sites for development, recreation and conservation. The extent to which they can contribute to these is significantly affected by processes (e.g. development, erosion and water abstraction) occurring in the catchments. Wise use of estuarine systems thus requires that trade-offs between various options for use are made in an objective manner and with the best information available.

The major aim of the 3-year research project is thus to produce decision support systems for the integrated management and conservation of estuaries, based on sound scientific and socio-economic principles. To achieve this aim it will also be a prerequisite that maximum co-ordination of estuarine research in South Africa be attained.



An estuary in the SE Cape

Research projects

Completed

- **295** Assessment of the instream flow requirements of rivers (University of Cape Town - Freshwater Research Unit)
- **412** Contribution to the estuaries research programme (University of Natal - Institute for Natural Resources)

Current projects

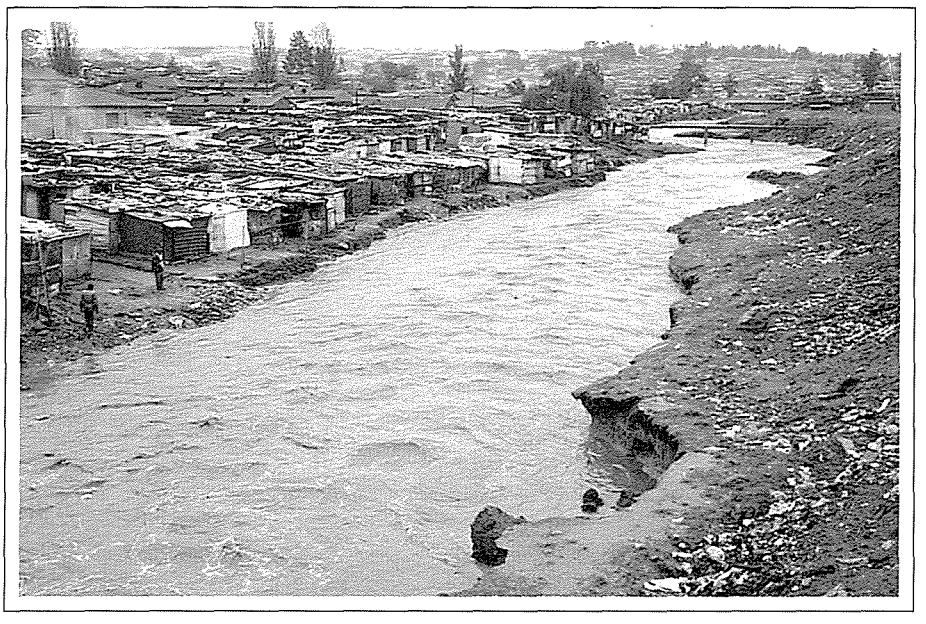
- **292** Freshwater requirements of estuarine plants (University of Port Elizabeth - Department of Botany)
- **294** Pre-impoundment study of the Sabie-Sand River system, Eastern Transvaal, with special reference to predicted impacts on the Kruger National Park (University of Cape Town - Freshwater Research Unit, and Rhodes University - Institute of Freshwater Studies)
- **350** Effect of pollution on the physiology of fishes in the Olifants River (E.Tvl.) (Rand Afrikaans University - Department of Zoology)
- **351** Effect of water quality variables on riverine biota (University of Cape Town - Department of Zoology)
- **376** Geomorphological response to changing flow regimes of the Sabie and Letaba River system (University of the Witwatersrand - Department of Botany)
- **406** Structural analysis of the water apportionment mechanisms in the Water Act 54/1956, in view of the requirements of competing user sectors (Advocate M Uys)
- **418** Catchment and land use: effects on water quality and estuaries (University of Fort Hare - Department of Zoology)
- **422** Rapid biological assessment of water quality impacts in streams and rivers (CSIR - Division of Water Technology)
- **426** Preliminary investigation of algal weeds in South African inland waters (University of Cape Town - Department of Botany)
- **428** Overview of the pesticide and heavy metal levels present in populations of the larger indigenous fish species of selected South African rivers (CSIR - Division of Water Technology)
- **463** Diversity and productivity of biotic communities in relation to fresh-water inputs in Eastern Cape estuaries (University of Port Elizabeth - Department of Zoology)
- **474** Developing an integrated approach to predicting the water use of riparian vegetation (University of the Witwatersrand - Department of Botany)
- **475** Development of a recirculating experimental stream system (Rhodes University - Institute for Water Research)
- **497** Geomorphological classification system for South African river systems (Rhodes University - Department of Geography)
- **501** Continuing research into the wetlands of Natal/KwaZulu (University of Natal - Institute of Natural Resources)
- **503** Effect of soil utilisation on water quality of the Gamtoos estuary (University of Port Elizabeth - Department of Oceanography)

New

- **505** Environmental status of the Orange River mouth as reflected by the fish community (University of the Orange Free State - Department of Zoology and Entomology)
- **525** Natural and unnatural factors regulating the structure and functioning of estuarine systems (University of Natal - Institute of Natural Resources)
- **545** Standard laboratory organisms for water quality studies (Rhodes University - Institute for Water Research)
- **576** Effects of different magnitude flows on riverine ecosystems (University of Cape Town - Freshwater Research Unit)
- **577** Decision support system for the integrated management and conservation of estuaries (University of Natal - Institute of Natural Resources)

13

Developing communities



Indications are that the rate of urbanisation is showing signs of decreasing. This has given the institutions providing water and sanitation facilities a brief respite and in some areas inroads are being made into the backlog, which, nevertheless, still remains enormous. It is, however, not just the provision of water and sanitation that matters; the manner in which the services are provided will have an impact on jobs and community organisation.

The current situation regarding access to water and sanitation services in the urban areas of South Africa based on work done for the WRC over the period 1991 to 1992 has been updated, and includes densely populated settlements which are not proclaimed urban areas and are generally located on the fringe of metropolitan areas.

Access to water supply

The service level of water supplied to people living in the urban areas of South Africa is given as follows:

House connection	59%
Yard taps	9%
Adequate standpipes	15%
Rudimentary standpipes	5%
Other (borehole, wells and river)	12%

The results of the survey indicate that approximately 18% of the people living in the urban areas of South Africa are without adequate access to a potable water supply.

A major portion, i.e. 66%, of the people without adequate water, are living in the metropolitan areas. Almost all are living in informal settlements and the lack of an adequate water supply is directly related to the backlog in housing/services provision in these areas.

About 5,7% of the people living in towns do not have an adequate water supply. The populations in many of the smaller towns are relatively stable and service provision is generally adequate, although an influx of people from rural areas as a result of the drought has been reported in some areas.

Of the people living in densely populated settlements, at least 20% are living without adequate water supplies. These dense settlements are widely dispersed geographically, including the TBVC and self-governing territories. Institutional capacity in these areas is universally weak and is a key factor, along with the lack of local resources, limiting the provision of adequate services.

Access to sanitation

Research results have revealed that 31% of the people living in urban areas in South Africa, do not have access to adequate sanitation. This figure is based on the number of people who only have access to buckets or unimproved pits, or who have no sanitation facilities at all.

Systems in operation are:

Water-borne	64%
Ventilated improved pit latrines (VIP)	1,4%
Septic tanks	2%
Other	1,6%
Pit latrines	21%
Buckets	8%
None at all	2%

The distribution of numbers between the VIP and the unimproved pit latrine, indicates a lack of awareness of the important differences between them and highlights the need for this to be addressed.

In many instances bucket collection systems were initially installed as an interim measure until funds could be secured for a full water-borne sanitation system, but have now become a seemingly permanent feature of the urban landscape in many parts of the country. While smaller bucket systems were reported to operate fairly satisfactorily, serious problems were experienced with large systems. From a health point of view bucket systems are not acceptable irrespective of the problems experienced with the administration of the system. Evidence was found of increasing opposition to bucket systems.

The current situation as reflected in the preceding paragraphs, together with the investment requirement and the recurrent cost implications to meet the needs of the South Africans involved, as well as the difficulties experienced by both community users and institutions, clearly indicate the extent of research needs in this regard. These are to become the subject matter of future WRC research projects in this work field.

During 1993 the WRC supported 22 projects directly related to developing communities (up from 9 in 1992), of which 4 ended during the year and 12 commenced.

Standing Committee on Water Supply and Sanitation (SCOWSAS)

SCOWSAS, established to address the inability of the existing water and sanitation sectors to meet the needs of all South Africans, was initiated by a group of professionals who were drawn from all quarters of South African society. The WRC played a significant role in the establishment of SCOWSAS, and is still contributing to its activities.

It is the intention of SCOWSAS to develop credible policy options designed to ensure that all South Africans have access to adequate and acceptable water supply and sanitation facilities. It is, therefore, very conscious of the need to be solution-orientated. The efforts of SCOWSAS are consequently concentrated in 3 priority areas:

- Education, training and affirmative actions in this sector
- Considering institutions that would best meet the needs of the country
- Determining levels of service, financial arrangements and tariff systems that would permit viable services to be sustained.

To achieve these aims, a number of subcommittees have been established covering *inter alia* the following topics:

- Institutional framework
- Pricing, finance, standards and technology choice
- Research needs and priorities: This subcommittee is the responsibility of the WRC. During 1993 SCOWSAS again made an input in the prioritisation of the research proposals received by the WRC in this field.

Co-ordinating Committee for Research on Water and Sanitation in Developing Rural and Urban Communities (CCRUC)

As one of its main strategies for research co-ordination, the WRC is following a policy of establishing and operating research co-ordinating committees for specific problem areas. Up till now the various problems associated with water supply, sanitation and pollution control in developing communities have been addressed by 4 separate research co-ordinating committees.

The WRC, recognising that the water supply, sanitation and pollution control research requirements of developing rural and urban communities are unique, consequently decided to establish the CCRUC to specifically attend to the water and sanitation research needs of these communities. The composition of the CCRUC is currently under consideration.

The CCRUC will begin to function early in 1994 with the development of a prioritised research framework as its first objective.

Completed projects

Hydrological investigation of stormwater runoff from the Khayelitsha urban catchment in the False Bay area, South-Western Cape *(No 323) Division of Water Technology, CSIR*

Recognising the need for an in-depth geohydrological investigation of stormwater runoff from Third-World type catchments, the objective of the study was to assess the magnitude of the stormwater contamination, identify pollution sources and assess the resultant effect on the receiving water body.

The stormwater runoff originating in the Khayelitsha catchment was found to be polluted throughout the year and mainly of a microbiological nature with high concentrations of nutrients and organic loads.

The major source of pollution was the litter and faecal contaminants which abound throughout the catchment, ascribed to the high population density, poor living conditions and a general lack of environmental awareness. In addition on-going violence and periodic strikes adversely affect basic services and result in the accumulation of garbage, blocking of drains and services and the local dumping of bucket latrines. All forms of urbanisation involving shacks resulted in contamination of the water leaving the catchment. The magnitude of the contamination appears to depend more on the population density than on the degree of infrastructure provided.

Cost: R445 000

Term: 1991-1993

Forced aeration composting of sewage sludge for rural communities *(No 341) BE La Trobe*

Sewage disposal in less-developed areas is generally by means of the bucket system as there is no infrastructure for water-borne sewerage. The night-soil arising from the buckets is conventionally disposed of in lagoons which have to be situated some distance from the community. The practice is generally accompanied by bad odours and fly breeding. In turn, refuse is often disposed of by uncontrolled landfilling which impacts adversely on the environment.

Forced aeration co-composting of night-soil with unpulverised refuse as bulking and filtering agent proved to be a suitable cost-effective process for the integrated stabilisation, disinfection and resource recovery of these two polluting waste streams.

The project has demonstrated that the stabilisation of night-soil (raw sewage) using unsorted domestic refuse as a bulking agent, is economically feasible as a low-cost means of treating these obnoxious waste streams, on a comparatively large scale.

The process makes use of natural biological means to treat these waste streams. Such a plant can be maintained by unskilled workers.

Cost: R54 120

Term: 1990-1993

Technical, socio-economic and environmental evaluation of sanitation systems for developing urban areas in South Africa *(No 385) Palmer Development Group*

Diseases related to inadequate water supply and waste disposal are major contributory causes of infantile mortality and also account for a large proportion of adult morbidity.

Given this situation, it is clear that much needs to be done to effect improvements from a social, health and economic point of view.

This study provided an overview of the provision of sanitation facilities to developing urban communities through a review of the current situation regarding the provision of sanitation and an evaluation of the various types of sanitation systems currently in use.

A series of 6 workshops was held across the country and from the input obtained on these occasions, strategies for the improvement of sanitation were developed.

The work carried out in the study is reported in detail in 24 working papers.

Cost: R280 600

Term: 1991-1993

Nitrate removal from potable water *(No 403) Department of Chemical Engineering, University of Pretoria*

Nitrates ingested in concentrations exceeding 10 mg/*l* cause a variety of negative effects in humans and animals, viz. methemoglobinemia, cancer, retardation of the motor reflexes, hypertension and escalating aggression.

This 1-year project demonstrated that biological denitrification is a less expensive and simpler method than nitrate removal by ion exchange. For the treatment of raw water with a concentration of 60 mg NO_3-N/*l* and a design capacity of 10 m^3/d, the estimated total costs (capital plus running) are R1,83/m^3 and R1,50/m^3 for ion exchange and biological denitrification respectively. The total costs for a design capacity of 20 m^3/d are as follows: R1,11/m^3 and R0,95/m^3 for ion exchange and biological denitrification respectively. Biological denitrification, therefore, is a better choice than ion exchange in view of its simplicity of operation and the lower capital and running costs.

Cost: R33 483

Term: 1991-1992

New projects

Development of drought response policy options for the cost-effective provision of water supply to rural communities subject to recurring drought *(No 506) Division of Water Technology, CSIR*

From the history of the development of drought schemes in South Africa, and the scheme to evaluate drought intensity, it is apparent that the drought policy has mainly focused on assisting the commercially orientated livestock and crop (dryland or irrigated) farming communities. Thus, a substantial part of the population consisting of the poorer rural subsistence communities which are more vulnerable to drought, have been largely neglected. It is estimated that 10 million people live in these rural communities. Of these, 48% do not have access to adequate, safe drinking water and 70%, 41% and 2% have a problem with distance, quality and availability of drinking water respectively.

The aims of this 1-year research project are:

- To identify susceptible subsistence farming areas in South Africa
- Investigate alternative water supplies

- Investigate back-up and emergency systems
- Establish a rationing and pricing policy
- Compile policy options relevant to South African conditions.

Groundwater contamination as a result of Third-World type urbanisation *(No 514) Division of Water Technology, CSIR*

Aquifers underlying informal and semi-formal settlements act both as a source of cheap, readily available drinking water and as a repository for wastes emanating from the sanitation systems and waste disposal activities associated with these settlements. Although the contamination problem is considered to be significant, few data are available to support this hypothesis as present studies in South Africa have concentrated on surface water. Contamination of groundwater not only results in the transmission of water-borne diseases within the local community, but discharge of shallow groundwater into surface-water courses allows the spread of pollution to unsuspecting communities downstream.

This 30-month project aims to ascertain the magnitude of any possible groundwater contamination originating from Third-World type urban catchments in South Africa, thereby providing the scientific input necessary for such guidelines.

Development of programmes to combat diffuse sources of water pollution in residential areas of developing communities *(No 519) Afrosearch CC*

The more concentrated the source of pollution becomes, the greater the impact it has on the immediate environment. News media are very quick to focus on pollution disasters such as oil tankers and chemical spills, but lower-level pollution events are not so startling and are therefore, largely, ignored. However, the longer term effects of pollution originating from increasing urban developments can be as catastrophic as their more dramatic cousins. Community management members usually lack the basic knowledge and are, therefore, ill-equipped to manage community projects effectively. It would be beneficial for elected committee members to undergo management training, even before a project is initiated, to enable them to participate in the decision-making process from the outset. This inevitably leads to greater acceptance of a scheme in all its stages. Projects of this nature are a response to the world-wide recognition for the need for courses which are directed specifically towards the level of the village management committees.

The project will be executed over an 18-month period.

Guidelines on appropriate technologies for water supply and sanitation in developing communities *(No 520) Division of Water Technology, CSIR*

During the next decade the provision of housing and services to disadvantaged communities will be the primary focus. Conventional technologies will give rise to capital expenditure and on-going operation and maintenance costs beyond the capacity of the economy. Such an approach will also not lead to any significant progress in the development of human resources.

The WRC is totally committed to supporting and being actively involved in social development projects. This will promote the use of more appropriate technologies which will significantly reduce costs and result in improved human resources development and more sustainable systems in the longer term.

A number of guidelines will be prepared during the project as well as a simplified "training package" on each topic, for use in the training of community level operators and managers.

The project will be executed over a 3-year period.

Community participation in erosion control

Water scheme cost recovery

(No 521) Umgeni Water

The primary aim of this study is to determine the acceptability and applicability of different cost recovery techniques for water supplies to informal urban communities. The need for this work was prompted by poor cost recovery for water supplies in developing areas, which is one of the major stumbling blocks to the longer term sustainability of these systems. It also limits the capacity of organisations to increase service coverage as all of their income goes towards subsidising the non-payment of water.

It is also realised that the use of technology without the correct community approach, has little chance of success. Hence an important consideration of this project will be to establish which approaches for community participation with respect to cost recovery are likely to ensure optimum success with each particular system.

The project will be executed over a 2-year period.

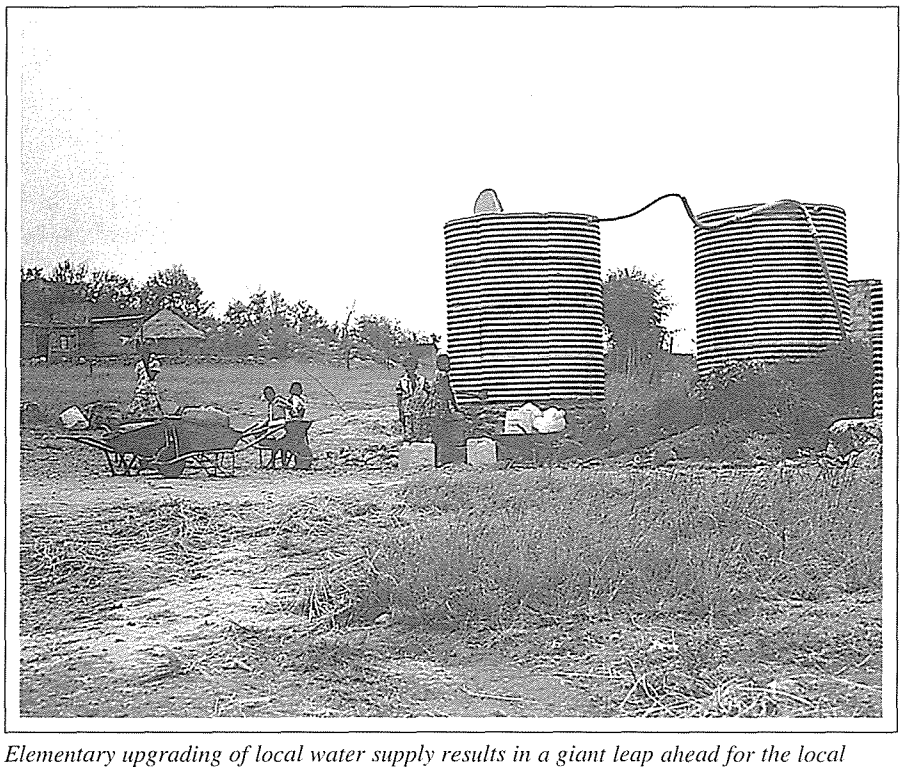
Dynamic cross-flow sand filter for rural water treatment

(No 539) Division of Water Technology, CSIR

Water clarification is an important step in the production of potable water. Although the technologies of flocculation and sedimentation are well understood, the control thereof could prove beyond the capabilities of unskilled operators if these were to be implemented in rural areas.

The dynamic cross-flow sand filter is a more appropriate technology for rural application. It functions like a slow sand filter but being self-cleaning requires little attention. Auto-cleaning is effected by causing a major portion of the raw water to flow across the sand bed to remove excess deposits.

The 2-year project aims to produce a technical guide for the design and operation of the dynamic cross-flow sand filter under South African conditions.



Elementary upgrading of local water supply results in a giant leap ahead for the local community

Determination of sludge build-up rates in septic tanks, biological digesters and pit latrines in South Africa *(No 544) Division of Building Technology, CSIR*

The necessity for providing sanitation to South Africa's burgeoning population has meant that systems other than water-borne sanitation have had to be used. A number of on-site sanitation options are available, and a part of the overall cost of the system is its maintenance, especially emptying digesters that have filled with sludge. The aim of this 3-year project is to identify and quantify factors affecting sludge build-up in selected systems, to determine the build-up rates in a representative sample of these systems and to develop methods for predicting build-up rates of sludge within the systems under investigation.

Water and sanitation in urban areas: Survey of on-site conditions *(No 561) Palmer Development Group*

The social conditions under which poorer people live in urban areas has a major impact on access to water and sanitation services and hence on stormwater runoff quality. This is particularly the case in areas where densities are high and the infrastructure is over-extended, resulting in a high proportion of people in these areas living in "backyard shacks". While inadequate provision of serviced land for poor people is a feature of our economy, the number of backyard shack dwellers is likely to increase. Indications are that there are many people living under these conditions whose access to sanitation, and to a lesser extent water supply, is denied. This forces them into a situation where their options are limited resulting in health risks and high organic and pathogen loads in stormwater runoff. The 1-year study will evaluate conditions affecting water and sanitation on individual sites in developing urban areas, particularly where there are multiple dwellings on the site. Such

multiple dwellings would typically comprise a formal house and one or more informal "backyard shacks".

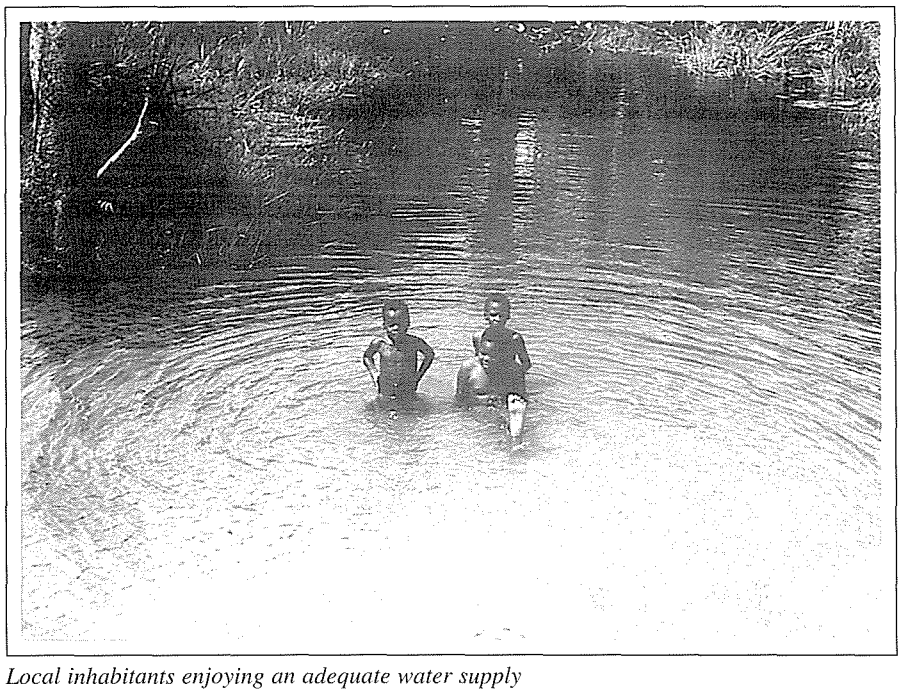
Effect of water supply, handling and usage on water quality in relation to human health indices in developing communities *(No 562) Division of Water Technology, CSIR*

The rapid urbanisation occurring in South Africa at the moment has resulted in some peri-urban communities with limited provision of water and sanitation. Under these conditions, an increase in disease, particularly water-borne, may be expected. World-wide, water-borne diseases cause very high mortality amongst people living under these conditions. The aims of this project are to examine patterns of water usage, to monitor changes in water quality from the time of collection to the time of usage for various usage patterns and to correlate water quality with health indices of the population. The project will be executed over a 4-year period.

SANPLAT - A simplified latrine system for rural and squatter areas *(No 563) Division of Water Technology, CSIR*

"Some for All, Rather than More for Some". This was the message which came out of the New Delhi Global Consultation on Safe Water and Sanitation for the 1990s, organised by UNDP. The rationale behind this statement was the need for a substantial reduction of costs of services through increased efficiency in the designs and use of low-cost appropriate technologies.

This concept is also very relevant to the South African situation where as many as 18 million people do not have access to adequate sanitation. Of these, some 7 million are located in rural or low density communities where SANPLAT is particularly suitable and at a cost of 10 to 20% of a VIP latrine. Squatter camps are another ideal application where these latrines can serve as an interim service pending more permanent tenure and upgraded services. This 1-year project will identify the features which such a system should have in order to be acceptable to local communities.



Local inhabitants enjoying an adequate water supply

Water and sanitation in urban areas: Financial and institutional review *(No 571) Palmer Development Group*

International experience teaches that sound financial policy and well-structured institutions play a crucial role in the provision of water and sanitation services. In South Africa, where there is a serious under-provision of these services, improvements in financial efficiency and institutional effectiveness are therefore particularly important. Proper organisational arrangements are also important in minimising the environmental effects associated with human settlements.

With the current transition, where political and social restructuring is taking place at national, regional and local level, the provision of water and sanitation services will be substantially affected by these changes and it is vital that policy development takes this into consideration.

This 18-month project is oriented towards research to provide background information for the development of new policy and organisational arrangements.

Development of a decision support system for the selection of the most appropriate sanitation option for developing communities *(No 586) Umgeni Water*

The provision of safe and adequate water and sanitation to developing areas has become an urgent priority in South Africa. The selection of inadequate or inappropriate sanitation systems may endanger the health of the community and fail to uplift their quality of life. Current decision-making procedures for the selection of sanitation systems are largely cost-driven with little consideration being given, for instance, to existing and future surface and groundwater quality scenarios.

Extensive evidence already gathered, indicates that the sewerage reticulation systems in many of the densely populated townships of coastal Natal result in the discharge of massive volumes of untreated sewage into the local watercourses. At the

other end of the sanitation spectrum, the installation of pit latrines into hydrogeologically unsuitable areas and the misuse of pit latrines, has resulted in the deterioration of surface and groundwater quality.

The diversity of factors affecting the selection of a sanitation system underlines the need for the development of a formalised multidisciplinary decision support system which will enable the most appropriate sanitation option to be selected on a practical environmental, sociological and cost-effective basis, removing much of the subjectivity from the current selection process.

The project will run for 3 years.

Research projects

Completed

- **323** Hydrological investigation of storm-water runoff from the Khayelitsha urban catchment in the False Bay area, South-Western Cape (CSIR - Division of Water Technology)
- **341** Forced aeration composting of sewage sludge for rural communities (BE La Trobe)
- **385** Technical, socio-economic and environmental evaluation of sanitation systems for developing urban areas in South Africa (University of Cape Town - Department of Civil Engineering and the Palmer Development Group)
- **403** Nitrate removal from potable water (University of Pretoria - Department of Chemical Engineering)

Current

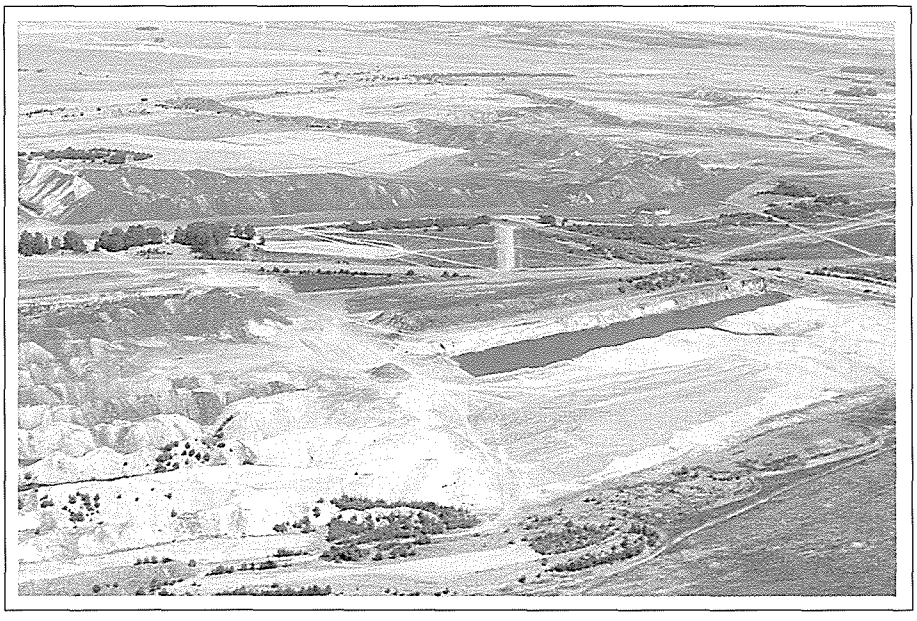
- **346** Study of the relationship between hydrological processes and water quality characteristics in the developing Zululand coastal region (University of Zululand - Department of Hydrology)
- **384** Water resources and sanitation systems source book with special reference to Natal/KwaZulu (Natal University - Department of Economics)
- **386** Development of a cross-flow microfilter for rural water supply (Umgeni Water and the University of Natal - Department of Chemical Engineering)
- **435** Development of a training programme on community water supply management for village water committees (CSIR - Division of Water Technology)
- **480** *Per capita* water demand in developing communities (Water Systems Management)

New

- **506** Development of drought response policy options for the cost-effective provision of water supply to rural communities subject to recurring drought (CSIR - Division of Water Technology)
- **514** Groundwater contamination as a result of Third-World type urbanisation (CSIR - Division of Water Technology)
- **519** Development of programmes to combat diffuse sources of water pollution in residential areas of developing communities (Afrosearch CC)
- **520** Guidelines on appropriate technologies for water supply and sanitation in developing communities (CSIR - Division of Water Technology)
- **521** Water scheme cost recovery (Umgeni Water)
- **539** Dynamic cross-flow sand filter for rural water treatment (CSIR - Division of Water Technology)
- **544** Determination of sludge build-up rates in septic tanks, biological digesters and pit latrines in South Africa (CSIR - Division of Building Technology)
- **561** Water and sanitation in urban areas : Survey of on-site conditions (Palmer Development Group)
- **562** Effect of water supply, handling and usage on water quality in relation to health indices in developing communities (CSIR - Division of Water Technology)
- **563** SANPLAT - a simplified latrine system for rural and squatter areas (CSIR - Division of Water Technology)
- **571** Water and sanitation in urban areas : Financial and institutional review (Palmer Development Group)
- **586** Development of a decision support system for the selection of the most appropriate sanitation option for developing communities (Umgeni Water)

14

Mine water



The South African mining industry is made up of a large number of independent mines covering a vast geographical area. Mine-water management developments over the last decade have focused mainly on the gold mining industry which, as a result, presently recirculates in excess of 80% of its water. Due to factors such as large inflows of poor quality fissure water and the generation of sulphuric acid through pyrite oxidation, it is estimated that the gold mining industry collectively still discharges a total salt load of 359 000 t/a to the surface- and groundwater environment (Pulles, W (1992) Water pollution: Its management and control in the South African gold mining industry. *J. Mine Vent. Soc. S. Afr.*, February 18-36).

The South African mining industry, particularly the coal mining industry, has recently become the focus of attention of the Department of Water Affairs and Forestry (DWA and F). This is evidenced by the development of a Water Quality Management Strategy for the Mining Industry by the DWA and F and the undertaking of detailed catchment studies and research programmes on the environmental impacts of mining, particularly in those areas where coal mining activities occur.

To assist the mining industry in its efforts to comply with the regulatory stipulations of the DWA and F, the WRC has increased its funding of mining related water research projects.

During the year under review 10 mine-water research projects were funded, of which 6 were new and 4 current.

Survey of current water management and treatment practices in the South African gold and coal mining industries *(No 527) Chamber of Mines of South Africa*

The South African mining industry covers a vast geographical area and consequently individual mines experience different water management problems. The mines have, therefore, developed and applied different strategies to reduce fresh-water intake and to treat the water for reuse or discharge.

In an endeavour to effect technology transfer the 2-year research project aims to:

- Prepare a comprehensive document setting out the current "state of the art" with regard to water management and treatment in the mining industry, which can be used as a practical tool by water management practitioners in the mining industry and which can serve to identify the best available technology not entailing excessive cost (BATNEEC)
- Identify knowledge gaps with regard to mine-water treatment and management as a guide to future research projects.

Development of an integrated and generic water quality simulation model for open-cast coal mining water circuits

(No 528) Wates, Meiring and Barnard Inc.

Due to its inherent economic advantages, the technology of open-cast coal mining has found significant application in South Africa. However, these mining operations cause substantial disturbance of the natural hydrological cycle in the mining area. To control such disturbances the DWA and F allocates allowable pollutant waste loads to specific catchments and it will be the task of col-

liery management to develop and implement a water system in compliance with the allocated waste load.

To assist colliery management in this regard, the 18-month project aims to develop a generic model which can be applied to any open-cast mining environment, and which can simulate and predict the effluent flow and pollution waste load emanating from a colliery complex under different hydrological conditions.

Prediction of pollution loads from coarse sulphide containing rock materials *(No 559) SRK (CE) Inc.*

Acidic saline leachate from coarse materials in mine dumps is termed acid rock drainage (ARD) and is perhaps the most significant contributor to pollution of South Africa's water resources.

A predictive mathematical model is needed not only to provide a quantitative estimation of waste quality issuing from a proposed or existing waste rock dump, but also to enable mine management to evaluate options (blending, stacking) for waste rock disposal and dump composition.

In addition to the development of the required model the 3-year project also aims to evaluate:

- Kinetic laboratory test methods which determine the propensity of coarse discards to develop ARD
- The practicability of inundation of acid-generating materials as a control technology under local conditions.

Preliminary assessment and review of the need for integrated passive water treatment systems for mine effluent streams *(No 570) Division for Mining Technology, CSIR*

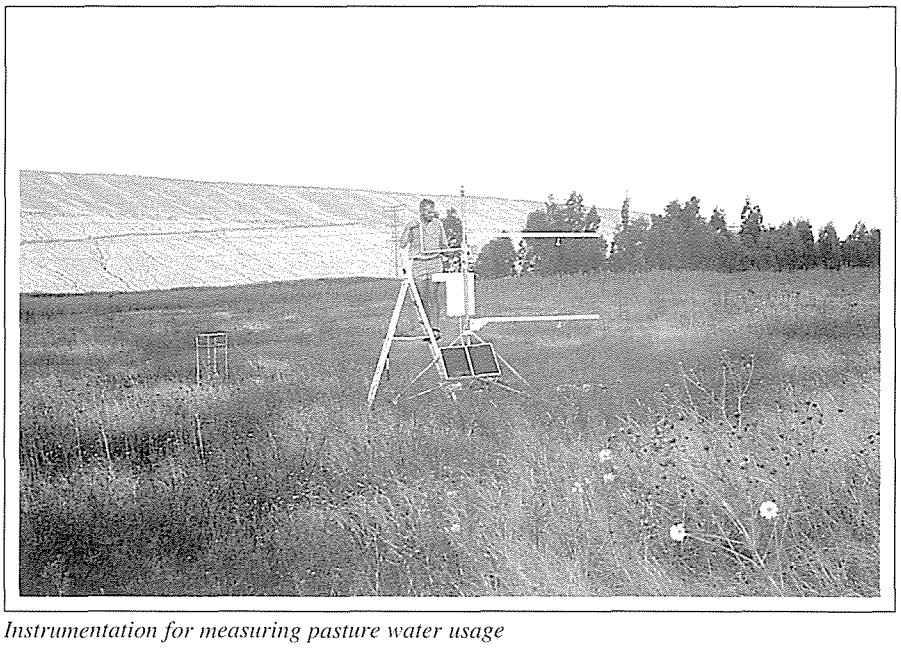
Effluent streams from mining operations have long been recognised as major contributors to the pollution load entering watercourses and eventually the water resources of the country. The principles and procedures of integrated environmental management have been accepted as a requirement by the mining industry.

The biggest problems occur when a mine closes and the effluent streams continue to flow, uncontrolled and untreated.

The 2-year project is looking at the magnitude of the problem in terms of the number of mines affected and the extent to which treatment of the high concentration effluents will benefit the country.

Calibration of models for the design of covers for open-cast mine and waste dump rehabilitation *(No 575) Wates, Meiring and Barnard Inc.*

Acid drainage, a major cause of water quality degradation in many coal mining areas, can fortunately be restricted by means of suitable covers to limit water percolation through the underlying acid generating strata. The 3-year project aims at establishing reliable design procedures for such finishing covers to enable acceptable rehabilitation of open-cast mines and waste dumps. A field-scale experimental site, established by DWA and F in Northern Natal, will be used to measure the water balance components and the collected data will be used to test and calibrate existing cover design computer models.



Instrumentation for measuring pasture water usage

Screening of crop, pasture and wetland species for tolerance of polluted water originating in coal mines *(No 582) Department of Plant and Soil Science, University of Pretoria*

Despite remedial actions, water which is toxic to most plant species will always emanate from mining sites. If a species, capable of surviving exposure to such waters, could be found it would enable both the utilisation of such waters and the upgrading of its quality in wetlands. Not only is there a world-wide dearth of information on suitable plant species, but information pertaining to local problem waters, climatic and soil conditions is practically non-existent. The 4-year project, therefore, aims to establish a facility for identifying plant species suitable for irrigation with problem waters or for use in wetlands to improve the quality of the water.

Experimental site in Northern Natal that will be used to calibrate models for the design of mine dump covers

Research projects

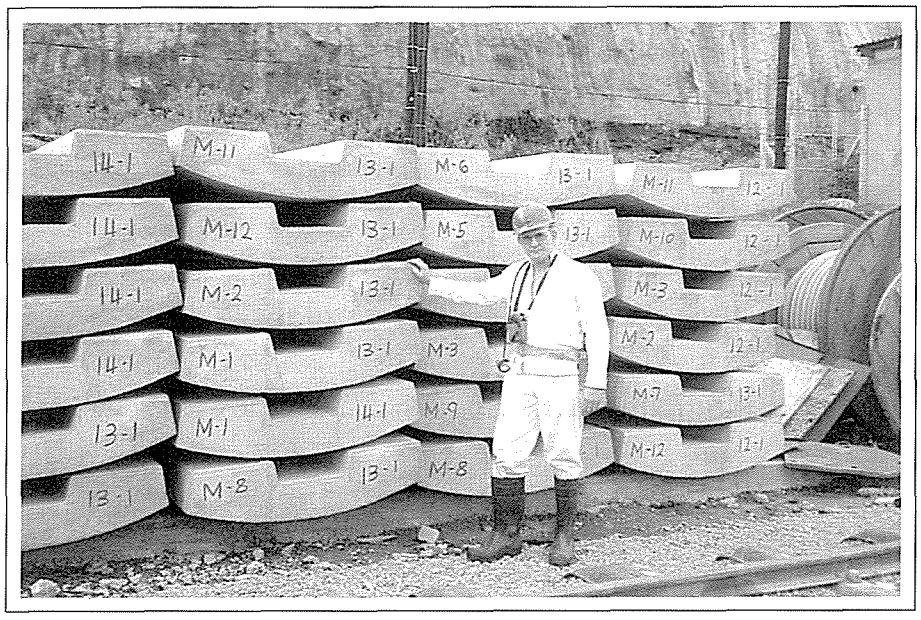
Current

- **413** Use of vegetation in the amelioration of the impact of mining on water quality - An assessment of species and water use (CSIR - Division of Forest Science and Technology)
- **454** Occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps (University of Stellenbosch - Department of Microbiology)
- **471** Optimisation of mine service water disinfection (University of Pretoria - Department of Chemical and Environmental Engineering, Division of Water Utilisation)
- **477** Guidelines and procedures to assess and ameliorate the impact of gold mining operations on the water environment (CSIR - Division of Mining Technology)

New

- **527** Survey of current water management and treatment practices in the South African gold and coal mining industries (Chamber of Mines of South Africa)
- **528** Development of an integrated and generic water quality simulation model for open-cast coal mining water circuits (Wates, Meiring and Barnard Inc.)
- **559** Prediction of pollution loads from coarse sulphide containing rock materials (SRK (CE) Inc.)
- **570** Preliminary assessment and review of integrated passive water treatment systems for mine effluent streams (CSIR - Division for Mining Technology)
- **575** Calibration of models for the design of covers for open-cast mine and waste dump rehabilitation (Wates, Meiring and Barnard Inc.)
- **582** Screening of crop, pasture and wetland species for tolerance of polluted water originating in coal mines (Universiteit van Pretoria - Department of Plant and Soil Science)

General



The concrete invert liners used in the floor of the tunnel and laid by the tunnel boring machine (TBM) (Photograph taken at the Inanda-Wiggins Tunnel near Durban)

Since 1990 the WRC has also been involved in financing research projects concentrating on certain geological aspects of dam construction. This involvement is justified by the fact that the current projects, either directly or indirectly, lead to lower construction costs which in turn result in the stored water being available to users at a reduced price.

In addition to the construction cost facet, the current projects also contribute to dam safety which, seen in the light of the comprehensive dam safety programme launched by the Department of Water Affairs and Forestry in 1989, constitutes another reason for the WRC's financial support.

During the year under review, the WRC funded 4 research projects relating to the geological aspects of construction, of which one project which commenced in 1993 differs from the current projects in that it concentrates on the hydraulic roughness of tunnels cut by machine.

New project

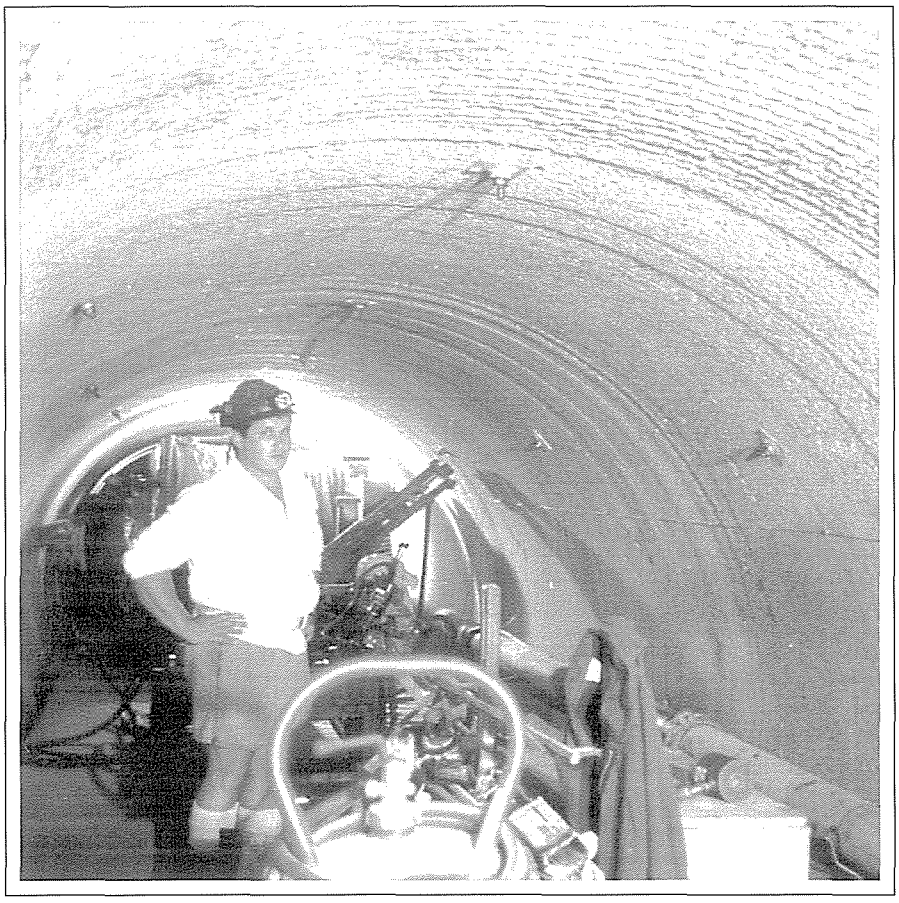
Hydraulic roughness of tunnels bored by machine through various rock-types *(No 579)*

Department of Civil Engineering, University of Natal

Very litle information is currently available on the roughness of the walls of tunnels cut by means of a tunnel boring machine (TBM) in different types of rock. Consequently the accuracy of hydraulic calculations is impaired. A change of 1% in the friction factor, e.g., will also cause a 1% change in head loss for a tunnel of given length and diameter. For the present it is unlikely that the friction factors used are within 5% to 10% (depending on the type of rock) of the actual values, with the accompanying effect on head losses.

Five tunnels of varying lengths are currently being bored in South Africa. Their diameters range between 3 m and 5,5 m, and the type of rock through which they are being cut, varies from soft sandstone to basalt and granite. This state of affairs presents the ideal opportunity to take actual roughness measurements of the newly bored tunnel walls. Upon commissioning of the tunnels at a later stage the effective friction factors will be calculated and correlated with the roughness measurements of the dry tunnels. Through this, information will be generated which will improve the accuracy of hydraulic design of tunnels.

The project will be carried out over a period of 4 years.



Tunnel cut by machine through granite showing smooth texture after initial ripple following replacement of TBM heads (Photograph taken at the Inanda-Wiggins Tunnel near Durban)

Research projects

Current

- **302** Erodibility of different rock formations under varying flow conditions (University of Pretoria - Department of Geology)
- **433** Engineering properties of important Southern African rock types with special reference to the shearing strength of concrete dam wall foundations (Technicon Pretoria - School for Civil Engineering)
- **502** Plunge pool scour reproduction in hydraulic models (CSIR - Division for Earth, Marine and Atmospheric Science and Technology)

New

- **579** Hydraulic roughness of tunnels bored by machine through various rock-types (University of Natal - Department of Civil Engineering)

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Research support services

South African Water Information Centre

The WRC, as part of its commitment to technology transfer, established the South African Water Information Centre (SAWIC) in 1974 to provide bibliographic information on water and act as a comprehensive referral centre for water-related enquiries.

One of the major undertakings of the Centre is the building and management of the WATERLIT data base. WATERLIT now contains more than 210 000 records and is growing at the rate of more than 1 000 references per month. In excess of 700 local and international journals are currently scanned for relevant information each month and conference proceedings and reports are also indexed.

During the past year SAWIC staff carried out 494 searches on behalf of users. In addition, 26 subscriptions to the WATERLIT CD-ROM were purchased. If each of these were used only 40 times this would amount to more than 1 000 additional searches. No figures are at present available on the number of searches carried out by users with direct access to the data base, but 188 users are currently making use of the monthly current awareness service.

With the current contract term drawing to a close it was deemed appropriate to review the activities and services currently offered by SAWIC. Feedback from users and potential users was obtained by means of a widely distributed questionnaire. The results of this questionnaire, together with the content of presentations on relevant topics, by invited speakers, were debated at a workshop held during June. The main conclusion reached was that SAWIC is essential to the South African water community and that the contract should be extended for a further 3 years.

A good deal of attention was paid to the future use of new computer technology for information services. Over the past 3 years the demand for computerised services has grown considerably and requests are increasingly being received for access to information sources directly from personal computers. A large number of users are now making use of the InfoAccess and Worldnet Gateway services available from CSIR Information Services to carry out their own literature searches of WATERLIT and other data bases.

The CD-ROM version of WATERLIT is being marketed locally and internationally and has proved particularly popular with universities and research groups.

Other matters discussed at the workshop, which will be followed up in the next year, included the possibility of adding abstracts to the WATERLIT references, the electronic delivery of references, a review of the pricing policy, development of relationships with other organisations in the fields of water and information science and developing new services based on new computer technology.

The Data Base of Research Projects in Water-Related Fields is now being managed and maintained by SAWIC. The data base is available on-line through the Computing Centre for Water Research and it is planned to make it available on the Internet. It is envisaged that all researchers will register their water-related projects on the data base so that it can act as a valuable source of contacts and information for all researchers and funding organisations.

Although computerised systems are increasing in importance, SAWIC staff are always available to assist with queries and referral to specialists.

Computing Centre for Water Research

During the mid-1980s the WRC and ISM took the strategic initiative to enhance communication and hence co-operation between water researchers in South Africa by founding the Computing Centre for Water Research (CCWR).

The mission of the CCWR is to support collaboration and the dissemination of knowledge, data and information amongst researchers and practitioners through advanced computing and communication technology in order to enhance water resources management. Central to the strategic vision of the CCWR is the belief that excellent communication between water researchers and practitioners at all levels is fundamental to the success of its mission. Every strategic thought, plan and action of the CCWR is therefore directed at the goal of developing excellent communication.

With South Africa becoming more integrated into the Southern African and international communities, the strategic initiatives of the WRC are coming to fruition. Faced with great challenges in the natural environment, whose lifeblood is water, South Africa needs to harness all the co-operative scientific expertise available. It is particularly encouraging to note that interdisciplinary communication is increasing and the CCWR, through UNINET, is at the forefront of many of these developments.

The CCWR is used by 136 water

researchers from 56 departments at 34 institutions country-wide. Some of the key areas of co-operation through the CCWR are:

- Agrohydrological modelling for use *inter alia* in the Kruger National Park Rivers Research Programme
- Water quality and quantity modelling in the Mgeni catchment
- Modelling for drought monitoring and management
- Estimating the impact of global climate change on water resources in Southern Africa
- Modelling the impact of atmospheric deposition on the water quality of the Vaal River
- Generation of stochastic sequences of climatic variables throughout the region
- Interactions between surface-, root zone- and groundwater
- Country-wide mapping of groundwater recharge.

Through this strategic initiative, the WRC has moved considerably closer to its goal of creating a culture of multidisciplinary team approaches to the complex challenges facing water research and practice in Southern Africa.

17

Transfer of information and technology

The promotion of information and technology transfer is one of the most important objectives of the WRC. This is very clearly defined in the Water Research Act, namely to "accumulate, assimilate and disseminate knowledge in regard to the results of such research and the application thereof, and promote development work for the purpose of such application".

For the promotion of its programme of information and technology transfer, the WRC has developed a number of activities. Although some of these activities are directed at the transfer of information, the emphasis falls mainly on technology transfer, i.e. the application of research results, since this will always represent the final dividend of the research investment.

Partnership research

Partnership research is regarded as a very effective method of enhancing technology transfer. The partnership principle is incorporated, as far as possible, in research projects, and means that the end user of the results participates in the planning and execution of the research.

Publications

The WRC's publications cater for three levels, viz. pure scientific, popular scientific and practical scientific.

Water SA

Water SA is the WRC's scientific journal which contains original research articles and review articles on all aspects of water science, technology and engineering. The journal appears quarterly and the first edition was launched in April 1975.

Water SA has a strict refereeing system whereby all articles submitted for publication are first referred to referees, whereafter a decision is taken on publication.

Water SA has an extensive local as well as overseas readership. It also enjoys world-wide coverage in the sense that it is covered by more than 20 international abstracting services who publish and distribute summaries of articles which appear in *Water SA*.

SA Waterbulletin

SA Waterbulletin is a bilingual bimonthly periodical. Within the broad spectrum of water research it aims to:

- Furnish information on water and water research in a popular scientific manner to the different interest groups in the water field
- Promote the transfer of technology by announcing the availability of reports, manuals, guides etc. which emanate from water research
- Promote communication between the WRC and authorities and individuals, such as researchers, engineers, technicians, government departments, local authorities and the industrial and agricultural sectors
- Convey social news and matters of interest (e.g. about conferences and personalities) to the water research community.

Manuals, guidelines and reports

At the conclusion of a project, and also while research is still under way, results are evaluated in respect of possible use and application and depending on the nature of the results a decision is taken on publication, dissemination and application thereof. More information on these publications appears in the relevant chapters and in the **Annexure**.

List of Commission publications

The **Annexure** to this annual report contains a list of publications (articles, papers and published reports) which appeared during 1993 and which emanated from research supported wholly or in part by the WRC.

Conferences, seminars, workshops and demonstrations

From time to time the WRC, on its own or in co-operation with other organisations, arranges such meetings. These afford ideal opportunities for promoting personal contact between research scientists or between research scientists and the users of research results. In this way the transfer of information and technology is greatly enhanced. More information on meetings held during the year is contained in the individual chapters.

Mass media

In this regard the accent falls on information transfer, and press releases, radio and television are used to this end.

Utilisation of overseas expertise

It is in the national interest that overseas expertise and knowledge be used where these are not available locally, and the WRC has developed various methods to achieve this. Overseas specialists, for example, are engaged as consultants and the WRC from time to time sends personnel and other experts overseas in order to obtain information on a particular problem area. More information in this regard appears in the individual chapters.

Commercialisation

In the future the WRC will focus increasingly on a further aspect of technology transfer, which is in progress already, viz. the commercialisation of research results by e.g. the private sector. The patenting of research results and the sale of publications and computer programs would be classified as such. In this way the WRC earns royalties, locally as well as abroad.

Financial statements

The Statement of Income and Expenditure and the Balance Sheet have been drawn up in terms of Section 14(2) of the Water Research Act, 1971 (Act No. 34 of 1971), as amended and certified by the Auditor-General and cover the period 1 January 1992 to 31 December 1992.

The Commission derives its income from rates and charges on water usage and on scheduled irrigation land. The tariffs for the 1993 financial year were 1,43c/m³ for water supplied for urban, industrial or domestic use, and 155c/ha for land scheduled for irrigation.

Statement 1

Balance sheet as at 31 December 1992

	Notes	**1992** **R**	1991 R
Capital employed			
Accumulated fund		**R63 695 953**	R58 370 177 *
Employment of capital			
Fixed assets	2	**874 238**	644 763
Investments and loans	3	**28 435 214**	25 043 430 *
Current assets			
Debtors	4	**15 409 806**	14 230 548
Deposits and amounts immediately recoverable		**19 186 523**	18 012 603 *
Bank balance and cash		**150**	478 473
Total current assets		**34 596 479**	32 721 624
Current liabilities			
Creditors		**198 669**	38 447 *
Income received in advance		**3 486**	1 193
Bank overdraft		**7 823**	-
Total current liabilities		**209 978**	39 640
Net current assets		**34 386 501**	32 681 984
		R63 695 953	R58 370 177

* Restated figures

(Signed) PE Odendaal
Executive Director

Pretoria, 26/7/93

Statement 2

Income statement for the year ended 31 December 1992

	Notes	**1992** **R**	1991 R
Net income	5	**5 325 776**	10 980 412
Accumulated fund at the beginning of year		**58 370 177**	47 389 765
Accumulated fund at end of year		**R63 695 953**	R58 370 177 *
* Restated figure			

Statement 3

Cash flow statement for the year ended 31 December 1992

	Notes	**1992** **R**	1991 R
Cash retained from (employed in) operations		**4 381 951**	8 667 628
Net income before non-cash items	1	**2 830 534**	8 310 159
Employed to increase operating capital	2	**(1 016 743)**	(2 376 182)
Investment income		**2 568 160**	2 733 651
Cash employed in (produced by) investment operations			
Replacement of fixed assets	3	**(302 393)**	(156 432)
		4 079 558	8 511 196
Cash effects of financing operations			
Decrease in short-term loans	4	**(687 774)**	(5 595 472)
Increase in long-term loan	5	**(3 391 784)**	(2 915 724)
		(4 079 558)	(8 511 196)

Schedule A

Notes to the financial statements

1. Accounting policy

The annual financial statements have been compiled according to the historic cost principle. The principal accounting policy is reflected hereunder and is consistent with that of previous years, unless stated otherwise.

1.1 Fixed assets and depreciation

Unless otherwise indicated, fixed assets are shown at book value and, where appropriate, are depreciated at rates which will result in each asset being written off over its useful life. The basis and rates of depreciation are shown for each category of assets. No provision is made for depreciation on land.

1.2 Research projects and research support services

Payments made in respect of research projects prior to the submission of audited statements shall be brought to account as advances and expenditure may only be charged against projects upon receipt of audited statements.

1.3 Investments

Investments are shown at cost.

1.4 Acknowledgement of income in general

Income is acknowledged on the accrued basis.

	1992 R	1991 R
2. Fixed assets		
Land at cost	**5 000 #**	5 000 #
Motor vehicles at book value	**56 003**	89 924
Less: Depreciation	**29 126**	33 921
	26 877	56 003
Office equipment and furniture at book value	**886 152**	613 552
Less: Depreciation	**43 791**	29 792
	842 361	583 760
Total fixed assets	**874 238 ***	644 763 *

Depreciation on office furniture and office equipment is being calculated on the balance method at a rate of 5% annually. Depreciation on motor vehicles is written off on a pro-rata basis calculated on annual kilometers travelled and the life expectancy in kilometers of the vehicles.

\# Purchased on 25 March 1975 and situated at Schaap Kraal, Site 477.

* Capital assets purchased by organisations with research grants are not included.

Schedule A (continued)
Notes to the financial statements

	1992 R	1991 R
3. Investments and loans		
Company for Research on Atmospheric Water Supply	**23 444 991**	19 683 265
The loan to the Company for Research on Atmospheric Water Supply does not represent an asset of the Water Research Commission. Upon termination of the finance contract the amount of the loan minus the amount realised on the capital assets purchased with contract funds is written off as current expenditure.		
Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	**4 234 284**	4 604 226
Unsecured loan repayable over 30 years with interest at 15% calculated on monthly balance		
Unlisted shares in Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	**755 939**	755 939
Total investments and loans	**28 435 214**	25 043 430

	1992 R	1991 R
4. Debtors		
Water research levies	**13 105 617**	11 934 431
Other	**2 304 189**	2 296 117
Total debtors	**15 409 806**	14 230 548

5. Net income

	1992 R	1991 R
Income		
Investment income	**2 568 160**	2 733 651
Water research levies	**39 464 755**	35 379 447
Other income	**172 099**	173 544
Total income	**42 205 014**	38 286 642

	budget 1992	1992 R	budget 1991	1991 R
Expenditure				
Administrative services	1 703 000	**1 766 461**	1 479 200	1 337 559
Audit fees	45 000	**41 649**	37 000	36 383
Rental and maintenance	948 500	**897 450**	827 500	787 641
Staff expenditure	4 369 600	**4 272 318**	3 644 500	3 771 069
Depreciation of fixed assets	80 000	**72 917**	62 000	63 398
Research projects and research support services	36 530 142	**29 828 443**	25 777 288	21 310 180
Total expenditure	43 676 242	**36 879 238**	31 827 488	27 306 230
Income over expenditure		**5 325 776**		10 980 412

Schedule B

Notes to the cash flow statement

	1992 R	1991 R
1. Net income before non-cash items		
Net income according to income statement	**5 325 776**	10 980 412
Adjustments for:		
Depreciation	**72 917**	63 398
Interest on investments and loans	**(2 568 160)**	(2 733 651)
	2 830 533	8 310 159
2. Employed to increase operating capital		
Decrease (increase) in debtors	**(1 179 258)**	(2 329 258)
(Decrease) increase in creditors	**162 515**	(46 924)
	(1 016 743)	(2 376 182)
3. Additions and replacement of fixed assets		
Motor vehicles	**-**	(2 825)
Office equipment	**(291 640)**	(150 679)
Office furniture	**(10 753)**	(2 928)
	(302 393)	(156 432)
4. Decrease (increase) in short-term loans		
Corporation for Public Deposits and other deposits	**(1 173 920)**	(5 538 442)
Cash on hand and bank overdraft	**486 146**	(57 030)
	(687 774)	(5 595 472)
5. Decrease (increase) in long-term loans		
Company for Research on Atmospheric Water Supply	**(3 761 726)**	(3 130 763)
Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	**369 942**	215 039
	(3 391 784)	(2 915 724)

Statement 4

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
1. RESEARCH PROJECTS			
161 Research into the treatment of wool scouring effluents	14 359,52	1 400 659,05	-
183 Research on the effects of urbanisation on catchment water balance	64 357,54	1 174 756,23	18 849,57
186 Research on epidemiological surveillance of potential changes in drinking water quality	-	369 283,77	7 084,35
195 Hydrosalinity studies in the Eastern Cape	193 590,69	1 394 362,62	*(20 458,46)
198 The development of methods to assess the impact of agricultural practices on water resources in Southern Africa	196 500,00	1 206 985,10	*(85,10)
208 Research on the development of criteria for sprinkler irrigation systems to combat surface sealing of soils	-	414 939,02	3 344,92
211 Research on groundwater abstraction in residential areas	-	185 289,64	15 710,36
212 Research on the use of electromagnetic exploration techniques for the development of groundwater resources	-	216 000,00	15 251,95
218 Research on economic evaluation of alternative irrigation scheduling strategies for wheat in the irrigated area of the Orange Free State region	25 522,53	300 505,95	277,47
219 The development of fixed and dynamic membrane systems for the treatment of brackish water and effluents	-	1 751 276,80	40 583,31
221 Research on geohydrological investigation and evaluation of the Zululand coastal aquifer	247 665,16	766 406,46	71 924,28
222 Research on the reconstruction of the climatic history of the last 2000 years in the summer rainfall regions of Southern Africa	30 100,00	214 993,11	1 025,89
226 Research on maximizing irrigation project efficiency in different soil-climate-irrigation situations	238 947,08	918 889,61	24 852,93
227 Research on the storage and utilisation of rain water in soil for the stabilisation of plant production in semi-arid regions	278 467,31	1 021 727,84	18 932,69
228 Research on the factors affecting the water-use efficiency of irrigated crops, with special reference to the physiological responses of these crops	254 961,26	1 263 684,09	72 038,74
229 Research on the estimation and evaporation of moisture stress in crops by means of remote control aerial surveillance	-	278 952,01	40 397,00
235 Hydrological modelling studies in the Eastern Cape	295 462,41	1 253 479,30	15 440,36
236 The development of a model to simulate flow in alluvial rivers	16 298,32	348 534,16	*(6 175,08)
238 Research on the design criteria for crossflow microfiltration	277 659,89	1 064 534,22	*(58 912,82)
239 Transfer of waste-water treatment management technology to the meat processing industry	20 778,57	157 778,57	*(1 173,06)
248 Research on chemical augmentation of biological phosphate removal	39 777,32	69 388,91	17 611,09
254 Research on the effects of varying water quality on the corrosion of different pipe materials in the PWVS/Klerksdorp areas	38 133,00	384 452,29	*(4 383,00)
255 Research on the development and testing of data logging equipment for the monitoring of water consumption patterns	-	86 120,77	12 379,23
256 Research on the evaluation of the design and use of irrigation systems in the Breë River with a view to the control of potential drainage losses	15 653,18	559 000,00	-
257 Research on the water-use efficiency of certain irrigated temperate pasture species	82 932,53	413 380,55	11 967,47
259 Research on the effect of water quality and chemical composition on the corrosivity in mild steel pipelines	36 662,50	66 461,88	909,31
260 Research on the relationship between climate and crop factors	43 595,59	179 037,41	22 604,41
261 Research on soil-plant-water relations in the upper reaches of plant available soil water	111 085,51	436 676,30	7 826,95
262 Research on moisture sensors to facilitate water management	54 000,00	429 068,81	*(9 222,49)
263 Research on the biological treatment of industrial water with the simultaneous production of single-cell protein	-	67 027,75	21 572,25
265 Research on human viruses in water	109 300,00	334 857,66	*(17,79)
266 Research on the extension of the management orientated models for eutrophication control	48 729,74	224 023,14	*(48 729,74)
267 Research on the evaluation and development of geophysical techniques for characteristing the extent and degree of groundwater pollution	-	437 258,00	25 942,00
269 Research on the evaluation of the four-electrode electrical conductivity and electromagnetic induction techniques of soil salinity measurement for use under South African conditions	61 140,00	214 445,00	2 942,00
270 Research on hydrological systems model development	530 075,00	1 669 981,00	23 219,00

Statement 4 (continued)

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
274 Technical support for the application of dynamic membrane plants for the treatment of industrial effluents	29 940,00	431 099,42	*(19 644,15)
275 The investigation into the evaluation of membrane technology for electroplating effluent treatment	111 083,89	215 000,11	-
278 Research on the prediction of South African summer rainfall variability from ocean surface temperature	80 000,00	343 683,25	-
279 Research on relationships between lightning and precipitation	55 000,00	299 941,00	-
280 The evaluation of full-scale flotation-filtration and chlorine dioxide plants	21 100,00	141 408,00	*(59 908,49)
282 The development of a combination of sedimentation flotation and sand filtration processes for water treatment (SEDIDAFF)	3 391,03	30 000,00	-
285 Research on and evaluation of various factors affecting dry-wet cooling	31 715,45	828 470,89	6 578,35
286 Research on development and evaluation of specific control methods for ameliorating low F/M bulking	190 000,00	490 972,06	-
288 Determination of the socio-economical and financial implications of the water restrictions in force from 1983 up to its annulment in 1987	3 056,00	102 999,71	-
290 Research on flood and furrow irrigation: A critical evaluation of design procedures and the computerisation of the most suitable procedures	50 942,98	159 653,78	34 057,02
291 A regional investigation into groundwater quality deterioration in the Olifants River catchment above the Loskop Dam, with specialized investigations in the Witbank Dam subcatchment	499 177,33	1 167 303,74	28 822,26
292 Research on the freshwater requirements of estuarine plants	123 839,31	179 390,53	591,29
293 Research on the relationship between low flows and the river fauna in the Letaba River	32 114,00	321 999,30	-
294 Research on a pre-impoundment study of the Sabie-Sand River system, Eastern Transvaal, with special reference to predicted impacts on the Kruger National Park	189 800,00	586 018,31	*(49 958,16)
295 Research on assessment of the instream flow requirements of rivers	180 358,94	429 404,52	23 595,06
296 Research on the quantitative structuring of national water planning objectives for use in decision support systems in South Africa	95 556,85	257 451,82	26 043,15
297 Research on the preparation of a review document on sediment transport in South Africa including revision of the sediment production map of Southern Africa	92 777,80	340 811,18	6 607,27
298 Research on the surface water resources of South Africa 1990	749 898,64	1 939 898,64	80 101,36
299 Research on the adaption and calibration of an urban runoff quality model	193 200,00	421 239,55	11 610,60
300 Research on the utilisation of geographical information system (GIS) and integrated environmental management (IEM) in the planning and management of water resources within river catchments	93 299,01	397 948,88	200 050,99
301 An investigation into the quality of water for animal production	111 324,47	255 100,67	68 075,53
302 Research on the erodibility of different rock formations under varying flow conditions	46 886,13	167 151,37	5 113,87
303 Research on the use of saline water for irrigation purposes and an assessment of salt tolerance criteria of crops	377 600,00	831 155,59	-
304 Research on the applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa	31 076,58	277 273,91	18 726,09
305 Research on interpolation and mapping of daily rainfall model parameters for South Africa	101 597,45	206 431,63	14 402,55
306 Research on techniques for seasonal and long-term rainfall forecasting in South Africa	86 953,43	212 148,06	11 746,57
307 Research on the influence of different water nitrogen regimes on crop canopy development, water flow resistance and crops yield, with a view to improvement of irrigation models	(26 306,50)	295 647,57	71 104,00
308 Research into the recovery of water and chemicals from ion-exchange regeneration effluents	80 136,47	198 334,57	12 165,43
309 Research on phase diagrams of complex precipitants	75 393,49	191 645,05	*(36 584,13)
310 Research on the integration of remote sensing, digital image processing and geographical information systems technologies for regional-scale groundwater resources assessment in South Africa	101 371,21	239 638,70	*(8 509,99)
311 Research on the development and evaluation of geohydrological and isotope hydrological methodologies for the identification of areas potentially suitable for waste disposal	180 000,00	344 997,54	*(25 000,00)
312 Research on the occurrence and accumulation of selected heavy metals in freshwater ecosystems affected by mine and industrial effluent	8 463,20	107 067,58	17 807,42
313 Research on the concentration ratios of selected radionuclides in aquatic ecosystems affected by mine drainage effluents	42 156,09	93 635,85	42 363,91
314 Research on biological phosphate removal mechanisms in the activated sludge process	51 000,00	141 938,98	-

Statement 4 *(continued)*

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
315 Research on the utilization of the fungus *Geotrichum* in waste water	51 836,00	139 999,22	-
316 Research on aspects of sewage sludge treatment and disposal	20 055,31	34 181,81	3 074,69
317 Research on urban catchment monitoring	10 599,81	95 150,95	19 960,05
318 Research on the optimization of biofouling control programmes	107 294,03	275 523,05	9 805,97
319 Research on monitoring the effect of catchment development on urban runoff and water balance	411 000,00	680 040,72	*(40,72)
320 Research on taste and odour forming micro-organisms occurring in South African surface waters	114 140,29	265 000,00	-
321 Research on bacteriophages as water quality indicators	68 336,68	184 710,23	5 363,32
322 A study on a mine-water treatment and monitoring plant: The Aquarius Plant	81 100,00	481 100,00	-
323 Research on a hydrological investigation of stormwater runoff from the Khayelitsha urban catchment in the False Bay area, South-Western Cape	132 697,00	444 999,81	*(21,70)
324 Research on pollution loads, dispersion and effects of urban runoff from the Motherwell township into the Swartkops River, Eastern Cape	13 507,17	70 512,71	-
325 Research on modelling of tubular reverse osmosis systems	210 869,82	516 027,53	*(49 827,53)
328 Full-scale study of chemical sludge bulking control	22 205,00	51 999,32	*(12 999,32)
331 Research on improved oxygen transfer for high biosludge concentrations	35 178,26	51 651,42	23 348,58
332 The development of guidelines for the design and application of dissolved air flotation/ filtration processes	-	75 000,00	*(18 750,00)
333 Research on the removal of suspended solids from pulp and paper effluents by employing a combined sedimentation, flotation and sand filtration process	31 877,08	49 107,29	5 892,92
342 Research on improvement in water usage control and waste-water treatment in the sorghum beer industry	206,00	46 999,17	22 000,00
343 Research on the development of an effective and environmentally safe larviciding programme for the control of the blackfly, *Simulium chutteri*, along the Orange River	89 293,78	141 969,18	19 988,00
344 An investigation into the contribution of groundwater to the salt load of the Breede River using natural and chemical tracers	129 500,00	179 000,00	-
345 The development of seeded reverse osmosis technology	-	40 000,00	10 000,00
346 A study of the relationship between hydrological processes and water quality characteristics in the developing Zululand coastal region	156 090,32	217 422,16	*(43 122,16)
347 A global farm approach to enhancing the economic efficiency of water and energy use for irrigation in the central RSA	127 850,65	254 528,42	17 549,35
348 Root development and water usage of commercial timber species	148 000,00	272 289,00	*(24 589,00)
349 Evaporation measurements above vegetated surfaces using micro-meteorological techniques	139 600,00	278 225,00	*(625,00)
350 The effect of pollution on the physiology of fishes in the Olifants River (Eastern Transvaal)	70 971,00	122 999,73	0,27
351 The effect of water quality variables on riverine biotas	106 546,25	186 891,07	17 253,75
352 Development of a method for the selection of suitable landfill sites, and of guidelines for sanitary landfill in municipal areas	88 753,86	144 686,71	1 113,29
353 Preparation of a manual on quantitative estimation of groundwater recharge and aquifer storativity	35 678,64	43 435,44	*(14 556,37)
354 Research on the evaluation and development of deep-bed filtration for the treatment of South African surface waters	74 498,98	106 974,76	29 043,24
355 Research on the neutralisation of water containing high concentrations of sulphuric acid with calcium carbonate	128 539,54	200 000,00	-
356 The consolidation of activated sludge research	11 000,00	144 199,25	-
357 Research on the microbiological transformations of metal contaminated effluents	94 234,24	286 849,39	9 865,76
358 The development of guidelines for toxicity bio-assaying of drinking and environmental waters in South Africa	140 000,00	244 000,00	-
359 An investigation into phytoplankton blooms in the Vaal River and the environmental variables responsible for their development and decline	112 314,46	194 784,57	22 785,54
360 Research on the mutagenicity of drinking water produced with conventional treatment methods of surface water sources	149 989,82	149 989,82	10,18
361 Research on the development of tolerant membranes	171 075,83	298 431,04	*(14 431,04)
362 Research on industrial application of membranes	101 994,18	174 174,37	9 325,63
363 The development and evaluation of small-scale potable water treatment equipment	84 545,21	165 209,54	57 090,46

Statement 4 *(continued)*

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
364 Research on field dilution studies on large off-shore pipelines	59 625,00	116 725,73	*(52 135,32)
365 Research on the evaluation and improvement of the anaerobic digestion/ultrafiltration (ADUF) effluent treatment process	131 338,01	212 000,00	-
366 Research on full-scale pilot plant studies on phosphate crystallization in biological systems	142 500,00	185 538,85	12 460,15
367 The development of a consolidated computer software package for the management of an irrigation scheme	25 000,00	49 000,00	-
368 A preliminary investigation of the nitrate content of groundwater and limitation of the nitrate input	7 681,00	69 999,83	2 319,00
369 The completion of research relating to the Disa model - A daily irrigation and salinity analysis system model	13 565,00	99 000,00	*(7 148,47)
370 A compilation of information on the magnitude, nature and importance of coastal aquifers in Southern Africa	48 437,51	48 437,51	11 562,49
371 An assessment of health aspects of the impact of domestic and industrial waste disposal activities on groundwater resources	28 612,51	47 993,00	-
372 Assessing the impacts of varying rainfall conditions on vegetation dynamics, production and certain hydrological properties of natural grassland, using a system modelling approach	115 300,56	156 741,19	68 290,07
374 The Southern Agulhas current and its influence on the weather and climate of Southern Africa	15 802,87	15 802,87	148 024,13
375 The development of a distributed hydrological modelling system to assist with water quantity and quality management in the Mgeni catchment, Phase II	339 037,00	385 681,00	74 319,00
376 The geomorphological response to changing flow regimes of the Sabie and Letaba River systems	272 317,14	272 317,14	25 246,76
377 The use of geographic information systems and other computer-aided drafting facilities for the production of geohydrological maps	292 378,74	514 378,74	29 621,26
378 The development of techniques for risk analysis and groundwater management of Southern African aquifers	340 368,97	568 086,97	21 131,03
379 Decision-making procedures for determination of crop water requirements	237 000,00	237 000,00	-
380 Techniques for microbial aspects of water quality investigation of South African rivers	540 974,71	636 015,80	78 642,91
381 The corrosion performance of various non-metallic piping materials and coatings in potable water	215 479,00	432 136,42	*(104 136,42)
382 The evaluation of the interdependent factors which determine the viability of irrigation farming	180 000,00	180 000,00	-
383 A holistic approach to affordable planning and maintenance of water and sewer systems	40 500,00	115 700,00	*(8 704,90)
384 A water resources and sanitation systems sourcebook with special reference to Natal/ KwaZulu	109 471,00	197 792,00	*(27 784,07)
385 Technical, socio-economic and environmental evaluation of sanitation systems for developing urban areas in South Africa	115 262,05	204 548,55	36 037,95
386 Research on development of a crossflow microfilter for rural water supply	249 100,57	522 653,98	*(18 153,98)
387 Research on the development and production of membrane systems	430 000,00	865 687,72	*(570 187,72)
388 The evaluation of various methods for the forming of free radicals for the oxidation of molecules in industrial effluents and potable water	266 302,28	371 718,17	*(10 618,17)
389 Scheduling irrigation of tuberous crops with specific reference to potatoes	63 828,50	145 509,99	72 052,00
391 Co-disposal of sewage sludge and refuse	25 000,00	45 000,00	-
393 The use of algae to bioassay for toxic substances in water	6 828,63	46 356,52	14 393,48
397 The evaluation of prototype capillary micro- and ultrafiltration membranes for industrial application	25 000,00	25 000,00	-
398 The degradation of mortar linings and concrete by micro-organisms in industrial water systems	80 000,00	80 000,00	-
399 The determination of exposure to chemical residues in South African food and water intake	-	27 271,73	6 728,27
400 Research into domestic meter replacement policy and testing of water meters	49 354,44	80 000,00	-
401 Establishing revised water quality criteria for the South African coastal zone	31 600,00	65 000,00	*(9 246,23)
402 Research on the modelling of flow through porous membranes	37 916,00	75 999,34	-
403 Research on nitrate removal from potable water	5 890,48	33 482,01	10 517,99
404 The preparation of a manual for waste load allocation in South Africa	192 000,00	273 641,36	*(123 677,06)
405 A situation analysis of water quality in the Buffalo River, Eastern Cape, with special emphasis on the impact of low-cost, high density urban development on water quality	217 929,56	382 702,04	43 157,97
406 A structural analysis of the water apportionment mechanisms in the Water Act 54/1956, in view of the requirements of competing user sectors	149 500,00	279 500,00	2 000,00

Statement 4 *(continued)*

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
407 Reassessment of the strategy with respect to industrial effluent discharge with special reference to advanced technology treatment methods: Phase I	6 819,00	88 999,50	6 819,00
408 Fats and oils in effluents	2 790,91	6 023,57	6 976,43
409 Phenols in the steel industry waste water: Origin, prevention and removal	5 756,74	11 871,63	27 128,37
411 Marine pollution: Pathogenic micro-organisms	63 631,63	116 131,63	3 868,37
412 Contribution to the estuaries research programme	50 000,00	100 000,00	-
413 The use of vegetation in the amelioration of the impacts of mining on water quality - An assessment of species and water use	151 021,75	250 676,64	67 478,25
414 Soil buffering of rain-water salinity in the Vaal Dam catchment	99 093,00	130 677,00	9 435,13
415 The application of resource economics to water management decision-making in South Africa	234 800,00	351 903,00	-
416 The application and performance of full-scale artificial wetlands for waste-water treatment in South Africa	74 067,88	74 067,88	*(24 207,32)
417 Optimal water utilisation by turf	38 190,30	38 190,30	2 909,70
418 Catchment and land use: Effects on water quality and estuaries	-	-	7 250,00
419 Water quality and quantity assessments in catchments with changing land uses in the Umzinto coastal area	176 455,96	176 455,96	*(77 755,96)
420 The long-term salt balance of the Vaalharts irrigation scheme	100 000,00	100 000,00	*(7 809,87)
421 The relationship between atmospheric deposition and water quality in a small upland catchment	132 599,02	132 599,02	61 000,98
422 The rapid biological assessment of water quality impacts in streams and rivers	185 241,05	185 241,05	41 758,95
424 The development of an urban component for the ACRU model	-	-	47 473,00
425 The development of an integrated catchment management system for the Crocodile River catchment	272 100,00	272 100,00	*(272 100,00)
426 Preliminary investigation of algal weeds in South African inland waters	63 600,00	63 600,00	*(11,00)
427 The development of electro-osmotic sludge dewatering technology	140 098,46	140 098,46	3 901,54
428 An overview of the pesticide and heavy metal levels present in populations of the larger indigenous fish species of selected South African rivers	115 788,48	115 788,48	21 611,52
429 Research on bio-augmentation technology for waste water treatment in South Africa	98 000,00	98 000,00	-
430 A comprehensive study of an iron-phosphate removal system	89 600,00	89 600,00	*(100,00)
431 A feasibility study of membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics	5 787,71	5 787,71	76 987,29
432 Microbiological corrosion of common piping materials in the PWV area	127 550,00	127 550,00	*(50 550,00)
433 Engineering properties of important Southern African rock types with special reference to the shearing strength of concrete dam wall foundations	140 247,77	140 247,77	19 752,23
434 Evaluating the long-term use of polypropylene for hot and cold water piping	-	-	122 300,00
435 Development of a training programme on community water supply management for village water committees	80 000,00	80 000,00	-
436 Mechanisms of short-term rainfall variability	79 900,00	79 900,00	-
437 An assessment of the potential for using stable carbon isotope ratios of wood charcoal as a climate indicator	46 700,41	46 700,41	31 629,59
438 The development of a real-time, non-conventional rainfall mapping system	160 561,60	160 561,60	15 238,40
439 Potential impacts of rainfall stimulation on water resources and forestry in the Nelspruit-Bethlehem target zone	174 715,45	174 715,45	*(33 292,46)
440 Identification of irrigation land in an intensively cultivated agricultural area in the South-Western Cape by means of satellite remote sensing	17 948,41	17 948,41	12 680,59
441 Determination of the relationship between transpiration rate and declining available water for *Eucalyptus grandis*	132 696,85	132 696,85	15 903,15
442 Development of improved flow gauging structures for South African rivers	110 166,41	110 166,41	-
443 The compilation of guidelines for the use of peroxone and other oxidants in the treatment of eutrophic water	98 485,90	98 485,90	2 514,10
444 Development of rigorous engineering methodology for designing vegetative erosion protection systems	89 251,68	89 251,68	*(17 670,44)
445 The removal of colour from Cape waters using ozonation and ultrafiltration	186 240,00	186 340,00	6 000,00
448 The improvement of injection nozzles for dissolved air flotation	34 900,71	34 900,71	24 099,29
449 Evaluation of non-conventional disinfection technologies for small water systems	71 627,35	71 627,35	27 372,65
450 Research on performance criteria for package water treatment plants	49 181,76	49 181,76	40 818,24

Statement 4 *(continued)*

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
451 The occurrence of protozoan parasites in South African drinking water	117 000,00	117 000,00	-
452 Research on the interaction between the boundary layer and Kendal Power Station natural-draught dry-cooling tower	200 000,00	200 000,00	-
453 Development of procedures to assess whole effluent toxicity	160 000,00	160 000,00	-
454 An investigation of the occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps	30 259,63	30 259,63	*(259,63)
455 Research on the anaerobic digestion of dairy factory effluents	45 100,00	45 100,00	-
456 The regional treatment of textile and industrial effluents	81 667,51	81 667,51	*(12 267,51)
457 Monitoring and optimization study of high-rate biofiltration, aerobic biological treatment processes for tannery and fellmongery waste water	59 450,33	59 450,33	6 409,67
458 Research on the development of an expert systems approach to water management in the fruit and vegetable processing industry	132 763,75	132 763,75	*(34 634,07)
459 The laboratory-scale treatment of acetic effluent by the anaerobic digestion/ultrafiltration (ADUF) process	39 800,00	39 800,00	-
460 The application of the anaerobic digestion/ ultrafiltration (ADUF) process to fruit processing effluent	35 500,00	35 500,00	-
461 To determine the reaction kinetics in a slurry precipitation and recycle reverse osmosis (SPARRO) seed reactor	54 700,00	54 700,00	-
462 Activated fixed and suspended cultures for nitrification	-	-	30 000,00
463 Diversity and productivity of biotic communities in relation to freshwater inputs in Eastern Cape estuaries	-	-	8 375,00
464 The use of yeast biomass and yeast products to accumulate toxic and valuable heavy metals from waste water	20 035,62	20 035,62	5 324,88
465 Detergent phosphorus in South Africa: Impact on eutrophication with specific reference to the Umgeni catchment	5 500,00	5 500,00	49 000,00
466 Fluoro-carbon coating of ion-exchange membrane surfaces to overcome fouling and general scaling	50 000,00	50 000,00	-
467 The development of an ultrafiltration pretreatment system for seawater desalination by reverse osmosis	65 500,00	65 500,00	-
468 A feasibility study for the provision of point-source water by enhanced solar distillation	52 047,21	52 047,21	*(13 047,21)
469 Studies on microbiological drinking-water quality guidelines	70 000,00	70 000,00	-
470 The application of health risk assessment techniques to microbial monitoring data	85 000,00	85 000,00	-
471 Optimization of mine service water disinfection	-	-	55 000,00
472 The characterisation of South African media for sand filtration	31 816,73	31 816,73	19 183,27
473 Magnetite as flocculant in water purification processes	3 482,59	3 482,59	16 517,41
474 Developing an integrated approach to predicting the water use of riparian vegetation	104 242,71	104 242,71	216 757,29
475 The development of a recirculating experimental stream system	189 106,84	189 106,64	49 424,16
476 The transfer of research results on the irrigation of vegetable crops into practice	237 296,47	237 294,47	40 403,53
477 Guidelines and procedures to assess and ameliorate the impact of gold mining operations on the water environment	166 000,00	166 000,00	-
478 Research on the saving of water with air-cooled heat exchangers	187 400,00	187 400,00	-
479 Research on a molecular approach to drought tolerance	136 615,00	136 615,00	2 585,00
480 *Per capita* water demand in developing communities	67 360,54	67 360,54	-
481 Research on geochemistry and isotopes for resource evaluation in the fractured rock aquifers of the Table Mountain Group	28 600,00	28 600,00	-
482 The development of a strategy to monitor groundwater quality on a national scale	102 512,41	102 512,41	*(2 512,41)
483 The compilation of a hydrogeological map of South Africa	70 886,30	70 886,30	31 843,20
484 An integrated multidisciplinary geodynamic/geophysical approach to groundwater exploration around the South African coastline	116 100,00	116 100,00	32 841,46
485 Development of a systematic method for evaluating site suitability for waste disposal based on geohydrological criteria	136 046,64	136 046,64	11 453,36
486 Catchment water quality deterioration as a result of water level recovery in abandoned gold mines on the eastern and central Witwatersrand	187 625,01	187 625,01	73 374,99
487 Analysis and interpretation of aquifer tests in secondary aquifers	322 874,33	322 874,33	10 625,67
488 Optimisation of the Rand Water system	103 915,96	103 915,96	96 084,04

Statement 4 *(continued)*

Statement of expenditure and advances outstanding in respect of research projects and research support services as at 31 December 1992

Project	Expenditure		Total advances outstanding as at 31/12/92 R
	1992 R	Total to 31/12/92 R	
489 The development of procedures for the control of unaccounted-for water in water distribution systems and for the reduction of water loss	216 408,74	216 408,74	*(3 944,51)
490 The development of flood damage functions and a computer program to determine the advantages of flood and flood damage control measures	85 899,59	85 899,59	85 100,41
491 Research on pond enhanced trickling filter operation (PETRO)	135 000,00	135 000,00	167 000,00
492 Research on the effect of the agricultural environment on water resources	128 655,00	128 655,00	48 645,00
493 The development and testing of a water balance model for a grassland catchment in the summer rainfall area of South Africa	217 173,88	217 173,88	*(139 173,88)
495 Biotechnological approach to the removal of organics from saline effluents	211 161,75	211 161,75	79 878,25
496 Research on human viruses in diffuse effluents and related water environments	54 274,56	54 274,56	142 325,44
497 Research on a geomorphological classification system for South African river systems	66 394,01	66 394,01	21 605,99
498 Collection and evaluation of runoff water quality data from a disused feedlot in Natal	43 129,39	43 129,39	11 870,61
499 The effect of exchangeable sodium percentage and clay mineralogy on the infiltration capacity of soils already sealed due to cyclic irrigation	54 791,27	54 791,27	3 408,73
500 Identification and verification of polluted areas in the dolomitic aquifer of the PWV area	70 000,00	70 000,00	*(20 000,00)
501 Continuing research into the wetlands of Natal/KwaZulu	29 718,00	29 718,00	10 032,00
502 Plunge pool scour reproduction in hydraulic models	46 532,00	46 532,00	*(12 650,00)
503 The effect of land use on Gamtoos Estuary quality	20 148,95	20 148,95	27 051,05
504 A manual on water purification and plant design. Phases 2 and 3: A design guide for water purification	22 127,50	22 127,50	26 302,50
SUBTOTAL	24 635 275,05	58 339 136,27	2 012 051,48
2. RESEARCH SUPPORT SERVICES			
South African Water Information Centre	699 989,84	1 566 000,00	-
Establishment of a Computing Centre for Water Research	2 706 700,00	2 706 700,00	*(202 972,82)
SUBTOTAL	3 406 689,84	4 272 700,00	*(202 972,82)
TOTAL	28 041 964,89	62 611 836,27	1 809 078,66

* *Excess expenditure over advances for projects*

Statement 5
Budget 1994

	R
ESTIMATED INCOME	**50 078 000**
Rates and charges in terms of Section 11 of the Water Research Act	47 870 000
Interest on investments	1 710 000
Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	498 000
TOTAL ESTIMATED INCOME	**50 078 000**
ESTIMATED EXPENDITURE	
Administrative expenses	**9 861 700**
Salaries and allowances	5 253 500
Subsistence and transport	857 000
Postal and telecommunication services	105 600
Printing, stationery and advertisements	117 800
General expenses	2 324 800
Technology and information transfer	1 203 000
Approved research projects:	**23 688 701**
CRAWS	1 970 000
Research on the design criteria for crossflow microfiltration	15 800
Research on hydrological systems model development	306 000
Research on a flood and furrow irrigation: A critical evaluation of design procedures and the computerisation of the most suitable procedures	52 000
A regional investigation into ground-water quality deterioration in the Olifants River catchment above the Loskop Dam, with specialized investigations in the Witbank Dam subcatchment	28 800
Research on the surface water resources of South Africa 1990	300 000
Research on the adaption and calibration of an urban runoff quality model	47 000
Research on the erodibility of different rock formations under varying flow conditions	10 000
Research on the use of saline water for irrigation purposes and an assessment of salt tolerance criteria of crops	209 700
Research on the applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa	127 000
Research on techniques for seasonal and long-term rainfall forecasting in South Africa	114 900
Research into the recovery of water and chemicals from ion-exchange regeneration effluents	121 000
Research on the development and evaluation of geohydrological and isotope hydrological methodologies for the identification of areas potentially suitable for waste disposal	56 500
Research on the occurrence and accumulation of selected heavy metals in freshwater ecosystems affected by mine and industrial effluent	10 000
Research on monitoring the effect of catchment development on urban runoff and water balance	275 000
Research on modelling of tubular reverse osmosis systems	11 000
Research on the development of an effective and environmentally safe larviciding programme for the control of the blackfly, *Simulium chutteri*, along the Orange River	81 300
A study of the relationship between hydrological processes and water quality characteristics in the developing Zululand coastal region	212 200
A global farm approach to enhancing the economic efficiency of water and energy use for irrigation in the central RSA	172 700
Root development and water usage of commercial timber species	42 700
The effect of water quality variables on riverine biotas	96 000
The consolidation of activated sludge research	105 800
An investigation into phytoplankton blooms in the Vaal River and the environmental variables responsible for their development and decline	154 000
The development and evaluation of small-scale potable water treatment equipment	169 000
Research on field dilution studies on large off-shore pipelines	11 200
Research on full-scale pilot-plant studies on phosphate crystallization in biological systems	43 261

Statement 5 *(continued)*
Budget 1994

	R
Assessing the impacts of varying rainfall conditions on vegetation dynamics, production and certain hydrological properties of natural grassland, using a system modelling approach	144 000
The Southern Agulhas current and its influence on the weather and climate of Southern Africa	219 000
The development of a distributed hydrological modelling system to assist with water quantity and quality management in the Mgeni catchment, Phase II	551 900
The geomorphological response to changing flow regimes of the Sabie and Letaba River systems	358 000
The use of geographic information systems and other computer-aided drafting facilities for the production of geohydrological maps	163 000
The development of techniques for risk analysis and ground-water management of Southern African aquifers	15 000
Techniques for microbial aspects of water quality investigation of South African rivers	58 600
The corrosion performance of various non-metallic piping materials and coatings in potable water	100 000
Research on development of a crossflow microfilter for rural water supply	60 000
The evaluation of various methods for the forming of free radicals for the oxidation of molecules in industrial effluents and potable water	34 000
Scheduling irrigation of tuberous crops with specific reference to potatoes	58 600
The preparation of a manual for waste load allocation in South Africa	45 000
A structural analysis of the water apportionment mechanisms in the Water Act 54/1956, in view of the requirements of competing user sectors	50 000
Marine pollution: Pathogenic micro-organisms	102 300
The use of vegetation in the amelioration of the impacts of mining on water quality - An assessment of species and water use	137 800
The application and performance of full-scale artificial wetlands for waste-water treatment in South Africa	115 000
Optimal water utilisation by turf	26 700
Catchment and land use: Effects on water quality and estuaries	12 700
Water quality and quantity assessments in catchments with changing land uses in the Umzinto coastal area	62 400
The relationship between atmospheric deposition and water quality in a small upland catchment	71 300
The rapid biological assessment of water quality impacts in streams and rivers	106 000
The effect of pre-programmed deficit irrigation on crop reaction	181 000
The development of an urban component for the ACRU model	87 500
Bio-augmentation technology for waste-water treatment in South Africa	128 600
Microbiological corrosion of common piping materials in the PWV area	53 800
Engineering properties of important Southern African rock types with special reference to the shearing strength of concrete dam wall foundations	123 500
Mechanisms of short-term rainfall variability	160 000
An assessment of the potential for using stable carbon isotope ratios of wood charcoal as a climate indicator	133 000
Determination of the relationship between transpiration rate and declining available water for *Eucalyptus grandis*	98 700
Development of improved flow gauging structures for South African rivers	190 000
The compilation of guidelines for the use of peroxone and other oxidants in the treatment of eutrophic water	91 000
Osonation in the production of potable water from polluted surface water	41 000
Research on performance criteria for package water treatment plants	180 000
The occurrence of protozoan parasites in South African drinking water	126 128
An investigation of the occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps	46 500
Research on the anaerobic digestion of dairy factory effluents	51 800
The regional treatment of textile and industrial effluents	180 000
Monitoring and optimization study of high-rate biofiltration, aerobic biological treatment processes for tannery and fellmongery waste water	567 000
Diversity and productivity of biotic communities in relation to freshwater inputs in Eastern Cape estuaries	8 400
Developing an integrated approach to predicting the water use of riparian vegetation	332 700
The development of a recirculating experimental stream system	310 200
Guidelines and procedures to assess and ameliorate the impact of gold mining operations on the water environment	164 000
Research on the saving of water with air-cooled heat exchangers	246 800
Research on a molecular approach to drought tolerance	173 000
Research on geochemistry and isotopes for resource evaluation in the fractured rock aquifers of the Table Mountain Group	145 000
The compilation of a hydrogeological map of South Africa	116 300
An integrated multidisciplinary geodynamic/geophysical approach to groundwater exploration around the South African coastline	152 900
Catchment water quality deterioration as a result of water-level recovery in abandoned gold mines on the eastern and central Witwatersrand	345 000
Analysis and interpretation of aquifer tests in secondary aquifers	357 500

Statement 5 (continued)
Budget 1994

	R
Optimisation of the Rand Water system	136 000
The development of procedures for the control of unaccounted-for water in water distribution systems and for the reduction of water loss	435 000
The development of flood damage functions and a computer program to determine the advantages of flood and flood damage control measures	160 000
Research on pond enhanced trickling filter operation (PETRO)	314 000
Research on the effect of the agricultural environment on water resources	509 400
The development and testing of a water balance model for a grassland catchment in the summer rainfall area of South Africa	317 000
Classification and hydrological modelling of low flows in Southern Africa	313 000
Biotechnological approach to the removal of organics from saline effluents	178 000
Research on human viruses in diffuse effluents and related water environments	264 400
Research on a geomorphological classification system for South African river systems	175 000
Continuing research into the wetlands of Natal/KwaZulu	5 600
Plunge pool scour reproduction in hydraulic models	119 000
The effect of land use on Gamtoos Estuary quality	14 000
A manual on water purification and plant design. Phases 2 and 3: A design guide for water purification	115 512
The environmental status of the Orange River mouth as reflected by the fish community	16 600
Improved estimation of plant and soil evaporation from cropped lands	62 000
Modelling the water balance on benchmark ecotopes	38 400
Palaeoflood hydrological analysis for selected South African rivers	141 000
The hydrological implications of afforestation in the North-Eastern Cape	200 000
Development of procedures for decision support in water resources management	179 000
The development of a computerized management system for irrigation projects	29 500
Groundwater contamination as a result of third world type urbanization	280 000
Groundwater abstraction in the Port Elizabeth municipal area	55 000
The application of seismic tomography and ground-penetrating radar for the detection of fractures and the determination of hydraulic properties of fractured rock aquifers	220 000
A case study of stormwater pollution control in a representative valley	106 600
The development of programmes to combat diffuse sources of water pollution in residential areas of developing communities	54 000
Guidelines on appropriate technologies for water supply and sanitation in developing communities	140 000
Water scheme cost recovery	89 000
A pilot study to investigate alternative management options to enhance the use of saline water for irrigation purposes	160 000
Natural and unnatural factors regulating the structure and functioning of estuarine systems	50 000
Distribution of fluoride-rich groundwater in the Eastern and Mogwase regions of Bophuthatswana: Influence of bedrock and soils, and constraints on utilisable drinking water supplies	77 300
A survey of current water management and treatment practices in the South African gold and coal mining industries	317 400
The development of an integrated and generic water quality simulation model for open-cast coal mining water circuits	222 600
Membrane characterisation by electrochemical measurements and membrane optimisation with computational fluid mechanics	228 700
Technology transfer of aquatic chemical speciation modelling	210 200
The development of characterising and cleaning techniques to classify foulants and to remove them from ultra- and microfiltration	81 300
Guidelines for the treatment of Eastern and Southern Cape coloured water	68 900
The use of filamentous micro-organisms for the purification of industrial effluents	92 000
The development of a dynamic model for the growth and bloom of algae in the Vaal River	45 000
Guidelines to coagulation and flocculation for South African waters	109 200
The development of a dynamic crossflow sand filter for rural water treatment	31 000
Evaluation of the use of bacteriophages as indicators for water quality	128 200
Biodegradation organic compounds and microbiological regrowth in drinking water	157 550
Causes and control of low F/M filament bulking in nutrient removal activated sludge systems	133 000
Bioremediation technology for the treatment of contaminated seepage water and soil in South Africa	246 000
The determination of sludge build-up rates in septic tanks, biological digesters and pit latrines in South Africa	50 000
Standard laboratory organisms for water quality studies	187 200
The development and demonstration of effluent treatment systems appropriate to the needs of the red meat abattoir industry	150 000
Synthesis of organic precursors for the development of novel tubular membranes for the treatment of industrial effluents	29 200
An investigation into the upgrading of Orange River water and secondary sewage effluent by means of ultra- and nanofiltration	34 200
Algal toxins in drinking-water supplies	110 000
Evaluation of the potential quantity of methane gas from 85 anaerobic household digesters	30 000

Statement 5 *(continued)*
Budget 1994

	R
Evaluation of immobilised semi-conductor particles for the photocatalytic oxidation of organic pollutants in industrial and municipal waste water	45 200
The application of capillary membranes in the biotechnological treatment of industrial effluents	34 100
A study of activated sludge microbial population dynamics for the optimization of biological phosphorus removal	88 000
The limitation of convection currents in clarifiers	51 750
Refinement of design parameters for sludge thickening by dissolved air flotation	25 800
The optimal operation of combined flotation/filtration of eutrophic surface water	18 000
The prediction of pollution loads from coarse sulphide-containing rock materials	200 000
Development of a crossflow microfiltration unit to improve the performance of anaerobic digesters at waste-water treatment works	230 000
The effect of water supply, handling and usage on water quality in relation to health indices in developing communities	287 500
The occurrence and distribution of algal species and related substances in a full-scale water purification plant	125 000
The development of an Exxpress unit for the production of potable water and the dewatering of waterworks sludges	150 000
Investigation into high-rate recirculation and solids contact optimisation of biological filtration plants	45 200
The preliminary assessment and review of integrated passive water treatment systems for mine effluent streams	50 000
Water and sanitation in urban areas: Financial and institutional review	108 500
An investigation of the contaminant attenuation capacity of the soil/aquifer system with special emphasis on the vadose zone	381 000
Water-use efficiency of cultivated subtropical forage and pasture crops	106 500
The potential for the use of economic instruments to protect the quality of water resources in South Africa	80 000
Calibration of models for the design of covers for open-cast mine and waste dump rehabilitation	275 300
The effects of different magnitude flows on South African riverine ecosystems	319 000
Decision support for the integrated management and conservation of estuaries	207 000
The evaluation of irrigation techniques used by subsistence and emergent farmers	300 000
Hydraulic roughness of tunnels bored by machine through various rock-types	3 400
The control of dam siltation in South Africa	240 000
A computerised weather based irrigation water management system	269 000
The screening of crop, pasture and wetland species for tolerance of polluted water originating in coal mines	112 200
The development of a laboratory river model to determine the environmental impacts of key xenobiotic compounds	28 500
An atlas of potentially water related disease in South Africa	8 000
Modelling flow through porous media	43 000
The development of a decision support system for the selection of the most appropriate sanitation option for developing communities	110 000
Evaluation of water pipe leaks in the Johannesburg municipal area	84 100
Demonstrating the potential of geographical information systems technology in hydrosalinity modelling by using the Disa model	21 200
Expected research projects	**11 638 400**
Other grants	**4 639 199**
Research and other grants	212 000
Specialist and consultation services	1 439 599
Research support services and facilities	2 987 600
ESTIMATED INVESTMENTS BALANCE	**250 000**
TOTAL ESTIMATED EXPENDITURE	**50 078 000**

Statement 6

Statement of receipts and payments for the year ended 31 December 1993

Receipts	1993 R
Balance on 1 January 1993	18 779 468
Investment at Corporation for Public Deposits	18 787 140
Cash on hand	150
Bank overdraft	(7 822)
Rates	783 173
Government irrigation schemes with canal systems	375 212
Irrigation Board Schemes	407 961
Charges	39 411 117
Metered water from Government schemes	33 029 607
Municipalities	6 377 592
Interest on charges in arrear	3 918
Other	1 952 556
Interest on investment	766 719
Loan: Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	1 036 348
Sundry income	149 489
Motor scheme and subsistence and transport advances	195 573
General suspense	170 489
Hydrological Information System	2 545 379
Value added tax	4 641 536
	R68 479 291

Payments	1993 R
Administrative expenditure	7 701 916
Salaries and allowances	4 932 659
Motor transport	23 956
Subsistence and transport expenses	311 676
General transport	364 177
Postal and telecommunication services	34 320
Telephone services	64 310
Printing	2 957
Stationery	85 213
Advertisements	26 829
Computerisation	69 121
Rental and maintenance	794 314
Entertainment	44 615
Office complex	68 148
Services rendered	15 562
Insurance	37 372
Collection services	426 754
Audit fees	59 370
Patent registrations and legal advice	147 426
Registration and subscriptions	77 707
Miscellaneous expenses	41 917
Loan: Erf Sewe-Nul-Ses Rietfontein (Pty) Ltd	73 513
Purchases: Fixed assets	88 404
Computer equipment	48 936
Office equipment	29 875
Office furniture	9 593
Technology and information transfer	840 485
Publications	573 691
Conferences	78 443
Publicity	188 351
Research expenses	34 807 210
Project advances	29 024 543
Research projects	3 892 768
Research and other grants	131 121
Specialist and consultation services	1 380 857
Research support services and facilities	377 921
Motor scheme and subsistence and transport advances	167 105
General suspense	1 070 748
Hydrological Information System	2 357 023
Value added tax	5 000 416
Balance as at 31 December 1993	16 445 984
Fixed investments	10 000 000
Investment at Corporation for Public Deposits	4 958 080
Cash on hand	150
Cash in bank	1 487 754
	R68 479 291

WATER RESEARCH COMMISSION
PRETORIA, 19/1/1994

(Signed PE Odendaal)
EXECUTIVE DIRECTOR/PE ODENDAAL

Annexure

PUBLICATIONS EMANATING FROM RESEARCH FINANCED WHOLLY OR PARTIALLY BY THE WRC

This **Appendix** contains a list of publications released in 1993. Requests for publications should be directed, as far as possible, to the authors.

Articles and papers (1993)

- Adams, JB and Bate, GC (1993) The effect of salinity and inundation on selected estuarine macrophytes - Management implications. Paper presented at 8th South. Afr. Mar. Sci. Symp., Langebaan. October.
- Adams, JB and Bate, GC (1993) Understanding the freshwater requirements of estuarine plants. Paper presented at 4th Eur. Union for Coastal Conserv. Congr., Marathon, Greece. April.
- Andersen, NJB and Ainslie, LC (1993) Neotectonic inversion - An aid to the location of groundwater. Paper presented at the "Africa needs Groundwater" Convention, Univ. of the Witwatersrand. 6-8 September.
- Basson, ND and Pieterse, AJH (1993) The occurrence and origin of THM substances in a full-scale plant purifying water from the middle Vaal River. Paper presented at WISA Conf., Durban. 24-27 May.
- Bate, GC, Rodriguez, FG and Adams, JB (1993) The influence of freshwater management on estuarine microalgae in semi-arid areas. Paper presented at 4th Eur. Union for Coastal Conserv. Congr., Marathon, Greece. April.
- Bath, AJ and Görgens, AHM (1993) Application of a two-dimensional model to simulate the water quality and hydrodynamics of the Vaal Barrage. *Proc. 3rd Bienn. Conf. of WISA*, Durban. May. **1** 66-77.
- Bath, AJ and Görgens, AHM (1993) Role of hydrodynamic simulation modelling in the management of water quality: The Vaal River system - a South African case study. *Proc. of the Environ. Physics Group (Inst. of Physics), Inland and Coastal Water Quality*, London. September.
- Bennie, ATP, Hoffman, JE and Coetzee, MJ (1993) Sustainable crop production on aeolian sandy semi-arid soils in SA. Paper presented at 1st East. and South. Afr. Crop Soc. Conf., Kampala. 15-17 June.
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- Botes, JHF, Bosch, DJ and Oosthuizen, LK (1993) Elicitation of risk preferences for irrigation farmers in the Winterton area. Paper presented at Annu. Conf. of the Agric. Econ. Assoc. of South. Afr., Cape Town. 27-28 September.
- Botha, JF (1993) Aquifer tests in hard-rock aquifers. Paper presented at the "Africa needs Groundwater" Convention, Univ. of the Witwatersrand. 6-8 September.
- Bredenkamp, DB, Janse van Rensburg, H and Botha LJ (1993) Manual on quantitative estimation of groundwater recharge. Paper presented at the "Africa needs Groundwater" Convention, Univ. of the Witwatersrand. 6-8 September.
- Brouckaert, CJ (1993) The use of computer simulation of tubular reverse osmosis in conjunction with pilot-plant studies. *Filtration and Separation* **30** (1) 59-62.
- Brouckaert, CJ, Jacobs, EP, MacTavish, F, Cowan, JCA and Hart, OO (1993) Cleaning strategies and membranes operating on red-meat abattoir waste streams. Paper presented at 3rd Bienn. Conf. of WISA, Durban. 24-26 May.
- Brözel, VS and Cloete, TE (1993) Adaptation of 33 *Pseudomonas aeruginosa* to 2,2 methylene bis (4 *Pseudomonas aeruginosa* to 2,2 methylene bis chlorophenol). *J. Appl. Bacteriol.* **74** 94-99.
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- Brözel, VS and Cloete, TE (1993) Resistance of Pseudomonas aeruginosa to sodium dimethyldithiocarbamate by adaptation. *Current Microbiol.* **26** 275-280.
- Brözel, VS, Pietersen, B and Cloete, TE (1993) Adaptation of bacterial cultures to non-oxidising water treatment bactericides. *Water SA* **19** (3) 259-262.
- Buckley, CA, Brouckaert, CJ and Kerr, CA (1993) RO application in brackish water desalination and in the treatment of industrial effluents. In: Amjad, Z (ed.) *Reverse Osmosis: Membrane Technology, Water Chemistry and Industrial Applications*. Van Norstrand Reinhold Publishing Company, New York. 275-299.
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- Du Plessis, P and Maree, JP (1993) Neutralisation of acid water in the chemical industry with limestone. *Proc. 3rd Int. Conf. on Waste Manage. in the Chem. and Petrochem. Ind.*, Salvador, Bahai, Brazil. 20-23 October.
- Du Preez, HH, Steenkamp, VE and Schoonbee, HJ (1993) Bioaccumulation of zinc and lead in selected tissues and organs of the freshwater crab *Potamonautes warreni*. *The Sci. of the Total Environ.* **134** 8 pp.
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- Everson, CS (1993) Proposed model structure to simulate evaporation from a grassland catchment. Paper presented at Workshop on the Field Water Balance in the Modelling of Cropping Systems, Univ. of Pretoria. 28 June - 1 July.
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- Kiker, GA, Lecler, NL and Schulze, RE (1993) Simulated maize and sorghum yields in the Rust de Winter-Libangeni region. Report to E Butler. 12 pp.
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- Le Roux, GJ, Cloot, A, Schoombie, SW, Pieterse, AJH and Roos, JC (1993) Modelling of silicon uptake by diatoms in the middle Vaal River. Paper presented at Annu. Conf. of the South. Afr. Soc. of Aquat. Sci., Johannesburg. July.
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