Water Research Commission

Knowledge Review

2001/02

water */'wɔ:te/ n. & v.* •*n.* **1** a colourless transparent odourless tasteless liquid compound of oxygen and hydrogen. Chem. formula: H_2O. **2** a liquid consisting chiefly of this and found in seas, lakes, and rivers, in rain, and in the fluids of living organisms. **3** an expanse of water; a sea, lake, river, etc. **4** (in *pl.*) part of a sea or river (*in Icelandic waters*). **5** (often as **the waters**) mineral water at a spa etc. **6** the state of a tide (*high water*). **7** a solution of a specified substance in water (*lavender-water*). **8** the quality of the transparency and brilliance of a gem, esp. a diamond. **9** *Finance* an amount of nominal capital added by watering (see sense 10 of *v.*). **10** (*attrib*) **a** found in, on, or near water. **b** of, for, or worked by water. **c** involving, using, or yielding water. **11 a** urine. **b** (usu. in *pl.*) the amniotic fluid discharged from the womb before childbirth. •*v.* **1** tr. sprinkle or soak with water. **2** *tr.* supply (a plant) with water. **3** *tr.* give water to (an animal) to drink. **4** *intr.* (of the mouth or eyes) secrete water as saliva or tears. **5** *tr.* (as **watered** *adj.*) (of silk etc.) having irregular wavy glossy markings. **6** *tr.* adulterate (milk, beer, etc.) with water. 7 tr. (of a river etc.) supply (a place) with water. **8** *intr.* (of an animal) go to a pool etc. to drink. **9** *intr.* (of a ship, engine, etc., or the person in charge of it) take in a supply of water. **10** *tr. Finance* increase (a company's debt, or nominal capital) by the issue of new shares without a corresponding addition to assets.

The Concise Oxford Dictionary Ninth Edition

Water Research Commission

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Water Research Commission

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Contents

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Chapter 1

Introduction

Dr R Kfir

The establishment of the Water Research Commission (WRC) in 1971 was an innovative response to the then current needs of the country. In the ensuing 30 years the WRC has made notable contributions to achieving mobilisation and development of research expertise over a wide range of disciplines. An important spin-off has been the significant expansion and upgrading of expertise in the South African water industry.

Internationally it has received acclaim for its many achievements and has moved into a position of acceptance and respect, which creates real potential for collaborative ventures.

Since 1994 a new focus has been required in terms of the socio-economic, technological and political challenges posed at a national level and the period 1994 to 2001 ushered in a phase of new thinking and new policies which paved the way for the substantial changes required in order to ensure sustainable growth and relevance .

The 15-month period under review has been an eventful one, with many changes to the way things had been done before, resulting in a comprehensive turnaround for the WRC. This process is continuing as the WRC is positioning itself to achieve its primary objective, which is to serve the nation as a dynamic hub for water-centred knowledge, innovation and intellectual capital as well as to provide leadership for research and development (R&D) through the support of knowledge creation, transfer and application.

Through its various funding- and networking-based activities and by aligning itself with national priorities and presidential imperatives, the WRC aims to engage stakeholders and partners in solving water-related problems which are crucial to South Africa's sustainable development and economic growth, while assisting in positioning the country in the African Continent through the WRC's involvement in the New Partnership for Africa's Development (NEPAD).

The new strategic direction of the WRC focuses on:

- An integrated approach to meeting South Africa's societal/water sector R&D needs
- Integrated solutions to invariably complex, interdisciplinary problems
- Ongoing strategic identification of needs (short-, medium- and long-term needs, both explicit and implicit)
- A set of key strategic areas (KSAs) for investing in knowledge creation, transfer and dissemination.

In order to meet the challenges ahead, a sound organisational basis is required and the following strategic initiatives have been launched and are well under way.

Restructuring and Transforming the Organisation

The key to this transformation is being relevant and effective and supporting both the creation of knowledge (by funding R&D) and the transfer and dissemination of the created knowledge.

- In order to improve efficiency and competitiveness to strengthen its local and international position as South Africa's water-centred knowledge hub, the WRC core competencies were re-visited and transformed by re-aligning and re-grouping the water research and dissemination components. Of the WRC's portfolio of 18 research fields, the field addressing ***Hydraulics*** has been closed and the current projects have been re-allocated to linking fields. These 17 fields have been re-grouped into 4 water-centred key strategic areas (KSAs), focusing mainly on knowledge creation. In addition one knowledge-centred KSA was added. This KSA will address the need for an integrated knowledge-management approach and will focus on knowledge dissemination, technology transfer and information management.

  The 5 KSAs are:
  - Water Resource Management
  - Water-Linked Ecosystems
  - Water Use and Waste Management
  - Water Utilisation in Agriculture
  - Water-Centred Knowledge

While each of the KSAs is unique and mutually exclusive (minimal overlaps), they collectively attempt to cover the complete spectrum of water-related topics of strategic importance. A crucial characteristic of a KSA is its *modus operandi*. In order to function effectively, each of the KSAs is aligned with the WRC's mission and vision having a clear business plan and forming an impact area where output and impact may be assessed. Each of the KSAs addresses a distinct research portfolio and provides for pilot or seed investigations, R&D projects/programmes and capacity-building initiatives. The KSAs also aim to support technology transfer, commercialisation and pilot implementation projects as well as other knowledge dissemination drives. They are headed at director level by top-level scientists/ engineers who are also successful research managers.

- The new strategy of the WRC, with its KSAs forming strategic portfolios of investment in the creation of knowledge, also calls for specific mechanisms to address key strategic issues of national importance. These issues will be dealt with in a number of crosscutting domains which will form integrating frameworks across the KSAs.

  The crosscutting domains will support programmes and projects which address the key issues within the portfolio of each KSA and also drive specific programmes/projects that are overarching and relate to all KSAs in a general manner.

  The crosscutting domains which aim to build focus on the role of water with regard to major strategic issues are the following:

  - Water and Society
  - Water and the Environment
  - Water and the Economy
  - Water and Health.

- Dissemination of knowledge requires an appropriate, sustainable knowledge base that will be effective in its ability to absorb new knowledge. The WRC aims to support and develop a representative, sustainable water-related knowledge base (intellectual capital) in South Africa. This includes all necessary competencies and capacity vested in the corps of experts and practitioners within academia, science councils, other research organisations, government (central, provincial and local) and the water industry.
- The WRC financial year was aligned to that of the State, in terms of the promulgation, by Government, of the Public Finance Management Act (PFMA).

The transformed operational activities officially commenced on 1 April 2002.

Capacity / Competence Development

The WRC supports the transformation of South Africa's water-related knowledge base (i.e. the water-related expert and practitioner portfolio in terms of race, gender, age and sustainability) in academia, science councils, other research organisations, Government (central, provincial and local) and the water industry.

Overall, there is a clear trend of increased involvement of designated individuals in academic and governmental institutions while the transformation of the water industry still shows a relatively low level of progress. At an organisational (academic) level, a number of historically disadvantaged institutions (HDIs) have, during the past decade, developed a significant capacity/competence in certain aspects of water-centred R&D. Examples are the Universities of Venda, Fort Hare and Western Cape as well as a number of technikons such as the Peninsula Technikon and the ML Sultan Technikon.

Innovation / Application of Knowledge

The WRC aims to provide the country with applied knowledge and water-related innovation by translating needs into research ideas and by transferring research results and new technology-based products and processes to the end-users.

The WRC is committed to improving the strategic management of innovative research and strives to increase the commercialisation of intellectual property (IP), generating wealth (in South Africa) as well as increasing the income stream to the WRC for further investment in R&D. Two WRC directors have recently attended a course addressing IP management issues and will support the organisation's drive in this regard.

Women in Water Awards

In order to recognise the role that women play in water management in South Africa, the WRC, the Department of Water Affairs and Forestry and the Water Institute of South Africa (WISA) have jointly developed the *Women in Water Awards*. This initiative aims to honour and celebrate the hard work of women, to highlight their participation in water management and the key role that women play with regard to water and poverty eradication, education and sustainable development both in rural and urban environments.

The launch of the *Women in Water Awards* in 2002 marked the beginning of an important

tradition in the water sector in South Africa. Each year during Water Week, awards will be presented to women who have played leading roles in five categories:

- Research (over 35 years old)
- Research (under 35 years old)
- Policy
- Management
- Community Development

At a gala event on 19 March 2002, the Minister of Water Affairs and Forestry, Mr Ronnie Kasrils, presented the first awards to the following women:

- Prof Carolyn Palmer, Institute for Water Research, Rhodes University, Grahamstown
- Dr Heather McKay, CSIR, Pretoria
- Ms Mapula Lebone, Tsinde Development Consultants
- Ms Marthie Janse van Rensburg, Trans-Caledon Tunnel Authority
- Ms Marna de Lange, IWMI
- Dr Robyn Stein, Bowman & Gilfillan Inc.
- Ms Janet Love, Reserve Bank
- Ms Ma-Tshepo Khumbane
- Ms Ethne Davey, Built Environment Support Group
- Ms Buyelwa Sonjica, Portfolio Committee
- Ms Nosipho Jezile, Working for Water
- Ms Makwena Lydia Ngwenya, Portfolio Committee
- Ms Mavis Sibetha, Working for Water, KZN
- Ms Nondyebo Taki, Working for Water, Gauteng

Marketing the WRC

During the past 15 months, the WRC formally exhibited at the following events:

- 21-22 May 2001
  Consultative Group of International Agricultural Research (CGIAR), Durban
- 11-13 September 2001
  13th Biannual Congress of the SA Irrigation Institute (SABI), Warmbaths
- 22-26 October 2001
  65th Annual Conference of the Institution of Municipal Engineering of Southern Africa (IMESA), Rustenburg
- 21-23 November 2001
  Conference on Appropriate Technology for Sustainable Water Supply and Sanitation Services, Muldersdrift
- 3-8 March 2002
  Environmental Flows for River Systems & 4th International Ecohydraulics Symposium, Cape Town
- 25-26 March 2002
  Workshop on the Protection and Strategic Uses of Groundwater Resources of the Trans-Boundary Limpopo Basin and the Drought-Prone Areas in the SADC Region, Centurion, Pretoria

In an attempt to introduce the WRC to non-research groups in South Africa, the organisation also participated in the following special publications:

- The WRC developed and edited an edition of *Archimedes* specifically addressing water (in co-operation with the Foundation for Education, Science and Technology, FEST). Copies of this youth magazine were distributed to all high schools during Water Week in March 2002.
- A number of articles addressing the role of the WRC were published in the technical and daily press (e.g. *Engineering News*, *Water 21*, *SA Irrigation*, various newspapers), both locally and internationally.

Table 1
Allocation of funds (%) per research field during 1999, 2000 and 2001/02

Field	1999		2000		2001/02	
	Past and present budgets					
	R	%	R	%	R	%
Water policy	2 308 624	4.8	2 487 100	4.0	1 970 680	3.3
Integrated water resource management	4 486 491	9.3	5 051 000	8.1	3 691 500	6.2
Conservation of water ecosystems	5 262 048	10.9	6 528 800	10.5	5 993 550	10.1
Catchment hydrology	2 906 207	6.0	3 328 400	5.4	2 829 200	4.7
Groundwater	4 370 655	9.1	4 971 500	8.0	4 552 670	7.7
Hydroclimatology	2 309 400	4.8	3 314 400	5.3	3 643 800	6.2
Municipal wastewater management	2 587 897	5.4	3 528 800	5.7	4 260 900	7.2
Water quality management	2 915 700	6.0	2 640 400	4.3	2 658 500	4.5
Mine-water management	4 371 700	9.1	4 109 800	6.6	3 371 000	5.6
Agricultural water management	5 012 129	10.4	5 779 100	9.3	5 240 180	8.9
Industrial water management	3 569 920	7.4	3 962 900	6.4	4 761 100	8.1
Membrane technology	2 634 692	5.5	3 036 700	4.9	3 553 800	6.1
Hydraulics	1 376 850	2.9	2 243 400	3.6	1 276 400	2.2
Rural water supply and sanitation	-	-	2 796 900	4.5	1 962 100	3.3
Water services: Institutional and management issues	-	-	2 342 900	3.8	2 583 600	4.4
Integrated urban water management	-	-	1 317 400	2.1	1 819 100	3.1
Potable water treatment	4 147 965	8.6	2 485 800	4.0	2 511 700	4.3
Health-related water issues	-	-	2 143 800	3.5	2 385 600	4.1
	48 260 278	100	62 069 100	100	59 065 380	100

Distribution of Funds among Research Fields

An overview of WRC funding per research field for 1999, 2000 and 2001/02 is given in **Table 1** and **Table 2** lists the research sectors which were responsible for the research during 2001/02, as well as the extent of their involvement. **Table 3** gives a breakdown of organisations receiving funds from the WRC during 2001/02.

From the tables it is evident that universities are involved in 156 or 51.49% of the total number of contracts. During this period under review the WRC financially supported 303 projects at a budgeted amount of R59 065 380 and 118 deliverables for projects were accepted by the WRC Executive.

Table 2
Research sectors responsible for the research during 2001/02

Research sector	Number of times involved	%
Universities	156	51.49
Private consultants	64	21.12
Science councils	49	16.17
Water boards	13	4.29
Technikons	11	3.63
Industry	4	1.32
Local authorities	2	0.66
Government	2	0.66
NGOs	2	0.66
Total	303	100

TABLE 3
Breakdown of organisations receiving funds from the WRC during 2001/02

	No of projects	2001/02 R		No of projects	2001/02 R
Agricultural Research Council	11	1 519 000	Palmer Development Group	2	111 200
Abbot Grobicki (Pty) Ltd	1	150 000	Palmiet CMP	1	28 000
Afridev (Pty) Ltd	1	351 400	PARC Scientific	1	218 700
BKS (CE) Ltd	3	121 500	Partners in Development	1	161 100
Business Partners for Development (BPD)	1	396 000	Peninsula Technikon	1	202 000
Cape Technikon	1	105 000	Prestedge Retief Dresner Wijnberg (CE)	1	88 200
Chamber of Mines	1	385 700	Potchefstroom University for CHO	4	760 700
Chris Swartz Utilisation Engineering	2	198 400	Pula Strategic Resources	1	332 400
Africon Engineering International	1	275 000	Pulles Howard and de Lange Inc.	4	971 600
Coaltech 2020	1	365 000	Rand Afrikaans University	1	195 000
Conningarth Consultants	1	110 500	Rand Water	5	1 098 700
Council for Geoscience	5	693 200	Rhodes University	20	3 909 900
CSIR	31	4 844 000	SA Weather Bureau	2	825 900
DB Thermal (Pty) Ltd	1	119 000	The Association of Water Boards	1	350 000
Development, Planning and Research	2	405 900	Semenya Furumele	1	200 000
Dinax Technologies cc	1	226 400	Sigma Beta (CE)	1	30 000
Du Pisani and Associates	1	139 300	Sigodi Marah Martin Development Consultants	2	544 500
Durban Metro Water Services	1	300 000	Sineke Developments (Pty) Ltd	1	273 500
DWAF	2	291 400	Southern Water Research and Ecological Consulting cc	1	273 000
Economic Project Evaluation (Pty) Ltd	1	124 500	SRK (CE) Inc	2	493 500
Ecosun cc	1	260 000	Stewart Scott (Pty) Ltd	3	839 800
Envirogreen and Freegold	1	35 700	Technikon Northern Gauteng	1	260 000
Eskom	2	276 000	Technikon Natal	2	373 700
Geohydrological and Spatial Solutions	1	79 670	Technikon SA	2	242 500
Greater Johannesburg Metropolitan Council	1	150 000	University of Cape Town	21	3 901 800
Envirogreen and Freegold	1	124 400	University Durban Westville	1	340 000
Highveld Biological Association	1	99 000	University of Fort Hare	15	2 400
Independent Economic Researchers cc	1	111 200	University of Natal	27	7 837 050
Innovative Water Solutions (Pty) Ltd	1	98 000	University of the North	2	435 700
In-Touch Community Development and Project Management	1	61 500	University of the Free State	15	2 419 480
Lenehan Engineering and Environmental Consulting	1	132 200	University of Port Elizabeth	7	1 026 000
MBB (CE) Inc	1	315 300	University of Pretoria	17	3 197 700
McIntosh Xaba and Associates	1	68 000	University of Stellenbosch	18	3 572 800
McCracken Solar Stills (Pty) Ltd	1	75 300	University of Venda	3	316 400
Metago Environmental Engineers (Pty) Ltd	1	335 300	University of the Western Cape	10	1 849 900
ML Sultan Technikon	4	546 000	University of Zululand	4	753 900
Market Survey and Statistical Analysis	1	271 580	Umgeni Water	7	946 900
Mvula Trust	2	394 900	Vista University	1	24 800
NCE cc	1	452 800	Wates, Meiring and Barnard (CE) Inc	1	25 600
Ninham Shand (Pty) Ltd	4	972 800	WITS University	4	724 600
Options to Solutions	1	110 000	WRP (Pty) Ltd	1	75 000
Pipeline Performance Technologies	1	192 000	Water Systems Management	1	226 000
PAA Ramsden Private Consultant	1	45 500			

The transformed operational activities officially commenced on 1 April 2002 and the* Knowledge Review *before you covers the 15-month period up to 31 March 2002 and presents a 2001/02 strategic overview and specific examples where research has led to improved technology, decision-making and operational management in terms of the current 18 research fields.

Chapter 2

Rural Water Supply and Sanitation

Dr NP Mjoli

Scope

Research in this field is focused on providing information necessary to support sustainable delivery of water and sanitation services to rural areas. "Rural" is defined as those areas with the lowest level of services and the greatest distance to the nearest service points. Rural areas include large-scale farming areas, most of the former homeland areas and several municipalities with limited or no potential to raise taxes sufficiently to meet the costs of basic services. Research in this field addresses technical, economic, social and institutional issues that are necessary to ensure that rural communities have access to safe and adequate water and sanitation services. Research supported within this field includes development of decision-support tools, preparation of guidelines and evaluation of appropriate technologies that are suitable for rural areas.

Rural Water Supply and Sanitation was established as a separate research field in 2000. Prior to this all research on development issues was under the field of ***Developing Communities***. In 2001/2 fewer projects were received because a new strategic plan was being developed (see Table 1 for investment in this field).

Links to Key Strategic Areas (KSAs)

Rural Water Supply and Sanitation has links to the following of the WRC's KSAs:

Water Resource Management

Demand management and water conservation at the domestic supply level impacts on water resource management. Effective demand management will reduce the need for the development of new water resources.

Water-Linked Ecosystems

Negative impacts such as discharge of untreated wastewater from domestic use can be detrimental to ecosystems. Water supply provision must be linked to environmentally friendly methods of ensuring that wastewater is treated adequately before discharge to water resources. Lack of poor sanitation poses a serious problem to the health of aquatic ecosystems. Therefore research in this field is supporting the delivery of safe sanitation services, i.e. safe disposal of human excreta.

Water Use And Waste Management

All of the research undertaken in this field falls within this KSA.

Water Utilisation in Agriculture

This field is indirectly linked through limited research to promote use of water for community gardens as a contribution to poverty reduction.

TABLE 1
Investment in **Rural Water Supply and Sanitation**

	1998	1999	2000	2001/02
Expenditure (total or committed)	-	-	R2 796 900	R1 962 100
% of research fund	-	-	4.51%	3.34%

Objectives

Primary

To support sustainable water and sanitation service provision for rural communities in South Africa. (Sustainable means that the infrastructure continues to provide quality service over time). Other important factors necessary to achieve sustainable water and sanitation services include community involvement, cost recovery, effective operation and maintenance, affordability and willingness to pay for water and sanitation services.

Secondary

- Effective institutional arrangements and support for water service delivery.
- Options for financing mechanisms for infrastructure projects.
- Development/evaluation of appropriate technology options for rural water supply and sanitation.
- Health and hygiene promotion for rural communities.
- Development of decision-support tools for local authorities and water service providers.

Research Projects

Portfolios of completed, current and new projects, which directly address the above-mentioned objectives, are presented below.

Completed

Guidelines on appropriate technologies for water supply and sanitation in developing communities

Environmentek, CSIR
(WRC Reference No 520)

The following guideline documents were produced by this research project:

- *Groundwater Exploitation, Use and Conservation*: This guideline document describes the occurrence of groundwater in nature and the approaches and methodologies applied to abstract groundwater as a water supply source.
- *Primary Health Care through Improved Water Supply, Sanitation and Community Education*: This guideline document describes the health impacts of water supply and sanitation, including disease transmission routes. It addresses the planning and implementation of a targeted health and hygiene education in a community.
- *Springs and Spring Protection*: This guideline document deals with the occurrence of groundwater at the near surface and the occurrence of springs. Different options for the development and protection of the spring source are described and the ongoing maintenance requirements are also addressed.
- *Small- Scale Desalination*: This guideline document describes the different types of problem salinity found in water, and the different options for treatment of these waters. These range from the relatively sophisticated technologies of reverse osmosis and electrodialysis to the age-old technique of solar distillation.
- *Pumps and Pumping Systems*: This guideline document describes the different types of pumps, the different energy sources that can be employed for pumping and the requirements of different pump installations. It also describes the methodology for selecting a pump for a particular application and proposes an operation and maintenance programme for different pumps.
- *Sanitation for Rural Communities*: This guidebook targets community leaders. It gives a description of different types of sanitation technologies that could be adopted.

Cost: *R430 000*
Term: *1993 - 1997*

Assignment of a financial cost to pollution from sanitation systems with particular reference to Gauteng

Department of Civil Engineering, University of Witwatersrand
(WRC Reference No 631)

This project developed a methodology for assigning financial cost of pollution from sanitation systems. The following costs were taken into consideration:

- Costs of surface water treatment
- Maximum additional cost of surface water treatment to deal with poor quality raw water
- Cost of groundwater treatment
- Cost of provision of different levels of service of water supply and sanitation in Gauteng in 2000.

This costing exercise showed that even conservative estimates of additional treatment costs assigned to pollution from sanitation systems are still less than half the cost difference between basic and full levels of service for water and sanitation.

Cost: *R155 000*
Term: *1994 - 1996*

A socio-biological study of the aquatic resources and their utilisation in an underdeveloped rural region, the Mutshindudi River catchment

Department of Zoology, University of Venda
(WRC Reference No 714)

The study addressed the following aspects of the Mutshindudi River catchment:

- *A socio-economic study of the inhabitants of the catchment*: Most communities did not have access to basic water supply and sanitation. Despite poor access to basic services, the incidence of water-borne diseases was relatively low; however, there was a high incidence of bilharzia.
- *Existing water reticulation network*: Almost all the villages in the catchment were experiencing problems with the existing water reticulation network that could not meet the increasing water demand due to the population increase.
- *The utilisation of riparian plants in the catchment*: It was shown that at least 31 species of riparian plants were utilised for firewood, fence construction, furniture manufacturing, medicinal purpose and as a source of food.
- *Fish as a resource in the catchment*: Most of the households carry out fishing on a regular basis; the annual fish harvest from the river is estimated at 2 500kg.
- *Agricultural water use in the catchment*: Agriculture is the main economic activity; the most common activities include traditional cattle farming, rain-fed orchards and irrigated agriculture.
- *Cultural importance of water*: Water sources such as Phipidi Waterfall are considered to be sacred and they are associated with supernatural beings. There are symbolic references at an abstract level to water rebirth throughout the vast array of cultural and religious beliefs and practices within the catchment.
- *Chemical quality of the river*: Concentrations of various chemical parameters were within acceptable levels; the water is relatively soft with a low concentration of dissolved solids.
- *Microbial quality of the river*: The faecal coliform counts of water from the river did not comply with standards of the World Health Organisation; this is due to poor sanitation in the catchment.
- *The structure and composition of plant communities in the catchment*: A total of 645 species belonging to 112 plant families were recorded. Noxious weeds were found to be a problem that requires urgent attention.
- *Fish distribution*: Natural fish distribution was mainly affected by temperature, geomorphology and habitat preferences. Species richness increased with a decrease in altitude and the highest number of species was recorded near the confluence of the Mutshindudi and Levubu Rivers.
- *Niche differentiation in rheophilic fishes*: The fish species found could be divided into three distinct groups, namely, relatively short gut length associated with carnivory and long guts associated with detritivory and herbivory
- *An index of biotic integrity based on rheophilic fish species*: Application of the biotic index indicated that the river was severely degraded due to siltation, increased turbidity and destruction of habitats as a result of overgrazing, cultivation, removal of riparian vegetation and disturbance of river banks.
- *The avifauna of the catchment*: A total of 125 bird species was recorded of which 110 species could be linked to a specific habitat. Significant differences were found between the occurrence of indicator species at different sites. The highest species richness was found in the upper catchment; this suggests that the quality of water in this part of the catchment was still good.

Cost: *R359 000*
Term: *1995 - 1998*

Sustainability and affordability of community-based integrated waste and wastewater management for dense informal urban settlements

SRK (CE) Inc
(WRC Reference No 767)

The project team experienced severe problems in securing resources to demonstrate through pilot projects opportunities for community-based water and waste management in the protection of the settlement environment and community health. The WRC approved a change in focus to grey-water management in dense informal urban settlements. The study showed that grey-water management was a common problem throughout South Africa, it was found in all categories of dense informal settlements. This problem was due to the failure to provide, operate or efficiently maintain the basic services such as water supply, sanitation, solid waste and stormwater management. The study provides guidelines for assisting communities and service providers in selecting technologies and management opportunities to suit the communities' need and affordability; the focus is on limiting the negative impacts of grey-water on the environment.

Cost: *R90 000*
Term: *1996 - 1999*

Application of visual settlement planning (ViSP) computer software applications technology in South Africa: Building the capacity of local communities in urban development

Department of Civil Engineering, University of Cape Town
(WRC Reference No 786)

Community participation at a local level is an essential component of sustainable urban development, but it is constrained by several factors, the most important of which is the lack of capacity at this level. An important contribution would be the use of technological advances in computer software for interactive decision-making. The goal should be the creation of innovative interfacing systems, which can then be used as tools in the interaction between development professionals and community organisations. These should be designed to simplify and contextualise the issues which are central to the decision-making process.

The research proposed investigated the potential applications of ViSP technology as a tool in participatory planning and design, exploring the way in which the technology could be made readily available to practising engineers and planners working in the field, to NGOs, and to CBOs.

The main results of this study are captured in two reports, with the emphasis of outputs emanating in guidelines. Therefore, in assessing and analysing the experience of and the use of ViSP technology in Brazil and determining its relevance to South Africa, the following observations were made:

- In Brazil urban population growth rates have declined since the 1960s, whereas in South Africa they are increasing and only expected to drop beyond 2005. The level of urbanisation in both countries is projected to continue.
- The current level of urbanisation in Brazil would imply that poverty is already spatially concentrated in urban areas, although it is generally understood that the worst living conditions still prevail in rural areas. In South Africa it is still concentrated in rural areas (75% of population).
- The statistics indicated that South Africa can expect, to a large extent, to follow the demographic trend of Brazil, with an increase in the concentration of both population and poverty in large urban centres. Further, there are parallels between the socio-economic conditions and levels of inequality in Brazil and South Africa. This has an impact on housing situations, which is similar.
- There are two approaches to upgrading. The first of these is fully community-driven upgrading. Experience from Brazil, however, coupled with an analysis of what it is that makes such projects successful, would indicate that it is unlikely to cope with the complexity of upgrading in a South African context. The alternative is to embark upon an integrated methodology, such as that developed in Belo Horizonte. Like community-based upgrading, this approach has been shown to be viable in specific areas. However, it too has serious problems, related in the main to the availability of adequate finance. This is a limiting factor in South Africa, where the housing subsidy is already over-extended and likely to be reduced over time. Furthermore, the South African situation tends to demand a greater level of community involvement, at the point of implementation, than in the case in Belo Horizonte. Nonetheless, there is much that can be learnt from this experience and applied in South Africa, both in terms of technical experience and organisational relationships (particularly those between local government and community).

In general terms, however, it would appear that the most appropriate approach to *in situ* upgrading in South Africa is one which combines the best features of both of these approaches. Thus the specific approach that was pioneered in Belo Horizonte in Brazil can be applied in South Africa, provided that it is modified to suit local conditions and to integrate the important elements of the community-driven process.

Cost: *R437 000*
Term: *1996 - 1998*

Field evaluation of alternative disinfection technologies for rural water supply projects

Division of Water Environment and Forestry Technology (Water Supply and Sanitation Programme), CSIR
(WRC Reference No 828)

This project sought to assess the performance of alternative disinfection systems that have been installed in rural or small community water supply systems. It further assessed what training, information and institutional support systems are required to ensure that these systems operate effectively. Finally the operational costs associated with each of the systems were investigated.

An important finding is that the disinfection system cannot function satisfactorily on systems where the level of maintenance and care-taking is low, and hence where breakdowns on the total water supply system are common and are not rapidly repaired. Longer term evaluations of installation, and on-site disinfection systems, installed in small communities in the Free State, where the level of operation and maintenance is significantly higher, will continue.

Cost: *R336 000*
Term: *1997 - 2000*

Decision support systems for the development of rural water supply schemes

Institute for Water Research, Rhodes University
(WRC Reference No 837)

The work undertaken in this project has resulted in the development of two interlinked products for use in practical application. These are:

- A generic decision support system (DSS) shell written in Delphi to provide an environment in which to create and develop any decision support system,
- A rural water supply DSS. The rural water supply DSS provides a step-by-step approach in rural water supply system design and operation. It has 6 main components:
  - Water supply project context
  - Feasibility studies
  - Detailed survey
  - Training
  - Budget, and
  - Business plan.

Each component is comprehensively addressed in the DSS. The rural water supply DSS was tested through a field study application.

Cost: *R380 000*
Term: *1997 - 1999*

Incorporation of water, sanitation, health and hygiene issues into Soul City, a multimedia edutainment vehicle

Soul City
(WRC Reference No 981)

The study investigated the feasibility of using 'edutainment' which combines learning with entertainment as a vehicle for promoting health and hygiene awareness. The study showed that mass media alone were not suitable for addressing health and hygiene at a national level. However, it could be part of an auxiliary strategy to support local level initiatives that are geared to address health and hygiene issues in a local context. It also showed that educational programmes around health promotion should adopt participatory strategies which are sustainable and dynamic in order to contribute to changed attitudes and behaviour. The local context of many water and sanitation problems, and the fact that people's health and hygiene behaviour depend on availability of water and sanitation infrastructure limit the prominent role of mass media in health and hygiene promotion. The multimedia edutainment vehicle can play a role in raising awareness about those water and sanitation issues that have a wider relevance.

Cost: *R100 000*
Term: *1998*

Community management of natural, human and financial resources relating to basic water supply projects

Lynette Dryer and Associates
(WRC Reference No 996)

Project 996 was finalised with a recommendation that the report not be publicised or highlighted.

Cost: *R140 000*
Term: *1999*

Assessment of the attended coupon-operated access-point cost-recovery system for community water supply schemes

Lima Rural Development Foundation
(WRC Reference No 1052)

The most severe constraint to sustainability of water supply and sanitation schemes is poor cost recovery. Cost recovery includes paying for services, that is capital costs and operation maintenance costs of schemes. When there is adequate cost recovery, a relationship between the water services provider and its customers is developed. Since services are paid for by the community, more reliable services are provided.

In order to improve cost recovery, a number of techniques and systems have been developed and applied. These range from tariffing, billing, prepayment systems through to the Mashakane Campaign. Prepaid systems (both mechanical and electrical), and many other systems have been applied as a quick-fix solution to non-payment. Many of these systems have had limited success and one of the reasons for this is that they were not well researched before implementation. The conventional modern technology prepayment systems have received greater support from local authorities, than from the consumer or communities.

Hence, this study assessed mechanical prepaid systems, in the form of the Attended Coupon-Operated Access-Point Cost-Recovery System, for community water supply schemes. Findings from the study highlight and indicate that:

- Coupon-attended systems still have some clear advantages in that they are cheap to install, contain a strong human element, ensure community participation, provide cash income for a number of community members and are easily adapted. This system's major detraction is that in order to be effective, it has to be accompanied by a high level of control and administrative discipline. This is, however, a necessary requirement on all water projects.
- The public standpipe will continue to play an important role in providing water to poorer rural families. For this reason an effective system of cost recovery at the public standpipe needs to be found.

The research team is of the opinion that a flat rate system is not only inequitable, but there is no way of preventing abuse and the "free rider" problem. This leaves the attended coupon system and ADUs as the only alternatives.

Cost: *R137 874*
Term: *1999 - 2000*

A pilot environmental and social baseline study for rural water supply and sanitation

Bumba Research and Human Development Consultancy
(WRC Reference No K8/304)

The main objective of this study was to develop a methodological model for conducting environmental and social baseline assessments for rural water and sanitation projects. The study showed that placing emphasis on participation and capacity building was necessary to gain the support of all tiers of government. The study also assessed community governance, this included community structures, decision-making processes, community participation, communication and interactions amongst structures of local governance. The baseline study collected data on physical location, topographic conditions, climatic conditions, settlement patterns and land-use patterns. The study through the exploration of the broader context of project planning and management for basic water supply projects identified the problem of poor service delivery by the implementing agencies. Poor infrastructure and lack of capacity made it difficult for local government to perform its function of service delivery efficiently.

Cost: *R99 275*
Term: *1998*

Current

Pollution of domestic water supply and health-related problems in the rural areas of the Molopo region of the Northwest Province

Departments of Nursing Science, Chemistry and Agriculture, University of the North West
(WRC Reference No 724)

Aims:

- To determine water sources of a selected number of villages in the Molopo region
- To determine the extent of pathogenic pollution of these sources
- To obtain the opinion of residents regarding the relationship between water supply and ill-health
- To undertake intervention and self-help projects for the protection of water sources and household water use.

Estimated cost: *R253 332*
Expected term: *1996 - 1998*

Handbook of water disinfection processes

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 770)

The aims of the project are to produce a handbook that:

- Describes water disinfection processes, principally chlorination and chloramination but including ozonation, peroxone, chlorine dioxide and ultraviolet treatments
- Is understandable by non-specialists in water treatment plants and informed lay-persons
- Can be used as an aid in effective education and training of plant personnel while avoiding detailed chemistry
- Can be used as a ready reference for daily use on water purification plants where disinfection is implemented.

Estimated cost: *R78 000*
Expected term: *1996 - 1997*

Reliability of small spring water supply systems for community water supply projects, and the enhancement of flows from springs

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 859)

In the eastern parts of South Africa many small-scale rural water supply schemes have been based on protected springs. This projects aims to determine the factors affecting the flow from small springs with potential for use as water supplies to rural communities and to evaluate spring protection and flow enhancement

techniques for their effectiveness and practicality.

Estimated cost: *R650 000*
Expected term: *1997 - 2001*

Development of guidelines for the management of rural groundwater resources

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 861)

Groundwater has been recognised as a very important water resource in the more remote rural areas of South Africa. This research project investigates the design and implementation of an affordable community-driven groundwater management scheme which would secure a water supply to the community over a long term and create a sense of ownership of the resources.

Estimated cost: *R310 000*
Expected term: *1997 - 2001*

Development of a framework for the calculation of a monthly tariff payable in stand-alone community water supply schemes

Mvula Trust
(WRC Reference No 886)

The operation and maintenance requirements for rural community water supply schemes differ considerably from schemes in urban areas which are operated by large water utilities. Further, it is important for planners to take into account the rural environments with limited employment opportunities, with many local residents depending for their livelihood on money which comes from migrant relatives in cities. This project is to determine the factors which constitute the monthly running costs of rural water supply schemes that are necessary to ensure sustainable operation and maintenance. This study is also developing a financial framework that will provide planners and water service institutions with guidelines on basic monthly running costs for these schemes.

Estimated cost: *R378 000*
Expected term: *1998 - 2001*

Fog-water collection: Implementation of an operational prototype system

Department of Geography, University of the North
(WRC Reference No 902)

A prototype fog-water collection screen, installed at a rural school in the Northern Province, is being evaluated in terms of quantity and quality of water delivered to meet the total water supply needs of the school.

Estimated cost: *R500 000*
Expected term: *1998 - 2001*

Water-supply management for small communities: Development of expert-systems-based decision-support software and a guidelines manual

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 962)

In South Africa, the problem of limited expertise in disciplines related to potable water, wastewater treatment and the environment, makes it necessary to find ways of making information accessible to those who lack specialised training in waste and water resource management. This study is developing expert-systems-based decision-support software that provides information on cost-effective water treatment options for small communities and also planning and design guidelines for small water-supply systems. The software will be used by rural local authorities who lack access to technical expertise.

Estimated cost: *R500 000*
Expected term: *1998 - 2001*

Continuous flow air-lift groundwater pump for rural applications

Green Energy Systems cc
(WRC Reference No 976)

This is a follow-up project to a WRC funded study that developed and tested a new pumping mechanism that utilises compressed air as an energy source. This study produced the prototype that performed adequately. In this follow-up study, the efficiency of the pumping mechanism is being investigated under a number of actual field conditions. These tests were preceded by the development of a design modification to provide for the possibility of a water source running dry. Six experimental installations serving actual informal settlements have been commissioned to allow monitoring of the pump performance under these conditions.

Estimated cost: *R352 000*
Expected term: *1998 - 2001*

Capacity-building and training needs of district councils and transitional rural councils in the management of community water and sanitation services in the Eastern Cape

Department of Development Studies, University of Fort Hare
(WRC Reference No 991)

Most rural municipalities have limited or no capacity to meet their constitutional obligation of providing basic services to communities they serve. Therefore, there is a need to investigate the capacity-building needs of these institutions so that they can be empowered to play a meaningful role in the management of water supply and sanitation services. This study aims to develop a model for the management of water supply and sanitation services at a community level.

Estimated cost: *R209 000*
Expected term: *1998 - 2001*

Development of generic and sectoral competencies in the water supply and sanitation training sector

National Community Water and Sanitation Training Institute (NCWSTI)
(WRC Reference No 1020)

Since 1994 DWAF has invested large sums of money in the training of rural communities in managing infrastructure projects. Currently there is lack of training standards and no formal methods exist to assess the quality of training programmes offered. There is, therefore, a need for the development of generic and sectoral competencies that will help to avoid the present situation where numerous training consultants develop their own competencies which are based on their own assumptions and criteria. This study is developing generic, sectoral and target modular-based competencies. These modular-based competencies are designed in accordance with sectoral needs and the National Qualification Framework.

Estimated cost: *R295 000*
Expected term: *1999-2001*

Cost improvement of solar still units for general use by rural communities in remote Southern African locations

McCracken Solar Stills (Pty) Ltd.
(WRC Reference No 1032)

Internationally the use of solar stills for the desalination of brackish water has been investigated for a considerable period. In South Africa solar still units have great potential in large areas of the country, but have found limited commercial application, mainly due to the relatively high up-front cost. To make solar stills commercially viable such units should cost about R500 each. Experimental and costing investigations on alternative substitute plastic materials have shown that this price might be achievable, but attention should be paid to the environmental durability of such a still. This project, therefore, aims to develop and demonstrate affordable and durable solar still desalination batteries for the provision of sufficient freshwater to smaller sized remote communities.

Estimated cost: *R338 000*
Expected term: *1999 - 2001*

Development of small-scale ultrafiltration systems for the provision of potable water at point source

Department of Chemical Engineering, ML Sultan Technikon
(WRC Reference No 1070)

A commercialisable small membrane treatment unit is being designed and evaluated for cost-effective treatment of contaminated surface waters for the supply of potable water to small communities. Since membranes present a positive barrier to micro-organisms, require no or little chemical addition and need very little maintenance, such plants are attractive for the supply of point-of-use potable water to small communities.

Estimated cost: *R630 000*
Expected term: *1999 - 2001*

Assessing the impact of gender in water and sanitation provision and maintenance

Networks for Development
(WRC Reference No 1087)

Water supply and sanitation projects are implemented as community projects; therefore, for the projects to be successful, both men and women should participate at all stages of the project planning and implementation process. This study assesses the impact of gender in water and sanitation services provision and maintenance. The findings of this assessment are being used to develop gender-sensitive approaches that would ensure effective participation of both men and women in water supply and sanitation projects. This study together with a project focusing on policy dimension of gender participation in water supply and sanitation projects (***Water Policy Field***) are contributing to the achievement of a gender-balanced approach within the water sector.

Estimated cost: *R150 000*
Expected term: *1999 - 2001*

Developing guidelines and methodology to implement operation and maintenance in rural water supply programmes

In-Touch Community Development and Project Management
(WRC Reference No 1099

In terms of policies of the past, inadequate attention was given to the capacity of people to control and manage development projects on a sustainable basis. Infrastructure development, and even water provision was seen as a financial and technical issue. This has left a legacy of non-involvement, non-payment and neglect in service provision, especially operation and maintenance. Current initiatives have attempted to address these problems. However, it is evident that not much change in the situation has been achieved. The problem generally rests in the technocratic nature of dealing with problems that are socially orientated. The aim of the study is to identify these institutional and capacity-building constraints that affect sustainability of O&M in projects.

Estimated cost: *R200 000*
Expected term: *1999 - 2001*

Development of a methodology and guidelines for the design of community-based O&M systems based on local capacity and practice

Mvula Trust
(WRC Reference No 1130)

Evaluation studies of new water projects show that poor operation and maintenance (O&M) of water supply schemes is responsible for the high failure rate of water projects. These studies have also shown that the O&M systems that were implemented were generally unresponsive to user needs. This highlights the importance of basing the development of O&M guidelines on local knowledge. This study explores different methods that communities have used to manage their water supply schemes prior to the implementation of new water projects. This study is also documenting local knowledge and experience that would form a basis for the development of O&M guidelines

Estimated cost: *R546 000*
Expected term: *2000 - 2001*

New

Use of selected key performance indicators in the benchmarking of rural water supply schemes: An aid to development of meaningful local government capacity

Partners in Development
(WRC Reference No 1222)

Since 1994, DWAF has spent large sums of money on training water committees to manage the new water supply schemes. As projects have moved into the operational phase, it has become apparent that training alone is not adequate to ensure proper management of water supply schemes. The new local authorities have limited knowledge on the nature of inspection needed to promote good management at community level. Therefore, the challenge is to develop simple and effective systems that are easily understood by water committees. These can be used to report to the community as well as to their local authority. This project will test a set of key performance indicators (KPIs) that have already been developed. These will be tested on a number of RDP projects that are presently being transferred from Umgeni Water to relevant District Councils in KwaZulu- Natal.

Estimated cost: *R271 000*
Expected term: *2001 - 2002*

Investigation of surface water supply in typical rural communities: Case studies from the Northern Province

Ninham Shand Consulting Engineers (Pty) Ltd
(WRC Reference No 1271)

Poor operation and maintenance pose a serious threat to the sustainability of rural water supply schemes. Other key factors that determine sustainability include affordability, institutional arrangements and cost recovery. There is a need to identify factors that are responsible for the failure of rural water schemes. This information will form a basis for the development of protocols for operation and maintenance that will take cognizance of realities that are faced by rural communities. The main aim of this research project is the development of an understanding of sustainability issues in community water supply schemes with special reference to rural communities in the Northern Province. The expected research output will be protocols for ensuring appropriate O&M for rural water supply schemes.

Estimated cost: *R170 000*
Expected term: *2001 - 2002*

A cost-recovery analysis of the trickle feed rural community water supply system

Lenehan Engineers and Environmental Consulting
(WRC Reference No 1272)

This research will investigate the cost-recovery efficiency of the trickle feed system. In this system a known quantity of water is delivered each day to a storage tank at each customer's house. This allows the implementation of a monthly prepaid cost-recovery system with relatively low administration. The Mvula Trust has identified the potential benefits of implementing the trickle feed system in rural areas. It is currently implementing trickle feed systems in pilot projects in Northern KwaZulu-Natal. Analysis of the cost-recovery efficiency of these projects will enable adequate assessment of this technology for future application. The main objectives of this research are to assess cost-recovery efficiency of trickle feed systems and to identify variables that affect cost-recovery in these systems.

Estimated cost: *R176 500*
Expected term: *2001*

Outcomes to Date of Current Programmes and Projects

New knowledge

Research in this field has provided decision-support tools, development and evaluation of appropriate technology, preparation of guidelines for supporting the delivery of services to rural communities and capacity-building for local authorities and water service providers.

Decision-support tools

The development of expert-systems-based decision-support software for small water-supply schemes is at the final stage; it is currently being tested with potential users. This software has been developed using existing international and national literature on the selection of water sources and water treatment technologies.

Guidelines

Previous studies done by the WRC, DWAF and the Mvula Trust have shown that poor operation and maintenance are responsible for the failure of most rural water projects. Several projects within this field are making progress in looking at factors that are critical to effective operation and maintenance of these schemes. Lessons learned from both successes and failures are being used to prepare best practice guidelines. Progress is also being made in the development and evaluation of key performance indicators for rural water service delivery.

Research is also looking at cost-recovery which is one of the problem areas for water service institutions. However, the new policy of free basic water has added a new dimension to the challenge of cost recovery because most rural households who collect water from communal standpipes will no longer be paying for this service because their level of consumption falls within the free basic water limit of 6kℓ per month. Researchers are incorporating this issue into their current research on cost recovery.

Capacity-building for local authorities and water service providers

A study on the development of generic and sectoral competencies has produced a comprehensive database of competencies that are necessary for the water service industry. This information has already contributed to the establishment of Local Government Water Sector Education and Training Authority (LGWSETA). New information has been generated on the skills required by rural local authorities to perform their functions adequately. A need for ongoing mentoring has been identified as a key factor in sustaining capacity building.

Benefits to South Africa

- Providing rural local authorities with decision-support tools to help them improve their decision-making with regard to water service delivery.
- Information on appropriate technology for water-service provision that has been evaluated in the local context; this will assist the decision-makers and implementing agencies in providing sustainable solutions for rural water supply and sanitation.
- Guidelines for operation and maintenance will help water service providers and rural communities in ensuring proper O&M for their water supply schemes.
- The database of generic and sectoral competencies will contribute to skills development within water service institutions.
- Overall benefit of ensuring access to reliable water service delivery would contribute to the improvement in the quality of life for rural people.

Innovation/application of knowledge

This is very applied research which is aimed at implementation of infrastructure projects and technology transfer to rural communities, local government and policy makers.
It will also provide researchers with information that will help them identify research gaps. The database of competencies within the water supply and sanitation sector is already being used by the Local Government Water SETA to develop skills development plans that will guide education and training within the water supply and sanitation sector.

Capacity/competence development

Capacity and competence developed through research in this field resides in NGOs such as The Mvula Trust, Consulting Groups such as Ninham Shand, Partners in Development, In-Touch Development Consultants, Lenehan Engineering and Environment Consultants, Networks for Development, CSIR-Environmentek and Universities, e.g. University of Fort Hare and National Water Supply and Sanitation Training Institute (NCWSTI). These institutions are involving many designated people in their research projects. The research outputs will contribute to the capacity building of local authorities, water service providers, implementing agents and also government officials. More than 50% of project leaders of the current projects come from designated groups. (see Table 2)

Knowledge dissemination

More than 10 workshops have been held with stakeholders as part of the research process. The decision-support software for small water-supply schemes has been presented to DWAF officials and representatives of small municipalities in demonstration workshops (two workshops).

The database on generic competencies required by the water industry has been presented to a workshop with the Interim Committee for the Establishment of the Standard Generating Body for water services and the Local Government Water SETA. A second workshop with representatives of Water Boards, local authorities and other role players from the Northern Province was used to demonstrate the database. The final version of the decision-support and the database software will be demonstrated at the WISA conference in 2002.

Leveraging of resources

In-kind contribution has been made by institutions such as LGWSETA who have assisted the project team in the development of the database of generic competencies for the water supply and sanitation sector. This institution has expressed an interest in becoming a custodian of this database. Officials from DWAF at both National and Provincial levels are providing assistance to the project teams because they believe that this research will help them achieve their goals.

International linkages

Informal linkages have been established with international institutions such as the World Bank-Water and Sanitation Programme, Water Supply and Sanitation Collaborative Council (WSSCC), Department for International Development (DFID), IRC, NORAD, UNICEF, Global Water Partnership (GWP) and International Water Management Institute (IWMI).

The WRC is currently hosting the secretariat for the South African Chapter of WSSCC.

TABLE 2

Institution/ organisation	Competence	No. of projects	No. of M.Sc.	No. of Ph.D.	Other degrees
Current projects (outcome and date)					
Univ of Fort Hare	Social and institutional aspects of water service delivery	1 1	1 Black male ongoing Black female ongoing	None	None
Ninham Shand	Social and technical aspects of water service provision	1	None	1 Black male ongoing (Wits Univ)	None
New projects (expected)					
CSIR: Bio/Chemtek	Microbiological processes in pit latrines	1	One or two students to be appointed from the Univ of Natal Durban	None	None

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Chapter 3

Water Services: Institutional and Management Issues (WSIMI)

Mr JN Bhagwan

Scope

Changes to municipal legislation and demarcation processes have had a huge impact on the municipal function of water services delivery. Also contributing to this impact is the evolving nature of water services legislation emanating from the National Water Act and Water Services Act and the enormous water supply and sanitation challenges that need to be addressed. International and local experience has indicated that technology alone does not contribute to sustainable services delivery and that strong institutions and management contribute significantly to successful programs. This area has consequently been highlighted as a priority strategic area requiring attention and capacity-building and has, since the year 2000, been recognised as a new WRC research field.

The purpose of this field is to support national initiatives to strengthen the capacity of new and transforming local government institutions and services providers to provide sustainable water services. Topics addressed by this field had previously been addressed both in the fields of ***Developing Communities: Water and Sanitation*** and the field of ***Water Policy Research***. Thrusts in this new field also complement national initiatives such as the Masibambane Project and will include areas such as partnerships, institutional processes and models, management systems and models, management information systems, cost-recovery and legislative aspects.

Since this field is very new, its scope in terms of the percentage of WRC research funds utilised is quite small (as shown in Table 1). Since 1995 the initial focus of the water service sector was mainly orientated towards rural issues of water supply and sanitation, with emphasis on community management. In the process, issues of concern in urban and peri-urban areas were being neglected. Subsequently, urban challenges have been recognised and ***WSIMI*** have been identified as priority. It is envisaged that the activity in this field will increase over time and the distinction between rural and urban issues would fall away, in line will the vision of new legislation.

To date the nature of projects in this field is short-term. The low investment in this field does not signify low-priority consideration by the WRC. In fact, a number of projects related to this field are being addressed in the ***Water Policy*** field. The proposed budget for 2002/2003 is small due to the receipt of a limited number of proposals of relevance and quality. WRC identifies research capacity constraints in this field and is committed to further investments in this field.

TABLE 1
Investment in **Water Services: Institutional & Management Issues**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	-	-	-	R2 342 900	R2 583 600
% of research fund	-	-	-	3.77%	4.39%

Links to Key Strategic Areas (KSAS)

The ***WSIMI*** field is not a strongly crosscutting field and it links mainly to the following WRC KSA, addressing:

Water Use and Waste Management

The ***WSIMI*** field is an important component of this KSA and its activities, as it directly impacts on the ability of responsible organisations to provide water services in an equitable, efficient and affordable manner and to manage the waste and other water polluting products in such a way that water quality is sustained at a level suitable for all water users.

Objectives

Primary

Support national initiatives to strengthen the capacity of new and transforming local government institutions and services providers to provide sustainable water services.

Secondary

- To acquire adequate understanding of management and institutional aspects of water services delivery in an evolving and challenging environment.
- To develop appropriate processes and methods that support sustainable water service institutions and legislation.
- To identify and find innovative solutions to critical problems with the management of essential municipal services.

The driving forces for ***WSIMI*** research for the coming years will be:

- The necessity for economic development and the alleviation of poverty.
- The required support for implementation of legislation (National Water Act and Water Services Act).
- Strengthening the functioning of water services institutions and local government
- The demand for human resource development and capacity-building to enable proper management of water services.
- The provision of information and guidance to attain greater coverage in water services.

Research Projects

Portfolios of completed, current and new projects, which directly address the above-mentioned objectives, are presented below.

Completed

Improved management of assets in the water supply industry with regard to possible privatisation

Department of Civil Engineering, University of the Witwatersrand
(WRC Reference No 897)

There are very few standardised data available on the assets held by water boards, water authorities and local government concerning the value and condition of their technical assets. These assets range from pipelines to purification works and water sources. The project investigated the necessity for asset management in water supply and sanitation. Main findings from this study are as follows:

- There is typically no institution-wide identification system for assets, and there are no standardised measurements for asset types. Each department in each institution typically refers to each asset by means of a text name. These are usually the same between departments, but often show slight, and sometimes significant, variations.
- There are no standards reports for particular institutions, and particularly no reports that were found to be common between two or more institutions.
- One of the findings of the case studies is the great diversity between institutions. Each institution uses very different processes and methodologies. Also, the current state of asset management at most institutions is very poor. Institutions typically have no central asset register, or if they do, it is purely for accounting purposes and lists only the assets identification and a value, either the current book value, or the insured value.
- The research identified from the case studies shows that the magnitude of an asset base differs a great deal from one water services system to another.
- Strong international parallels were found particularly between the Australian approaches to asset management planning, for the fact that asset management is being adopted concurrently with water reforms. However, the socio-economic conditions within water services industries in Australia and New Zealand differ significantly to those of South Africa. Although there were differences in implementing asset management planning internationally, valuable foreign experiences were evaluated and some were adopted in this research project.
- It is believed that the benefits of this research project will contribute particularly to the process of compilation of Water Services Development Plans (WSDP) as required by the Water Services Act of 1997 and also for the benefit of the Integrated Development Plans required by the Municipal Systems Act of 2000 for the water services authorities and providers.
- The management of small- to medium-sized community water services systems should be particularly targeted as the asset base and extent are usually new, not very large and manageable. Also the skills base is usually in its infancy and in need of suitable guidelines.

Cost: *R445 352*
Term: *1998 - 2000*

The institutional structure for the management of a rural water and sanitation supply scheme involving five local authorities

Association for Water and Rural Development
(WRC Reference No 958)

The main objectives of this project were to establish a sustainable water management system involving co-operation between local government, water committees and NGOs , and to develop models of appropriate management structures. The study highlighted the importance of ensuring that the decentralisation of water service provision is supported by involving rural local government in participatory processes that provide a clear explanation of the reasoning behind decentralisation approaches and the range of management options. Decentralisation of water services requires a coherent plan that links a range of socio-economic, technical, organisational, financial, policy and regulatory choices; this is necessary to ensure sustainable service provision. It is important to ensure that the establishment of water boards is directly linked to that of a water service authority. The establishment of Bushbuckridge Water Board progressed independently from that of local government structures within its supply area, consequently, this water board struggled to obtain water service contracts from the five local authorities in its supply area. The study highlights the need for the establishment of an intrinsic link between water boards and local government because this is key to sustainability of both institutions. Information and participation are essential pre-requisites for ensuring cost recovery and the sustainability of water boards and local government institutions. Local communities must play an important role in the endorsement of local government choices on the form of the water service provision model.

Cost: *R120 000*
Term: *1998 - 1999*

The institutional arrangements and support facilities required for sustainable community water supply

WSM (Pty) Ltd
(WRC Reference No 959)

The main objective of this project was to initiate establishment of an effective and efficient institutional structure for the operation, maintenance and management of rural water supply schemes. The study found that the link between the district councils and communities was weak and there was inadequate capacity to address all the water service functions. It was found that tribal authorities had considerable influence in many areas and they played an important role in the enforcement of payment for services. They can play a role in facilitating communication between the district municipalities and communities. Most rural water supply schemes were operated and maintained by DWAF and water boards. The billing and revenue collection depended on the level of service, tariff and payment method. A flat-rate tariff was usually used for communal standpipes, while yard and house connections were charged a usage rate. Prepaid meters were preferred for rural areas because they reduce the management costs. The Bakenberg local municipality located near Potgietersrus was used to apply the experience gained from this project.

Cost: *R500 000*
Term: *1998 - 1999*

Benchmarks and key performance indicators in water and wastewater services

P Pybus Consulting Engineer cc
(WRC Reference No 1053)

Benchmarking (BM) is a process of continuous improvement based on a comparison of the methods of operation and performance achieved by different organisations, known as benchmark partners, carrying out similar operations. By comparing the methods used by the different organisations, the good features of each can be identified and promoted in practice. In the South African context, a system of benchmarking will prove useful for emerging local authorities, who can be mentored by the more formal local authorities. This will facilitate progression towards best practice in the water and wastewater sector.

In meeting the broad objectives of this study, the main result is an output in the form of a report entitled: A Guideline for the Implementation of Benchmarking Practices in the Provision of Water Services in South Africa.

The report contains chapters that provide:

- An introduction to the concept of BM
- Local and international initiatives
- Examples of successful BM
- BM and its relevance to SA municipal services legislation
- Guidelines on how to BM
- Proposal of set of BM areas and related performance indicators
- Recommendations for setting up an SA - BM process

Some important observations and conclusions are:

- There are a number of success stories from commercial and public enterprises resulting from BM
- South African legislation has created a climate that encourages BM
- A centralised database will be needed to manage a BM system

Cost: *R290 957*
Term: *1999 - 2000*

Information management for the water services sector, with specific reference to the regulatory system

Palmer Development Group
(WRC Reference No 1142)

There is currently an urgent need to deal with regulatory issues in the water services sector. DWAF and other government departments are in the process of addressing regulatory strategy but there is still a large amount of work to be done. In implementing such a strategy, information plays a key role. The regulator, whoever that may be, requires information to monitor the performance of water services providers and/or the water services authorities who appoint them. This information, the right amount and type of information and the system used to manage it, is central to the effective functioning of the regulator. This project addressed the information requirements of the industry as a whole, through research to establish industry requirements and international best practice.

The study has identified and raised a number of key issues related to management information and regulation. As far as possible, the report as an output goes further and begins to flesh out and debate these issues. Some of the key issues identified by this study were:

- Where should ownership of a Management Information System aimed at supporting the water sector be vested?
- In terms of the legislation, including the requirements of the Water Services Act and the National Water Act, the Minister is responsible for ensuring that there is a National Information System on water services and in a range of water resource areas.
- The study has indicated that there are a number of associations and institutions which currently support the water services sector. These include SALGA, The Association of Water Boards, and the WRC.
- The survey of water service authorities and water boards indicates that most respondents would favour either an independent body responsible for the management information system, or see the WRC as an appropriate institutional home for such a system. Given that the establishment of a national information system (NIS) is legislated as a function forming part of the responsibilities of the Minister and given that an NIS has been established in the department, it is recommended that this function remain within DWAF.
- While the experiences of other countries and the business sector are useful in identifying good and best practice when it comes to developing management information and defining key performance indicators, only after the issues raised are thoroughly debated and resolved, can the specification of a management information system to support regulation be finalised.

Cost: *R176 339*
Term: *2000 - 2001*

Current

Identifying examples of successful cost-recovery approaches in low income, urban and peri-urban areas

Sigodi Marah Martin Development Consultants
(WRC Reference No 1131)

In spite of a high level of publicity and political attention, the Masakhane campaign is perceived to have met with very limited success. Opinions vary on the cause of this, and although some work has been done in the field, the problem has not received the consistent, detailed study, that a matter of this importance deserves. In particular insufficient attention has been paid to the factors which generate success. This research is providing an opportunity to study these issues in depth. In particular, by concentrating on the successful models it will enable stakeholders to understand the role that the factors of political pressure, of administrative methods, of billing and collection systems, sanctions and community values will play in these issues. This study is expected to result in important gains in respect of understanding this problem, which can be translated into higher levels of payment and an increase in the level of development for the disadvantaged members of society. The outputs of this study are of relevance to the concept of customer management and complements the WRC study on customer management.

Estimated cost: *R438 000*
Expected term: *2000 - 2001*

Innovative partnership to improve water and sanitation services in deprived urban and peri-urban areas: KwaZulu-Natal pilot project, Inanda-Ntuzuma, Durban, Edendale, Pietermaritzburg

Durban Metro Water Services, Mvula Trust, Pietermaritzburg TLC, Compagnie Generale des Eaux, Umgeni Water
(WRC Reference No 1139)

The Business Partners for Development (BDP) project is an innovative approach and attempt to address water and sanitation issues in urban and peri-urban areas in developing countries. It is about bringing together private sector, public sector, non-governmental sector and civil society, towards addressing water and sanitation needs. The rationale is that sharing of experience and lessons between the Durban and Pietermaritzburg pilot projects will contribute towards improved services delivery in the future. An important aspect is the capturing of lessons and experience on the partnership. The key aspect is supplemented by aspects that transform services delivery from a beneficiary/recipient approach to a customer approach, where the customer is part of the development process. The project is a learning and exploratory exercise and findings will provide answers to local, as well as global questions on how to provide services to poor urban areas and informal communities.

Estimated cost: *R880 000*
Expected term *2000 - 2001*

Option of corporatisation for establishing new water services providers

Palmer Development Group
(WRC Reference No 1141)

Corporatisation is essentially a process of transforming an existing public sector services provider into a company, which would typically be wholly or partially owned by local government. Corporatisation has a particular advantage for South African conditions in that it can be used to form co-operative service provision arrangements between neighbouring local authorities. However, it is evident that there is a shortage of practical insight into this topic and a need for co-ordinated research to gather local and international experience on corporatisation, interpret this for current local conditions, and transfer this knowledge to all water services authorities in a way which will be useful to them. The overall aim of this research is to investigate the suitability of corporatisation for municipal service provision in South Africa, and to increase awareness of the corporatisation option within the water services sector.

Estimated cost: *R170 000*
Expected term: *2000 - 2001*

Pilot initiative to implement shallow sewerage technology in Durban

Durban Metro Services
(WRC Ref No 1146)

Sanitation, because of the major impact it has on health and quality of life, is a service with a high priority. The level at which such sanitation services are provided, and the arrangements for implementing the associated projects, are possibly the most debated and contentious issues in the field of urban service

provision. Findings from a previous WRC study indicated that shallow sewer systems provide a viable intermediate sanitation alternative, with a total cost between Ventilated Improved Pitlatrines (VIPs) and conventional sewerage. With this as a stimulus, the Durban Metro Water was the first local authority to indicate interest in taking the recommendations further. This study is a partnership between the WRC, Durban Metro Water Services and Water Supply and Sanitation Services (WSSA) in an initiative to pilot and test the technology local.

Estimated cost: *R 600 000*
Expected term: *2000 - 2001*

New

Institutional and social economic review of the use/application of electronic prepaid meter technology in the provision of water supply services to urban and peri-urban areas

Sigodi Marah Martin Development Consultants
(No 1206)

The use of prepaid meter technology in water supply management is beginning to gain greater emphasis after its initial application achieved limited success. This could be attributed to the quick-fix approach adopted for the sole purpose of cost recovery during a period when the technology was not properly tested and experienced many technical teething problems. The problems were compounded by lack of community education and understanding and more important, the high cost of the technology. This situation created a great deal of uncertainty in many water suppliers regarding the use of the technology, stating the lack of knowledge around the institutional requirements and other support mechanisms required to sustainably support the technology as the main reasons
The objective of this study is not specifically to look at technical issues, but to look at the important services issues that make water services provision sustainable. Of importance is that the outputs will contribute towards development of policy and guidelines in the use of prepaid systems for provision of water supply services.

Estimated cost: *R375 500*
Expected term: *2001 - 2002*

The preparation of a guideline for water services providers dealing with customer services issues

Umgeni Water
(WRC Reference No 1207)

Recent experiences internationally and locally emphasise the need for a customer focus in the provision of services. Moreover, related to water services provision, literature indicates the importance of this customer orientation is contributing to the sustainability of services. This recognition has also influenced much of the new water legislation and will become a requirement with the enaction of the Municipal Services Bill, whereby all municipalities will have to develop and demonstrate a customer management plan.

The fact that the concept of customer service has received little attention in South Africa, is perhaps related to the historic situation where water supply and sanitation services were provided on a monopolistic take it or leave it basis, particularly in the case of poorer customers. It is now recognised increasingly that successful water services provision is strongly associated with the application of good business principles. This implies a service orientation, with a primary focus on the customer. It also implies a mutually beneficial relationship between customer and service provider where the customers must fulfil their responsibility to pay for the service.

The aims of the project are:

- To assess international best practice with regard to customer service by water services providers.
- To undertake two case studies of water services providers in South Africa who are currently providing successful customer services locally.
- Based on local and international findings, to communicate the findings relating to customer services through a guideline and workshops for water services providers in South Africa.

Estimated cost: *R370 000*
Expected term: *2001 - 2002*

Least-cost planning for the water services section in South Africa

Semenya Furumele Consulting
(WRC Reference No 1274)

As water shortages and needs increase, competition for water amongst all sectors (urban, rural, industrial and agricultural) will also become more intense. Increasing population and improving living standards have led to growing water demand and unfortunately to more pollution which effectively reduces availability of water. The environmental implications are also becoming more extreme owing to greater land-use changes and more extreme hydrological changes, possibly due to extreme climatic changes. Water conservation (WC), and water demand management (WDM) are no longer only options, but must be implemented immediately, especially in South Africa where the resource is not only scarce, but also limited.

In a scenario of rising cost, demand growth, resource constraints, financial constraints, environmental concerns, political and legal constraints, public scrutiny and accountability and advances in analytical capability, least-cost planning (LCP) is emerging as an indispensable tool to meet the prevailing challenges. This study aims to:

- Explore the subject of LCP in general.
- Review local and international LCP initiatives (methodology and processes).
- Identify constraints and opportunities of LCP in the water services sector.
- Identify potential interaction of LCP with other planning practices and protocols.
- Overview the water services and institutions in South Africa.
- Develop framework for implementing LCP in South Africa.
- Illustrate the potential of LCP through a case study in Gauteng.
- Explore a computer model for LCP in the water services sector.

Estimated cost: *R200 000*
Expected term: *2001 - 2002*

Development of a framework for the economic evaluation of water demand management (WDM) measures

Independent Economic Researchers cc
(WRC Reference No 1275)

As a consequence of the high degree of emphasis placed on supply augmentation as opposed to demand management in past water resource planning, cost-benefit and other economic evaluations of water demand management measures have lagged far behind evaluations of supply-side measures in South Africa. Now that the great potential of demand management has been recognised and is being actively encouraged, there is a need for more research on how evaluations have been carried out and how they can best be carried out.

The current debate on the impact and effectiveness of WC/WDM is tested on the economic evaluation of intervention measures against those of supply augmentation measures. Economics of supply-side management is well developed, that of demand-side management is not well understood. It is therefore important that some guidelines be developed for understanding of economic evaluation applicable to WDM/WC. The study aims to:

- Establish a framework and broad guidelines for the economic evaluation of WDM in Cape Town with application to South Africa.
- Assist in decision making between alternative WDM in Cape Town in order to optimise financial and other resources used in WDM.
- Raise the profile of water demand evaluation in relation to supply augmentation evaluation thereby contributing to more balanced decision making between WDM and supply augmentation measures.

Estimated cost: *R111 200*
Expected term: *2001 - 2002*

Investigation into the minimum flush volumes required for settlement of faecal solids in domestic septic tanks using controlled experiments

Du Pisani & Associates
(WRC Reference No 1285)

The WRC has funded two projects to investigate the biological processes taking place in on-site low-flush sanitation systems and the rates of sludge build-up in these systems. The results from this research were inconclusive because conditions under which the domestic on-site systems were used, were different. Therefore, it is necessary to determine the minimum flush volumes required for the settlement of faecal solids in domestic septic tanks under controlled conditions. The study will also establish a link between water use and sludge build-up rates; this information will assist manufacturers in improving the design of on-site sanitation tanks. The main objective of this research is to establish the minimum flush volumes required for settlement of faecal solids in septic tanks. Systems that receive sullage and systems where only toilet wastes enter the tank will be studied. This research is applicable to solids-free sewer systems and on-site disposal systems.

Estimated cost: *R266 000*
Expected term: *2001 - 2002*

Creating a monitoring and evaluation system for water and sanitation delivery in small Northern Cape municipalities

McIntosh Xaba & Associates
(WRC Reference No 1287)

In terms of the Municipal Structures Act (1998) and the Municipal Systems Bill (1999), performance management will become an increasingly important philosophy in local government. At the same time, the further re-demarcation process of 2000 offers valuable opportunities for injecting performance management elements in local government practice. There is a need for a well-planned monitoring and evaluation system for water and sanitation delivery in small municipalities. The main objective of this study is to design appropriate monitoring and evaluation procedures for water and sanitation services provided by local authorities.

Estimated cost: *R100 000*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

Being a fairly new subject area for research in South Africa and due to past biases on technical and operational issues in service delivery, every aspect of knowledge generated can be considered as innovative. One could consider this complete field and its activities in the present environment as a "learning process". Thus through research the areas of understanding the water services business are being formalised. WRC "Management Guidelines" and "Financial Models" have introduced the importance or critical nature of these disciplines in municipal management. The repercussion of this knowledge is acknowledged by the fact that Chief Engineer is no longer the competency required to run a municipality, but Municipal Manager.

The WRC's contribution on cost-recovery is significant, contributing to the understanding of the differences between no payment and non-payment and the relationship to poverty. WRC research on 'subsidies' or 'free water' has to some degree contributed to the concept being adopted.

The importance of institutional relationships and processes to the sustainability of water services was also emphasised by this field. The outputs clearly indicate that technical solutions are not the only solutions to South Africa's water management challenges.

Benefits to South Africa

This field is mainly contributing to the knowledge base of a subject and activity area that is fairly new to the sector. In the process, this knowledge is building wider capacity and informing national processes. This is allowing a platform for debates and transformation. This field is in a complete learning phase and this scientifically based knowledge is proving to be useful. It is too early yet to measure direct benefits but the research is already making a contribution and impact as indicated in the section on **Application of Knowledge**.

Innovation/application of knowledge

Being a fairly new subject area for research in South Africa and due to past biases in technical and operational issues in service

delivery, every aspect of knowledge generated can be considered as innovative. Of WRC research the focus in this field actually started in the early 90s and gained momentum towards the middle of the 90s, under the previous field of ***Developing Communities: Water Supply and Sanitation (WSS)***. Activities during this period focused on generating knowledge on WSS issues, highlighting the WSS problem and information gaps. Much of this knowledge has been used as input to the formulation of the White Paper on Water and Sanitation and strategies. This work has been well utilised and referenced both locally and internationally.

The field covered a wide area of subjects and this was due to the multitude of challenges and requirements of the field. A focused area on Management and Planning aspects shaped thinking around the development of the Water Services Act and its component the Water Services Development Planning (WSDP). The WSDP is regarded as an innovative method and process and is being applied widely both locally and internationally. The DBSA has taken custodianship of this model and makes the application of the model a pre-requisite in its funding process. Applications of the model indicate the vulnerability of emerging water boards, while prompting improved strategies for sustaining water boards.

The most important benefits of research outputs have been the contributions to the quality of life of the people of South Africa through supporting the capacitation of local government to provide improved and sustainable services. This also contributes to economic growth and prosperity.

Research outputs in this field have also provided leadership in management and institutional issues. Guidelines on the participation of the private sector in water services provision, provided clarity on issues and constraints. This paved the way for Government to develop appropriate strategies and policies for private sector participation (PSP) involvement. Studies on asset management pointed to the poor status afforded to this most important aspect of the water services business. This area was neglected by new legislation and incorporation of WRC outputs and recommendations is now being addressed.
The WRC initiatives on benchmarking and performance indicators have generated great interest and activity in the water sector. Research has also identified issues related to water services by intermediaries and services on private land. This is specifically related to communities living on private land (e.g. farms) and the responsibilities of landowners for service delivery. As a result processes have been set in motion at a national level for the problem to be addressed.

Thus, over a short period of time, this field has been contributing significantly by generating sound knowledge that is highly applicable and is supporting the evolution of policy and strategies. However, the nature of most of the projects is such that few immediate impacts will be evident in the short term and will mostly result in long-term benefits.

South Africa's innovative water legislation and the support mechanisms such as outputs from water-related research have received international recognition and much of this is benefiting the SADC and wider African region.

Capacity/competence development

As this is a new field initiated in the year 2000, comparative benchmarking of achievements is premature. It is important to highlight that consultants have dominated activities in this research field. In terms of capacity-building of PDIs, there is a definite improvement in their involvement in research as the consulting fraternity transforms. Recent developments have seen more PDIs getting into this field as a wider skill base is required over traditional technical skills for this research area, and these wider skills are available as opportunities open up. Many of the completed studies to date were designed to build wider capacity in the sector.
An important area to highlight is the lack of research capacity and involvement at an academic level maybe due to the existing operational and management nature of research. It also needs to be highlighted that the skills required in this field are much wider than conventional engineering competencies, with competencies in economics, legal, policy and management being identified as essentials.

Achievement to date regarding involvement of PDIs on projects completed in the past two years is as follows:

Female researchers	4
Black researchers	5
Ph.D.s	2

Knowledge dissemination

The lack of scientific dissemination instruments that support this field of research has resulted in very few papers being published. However, research activity in this field has resulted in numerous specific workshops and conferences that have created a platform for dissemination. The WRC has also been instrumental in arranging and facilitating these conferences and workshops, many in partnership with DWAF and WISA. This has been supported by improved WRC dissemination mechanisms that ensure that the majority of the user group receives research outputs.

In terms of publications, papers, etc., the following can be reported:

Conference papers	12
Articles and papers	15
Conferences	3
Workshops	6

Leveraging of resources

Outside contributions to research projects are mainly of an in-kind nature and from partnerships. The most notable example of these relates to the pilot studies on innovative partnerships in services delivery and sanitation technologies. These are highlighted below:

R2 000 000:	Pilot shallow sewerage project (Durban Metro, WSSA)
R13 300 000:	Business Partners for Development (Durban Metro Water Services, Vivendi Water, Pietermaritzburg TLC, Mvula Trust and WRC).

International linkages

Much interest has been received from agencies such as the World Bank Water and Sanitation Program, WEDC, IRC, UNEP, UNDP, Water Utility Partnership (WUP), Union of African Water Suppliers (UAWS), etc. for sharing of information and networking. Progress is underway in formalising these relationships.

The WRC has representation on the WHO's Water Supply and Sanitation Collaborative Council (WSSCC). WRC staff have been responsible for the launch of the local chapter of WSSCC.

The WRC also has strong linkages with the International Water Association's Foundation for Developing Countries. WRC with WISA facilitated its first conference in the year 2000.

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Chapter 4

Integrated Urban Water Management (IUWM)

Mr JN Bhagwan

Scope

The ***IUWM*** field focuses on the management of technical aspects of water services. This is a new field that has emerged as a direct result of conclusions drawn by international and local agencies that sanitation, waste disposal, urban stormwater and runoff, water reticulation, etc. cannot be considered to be stand-alone issues as they have in the past.

In the ***IUWM*** approach consideration is given to the collective impact of all possible water-related urban processes (of which the management of human excreta or sewage is only one) on issues such as human health, environmental protection, quality of receiving waters and urban water demand. Individual processes are then planned and managed in a way that the collective impact, with due consideration of the interaction among processes, is optimised as far as possible.

This relatively new research field was introduced in the year 2000 with a long-term view of ensuring that greater planning and integration would occur in the management of urban water. The field focuses on technical aspects of the management of water supply and distribution systems, management of urban runoff and water conservation and demand management. Currently, many of these and related aspects are still being addressed by other research fields.

The percentage of WRC research funds utilised in this field is shown in Table 1. In 2001/02 it commanded 2.1% of the total research budget. This modest budget is due to the fact that innovative and novel technical solutions are scarce in this field. The field has already enjoyed its period of innovativeness which resulted in huge strides in technical efficiency in the sector. Another observation is that the research sector has not yet fully absorbed the new technical challenges of municipal services delivery, which aligns itself more towards integration of the technical aspects with the business aspects. As these challenges become acknowledged, there will be a shift in paradigm amongst experts and this would eventually see a new surge in innovative research activities. Our observation is that the sector is in transformation. Accordingly, the WRC will provide leadership on ***IUWM*** and integrate the relevant projects undertaken in other fields into this new field.

TABLE 1
Investment in **IUWM**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	-	-	-	R1 317 400	R1 819 100
% of research fund	-	-	-	2.12%	3.1 %

Links to Key Strategic Areas (KSAs)

IUWM mainly falls into the **Water Use and Waste Management** KSA and also has strong linkages to the following of the WRC's KSAs:

Water Use and Waste Management

This field fits directly into the scope of this KSA as it relates directly to supporting institutions to provide water services in an equitable, efficient and affordable manner and to manage waste and other water polluting products in such a way that water quality is sustained at a level suitable for all users. This KSA will also focus on the management of demand on the water resource.

Water Resource Management

As most water resource management activities are undertaken for the purpose of making safe water available for use, this field is of significance for this KSA. The concept of integrated water resource planning requires the integration of planning around the management and usage of urban water resources. The link with this KSA is with regard to the reliability and availability of the resource and management of the use of the resource in times of severe shortages, which impacts on quality of life and economic growth. This KSA supports activities that promote the conservation of the water resource.

Water-Linked Ecosystems

Being sensitive to environmental changes, ecosystems can be impacted severely by water usage activities. Thus there is a link between urban water usage and ecosystems, as both abstraction and return flows impact on the functioning of ecosystems.

Objectives

Primary

Finding innovative solutions and knowledge to effectively address operational problems and management aspects relating to the supply of water, sanitation, waste and stormwater. The focus is on improving technical efficiency and effectiveness of services.

Secondary

Development of appropriate techniques, innovative technologies and systems for improving the supply and distribution of water and for managing urban runoff and effluents.

Research Projects

Portfolios of completed, current and new projects, which directly address the above-mentioned objectives, are presented below.

Completed

Research on appropriate management of urban runoff in South Africa

Water Systems Research Group, University of Witwatersrand and Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 598)

As the aim of this study was to establish general guidelines for the management of urban runoff water quality, especially focusing on dense settlements, the methodology used has resulted in the following outputs: Six reports have been generated, these being:

- *Appropriate Management of Urban Runoff in South Africa - Integrated Report*
- *A Synthesis of Urban Runoff Studies, with Special Reference on Runoff from High Density Settlements*
- *Expert System for Design of Stormwater Management Systems for Urban Runoff Quality*
- *A Study on the Fate of Urban/Stormwater Runoff from Alexandra Township in the Jukskei River*
- *Some Observations on the Response of a Created Wetland to Simulated Flood Hydrographs*
- *Options for the Interception and Treatment of Urban Runoff*

The following are important conclusions from the study and reports:

- Urban runoff quality is a country-wide problem, the causes of which must be addressed. Past attempts to intercept urban stormwater and channel it through a single stormwater system to receiving water have failed. As stormwater quality may be worse than treated sewage effluent and sometimes even raw sewage, treatment of stormwater at some stage before discharge to the receiving waters has to be considered. Present engineering stormwater management options do not cater for improving stormwater quality.
- The impact of low-cost, high-density urban land use on the catchment warrants serious attention. Appropriate sanitation and waste disposal for peri-urban areas requires fundamentally new approaches. It is imperative therefore that applied research into these areas be conducted for the protection of South Arica's limited water resources.
- Diffuse sources of pollution from urban runoff and informal settlements should be tabled as part of an integrated catchment management plan.
- Where previous or existing stormwater management strategies in South Africa were examined, the following problems were highlighted:
  - Planning and development up to 1994 did not include long-term planning for urban runoff problems or strategies for coping with increased runoff due to rapid increases in settlement area and density
  - Generally, insufficient (if any) space was reserved for future stormwater management or treatment facilities
  - The encroachment of shacks onto river banks endangers lives during floods and causes serious water quality problems that have to be dealt with urgently
  - Remedial actions without active participation of the affected residents have invariably failed.

- The three main choices to be considered in urban runoff volume control are:
  - Reducing flows entering the drainage system
  - Increasing the capacity of the drainage system
  - Attenuating flows within the drainage system.
- The problem of polluted urban runoff appears to be ubiquitous and inevitable. However, with careful planning and design of urban areas and of stormwater reticulation systems, it is possible to reduce pollutant loads carried by urban runoff, and hence to mitigate the effects on receiving water quality. Some states in the USA have promulgated Best Management Practices© for urban catchments, similar to those for agricultural catchments, in order to protect downstream water resources. Such an approach is likely to be of benefit in South Africa also.
- Urban runoff pollution control measures: Urban runoff can and does have a serious impact on the quality of surface waters in South Africa. A combination of sound urban environmental management practices, active participation of affected parties and legislation (such as stormwater discharge permits), may be required to achieve adequate reduction in pollution levels in runoff from such settlements.
- Appropriate solutions to urban runoff management problems are multi-faceted, reflecting the complexity of the problems themselves. Solutions encompass control or reduction of pollution at source, through to interception and treatment of runoff prior to discharge to receiving water bodies. Socio-economic, environmental and technical aspects need to be integrated at the planning level when designing management options. Issues such as installation costs and required maintenance levels may become key deciding factors.
- Microbiological pollution, nutrients and litter, typical of runoff from townships, were found to be the major pollutant problems. Settling of a number of the pollutants, especially those adsorbed or complexed to the suspended solids (phosphates, lead and iron) or in particulate form (organic nitrogen and BOD in the form of organic matter), was found to be a major removal process for non-point source pollution during steady state conditions. During storm events, the major process occurring is the entrainment of pollutants from the river bed.
- A comparison between the Jukskei River and similar studies in South Africa was done. Very high concentrations of lead and iron compared to other studies were recorded. The faecal coliform concentrations were very similar to those in other similar areas. The high concentrations of faecal coliforms represent a health problem. From the studies, however, these coliforms were seen to decrease quite rapidly as they are exposed to an alien environment in which there is intense sunlight and predation. Just 6 km downstream the majority of the faecal coliforms were found to have been assimilated.
- The ammonia and sulphate concentrations were similar to those observed in the Hennops River Valley study with the resulting oxidation products being similar to those in Khayelitsha. A high concentration of ammonia at Alexandra, where most of the pollution is discharged into the river, was recorded. This was rapidly converted to nitrates by nitrification. The chloride concentrations were much lower than those observed in other studies. Many of these studies, however, were in areas that are closer to the sea where high chloride concentrations are expected.
- The problems that could arise due to the high concentration of nutrients, BOD and low DO concentrations are euthrophication of the waters, fish kills due to the low DO concentrations and aesthetically displeasing benthic sludge on the river bed. There is no excess vegetation growing in the river itself and low concentrations of chlorophyll-a were detected in the river, which shows that no eutrophication has taken place, although quite luxuriant vegetation is seen along the banks of the river. Fish, especially the catfish (Barbel), were seen in the river which indicates that some aquatic life is still possible. The biggest problem, however, seems to be the health threat to the people downstream.
- Large concentrations of *Ascaris* eggs, which are indicative of human sewage pollution, were found down the whole length of the 6km reach used for the study (Van Deventer, R, pers. comm). *Ascaris* eggs are used as indicators of the presence of parasites in the water as they are present in large concentrations in polluted waters and are easily detected. After *Ascaris* eggs (roundworm) had been detected, tests for other parasites were carried out.
- Parasites like tapeworm, whipworm (trichuriasis), hookworm and blood flukes (schistosomiasis) were detected in the Jukskei River water. All the diseases in the faecal-oral category are caused by pathogens transmitted in human excreta, normally faeces. A rapid rise in the concentration of faecal coliforms at the Alexandra Monitoring Point has been observed with a high of 31 million/100 mℓ being recorded at Alexandra in September, 1994. The presence of these faecal coliforms indicates that there may be bacteria present that are transmitters of various bacterial diseases including a number of diarrhoeas and dysenteries, enteritis, cholera, typhoid as well as a number of other diseases.
- The main problem associated with non-point source pollution coming off catchments such as Alexandra, is that costly at-source diversion treatment processes would not be viable, as there is a constant influx of people to the area so there is always a shortage of amenities. The river may then be the only option available for treatment of the runoff being discharged into it.

Cost: *R630 597*
Term: *1994 - 1997*

The use of chloramination and sodium silicates to inhibit corrosion in mild steel pipelines

Rand Water Research
(WRC Reference No 779)

Corrosion costs South Africa billions of Rand every year in lost assets. World-wide, millions of man-hours are spent annually, trying to develop alternative, cost-effective, materials as well as developing techniques to inhibit, prevent and even to overcome corrosion. Steel water distribution mains and reticulation systems are no exception. These pipe systems represent a large proportion of the capital investment of water supply

authorities and are prone to damage by aggressive or corrosive waters leading to financial losses, resulting from both water lost due to leakage and the cost of repair.

Although the inhibiting action of monochloramine and sodium silicates against corrosion has been described, it is seldom utilised for that purpose in the production and distribution of potable water. This project proposed to investigate the benefits and disadvantages of these two alternatives and to make recommendations for their possible use.

The results show clearly that the corrosion rates initially are very high and do not reflect the method of treatment. In the weight-loss experiments, lower corrosion rates were measured with the addition of monochloramine, even when it was dosed in combination with sodium silicate. Lower corrosion rates were measured with incremental higher dosages. The addition of only sodium silicate had no effect on the measured corrosion rate when compared with the control sample without any additives. Although the analysis of the corrosion products indicated the presence of silicate, it can be concluded that it had no effect on the corrosion rate. However, there is overwhelming evidence in the literature that supports the claim that sodium silicate is an effective corrosion-inhibitor. The results clearly show that, at higher monochloramine concentrations, higher corrosion rates are measured. At lower dosages, corrosion was also stimulated. It appears then that there is a narrow margin within which the monochloramine concentration should be maintained to protect the mild steel pipelines.

This has a significant practical implication since monochloramine can be used to passivate the surface of corroding metal, provided that concentrations are controlled within the required limits.

Cost: *R64 600*
Term: *1996 - 1997*

The development of a stochastic technique for the optimisation of pipe and reservoir systems

Department of Civil and Urban Engineering, Rand Afrikaans University
(WRC Reference No 985)

Stochastic analysis of systems is a technique that has been applied with great success in numerous different fields, including water supply. The main advantage of the technique is that it is possible to link the risk of a bulk water supply system failing to the cost of the system. This means that if the acceptable risk of system failure is known, as is the case with design guidelines for developing communities, the optimum reservoir capacity might be determined using the stochastic technique. Experience with the technique has shown that in many cases the "48 h of annual average daily demand" rule specified in the "Red Book" for the sizing of reservoirs results in over-estimation (with resulting over-spending) of the required reservoir capacity.

As per the set objective the study has culminated in the following:

- Estimates were derived for a typical urban bulk water supply system. The number of supply interruptions is typically between 0.1 and 1 interruptions per year, and the total annual interruption duration ranges between 1 and 10 h per year.
- The approach can be extended to a typical branched configuration as found in many cities, i.e. where water is supplied to a primary reservoir, from where it is further distributed to secondary reservoirs. The analysis of the Windhoek reservoir system, as an example, showed that about 8 h of the annual average daily demand (AADD) of the combined secondary reservoirs should be allocated to the primary tank if the primary tank has only an Atransfer@ function.
- The analysis of the Mabeskraal system showed how the method is applied to a long, linear Abackbone@ system with small side reservoirs. In such systems, tank sizes should increase with distance from the source. Generally, the tanks can be significantly reduced in size (to between 12 h and 24 h of AADD) without a compromise in supply security.
- The Mabeskraal analysis also pointed to some important differences between urban and rural systems. The demand peaks are much more attenuated, due to on-site storage and the use of standpipes. There is also stronger serial correlation between consecutive days than in urban areas. Pipe breaks are less frequent in rural areas, and repair times generally longer.

Cost: *R106 600*
Term: *1998 - 2000*

Evaluation of the application of genetic algorithms in the planning, design and management of water supply systems

Department of Civil Engineering, University of Pretoria
(WRC Reference No 1144)

Since the government has set the objective of supplying safe water to all the citizens of South Africa the quest for optimal utilisation of scarce capital has been strongly promoted. Techniques like stochastic assessments, linear programming and multi-objective analyses have been used to evaluate and optimise different characteristics of water supply schemes. Preliminary indications are that the degree of accuracy that can be achieved by genetic algorithms (GAs) is much better. In complex water distribution systems, the alternative options when evaluating the extensions to water supply systems become numerous and, therefore, a procedure to evaluate the alternatives is required. Genetic algorithms provide a procedure for the evaluation of all possible solutions and their application in the water supply field should be evaluated.

The study aimed at evaluating the application of genetic algorithms in the optimisation of different components of the water supply scheme. Findings indicate that:

- GAs are not used to their full potential in the optimisation of the water industry in South Africa.
- Potential applications of the technique within the South African context are:
  - Hydrology and water resource assessment
  - Network optimisation
  - Optimisation of rehabilitation, extension and upgrading of distribution networks

- Operation and maintenance scheduling of pumps and purification plants.

- Little formal teaching on GAs is included in the curriculum of civil engineering in South Africa.
- Feedback from Rand Water reflected the need for the development of software utility programs that can be used in practice and stimulate the further exploitation of this technique.
- The pipeline diameter optimisation program (GAPOP) that has been developed has been well accepted in practice.
- As a demonstration of the concept, a small software program called GAPOP (Genetic Algorithm Pipeline Optimisation Program) was developed. The program optimises gravitation pipelines and pumping pipelines, against costs. The output is demonstrated graphically.

Cost: *R100 000*
Term: *2000 - 2001*

Benchmarking of leakage for water suppliers in South Africa

WRP Consulting Engineers (Pty) Ltd
(WRC Reference No 1145)

Leakage is an important component of unaccounted-for water (UAW) in distribution systems. The current situation in the water services sector is alarming. It is estimated that an average of 28% of all potable water supplied in the country is lost, costing the sector and communities billions of Rand. Compared to international figures these levels could be considered to be very high.

Leakage levels are rapidly becoming of major importance in South Africa and there are no guidelines or benchmarks available to indicate acceptable limits or a system that provides constant updates for the sake of comparison. Another problem is that most organisations tend to express their leakage levels in terms of percentage of water input to the distribution system. Although this is the simplest and most straightforward method of expressing losses, it is also the most unreliable and misleading method. To overcome this problem, it was necessary to derive a methodology that can be applied to a wide range of water suppliers from rural to high-density urban areas.

In meeting the objectives of this study, the following outputs/results emanated:

- A software model called BENCHLEAK and associated user-guide. The model facilitates the evaluation of leakage levels and, in particular, non-revenue water in potable water distribution systems. BENCHLEAK is supported by a user manual that contains full details of the leakage benchmarking procedures and explains the background to the development of the ILI.
- Application of data from 35 local Water Supply Authorities was analysed. The following are the important conclusions emanating from this objective:
  - The information required to calculate the various performance indicators used in this case study, is often not available from the water suppliers despite the fact that the information is very basic. For example, many water suppliers have difficulties in providing information such as the total length of mains, number of service connections, total system input volume, etc.
  - BENCHLEAK can be used for large systems as well as small systems. In this regard it can effectively be used down to a zone level if required to highlight specific problem zones in the same distribution system.
  - Water supply systems in South Africa are poorly metered.
  - The ILI values for participating water suppliers range from 1.0 to approximately 28.0 with an average in the order of 7.0. This can be compared to ILI values calculated by International Water Data Comparisons Ltd. for 27 supply systems in 19 countries that range from 1.0 to 10.0 with an average value of 4.2.

Cost: *R189 579*
Term: *2000 - 2001*

Current

Impact of urbanisation and industrialisation on the environment

Department of Chemistry (Mamelodi Campus), Vista University
(WRC Reference No 717)

Increase in urbanisation results in a dramatic increase in industrial and domestic waste. Of major concern is the generation of toxic chemicals and heavy metals. This study aims to investigate the occurrence of polynuclear aromatic hydrocarbons (PAHs) as an indicator of pollution of urban water catchments. PAHs are potentially carcinogenic and the outputs will provide information on a subject area lacking knowledge.

Estimated cost: *R380 000*
Expected term: *1995 - 2001*

Economic model for leakage management

BKS (Pty) Ltd.
(WRC Reference No 898)

The problem with active leakage control is that it is often not clear how frequently the water supplier should scan an area for unreported leaks. In some cases once every two years is sufficient and in other cases once every six months is in order. This action has financial implications and could render leakage initiatives unviable. The study intends to develop a software program that would assist a water supplier in determining leakage interventions. The proposed software will set out to explain the various costs associated with active leakage control. Using the software the water supplier will be able to provide certain basic information from which the model will calculate various economic indicators from which the water supplier will be able to determine the optimum cycle for active leakage control for a specific area.

Estimated cost: *R197 000*
Expected term: *1998 - 2001*

Monitoring leachate and biogas emissions from existing experimental field cells

Department of Civil Engineering, University of the Witwatersrand
(WRC Reference No 995)

Municipal solid waste disposal sites often pose a major potential risk to underlying groundwater resources. However, recognising that in the semi-arid parts of South Africa the infiltration of rainwater may be insufficient to generate significant volumes of leachate, a more appropriate guideline document for the design of waste disposal facilities has been

developed, through a WRC project, that takes cognisance of the local climate when defining leachate collection and control facilities that are required for a particular landfill. Adherence to the current new Minimum Requirements for Waste Disposal guidelines of DWAF may nevertheless still entail the incurrence of a very large cost for many municipalities and these costs could become prohibitive in the provision of essential services of waste disposal. This project forms part of ongoing research to refine the existing guidelines, by investigating typical streams of waste from developing areas and the quantity and quality of leachate produced. This information would contribute to refining the new Guidelines such that they can make waste disposal more affordable, without compromising environmental integrity.

Estimated cost: *R118 000*
Expected term: *1999 - 2001*

Water leakage: Pressure management model

WRP Consulting Engineers (Pty) Ltd.
(WRC Reference No 997)

Water demand management is rapidly becoming a major issue in South Africa as the country's water resources become fully utilised. The options of new water infrastructural developments and major water transfers are becoming limited and in all cases more expensive. Over the past two years it has become apparent that South Africa must look to better water-use efficiency in order to curb the growing demands and in so doing, reduce the need for new water transfer schemes. It is generally accepted that in South Africa it is unrealistic to eliminate the need for further water transfers. However, it is realistic and necessary to postpone such developments as long as possible through greater water-use efficiency and proper water demand management.

The aim of the project is to produce a user-friendly Windows-based software package to assist water suppliers in evaluating whether or not they can reduce water consumption through pressure management. The pressure management model developed called PRESMAC complements the WRC night-flow analysis and financial analysis model SANFLOW. A comprehensive user guide supports and accompanies the model and includes several actual examples from South Africa where pressure management has been used to reduce water consumption. The model provides a simple and easy-to-use tool to enable water suppliers to evaluate the savings in water consumption and reduction in burst and background losses that can be achieved through pressure reduction.

Estimated cost: *R318 937*
Expected term: *1999 - 2001*

Cultivation of high-value aquatic plants in restored urban wetlands for income generation in local communities

Abbot Grobicki (Pty) Ltd.
(WRC Reference No 1054)

The main objective of this pilot project is to establish an urban wetland on Cape Metropolitan Council-owned land which is planted solely with arum lilies, and to assess the viability of cultivating and cutting the lilies as a sustainable income-generating project for the local community. Secondary objectives are to optimise wetland design in order to meet the needs of urban horticultural/agricultural activities; to evaluate the improvement in water quality, in terms of gross litter control, physico-chemical parameters and microbial content of the water; to assess the economic benefits of wetland horticulture schemes to local communities, and to evaluate the sustainability of such schemes.

Estimated cost: *R550 000*
Expected term: *1999 - 2001*

Effects of leak repairs and direct billing of tenants for water in high-rise inner-city buildings

(Greater Johannesburg Metropolitan Council)
(WRC Reference No 1143)

Over the past few years there has been a sudden population migration to the inner city urban hives. The inner city population is one which is relatively new, having previously been excluded from the inner city residential environment due to apartheid legislation. Linked to this development there has been inner-city decay, resulting in poor environments, unsanitary conditions, neglect of maintenance of buildings, overcrowding, etc. The water services sector has been significantly affected by this development, with high water losses and consumption recorded in these areas. The situation is common to many of the metropoles of the country. The proposed pilot project falls within the part of the inner city which is included in a bigger Western Joubert Park Precinct Pilot Project that have education, social development, residential renewal and rehabilitation as focal points. The effects of the proposed project are required to be closely monitored, together with the broader social and physical results of the proposed interventions, in order to make recommendations as to possible local authority legislational or policy changes with regard to service delivery and billing systems.

The proposed pilot project will test the effects of leak repairs and direct billing on water conservation and on levels of payment. However, a central issue will be testing the social impact of education programmes on inner city residents. Fifteen buildings have been chosen in the Inner City of Johannesburg, specifically in an area which is the focus of other initiatives that are aimed at social and physical development, directed at relatively new inner city populations. The project aims to:

- Document baseline data relating to water consumption, levels of payment for services and attitudes and awareness of residents in some inner-city buildings.
- Establish monitoring, reporting and data management systems as the indicators of the project.
- Develop educational systems and documentation around services issues and report on the effects of the interventions on social attitudes and awareness.
- Report on the effects of the interventions on water consumption and on levels of payments in the pilot buildings.
- Indicate to the Greater Johannesburg Metropolitan Council the direction in which policy should be changed with regard to service delivery and billing systems and/ or services supporting education programmes.

Estimated cost: *R440 000*
Expected term: *2000 - 2001*

New

Development of a model to estimate hour-day factors in potable water distribution systems in South Africa

WRP Consulting Engineers (Pty) Ltd
(WRC Reference No 1205)

The accuracy in determining leakage in distribution systems is very important. However, the process is very time-consuming and expensive. The WRC funded the development of the SANFLOW model to assist in this regard. Although an analytical model, it is very quick and easy in determining night-flows in a system. In many cases a water supplier will estimate the leakage from a zone directly from some ad hoc measurements of the minimum night-flow and then simply scale the result up by 24 to obtain the daily leakage, and then scale up again by 365 to estimate the annual leakage rate. Recent analyses undertaken in the UK indicate that this rather simplistic approach can be quite misleading and that even within a single zone metered area the HDFs (hour day factors) can vary significantly from day to day depending upon the variations in inlet pressures and demand patterns. This problem is an area of concern and impacts on the current concepts and tools. Hence, it is an important problem to investigate in order to enhance current tools. This proposal attempts to address this with the aim:

- To develop a computer program to calculate the HDFs for any selected potable water distribution system of zone-metered area.
- To write a comprehensive user guide explaining the use of the model, as well as the concepts and use of HDFs.

Estimated cost: *R150 000*
Expected term: *2001*

Investigation of the performance of domestic copper pipe in coastal areas

Pipeline Performance Technologies
(WRC Reference No 1208)

Basic copper corrosion is well researched and documented; however, the exact cause of leaking domestic and industrial copper pipes is not well understood at present. A developing phenomenon in coastal areas is the reporting of cases of pin-hole ruptures. This situation is not normal, especially where copper is the recommended material for use with softer waters and in coastal areas.

In the Blaauwberg Municipal Area a number of these incidents have occurred in the recent past, resulting in unsatisfied customers and an impact on the insurance industry. This situation has left the municipality in some difficulty, as they do not have any solutions to the problem.

Aims are to:

- Fully investigate the cause of the corrosion (pin-hole ruptures) in domestic copper pipes in the Blaauwberg Municipal Area and other municipal areas.
- Research, understand and document the mechanism of this type of corrosion.
- Provide technical cost-effective solutions to municipal authorities to eradicate the problem.

Estimated cost: *R192 000*
Expected term: *2001*

Development of a methodology to determine the effectiveness of water conservation (WC) and water demand management (WDM)

Stewart Scott
(WRC Reference No 1273)

Water demand management and water conservation measures can facilitate a more efficient utilisation of existing supplies through a beneficial reduction in water use. By considering measures which may improve the efficiency of utilisation of existing supplies and which may reduce future levels of water use, more efficient water planning can be undertaken. A WDM/WC measure is practice or action which results in a beneficial reduction in water use or loss. This reduction in water use or loss conserves supply, making some portion of the existing or future supply available for uses which would not have been served otherwise.

The effect that WC and WDM measures previously had on the reduction of water use as described by historically determined reduction, coverage and interaction factors can therefore be applied within a planning context so that possible future environmental, social and economic impacts can also be estimated. An example of an environmental impact could be the effect on environmental water reserve due to the magnitude and timing of reduced water usage to both the demand on supply and on return flow to the natural watercourse. An example of a social impact could be the public acceptability of WC/WDM education programmes.

The potential value of the results of this research project is that it will facilitate the optimal selection of WC/WDM measures prior to their commencement as well as reduce the potential of implementing expensive and inappropriate measures for a particular situation.

Estimated cost: *R190 000*
Expected term: *2001*

Sanitation demand and delivery in informal settlements

Peninsula Technikon
(WRC Reference No 1280)

This research project aims to broaden the benefits that may be derived from a particular project that is currently being implemented in informal settlements in Khayalitsha. The purpose is to derive added value from the project experience by means of rigorous research for evaluative purposes. The research approach and methodology is to develop a substantial research product from in-depth examination of each key component of sanitation delivery, so that the lessons may be applied by local authorities, both locally and more widely.

The research methodology is based on action research, as appropriate for the adopted project-based learning approach. Qualitative research is appropriate to the scope of the initiative, which spans across the perspectives of sanitation role-players, and is based on their active participation in investigation and reflection. Quantitative data will be utilised to complement the investigation and its outcomes.

Aims

- Community demand: Draw lessons from the collaborative and participatory approach and the creation of community demand for sanitation and hygiene awareness.

- Service provider protocol: Investigate the institutional, technical, social and financial aspects of developing a sanitation protocol guiding sanitation options for local authorities in peri-urban areas, based on evaluation of the current approach in relation to broader experience;
- Community response to delivery: Evaluate the factors influencing sustainability of sanitation services, in terms of approach to delivery and options, by taking community responses and roles into account.

Estimated cost: *R250 000*
Expected term: *2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

In this field many of the current and completed projects digest and package knowledge generated into a more appropriate format. The areas where knowledge has been generated are as follows:

A great deal of understanding and new skills have been developed in optimisation techniques for water supply systems. This knowledge base is internationally recognised and of relevance and significance to a water sector which relies heavily on mass transfer schemes. Knowledge of pumping regimes, pipeline diameters and scheduling of water supply has had a contributory effect on reducing capital and operational costs.

Links between water quality and performance of pipe materials generated knowledge that has enabled improved strategies and methods to be put in place for improving the performance of pipe materials and thus the life of infrastructure at all levels in the distribution chain. The result of this is huge savings for services providers. The biggest impact of this knowledge has been the benefit to large transfer schemes, which has highlighted the importance of selection of materials and rehabilitation. The scientific understanding is now being utilised in a pragmatic manner.

Significant knowledge generation is evident in the area of water conservation and water demand management. WRC outputs have challenged the supply-orientated paradigm for years and influenced the demand-side paradigm. This knowledge base has created the impetus for a paradigm shift.

Significant development of new concepts of leakage detection and water loss management has been achieved, with South Africa considered as international leader in water loss management. These outputs directly support water institutions in applying these concepts in reducing losses.

Benefits to South Africa

In a country where efficient use of water is critical for sustainability of the water resource and in which constraints of capital and capacity exist, improving efficiencies of infrastructure and operational costs are of great benefit.

The most important contribution of research in this field has been in extending the life expectancy and reliability of water infrastructure. This has had the greatest impact on large transfer schemes. Optimisation of pumping and operational costs has resulted in huge savings in water supply and distribution. Rand Water and Umgeni Water have applied the new understanding of deterioration in pipes to their large-diameter pipelines. The replacement of large-diameter pipes used in transfer schemes is a complicated and expensive exercise and this knowledge has contributed to improving management of water quality and pipe linings, avoiding the need for replacements.

In the area of water loss management research, the outcome has had two main benefits: Firstly, it allows greater use of existing infrastructure and the postponement of new schemes; secondly, the water saved assists in greater coverage and meeting historic backlogs in services.

Overall the contribution has been to ultimately reduce the cost of water supplied to the consumer and make services more affordable to South Africans, as well as reduce impacts in the water environment, thus contributing to increased quality of life and economic growth.

Innovation/application of knowledge

Examples of application of knowledge have been given as part of the description of benefits to South Africa. In addition, knowledge generated through current programmes and projects is already being applied in the following ways:

- The Water-Audit Reporting methodology has influenced the development of the Water Supply Regulations and the model is a requirement for standardised reporting as part of the SABS 0310.
- Local authorities, in tackling water loss problems, are preferentially using water loss software generated by the WRC. The models are also receiving increased international interest, which is evident by the number of requests and indications of international agencies such as UNHCS to adopt the models.
- Major water boards and municipalities are using optimisation techniques and models in their day-to-day operations.
- Development of water demand management strategies and protocols has been enabled.

Capacity/competence development

Since this is a new field, providing extensive statistics on capacity building is premature. However, through benchmarking achievements from the year of introduction of this field, the following can be reported. Capacity and competence developed through current WRC programmes reside in the following institutions:

CSIR MATTEK	Pipe material technology
Consultants	Various topics
WRP Consulting Engineers	Water loss management
Wits University - Water Systems Research Group	Deterministic probabilistic techniques
RAU University - Water Research Group	Stochastic probabilistic techniques
Pretoria University	Genetic algorithms and hydraulics in pipes

Statistics pertaining to groups involved in WRC projects completed since January 2000, are as follows:

Students	2
Ph.D.	2
M.Sc.	5
Females	2
Black consultants	1
Black researchers	1

The involvement of previously disadvantaged South Africans in this field has not yet reached satisfactory levels. Attempts to establish reasons have indicated that the subject area is not sufficiently lucrative to attract students, especially Black students and consultants. By contrast, reports received from project leaders at academic centres indicate that the demand for post-graduate training from students from the SADC countries is large. It is apparently perceived that national funding levels are inadequate to sustain meaningful career opportunities. Retention of developed capacity has been a problem due to the dynamics of change at academic institutions and the fact that most of these academic groups are self-funded. Further, much activity in this field forms the core component of operations of many members of the consulting fraternity; hence their academic involvement has been limited.

However, there is greater involvement of PDIs in projects; in the year 2001 study in this field was for the first time undertaken by an emerging consultant.

Knowledge dissemination

Specific information on knowledge dissemination in programmes within this field is presented in the following table for the period as from January 2000.

Number of:	**2000/2001**
Articles and papers	14
Conference presentations	6
Workshops	3

Special training sessions on water loss management were held at a variety of venues in the country to demonstrate WRC models and outputs. A special session was held at WISA 2000.

Greater impact has been seen by the WRC focusing on distributing outputs from this field to all local authorities, since the outputs from this field are mainly aimed at application of research results. This wide coverage has the appreciation of the water services industry.

Leveraging of resources

Outside contributions to research projects are mainly of an in-kind nature. The most notable example of these relates to the management of distribution systems. Rand Water and Umgeni Water over the years have provided valuable resources in the form of support and the use of the infrastructure for testing and experimental work.

Financial inputs to the study to the value of R1 500 000 have been made by Eskom and DWAF to the Mount Pleasant pilot study on combined service metering.

International linkages

The WRC's international recognition came in the form of Dr McKenzie being invited to the USA and Australia to provide training on water loss models developed for the WRC. The international sector regards South Africa as leaders in water loss management and water demand management. Dr McKenzie will be developing models for Australia similar to the WRC models.

Professor Stephenson of Wits was invited to write a chapter on Urban Water Management for the United Nations Development Programme.

There has been a growing interest of many international agencies such as the UNHCS, the Water Utility Partnership, Western Australian Water Association etc., to adopt the SA water loss models developed by the WRC.

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Chapter 5

Potable Water Treatment

Dr IM Msibi

Scope

The ***Potable Water Treatment*** field embraces all processes and technologies (conventional and non-conventional) that are used to remove turbidity, chemical pollutants and micro-organisms from water, and to maintain and/or improve the resultant quality of water thereby ensuring fitness for human consumption.

Issues such as development and optimisation of cost-effective treatment methods for the best water quality production, minimising risk from treatment processes and quality degradation in distribution systems, and the challenge of providing safe water to rural communities, have remained priority areas in this field of research.

The scope of the field in terms of the percentage of WRC research funds utilised has varied as shown in Table 1. Potable water treatment is interlinked with other research fields, such as ***Health-Related Water Issues, Rural Water Supply and Sanitation, Membrane Technology*** **and** ***Water Services: Institutional and Management Issues***. Investment in this field may therefore constitute an investment in the fields listed above, while specific investments on the other mentioned fields will be directly linked to the potable water field. This would explain the variation in the percentage of WRC research funds invested in this field. The emergence of some of the above-mentioned fields has resulted in some of the projects that would have been funded under ***Potable Water Treatment*** being funded under the other fields, e.g. as health-related water issues. Hence, the continual decline in the budget, in percentage terms, does not mean less funding for potable water treatment, but that this has been unbundled.

Links to Key Strategic Areas

Potable water is a specific and specially treated kind of water. The quality of the source water determines what treatment processes will be suitable, hence this area of research may be considered downstream of many other research fields.

Water Resource Management

For the sustainability and quality of the source water, water resource management will remain important. The cost and the quality of potable water are related to the nature of the catchment and the management thereof.

Water-Linked Ecosystems

The self-purification capacity of non-degraded aquatic ecosystems minimises treatment requirements of water for potable use.

TABLE 1
Investment in **Potable Water Treatment**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R2 818 400	R2 593 402	R4 147 965	R2 485 800	R2 511 700
% of research fund	7.0%	5.8%	7.8%	4.0%	4.3%

Water Use and Waste Management

Potable water is a major research field that falls wholly within this KSA.

Water Utilisation in Agriculture

Agricultural activities can lead to chemical and/or microbiological contamination of source water, and can have a major impact on treatment requirements.

Objectives

Primary

To acquire adequate understanding of potable water treatment processes and related activities and to be able to assist in treating our scarce water resources in the most efficient and cost-effective way to an acceptable quality for potable use and in the best interests of South Africa and all its inhabitants.

Secondary

- Promotion of efficient and cost-effective treatment of water through effective and co-ordinated research:
  - Optimisation of treatment processes to deal with emerging problems;
  - Development of new processes to deal with problems such as taste, odour, and microbiological quality;
  - Alternative technologies for potable water treatment.
- Management and assessment of deteriorating water quality in in-treatment and post-treatment environments:
  - Filter wash water recycling;
  - Distribution networks and reservoirs;
  - Fate of chemicals used in drinking water treatment; and
  - Disinfection by-products.
- Provision of information and guidelines on potable water treatment and supply:
  - Communication of best practices;
  - Public concerns on water quality issues; and
  - Information on alternative approaches.
- Cost-effective, sustainable provision of drinking water to previously unserved communities:
  - Appropriate and alternative technologies;
  - Integrated approaches to rural water supply;
  - Information on emerging technologies for small communities;
  - Specific problems such as fluoride and nitrates in water;
  - Disinfection alternatives; and
  - Monitoring and communication infrastructure.

Research Projects

Portfolios of completed, current and new projects, which directly address the above-mentioned objectives, are presented below.

Completed

Application and efficiency of "mixed oxidants" for the treatment of drinking water

Scientific Services, Rand Water
(WRC Reference No 832)

Chlorination in various forms is regarded as a reliable, cost-effective method for disinfecting water for drinking purposes. This is used on both small, remote plant and large, sophisticated plant. The application of chlorine presents problems, especially in remote areas where the following could be experienced:

- The area is far from point of manufacture of chlorine;
- Transport and deliveries are unreliable;
- Insufficient expertise on dosing of chlorine, especially gaseous chlorine, exists;
- Electricity supply is unreliable or lacking; and
- Quality of chlorine gas causes problems at the point of dosing.

The results obtained in this study confirm that there are aspects of the production of mixed oxidants that are not well understood and therefore not well defined either. There also seems to be an overlap between the new emerging science of electrochemical activation of water (ECA) and the electrochemical formation of mixed oxidant solutions by electrolytic means. The results and effects claimed to be achieved by the application of ECA technology sometimes border on the meta-physical and not enough conclusive evidence is available to either support or discard the claims made.

Cost: *R130 000*
Term: *1997 - 1999*

Photocatalytic purification of drinking water

Chemistry Department, University of Stellenbosch
(WRC Reference No 834)

Microcystins are a group of cyclic heptapeptide hepatotoxins produced by several species of blue-green algae (cyanobacteria). The microcystins, produced by *Microcystis aeruginosa* and other related algal species, are the most common algal toxins in freshwaters.

- This work developed and established the optimum performance characteristics of a novel design of photocatalytic reactor for purification of raw drinking water containing humic acids, clay colloids and other organic pollutants.
- It also evaluated and established the optimum performance characteristics of photocatalytic reactor designs for the decomposition of microcystins in various potable water samples.

As a result the existing model of a falling film photocatalytic reactor based on TiO_2 catalyst (Degussa P-25), operating as a slurry-phase system, has been tested and optimised for the destruction of:

- *Para*-chlorophenol as representative of industrial pollutants; and
- Selected microcystin toxins

It was established that the destruction of the above-mentioned compounds followed first-order kinetics when the reactor was operated in recirculation and flow- through modes.

Cost: *R263 000*
Term: *1997 - 1999*

Water quality deterioration in potable water reservoirs relative to chlorine decay

Scientific Services, Rand Water
(WRC Reference No 921)

Since chlorine content is one of the most important variables used to indicate water quality, special attention should be paid to its decay and factors influencing its decay in reservoirs. As chlorine concentrations deplete within the reservoir, the overall quality of the water deteriorates as a result of increasing microbial flora. This study reports the factors contributing to the loss of chlorine residuals in water storage facilities, and it was able to:

- Relate chlorine losses to the water age (based on RTD-values and kinetic models);
- Account for chlorine losses due to wall and bottom effects;
- Account for atmospheric losses;
- Relate the bacteriological quality of the water to the levels of chlorine in the reservoirs; and
- Compare the bacteriostatic effect of monochloramine and free residual chlorine in reservoirs.

Cost: *R168 000*
Term: *1998 - 1999*

Supercritical fluid regeneration of activated carbon applicable to water fraternity

Centre for Separation Technology, Potchefstroom University
(WRC Reference No 923)

The excellent adsorption properties of activated carbon stem from a large surface area of up to 1 500 m^2/g. A surface area of this dimension is obtained in the manufacture of activated carbon by subjecting all conceivable forms of carbonaceous material (wood, coal, nut-shell) to high temperatures and thus transforming them into a labyrinth-like pore structure. Activated carbon is classified according to the type of raw material, the magnitude of the surface area, the size, shape, density and hardness of the particles and the nature of the pore structure.

From the results of this investigation the requirements for the supercritical fluid regeneration of activated carbon exhausted in "real-world" water purification systems could be derived. These include that samples should not have been subjected to thermal regeneration before, that samples should be free of impeding biological growth and aged adsorbed species and that optimum supercritical conditions (high temperature for effective desorption, high density for guaranteed dissolution) should be selected.

Cost: *R125 000*
Term: *1998 - 1999*

Trouble-shooting guide for the domestic consumer

Scientific Services, Rand Water
(WRC Reference No 963)

A collection of frequently asked questions (FAQ) about water quality issues in urban areas, stretching over 17 local councils in South Africa, is presented. The FAQs received by all respondents fall into 15 categories, namely: Colour, taste and odours; white water; fluoride; hardness; home treatment systems; health; chlorine; worms; bottled water; iron; gardens and plants; perceived deterioration of water quality; chemical and microbiological content; and the comparison between municipal and borehole water.

These were analysed according to consumers' income group, those aspects that are readily perceivable by the primary senses (colour; tastes and odours and white water) occurred at the highest levels across all income groups. Fewer questions came from rural communities (consumers), and this exposed the need for education and training about fundamental issues such as disease, hygiene and water itself. Also of importance is that it appears as though there is a belief that water quality and disease are not related.

The outcome of this study is a trouble-shooting guide in the form of a 20 question-and-answer fact-sheet, to be used by consumers.

Cost: *R 110 000*
Term: *1998 - 2000*

Evaluation of phase removal processes at SA water treatment plants in terms of particle size and number

Department of Civil and Urban Engineering, Rand Afrikaans University
(WRC Reference No 1024)

Many of the recent advances in the understanding of water treatment have been derived from the fact that modern particle counters provide much more information than merely the turbidity of the water. Nevertheless, turbidity is still the main measure of particle concentration used in SA.

In this work particle counting is presented as bringing a new technology that is finding increasing acceptance in the potable water treatment field. However, this technology, together with its new concepts, needs to be explained to familiarise the water treatment practitioners with this technology. This study therefore looked at 6 particle-counting issues, to illustrate the use and benefit of particle counting:

- A mechanism through which raw waters that have to date been classified along conceptual lines, can be sorted into distinctive groups according to the particulate matter suspended in it.
- The relationship between particle size and *Cryptosporidium* oocysts and *Giardia* cysts in filtered water was investigated.
- The effect of pretreatment using ozone on the clarity of filtered water was determined.
- The use of particle counting as a feed-back control mechanism in treatment plants was investigated.
- Flocculation theory differentiates between sweep floc and charge neutralisation and the second is considered to be more effective than the first.
- Control of filter start-up hydraulics appears to be the only viable alternative for many plants to reduce the impact of the filter-ripening curve on final water quality.

Cost : *R261 000*
Term: *1999 - 2000*

Investigation into the use of particle size analysis for monitoring and optimising plant performance for the production of potable water

Process Facility Department, Umgeni Water
(WRC Reference No 1025)

Turbidity is a gross measure of the quality of potable water. Particle counting and size analysis are fundamental to a deeper understanding of flocculation, settling and filtration processes. The primary objective of water treatment is the removal of particles.

This project investigated the use of particle size analysis as a control parameter for the optimisation of water quality, and compared this to the control using zeta potential and streaming current. It studied the effects of pretreatment processes such as ozonation and coagulation on the clarity of the filtered water by measuring particle size; and considered the use of particle size analysis together with CFD for the optimisation of water treatment equipment.

The report stresses the importance of standardisation of this technology and also includes a substantial amount of fundamental principles and practices useful to potential users considering the implementation of this technology. The document is accessible to both semi-skilled operators of treatment plant as well as highly skilled professionals considering the use of particle counters in a number of applications ranging from fundamental research to day-to-day operation of treatment plants.

Cost: *R250 000*
Term: *1999 - 2000*

Current

Evaluation and optimisation of a cross-flow microfilter for the production of potable water for rural and peri-urban areas

Pollution Research Group, University of Natal
(WRC Reference No 662)

The supply of potable water to rural and peri-urban areas is a national development priority. This may be effected by the installation of package microfiltration plants which can operate at full capacity within days of purchase. Cross-flow microfiltration has gained recognition as a technology that can produce high quality water at an economically viable production rate. Certain modifications have to be implemented in existing equipment to render it robust, reliable, cost-effective and easy to clean. The dead-end mode of operation of the cross-flow microfilter appears to be a very attractive option - yielding a similar permeate production rate to the normal high-velocity cross-flow microfiltration, but at a significantly reduced energy consumption. Such a mode of operation may be ideal for use in rural areas.

Estimated cost: *R383 000*
Expected term: *1995 - 1996*

Compilation of a computerised, diagnostic system for algal-related water purification problems

Scientific Services, Rand Water
(WRC Reference No 679)

Certain algal species prevalent in South Africa's eutrophic waters are more problematic than others in that they are more difficult to remove, cause more taste and odour problems and generally increase the cost of water purification. A need exists at water treatment utilities to rapidly identify these problematic algal species and to take corrective action.

The aims of the project are therefore to:

- Compile a diagnostic identification system, allowing treatment plant personnel to identify problematic algae from computerised photographs of these algae; and
- Provide plant personnel with an accompanying computerised decision-support system to subsequently assist them in taking the necessary and cost-effective corrective actions.

Estimated cost: *R446 400*
Expected term: *1995 - 1998*

Development of a strategy for disseminating information from the hydrogeological mapping programme to village water committees

Water Systems Management
(WRC Reference No 734)

Groundwater is an important water source in most rural communities. Incorrect understanding of its nature and properties, however, has led to the poor confidence many communities have in this valuable resource. Because of the scarcity of water, it is of the utmost importance that communities gain confidence in groundwater and use it in a sustainable manner.

The need to ensure that communities are kept well informed and have access to information on their water supplies, is in line with the *White Paper on Water Supply and Sanitation* recently released by the DWAF, which clearly states that communities will be given the responsibility of operating and managing their own water supplies. This is particularly relevant to groundwater resources which are most effectively managed at a local level.

The dissemination of information collated during the Department's now ongoing hydrogeological mapping programme will thus be of utmost importance if government policy on water supply and the water supply goals of the Reconstruction and Development Programme (RDP) are to succeed in rural areas. To ensure that this dissemination takes place effectively, the following objective has been formulated:

- Transfer of hydrogeological knowledge, arising out of the regional hydrogeological mapping programme, to communities so that they can understand and manage their own groundwater sources on a sustainable basis.

A key outcome of this project will be an expectation that communities will start to plan their groundwater resource development more strategically.

Estimated cost: *R200 000*
Estimated term: *1996*

Systems for the abstraction of surface water through river sand-beds

Chunnett, Fourie and Partners (CE)
(WRC Reference No 829)

A number of areas in South Africa have river waters with high sediment load or turbidity. Numerous problems are associated with the storage, abstraction and treatment of such waters, including:

- Accumulation of sediments in instream reservoirs, off-take structures and raw water pump sumps;
- Rapid wear of raw water pumps and higher cost of chemicals for flocculation;
- Lower capacity of water treatment plants due to more time required for flocculation, sedimentation and filtration; and
- More regular cleaning of sedimentation tanks, filters and higher water loss.

If water is abstracted through a river sand-bed as opposed to being abstracted directly from the river, the sand can act as a natural filter and raw water with low turbidity can be supplied to water treatment plants. Many of the above-mentioned problems associated with high sediment-load waters could be drastically reduced.

An earlier study demonstrated that the use of such alternative systems could result in savings of up to R8.5 m. over a period of 20 years. The aims of this new project are to:

- Establish a directory of systems in South Africa that were designed and constructed for the purpose of abstracting surface water from sand-beds;
- Determine whether there is a correlation between low yield of abstraction system and factors such as design, method of construction, geology, surface water quality and total bacterial count; and
- Establish guidelines for the design, construction and operation of river sand-bed abstraction systems, based on information obtained from the survey of the abstraction systems and from an in-depth case study.

Estimated cost: *R449 000*
Expected term: *1997 - 1999*

Development and implementation of gas and liquid chromatographic organic water profiles as a management tool

Scientific Services, Rand Water
(WRC Reference No 831)

Tastes and odours and organic micropollutants are major concerns in organic drinking water quality. The analysis of individual organic compounds is time-consuming, labour-intensive and generally very expensive - there are too many compounds. Numerous separation, concentration and extraction techniques have been developed and the resin-based techniques seem to have the largest and the most flexible band-width. To identify the components of a complex mixture, the GC and HPLC are the most versatile and general.

Current methods such as those by Van Rensburg, who developed an Organic Pollution Index, have certain drawbacks such as lengthy extraction procedures that are prone to errors. Development of this technique will therefore involve improvements in three areas:

- Preconcentration technique;
- Chromatography to encompass a GC analysis phase and an HPLC analysis phase; and
- Analysis to use neural networks to establish the definition of the profiles.

Hence the research aims are to:

- Enlarge and develop GC and HPLC methods to determine the organic profiles and fingerprints of the volatile fractions in both source and drinking water;
- Monitor differences in the sample profiles and group major troublesome compounds; and
- Formulate guidelines, removal efficiencies and cost of the different treatment processes.

On distribution of the technology of the completed project, other water suppliers can obtain profiles of their particular water supply that can, in time, be networked/analysed to give an overall picture.

Estimated cost: *R551 000*
Expected term: *1997 - 1999*

Measurement of COD (organics) in drinking waters and tertiary effluents

Department of Civil Engineering, Water Quality Group, University of Cape Town
(WRCF Reference No 833)

There has been a progressive decrease in river water quality with time in many regions of South Africa, especially in the Gauteng and Umgeni regions. In part, this deterioration is reflected by an increase in dissolved organic content. Removal of such organics (usually with activated carbon) requires continual monitoring of dissolved organics entering and leaving the treatment plants. Using such methods as total organic analysis requires expensive instrumentation and long time-scales between sampling, analysis and feedback.

Measurement of COD (chemical oxygen demand) using potentiometric titration appears to be a cheap practical alternative to total organic carbon measurement. Current methods for measuring COD use colorimetric (end-point) techniques - these are adequate for high COD waters (e.g. sewage waters down to about COD 50 mg/ℓ).

The potentiometric method that is proposed does not depend on an end-point identification in the titration but uses a modified Gran method allowing more accurate and precise measurements. Hence the aims of this research are to:

- Develop the methodology for measuring COD in waters containing low concentrations of dissolved organics (i.e. treated and pretreated drinking water);
- Apply this methodology to quantifying dissolved humics (colour) in waters; and
- Disseminate the methodology on a national basis addressing all laboratory personnel.

A manual of practice will be produced for implementing the technology. Also a user-friendly computer program will be developed for use by personnel not acquainted with extended redox Gran-function analyses.

Estimated cost: *R163 000*
Expected term: *1997 - 1998*

Chemical and microbiological evaluation of the performance of commercially available home treatment devices

Scientific Services, Rand Water
(WRC Reference No 873)

Most household treatment devices are oriented toward improving chemical and aesthetic aspects, and ignore microbiological contamination. In most of these cases the water may be subject to re-contamination when stored for drinking later. Given that Rand Water meets all accepted criteria for water for domestic consumption, and that the small amount of activated charcoal used in most of the home treatment devices is

subject to de-activation and saturation, the half-life of these devices could render them little more useful than placebos for the unduly concerned. People might also use these devices on non-accredited water in the hope of purifying it. Hence claims made with respect to the performance of these devices and the quality of water produced need to be evaluated.

The objectives of this project are to:

- Evaluate and compare the efficiency and effectiveness of commercially available home treatment devices with respect to microbiological and chemical performance;
- Examine the cost/benefit of the various devices; and
- Compile a technical pamphlet with guidelines for consumers who wish to purchase these devices.

Further, the results can be used to compile a standard (such as *SABS 1657:1996 Specification for Bottled Natural Water*) to which suppliers of these devices must conform.

Estimated cost: *R99 000*
Expected term: *1997*

Optimisation of an automatic backwashing filter for the cost-effective production of potable water for rural areas

Department of Civil Engineering, University of Natal and Scientific Services, Umgeni Water
(WRC Reference No 919)

The choice and complexity of a water treatment process for potable water production is influenced by the water quality, water quantity, physical location and the availability of resources for operation and maintenance, and not necessarily by the capacity of the plant. The smaller plants generally used in smaller isolated communities, remain under pressure to reduce both capital and operating cost. The challenge to designers is therefore the provision of low cost, low-maintenance plants without compromising performance. Processes must be simple so as not to require highly skilled operators.

It is against this background that the automatic backwashing gravity filter will be evaluated as it has no internal moving parts, requires no operator intervention, no electricity, can accommodate a wide choice of filtration media and is suitable for gravity-powered chemical dosing systems. The objectives of this project are to:

- Assess the suitability of a proprietary automatic backwashing filter for inclusion in low-maintenance treatment processes for potable water production from surface waters and the removal of iron and manganese from groundwater supplies;
- Propose, where necessary, design modifications aimed at improving the reliability and reducing the capital costs of such an automatic backwashing filter; and
- Propose specific operating rules by which the unit should be operated and maintained and to prescribe minimum levels of operator supervision.

Estimated cost: *R138 000*
Expected term: *1998 - 1999*

Evaluation of a filter wash-water recovery plant to establish guidelines for design and future operation

Scientific Services, Rand Water
(WRC Reference No 920)

Filter wash-water contains high concentrations of impurities which originate from raw water sources. In most water purification plants this water is returned to the beginning of the process for re-treatment. The impurities are mainly suspended matter but can also include micro-organisms, algae and taste- and odour-causing substances. Pathogenic micro-organisms such as *Giardia* and *Cryptosporidium* are known to pass through conventional treatment processes under certain conditions and to resist disinfection by conventional means. The disadvantage of recycling filter wash-water back to the head of the process is that the above micro-organisms can be concentrated in the system.

The aims of the project are to establish guidelines for the design and future operation of filter wash-water recovery plants with emphasis on the following:

- Removal of suspended matter;
- Removal of pathogenic bacteria;
- Removal of taste- and odour-causing compounds and algae; and
- Establishment of design and treatment requirements and operational procedures to produce water of potable quality.

Estimated cost: *R214 000*
Expected term: *1998 - 1999*

STASOFT IV - A user-friendly computer program for use in the treatment of municipal water supplies

Department of Civil Engineering, University of Cape Town
(WRC Reference No 922)

The original STASOFT (III) was developed for the WRC in 1989, and is used in South Africa for calculations involving pH control and mineral ($CaCO_3$ and $Mg(OH_2)$) precipitation and dissolution and gas (CO_2) interaction between water bodies and the air. The demand and expectation for much higher standards of user-friendliness, ease of learning and consistency of action among users of computer software has increased. For example, facilities offered by the Windows operating system were not available at the time the current STASOFT program was developed.

It is therefore proposed to bring STASOFT up to modern standards, whilst incorporating the following improvements:

- Consolidation on one display screen of the original, treated and equilibrated water compositions - immediate recomputation and redisplay;
- Increased number of treatment options to address pH control in such processes as coagulation/flocculation/disinfection; and
- Elimination of "bugs" and other shortcomings.

The aims of this project are to produce an upgrade of the existing computer program STASOFT (III) to be called STASOFT (IV) so that:

- The program can be more easily used by design engineers and chemists working in the water field; and
- The capabilities of the existing program are extended to more facets of water treatment unit processes - in particular to the coagulation/flocculation/disinfection processes.

Estimated cost: *R156 000*
Expected term: *1998 - 1999*

Characterisation and chemical removal of organic matter in South African coloured surface waters

Chris Swartz Engineering
(WRC Reference No 924)

The Cape coloured waters are known to have considerably high colour levels, and this is due to high natural organic matter. This project aims to characterise the natural organic matter in South Africa and to develop operational coagulation diagrams for the removal of the organic matter in order to improve the effectiveness and cost-efficiency of treatment of these coloured waters. Finally it will draft guidelines on the treatment of South African coloured surface waters.

Estimated cost: *R 317 000*
Expected term: *1998 - 2001*

Modelling of flocculation, thickening and sedimentation in water treatment

School for Mechanical and Materials Engineering, Potchefstroom University for CHE
(WRC Reference No 998)

South Africa is a semi-arid country running out of water for all its needs. The problem of decreasing availability and increasing cost of water can be addressed in a number of ways. The first order of priority should be to make the best possible use of what is available, i.e. to effect a significant saving in water consumption. One method to attain this is to optimise water treatment processes. A significant loss of water occurs during treatment due to inefficiencies in the sedimentation/clarification and filtration processes. The reason for the losses in the sedimentation process is the lack of a comprehensive understanding and model of the process itself that can be used to optimise design and operation. Availability of such a tool will improve the technique considerably.

One reason for this lack of a comprehensive model is the nature of the material that is removed from the water during sedimentation. It varies from low concentrations of organic material (micro-organisms), with a density very close to that of the water, to very dense inorganic compounds in crystalline form. The flocculent used can also cause formation of flocs with very different characteristics, from gel-like to dense.

The project aims to:

- Collate the information available in literature on the characteristics of floc and models of floc settling;
- Develop and improve the available models of floc settling by incorporating information about the characteristics of different types of floc;
- Integrate the information and models about floc settling into models describing sedimentation basin dynamics;
- Use the sedimentation models to simulate and investigate the sedimentation process in order to obtain a better understanding of the physical processes involved; and
- Develop a set of guidelines for the design and operation of sedimentation basins.

The intended output will be a set of guidelines for operation and design of clarifiers and thickeners, and computational fluid dynamics (CFD) models for design and operation of clarification and thickening for research, design and remedial purposes. The project will increase knowledge of the operation of clarifiers and thickeners.

Estimated cost: *R269 000*
Expected term: *1999 - 2001*

Inhibition of biofilm regrowth in potable water systems

Department of Biochemistry and Microbiology, University Fort Hare
(WRC Reference No 1023)

The degradation of the bacteriological quality of water in distribution systems is one of the main problems facing suppliers of potable water. The major water quality objectives in water supplies consist of the removal of micro-organisms which cause "water-borne disease" and the prevention of contamination of drinking water by these organisms during distribution. A recent study by Muyima and Ngcakani (1998) (*Water SA* **24** (1) 29-34) showed that Alice drinking water is of poor quality. The regrowth of heterotrophic bacteria, total and injured coliforms in the chlorinated water between 15 and 23°C was recorded, and all indicators were above acceptable guidelines. Potable water purification in Alice involves sedimentation, sand filtration, and chlorination, using chlorine gas. Although chlorine has been reported to be an efficient disinfectant in the treatment of drinking water, it has also been reported that bacterial regrowth occurred in water when chlorine residual disappeared. It has also been shown that the maintenance of chlorine residual does not eliminate all bacteria in water distribution systems. In another study it was shown that greater persistence of monochloramine residuals inhibits bacterial regrowth.

This project is expected to investigate the inhibition of bacterial regrowth and biofilm regrowth, especially that of coliform bacteria in Alice drinking-water systems. The use of chlorine as the primary disinfectant followed by monochloramine as a secondary disinfectant will be investigated, and where necessary, laboratory-scale units will be used.

Estimated cost: *R180 000*
Expected term: *1999 - 2000*

Consolidation and transfer of limestone-mediated stabilisation technology for small- to medium-scale water users

Cape Water Programme, CSIR
(WRC Reference No 1026)

It is estimated that 40% of surface waters of South Africa characteristically have low alkalinity, calcium and pH levels. The affected area includes most of the Western Cape and the southern and eastern seaboards, including the Durban region. Furthermore, virtually all the groundwaters of the southern and eastern fringes of South Africa have similar characteristics. The waters described are aggressive to cement-type materials and are corrosive to metals, attacking conduits, fittings and appliances. For the many cities, towns and small communities utilising soft, acidic waters for domestic supplies, this can have significant financial consequences.

The WRC report *Stabilisation of Soft Acidic Waters with Limestone* (Report No 613/1/98) documents the process of identifying a suitable limestone deposit, describes the designs of various small-scale stabilisation systems and presents the results of trials with these systems. This project will therefore continue this work by focusing on the effective transfer of this technology and implementation of limestone-mediated stabilisation. It will also focus on groundwater stabilisation and iron removal, colour limit of feed water and protection afforded by partial stabilisation. Guidelines will be produced and workshops for technology transfer will also be arranged.

Estimated cost: *R275 000*
Expected term: *1999 - 2000*

Development and assessment of the limestone-mediated side-stream stabilisation process, with emphasis on use thereof by Rand Water for stabilisation of Lesotho Highlands scheme water

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1027)

Rand Water is in the process of considering options for transport and treatment of the Lesotho Highlands Scheme water. To date Rand Water has abstracted some 95% of its raw water from the Vaal Dam. However, it is expected that by 2008, 50% of raw water will be Lesotho Highlands water. This water is chemically very different to the Vaal Dam water. In particular it is relatively soft and acidic, requiring conditioning to prevent attack on cement and metal structures. The side-stream stabilisation process (SSP) offers a potentially attractive alternative to conventional lime and carbon dioxide mediated stabilisation.

This project will focus on developing a calibrated mathematical model describing the aqueous, gaseous and solid phase chemistry of the carbonate weak/acid system and influencing parameters. Also the desirability and suitability of the SSP for the various Lesotho Highlands water treatment/transfer scenarios will be determined. Further motivation for industrialisation and full-scale implementation will be assessed.

Estimated cost: *R300 000*
Expected term: *1999 - 2000*

Support, maintenance and debugging of WATREX - Expert system for water treatment plant design

Sutherland Associates
(WRC Reference No 1041)

The WATREX program, or Expert System for Water Treatment Plant Design, is a program for the computer-assisted design of drinking-water treatment plants. It is in the final stages of evaluation before it is to be distributed. This program has excellent potential to elicit a great deal of interest - both locally and abroad. However, after distribution has commenced, it is of the utmost importance that a user service for the program be maintained, at least for the initial period until most of the "bugs" discovered and reported have been sorted out. Feedback from the users can be used to refine the operation of the program and this will lead to both the expansion and refinement of the knowledge base behind the program. Specific aims of the project include the following:

- Compilation and distribution of the WATREX program to interested users;
- Continued improvement of the operation and integrity of WATREX (debugging);
- Refinement and expansion of the knowledge base behind WATREX; and
- Provision of on-line support to WATREX users in order to enhance usage and obtain direct feedback.

Estimated cost: *R84 000*
Expected term: *1999*

Evaluation of powdered activated carbon (PAC) for the removal of taste- and odour-causing compounds from water and the relationship between this phenomenon and the physico-chemical properties of the PAC and the role of water quality

Process Development, Rand Water
(WRC Reference No 1124)

The presence of nuisance compounds like geosmin and 2-Methylisoborneol (MIB) in drinking water often leads to consumer complaints. Unfortunately, toxic compounds like microcystin may go by unnoticed. Very few water treatment plants in South Africa are equipped to remove such troublesome compounds as unit treatment processes for the removal of taste and odour compounds and other metabolytes are usually not installed. This is because the problems normally occur sporadically or seasonally. There is seldom any associated health risk and treatment costs are high.

Since PAC is required intermittently, the selection of the correct type of material could present a problem as water quality may change, and may have an influence on the adsorption of the nuisance compounds. In the absence of available information, it is important to establish the possible relationship between the physico-chemical properties of PAC and the removal of taste- and odour-causing compounds from water and to also investigate whether water quality could influence the efficiency of removal.

The aims of this project include setting guidelines for the evaluation of PAC for the removal of taste- and odour-causing compounds like geosmin and 2-MIB from water. It will also look at the relationship between the physico-chemical properties of PAC and the removal efficiency of taste- and odour-causing compounds from water. Finally, it will try to establish whether compounds exist which mimic geosmin/ 2-MIB with regard to the removal by PAC and which are cheaper and easier to evaluate. The whole process will be evaluated nationwide.

Estimated cost: *R400 000*
Expected term: *2000 - 2001*

Small water treatment systems: A case for development of an approval/ certification system

Options to Solutions
(WRC Reference No 1125)

The supply of clean, safe drinking water in rural South Africa has been largely hampered by failures of small treatment systems. This project is aimed at building a case for an appropriate pre-approval/ certification/ evaluation system which when adopted will drastically increase the treatment system's predictable mean time before failure.

Estimated cost: *R 290 000*
Expected term: *2000 - 2001*

Development and evaluation of new South African ozoniser technology for removal of pathogenic organisms, possible enteritic viruses indicated by bacteriophages, and tastes and odours present in Hartbeespoort Dam water
PARC Scientific
(WRC Reference No 1127)

Ozone is recognised as very effective in the removal of pathogenic organisms, enteritic bacteriophages, tastes and odours from eutrophic waters. This project is aimed at developing an optimised, energy-efficient, modular power supply compatible with a recently developed ozone generator. It will further establish the operational parameters and design a full-scale ozonation system. This will result in a cheaper, but more efficient ozonation system

Expected cost: *R 398 000*
Estimated term: *2000 - 2001*

Development of guidelines for the disposal of water treatment sludges to land
School of Applied Environmental Sciences, University of Natal
(WRC Reference No 1148)

South Africa's turbid waters give rise to the production of huge quantities of sludge during the water treatment process. Chemical precipitants are added to the turbid waters to promote flocculation. Once flocculated, the solid fraction that settles under gravity is transferred to drying beds, while the supernatant is filtered and clarified for domestic consumption. The dewatered solids (sludges) are regarded as industrial wastes and must be disposed of accordingly. The traditional method of sludge disposal has been by landfilling, but given the economic constraints associated with landfill maintenance, alternative methods of sludge disposal have to be considered. A disposal option that is gaining increased acceptance internationally is the application of sludge directly onto land.

Land disposal is based upon the fundamental tenet that the physical, chemical and biological properties of the soil can be used to digest the applied waste without inducing negative effects on soil quality, groundwater or plant growth. Sludge could have two opposing physical effects on soils, *viz*. the polyelectrolyte could improve soil structure, or the fine silt and clay could lead to structural degradation. Chemically, the behaviour of heavy metals and the high phosphorus-fixing ability of the sludge also give rise for concern. These concerns will be evaluated as part of this project.

Estimated cost: *R650 000*
Expected term: *2000 - 2002*

Fluoride removal from water with unconventional low-cost media
Department of Civil and Urban Engineering, Rand Afrikaans University
(WRC Reference No 1183)

The excessive presence of fluoride in isolated rural parts of South Africa is well-known and documented. Its removal is a high priority for water managers, as evidenced for example by the workshop on its removal hosted by the WRC in March 1999. In a review presented at this workshop, one alternative approach to fluoride removal (other than the usual methods of chemical precipitation, or ion exchange/adsorption on conventional media) is a method reported from Sri Lanka. Here the water is percolated through a bed of clay brick fragments with reported success. The health and cost benefits of such a low-cost method are obvious, and especially so to rural South Africa.

Despite the enormous appeal and potential of this technology, a two-stage approach to the problem is proposed due to the high risk of the project. This first stage (this project) will only include the necessary exploratory work to determine whether the technology holds any potential at all. Should the reported success from Sri Lanka be duplicated, one should then advance to a second, more exhaustive stage, backed by the necessary scientific evidence. Hence, the aims are as follows: To make a rapid assessment of the potential of clay brick for the removal of fluoride from rural water supplies and to assemble the necessary fundamental information to formulate a rational, well-motivated follow-up research proposal, should the technology show sufficient promise.

Estimated cost: *R90 000*
Expected term: *2000 - 2001*

Assessment of procedures used in Southern Africa to evaluate chemicals used in water and wastewater treatment
Department of Process Services, Umgeni Water
(WRC Reference No 1184)

A large number of chemicals are used in the production of potable water and in the treatment of wastewater effluents. In potable water treatment, chemicals such as inorganic salts and polymeric organic coagulants are used for primary coagulation, as coagulant aids and for sludge dewatering; lime and soda ash allow for pH correction and water stabilisation; caustic soda is used for pH adjustment; powdered activated carbon (PAC) can remove taste and odour compounds and micropollutants such as atrazine; bentonite aids coagulation; and ammonium hydroxide is used in chloramination.

At present there are some recommended tests available for the assessment of some of these chemicals such as the *SABS 459 1955 Standard Specification for Lime* which is used for chemical and metallurgical purposes. However, the tests described in this specification are, for the most part, outdated gravimetric procedures which are particularly time-consuming. In the case of polyelectrolytes used for primary coagulation during potable water treatment, there is currently no legislation or regulation system available in this country to control the use of these chemicals and no standard tests are available to measure the effectiveness of these chemicals for coagulation.

This lack of standard tests in the water and wastewater chemical industry makes it difficult to assess or compare these products and this can have negative health and environmental implications. A handbook containing standard tests, which have been properly evaluated and which, for the most part, can be performed using relatively simple equipment, would be of great benefit to the entire water industry. The main aims of this project are to:

- Assess the various procedures used in Southern Africa to evaluate the different chemicals used in water and wastewater treatment;
- Identify the critical determinants for the evaluation of these chemicals and to recommend standard procedures; and

- Produce a handbook for all Southern African water and wastewater authorities which can be used for the evaluation of the chemicals used in water and wastewater treatment. This handbook would set out standard procedures for the assessment.

Estimated cost: *R89 000*
Expected term: *2000 - 2001*

Design manual for small water treatment plants for rural communities with specific emphasis on community involvement and the use of indigenous treatment technologies

Chris Swartz Engineering
(WRC Reference No 1185)

A large number of small water treatment systems installed in South Africa are subject to failure during their lifetime. According to feedback at a recent conference held in East London (*Appropriate Practice Conference, March 1999*), of a number of more than 50 small treatment systems that were installed in Southern Africa, only a small percentage are performing according to the requirements and can be considered to be successful water supply projects. This implies that a failure to gain the support and participation of the communities during the initial stages of successful water supply projects may result in failure of the system. It is of utmost importance that the communities accept the technology and that the technology should work for the community.

A number of guideline documents have been drawn up about various aspects of rural water supply, and on the different technologies used in rural water treatment plants (WRC Report Nos. 231/1/93, KV 58/94, TT 68/95, 449/1/95, 450/1/97, and 354/1/97; various Technical Guides by the CSIR Division of Water Technology). However, none of these guides specifically address the pitfalls that should be guarded against when designing small treatment systems, and which often lead to failure. There is, therefore, a need for a comprehensive design manual for small rural water treatment plants, which specifically identifies pitfalls to be avoided in the design of these plants, and which contains the very important guidelines on how to obtain community support and participation in the project. Because many of the treatment systems designed by engineers for rural applications are over-designed or inappropriate (too sophisticated; community does not accept the technology), the aim is also to provide guidelines on how the "simpler" and indigenous technologies can be used to ensure community participation, cost reduction and sustainability of the systems.

Estimated cost: *R95 000*
Expected term: *2000*

New

Alternative approaches for sustainable water supply schemes

Options to Solutions
(WRC Reference No 1223)

There is a need to be more creative in approaching the delivery of water services so that delivery encompasses the holistic objectives of ensuring sustainability. There are various options that could be explored, and this project is doing that. It reviews the different approaches that have the potential to render water supply schemes sustainable. Further, it carries out specific technical and economic analyses on identified projects representing an individual approach and will finally develop and disseminate the demand-led planning tool (guideline) that will promote and support a technically viable approach, integrating rural water supply with community activities.

Estimated cost: *R 496 100*
Expected term: *2001 - 2003*

Ultraviolet light in combination with cavitational flow

Rand Water
(WRC Reference No 1224)

Infections by protozoa, specifically *Giardia lamblia* and *Cryptosporidium parvum*, are now accepted as common world-wide causes of acute, self-limiting diarrhoeal disease in the human host. This project is looking at the use of UV light alone or in combination with either/or low cavitation and ultrasonic treatment to destroy protozoan cysts or oocysts in water. It is seeking to establish minimum energy input required and to design the ultraviolet light treatment system.

Estimated cost: *R 300 000*
Expected term: *2001*

Coagulation and cationic polymers

Umgeni Water
(WRC Reference No 1225)

Coagulation is an essential part of water treatment, playing a role in the overall separation of solids and liquids and providing a primary barrier against water-borne diseases. Despite the advantages of using polyelectrolytes as coagulants, no method exists on which to base selection, and many of the chemical reactions which take place when polyelectrolytes are added to water, are not well elucidated. This project will characterise these reactions and aims to determine the effect of natural organic matter. It will further develop procedures and tests to enable accurate and easy selection of polyelectrolyte coagulant type and dose for a particular type of water.

Estimated cost: *R 204 000*
Expected term: *2001 - 2002*

Chemical dosing system (CDS)

Peninsula Technikon
(WRC Reference No 1281)

Existing chemical dosing systems in small and rural water treatment plants were previously found to be inappropriate due to their stringent operation and maintenance demands. As a result, they become ineffective and unreliable. This project is currently developing a simple, reliable and effective chemical dosing system. Its effectiveness will be evaluated on a pilot-scale water treatment plant. This plant will incorporate roughing filtration and slow sand filtration.

Estimated cost: R 202 000
Expected term: 2001

Removal of fluoride from drinking water

Department of Civil Engineering, Rand Afrikaans University
(WRC Reference No 1289)

The deleterious health effects of excessive fluoride are well known. However, fluoride removal methods are difficult to implement due to cost and complexity. Currently, the most promising development is a simple

domestic unit containing brick fragments as adsorption medium. This project is currently seeking to understand the fundamental mechanisms whereby fluoride is adsorbed onto baked clay and how it is affected by the firming temperature. It will also demonstrate the feasibility of a clay-based domestic fluoride removal unit in a rural village currently plagued by excessively high levels of fluoride in its drinking water.

Estimated cost: R 495 000
Expected term: 2001 - 2003

Outcomes to Date of Current Programmes and Projects

New knowledge

Applied projects in this field stem from a proactive and comprehensive approach to assessing the research needs of the water supply community. The ability to obtain and use relevant input regarding ongoing and emerging issues for research is seen as a cornerstone of success. Research responses to community water supply concerns and issues are typically identified within the context of five strategic goals that provide definition for the mission of the **Potable Water Treatment** field:

- Improved drinking water distribution infrastructure and processes therein, for the reliable delivery of high quality water to the customer's tap. As a result, water in the distribution system is viewed as a perishable product, which has a shelf-life (the time it spends in the distribution system), packaging (piping and storage facilities) and which contains a preservative (secondary disinfectant). This has improved our understanding of how potable water should be handled after treatment. Further, we are now in a better position to deal with aggressive acidic waters and corrosion, inhibition of biogrowth, management of water quality and post-precipitation.
- Protection of the consumer from risks associated with chemicals, particularly organic chemicals. A number of natural organic compounds have been characterised and their reactions with disinfectant and removal processes is a subject of further studies. Addition of chlorine may result in disinfection by-products. Our research indicates that the most promising approach to removal or elimination of the resultant THMs and other suspect carcinogens is to remove the organic substances before adding chlorine. Progress has been made in terms of performance characterisation of granular activated carbon for removal of organic substances in water. Current studies are also focusing on powdered activated carbon.
- Improved water treatment processes to obtain optimum water quality and system reliability. The development and optimisation of processes such as coagulation, flocculation and sedimentation has prompted a new interest in producing high quality drinking water with minimal quality monitoring. There has been excellent progress in the development of ozone technology, multiple media filter beds, and particle counting to optimise filter performance. The development of these technologies has put the industry in a position to deal with intermittent outbreaks such as *Cryptosporidium*.
- Provision of science, technology and management support to small water treatment systems for improved supply of water to rural communities. This area received a boost in that the problem of fluoride in rural water supplies could possibly be eliminated by the use of easily available clay bricks. The WRC has embarked on an integrated approach to rural water supply that is proving to be a huge step forward. The integration of a water supply project with catchment management and income-generating projects is a priority research area.

Benefits to South Africa

In terms of producing good quality potable water, South Africa, because of its investment in research, ranks among the top few in the world. Treated potable water in South Africa is generally safe, with very low probability of water-borne disease. The high priority challenge that remains is to extend this knowledge to benefit rural areas, specifically. The fact that most of the research in this field is carried out by water boards has resulted in expertise being built where it is needed the most. The advantage is that the benefit of such research will be passed on to the consumer immediately. As potable water is an issue for all, such benefits are available to all, even though there is a limitation in terms of reaching all. This is addressed in another WRC research field, ***Rural Water Supply and Sanitation.***

Further, as a result of research in this field, South Africa:

- Has the capability (skill) to treat any type of water found in South Africa;
- Is applying advanced water monitoring systems. This ensures optimal application of the above- mentioned processes; and
- Has available a variety of locally developed and manufactured systems, ensuring a wide range for the choice of appropriate system.

Innovation/application of knowledge

Knowledge generated through current programmes and projects is already being or will be applied as exemplified below:

- The dissolved air flotation (DAF) process is in use at waterworks such as Midvaal Water for removal of turbidity and organic matter from water abstracted from the lower Vaal River.
- Ozone is used in plants such as Umgeni and Midvaal for the oxidation of organic matter in order to control the formation of disinfection by-products or as a disinfectant.
- Granular activated carbon (GAC) filtration is used in plants such as Rietvlei Dam and Vaalkop Dam to treat eutrophic waters.
- Colour removal through coagulation and flocculation is used by Cape Metro Council and others to effectively deal with Cape coloured waters.
- Acidic and aggressive water stabilisation, as used in Stellenbosch, and other smaller waterworks, protects the water distribution infrastructure.
- Packaged water treatment plants are used in rural and isolated areas.

Capacity/competence development

Capacity and competence developed through current WRC programmes resides in the following institutions:

Water Boards: Rand Water, Umgeni Water, Cape Metropolitan Council; capacity building

in these water boards is translated to be enhancement of technical capability and competency, not only for the participating staff, but for the benefit of all water boards. Positive results are usually directly exploited for the benefit of potable water users. It has proven to be the critical place to build capacity.

Rand Afrikaans University: The Water Research Laboratory in the Department of Civil Engineering, has acquired considerable expertise in water treatment processes. The WRC is working with them to transfer knowledge to black researchers. The first Black Ph.D. student will graduate next year.

University of Cape Town: The Department of Civil Engineering commands a wide range of research skills in carbonate chemistry, water conditioning and distribution networks. One Black Ph.D. Student and two White female Ph.D. students graduated last year.

University of Fort Hare: Research capacity is currently being nurtured in the field of disinfection and biofilm regrowth. This is a previously disadvantaged institution. The first M.Sc. students under this initiative have been registered this year.

Wits Technikon: Research capacity is being nurtured, starting last year. The focus is on removal of organic matter from water.

General

Involvement of previously disadvantaged researchers is on the increase, but not from within the water boards. Since the water boards are the focus of our research activities, this may limit growth in this initiative.

Knowledge dissemination

Knowledge dissemination has taken place through scientific articles and conference presentations/workshops as indicated below:

- Scientific articles: 9
- Conference presentations: 8
- Courses/workshops/demonstrations: 3

Leveraging of resources

Outside contributions to research projects are mainly of an in-kind nature. This is especially evident in the research carried out by water boards, as they normally do not include costs for staff, equipment and in some cases analysis. In general this reduced the cost of research projects by more than 50%. DWAF, through its Mechanical Laboratory, has performed sand grading and analysis free of charge for some of WRC projects (amounting to a contribution of R400 000).

International linkages

The following international research institutions have made contributions to current research, and will continue to do so in the future:

Vrije Universiteit, Amsterdam, Netherlands
University of Massachusetts, USA
University of Texas

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Chapter 6

Health-Related Water Issues (HRWI)

Ms APM Moolman

Scope

Until 1999 health-related water research was being addressed under a number of WRC research fields. During late 1998 it became apparent that there was a need to focus and co-ordinate health-related research and provide leadership and direction in this research area. The ***Health-Related Water Issues (HRWI)*** field was officially constituted in April 2000.

The ***HRWI*** field focuses on research that will assist in the protection of quality of water; prevention of health-threatening water quality deterioration; and assuring that the water delivered to users is safe and acceptable. Research is done with the aim to save lives to reduce costs and efforts for the treatment of the symptoms of disease, as well as for the purification and disinfection of affected waters.

A holistic, multidisciplinary approach is followed to develop a comprehensive understanding of the origin/sources and spatial extent of pollution; its effects on water quality; water usage patterns; the effects of the deteriorated water quality on animal and human health and the need for water treatment. The emphasis is on a pro-active approach of identifying and addressing "causes", rather than a passive response to "symptoms". This approach should ensure research products that are relevant, user-friendly, practical and scientifically valid.

Although the major part of research on health is done under this field, the support by other research fields is still evident. Funding up to 1999 was not allocated separately but was included in the budgets allocated to the other fields. From 1992 to 1999 an average of R1 225 000 was allocated to health-related research as defined in the strategic plan and objectives. This, however, could give a false impression as health-related research has vested interest in most of the other fields (as often health protection is the overarching reason why this research is undertaken).

The scope of the field in terms of the percentage of WRC research funds, utilised as shown in Table 1, has, however, increased over the past years. The main reason for this increase is that health and as such health-related research is one of the three presidential imperatives that needs to be addressed for the well-being of South Africa. Recent development and improvement of analytical techniques to detect the origin and causes of diseases and substances that have a detrimental effect on health have added to the growth of this important water research field. The interest in this research field has expanded over the past six years and is reflected in the growth in the research institutions involved, especially HDIs.

TABLE 1
Investment in **Health-Related Water Issues**

	1992 - 1999	2000	2001/02
Expenditure (total or committed)	R1 125 500 (ave/year)	R2 143 800	R2 385 600
% of research fund	-	3.45%	4.06%

Links to Key Strategic Areas

The **HRWI** field is a strongly cross-cutting field as the term health implies human, animal and ecosystem health. There is a linkage and to some degree an overlap with other current research fields such as aquatic ecosystems, drinking water, waste treatment, agriculture and water quality, the latter to the extent that it is included in the objectives of the **HRWI** field.

The linkages to the four WRC KSAs are clearly recognisable.

Water Resource Management

The contribution of the **HRWI** field to this KSA will be in the investigation of health-related water quality information for the protection of human and animal health through the assessment of health risk, the management of water resources and the development of protocols, guidelines and manuals that will add to the knowledge on water quality at all levels of society.

Water Use and Waste Management

Links are through basic research in the **HRWI** field towards understanding the origin and extent of pollution and the demands it places on the treatment of water and waste. The protection of human health could be gained.

Water-Linked Ecosystems

Protection of the aquatic environment and the clear relationships between environmental pollution and human as well as animal health are addressed.

Water Utilisation in Agriculture

Strong links exist through investigation of the relationship between water and human and animal health due to aqua- and agricultural activities, agricultural industries and wastewater, as well as through the products delivered by the agricultural sector.

Objectives

Primary

To protect human and animal health and that of the aquatic environment by investigating the sources, persistence, effects and epidemiology and risk assessment of pollutants in water and to assess the effectiveness of treatment and intervention procedures.

Secondary

- To obtain adequate understanding of the origin, survival and persistence of microbial, chemical and other biological (toxin) pollutants in water;
- Development of appropriate techniques, technologies and systems whilst focusing on applied science;
- Health risk, epidemiology - the extent of impact of pollutants on human health; and
- The integration, collation and interpretation of water quality information gathered for monitoring, risk assessment and management of water resources.

Research Projects

Portfolios of new, current and completed projects which directly address the above-mentioned objectives, are presented below.

Completed

Enteropathogens in water: Rapid detection techniques, occurrence in South African waters, and the evaluation of epidemic risks (health related)

Division of Water Environment and Forestry Technology, CSIR
(WRC Reference No 741)

The aims of this study were to:

- Apply and optimise rapid and sensitive methods for the detection of pathogenic *Vibrio cholerae*, *Shigella* spp. and *Salmonella* spp. in water
- Evaluate the sensitivity and selectivity of the technology for the detection of enteropathogens in environmental samples
- Determine the epidemic risks associated with levels of these pathogens in water.

Results:

- It has been indicated that it is possible to detect as few as 20 CFU/ml from environmental water samples using the polymerase chain reaction (PCR) technology.
- Analysis of an environmental sample using the PCR and the hemi-nested PCR for confirmation, could be completed within 10h as opposed to as long as 7 d using conventional methods.
- A potential health risk was identified for three pathogens following the calculation of hypothetical numbers of infection by accidental ingestion for daily and yearly risk of infection based on the numbers obtained using the most probable number (MPN) method. The risk by ingestion was found to be higher than the acceptable figures for risk of infection of 1: 10 000.

Cost: *R294 000*
Term: *1996 - 1998*

Health impact of water-borne viruses and methods of control in high-risk communities

University of Pretoria, Department of Medical Virology
(WRC Reference No 743)

The purpose of this project was to establish indicator systems for the practical and reliable monitoring of the virological safety of water supplies and the efficiency of water treatment processes.

The objectives were as follows:

- Optimise techniques for the recovery of viruses from water
- Assess the correlation of viruses circulating in a community to viruses

detectable in the wastewater from the community
- Assess the implications of viruses in wastewater from informal settlements for sanitation and for the protection of water sources
- Assess the risk of water-borne human viral infections constituted by animal wastes
- Evaluate the reliability of practical indicator organisms for assessment of the virological quality of water
- Formulate recommendations for the control of water-borne viral diseases and practical routine monitoring of the virological safety of water.

This study showed that:

- By using reverse transcriptase polymerase chain reaction (RT - PCR), it is possible to detect low levels of a wide variety of enteric viruses in treated water, where conventional indicators for assessment are inadequate (heterotrophic plate counts had been less than 100/mℓ. Total and faecal coliform counts of 0/100mℓ, and negative results in qualitative presence-absence tests for somatic and F-RNA coliphages on 500mℓ samples).
- 24% of the samples were positive. Entero-viruses were detected in 17% of the samples; 4% adeno-viruses and 3% Hepatitis A.
- These viruses are not cytopathogenic and would not be detected using cell propagation techniques.
- Results support epidemiological reports of low-level transmission of viral infections by drinking water supplies.
- The viruses detected may be infectious and constitute a potential health risk.

The water supplies tested would fail national and international water quality guidelines that state drinking water should be free of viruses.

Since the Guidelines themselves are based on outdated technology (as at June 2000) it may be suggested that the Guidelines are due for revision.

This investigation underlines the need for further studies in order to set guidelines for the virological quality of drinking water.

Cost: *R999 000*
Term: *1996 - 1998*

Detection methods for studying the ecology of* Legionella *in cooling water systems

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 827)

The aims of the project were to:

- Isolate the *Legionella* species present in South African industrial cooling water systems;
- Evaluate currently available identification and enumeration methods for the *Legionella* species;
- Develop PCR for the identification and enumeration of *Legionella*;
- Compare methods in terms of cost, applicability to field conditions, sensitivity, specificity and availability;
- Optimise the recommended method with reference to the relationship between *Legionella* and protozoa, interference by cross- reactions with other micro-organisms, antigen preparation and expression of antigens;
- Determine the ecology of *Legionella* in the biofilm and water phase in cooling towers; and
- Recommend a standard method for detection of *Legionella* in industrial water systems.

Results

- The *Legionella* species present in industrial cooling water systems was isolated.
- The available identification and enumeration methods for *Legionella* species were evaluated using type cultures (ATCC) and isolated Legionella species.
- The standard PCR methods and commercial kits for identification and enumeration purposes as well as new applications of PCR were evaluated.
- The study was unable to identify all protozoa commonly found in industrial cooling water systems in view of their huge numbers.
- A novel method and its application for the study of *Legionella* species in biofilm and water phase of cooling towers were tried.
- Methods were compared in terms of cost applicability to field conditions, sensitivity, specificity and availability.
- Guidelines for a standard method for detection of *Legioinella* in industrial water systems are proposed.

Cost: *R121 000*
Term: *1997 - 1999*

Assessment of Domestic Water Supplies Vol. 5: Management Guide

BKS Inc
(WRC Reference No 1123)

The *Management Guide* is the 5th of a series of guideline documents aimed at assisting laypersons and specialists to assess the quality of domestic water supplies. The series draws together the results of many research projects and the collective knowledge of experts in the field.

The aims of the project were to:

- Present information in a manner which is scientifically credible, but at the same time, easy for lay people to comprehend;
- Stimulate community members to become involved in the management of their own community water supplies;
- Identify the responsible authority for selected portions of the water supply system;
- Provide guidance regarding water quality management, specifically with regard to the planning of a new water supply scheme; and
- Indicate best practice for the implementation of a proposed water supply scheme, and the operation of an existing water supply scheme as well as the actions to be taken in emergencies when something goes wrong at specific points in the domestic water supply system.

This *Management Guide* (TT 162/01) is available on request from the WRC.

Cost: *R115 000*
Term: *2000 - 2002*

Current

Effects of water supplies, handling and usage on water quality and quantity in relation to health indices in the Eastern Cape Province (Prowater Health)

Department of Development Studies, University of Fort Hare

(WRC Reference No 727)

The aims of the project included:

- The determination of the quality of water at the point of provision at selected sites;
- The examination of usage patterns, for all domestic purposes as well as farming. The quantity of water used as well as the identification of water treatment by the end-user prior to use;
- The development of surveillance techniques as well as the testing and evaluation of such techniques, incorporating sanitary inspection and water quality monitoring; and
- The prioritisation of remedial action strategies to protect the user from the risk of water-borne diseases.

The following interim conclusions have been reached:

- Intersectoral co-operation plays a key role in planning and operating a water quality surveillance programme.
- There is an urgent need for training material or guidelines for the implementation of surveillance programmes.
- Water quality problems that were noted include:
  - Faecal coliform pollution of surface water is widespread in the district under surveillance. Two clinics in the district had experienced major outbreaks of water- borne disease (*Shigella*, gastro-enteritis, diarrhoea)
  - Human users share water sources with domestic animals such as pigs and cattle.
  - The majority of water end-users do not make use of water purification methods
  - Elevated concentrations of iron and manganese and salt were identified in a significant number of dams and boreholes.
  - The effects such as staining of clothing or unpleasant taste caused users to switch to unsafe surface water.
- Consumer involvement and effective transfer of information is all-important

Estimated cost: *R410 400*
Expected term: *1999 - 2002*

Bacterial pathogens in groundwater

Department of Microbiology, University of Durban-Westville

(WRC Reference No 821)

Well-documented outbreaks of microbial diseases traced to contaminated groundwater have destroyed the widely held misconception that groundwater is safe from pollution. This has necessitated a reassessment of what is known about the fate of the pathogenic micro-organisms in soil and groundwater. This project determines the fate of pathogenic bacteria in the sub-surface environment, including the viable-but-not-culturable organisms. The study also evaluates the application of molecular methods for the detection of the viable-but-not-culturable pathogens.

Estimated cost: *R250 000*
Expected term: *1997 - 2001*

Development and testing of a simple testing kit for the detection and quantification of* Cryptosporidium *and* Giardia *in water supplies

Umgeni Water

(WRC Reference No 825)

Occurrence and source of* Cryptosporidium *and* Giardia *in catchment areas and wastewater works

Umgeni Water

(WRC Reference No 927)

Evaluation of alternative disinfection processes for the removal of protozoan oocysts, cysts and other micro-organisms in the treatment of final wastewater effluents

Umgeni Water

(WRC Reference No 1030)

The above-mentioned three projects form part of the programme on the detection and quantification of *Cryptosporidium* oocysts and *Giardia* cysts in water supplies.

Cryptosporidium and *Giardia* are self-limiting disease-causing pathogenic parasitic protozoa for which no medication is available. Well-trained and experienced technicians are required to conduct presently available and expensive test methods to detect these pathogens. Additional knowledge is needed on the presence, viability and removal of pathogens during wastewater treatment processes and evaluation of the contribution of sources to their occurrence in the aquatic environment to prevent possible pollution from these sources. These pathogenic cysts and also viruses are highly resistant to chlorine. It is therefore obvious that effective disinfection of wastewater effluents is also required.

- **The development of a simple testing kit (No 825)**
  This project is succeeding in developing a sensitive, cheap and simple kit that can be applied to turbid as well as clear waters to accurately analyse water supplies for the presence of these pathogens. The portable kit consists of a glass tube with polystyrene beads with antibodies attached that could be used in the field for environmental waters, and a low-cost unbreakable "spectrophotometer" with which readings on slides in different shades of yellow could be measured as an additional tool for more accurate detections than the human eye is capable of.
- **The detection and origin of these protozoa (No 927)**
  This project aims to establish a PCR method and to compare and contrast it with other methods used at the CSIR, Rand Water and Umgeni Water such as immuno-fluorescence microscopy, flow cytometry as well as investigating the various concentration methods available. This method is used to investigate the occurrence of the parasitic protozoa in a catchment area and within a community to seek a correlation with the occurrence of diarrhoea. It will further investigate the presence, viability and removal of the parasites during wastewater treatment processes and evaluate the contribution of this source to their occurrence in the aquatic environment.
- **The disinfection of wastewater effluents (No 1030)**
  This project aims to evaluate different disinfectants such as chlorine, ozone, UV, peracetic acid, hydrogen peroxide, bromine and combinations of some of the mentioned disinfectants. The micro-organisms tested for are *E. coli*, coliform

organisms, faecal streptococci, total colony counts, coliphages, *Cryptosporidium* and *Giardia*. Both laboratory and pilot plants are being conducted for the development of a simple method for adequate disinfection of wastewater, which would be beneficial to rural communities as well as for the design of wastewater treatment plants and operational guidelines.

Project No 825 Estimated cost: R308 000
Expected term: 1997 - 2001

Project No 927 Estimated cost: R 300 000
Expected term: 1998 - 2001

Project No 1030 Estimated cost: R 207 000
Expected term: 1999 - 2001

Assessing the causes and pathways of water-borne diseases in rural settlements with limited formal water supply and sanitation

Umgeni Water
(WRC Reference No 925)

The aims are to:

- Identify, describe and quantify selected health impacts associated with the microbiological quality of the water supply sources, household containers and hand washes of rural settlements with and without the minimum RDP specified water supply and sanitation infrastructure;
- Identify and describe the critical factors (pathways) relating inadequate water supply and sanitation with negative health impacts in rural settlements with different water supply levels;
- Identify the most appropriate methodologies and indicators to identify and evaluate the health impacts of inadequate domestic water supply and sanitation in settlements with limited formal water supply; and
- Provide epidemiological information necessary to calibrate and test the monitoring procedures in terms of adequacy for describing health risks.

Estimated cost: R204 750
Expected term: 1998 - 2002

Assessment of the extent of oestrogenic activity in Western Cape water resources

Department of Zoology, University of Stellenbosch
(WRC Reference No 926)

Human, agricultural and industrial activities are releasing large numbers of man-made chemicals into the water environment, from where they may enter the food chain and cause bioaccumulation in wildlife and humans. A wide range of these chemicals has been implicated in mimicking the action of oestrogens. This project aims to:

- Do a literature study to review the state of the art internationally and locally in order to develop a framework for the programme.
- Assess the extent of possible environmental pollution by these chemicals from industrial, agrichemical and sewage treatment effluent. These are being done by investigating:- the physiological effect of oestrogenic water on animal health with the frog (*Xenopus laevis*), the turtle (*Pelomedusa subrufa*), freshwater fish (*Tilapia* and *Carp*) and crocodile eggs.
- Develop and validate selected screening methods, including for example a sensitive YEAST screen and a frog liver vitellogenin assay.
- Investigate the development, validation and implementation of a battery of bioassays to detect oestrogenic activity in South African waters by means of a risk assessment of these chemicals.
- Evaluate water handling, specifically extraction and concentration techniques and developing a protocol that would be used by all the participants in the programme.The new biomarkers that are investigated for possible inclusion in the bioassays are polyclonal for zona radiata proteins and monoclonal antibodies; for *Xenopus laevis* and invertebrates (fish) vittelogenin, and the male nuptial glands in *Xenopus laevis* for anti-androgenic EDC. Mechanisms of action on EDCs at cellular level (enzyme biomarkers), steroidogenesis inhibition, and the effect on immune systems are also studied. Further studies include transforming existing bioassays for the South African conditions and validation of protocols developed in the previous project.

Expected cost: R463 000
Estimated term: 1998 - 2001

Molecular characterisation of F-RNA coliphages in South African water sources

Department of Medical Virology, University of Pretoria; Department of Microbiology, University of Venda
(WRC Reference No 928)

Viruses are more resistant to water treatment and disinfection processes than faecal bacteria. Tests for viruses are relatively expensive and complicated and better indicators are being sought. F-RNA phages have attractive features for this purpose; some F-RNA phages are specific for humans and others for animals, i.e. indicating the origin of pollution. There is also a need for simpler, more economic, but effective viral detection methods. These needs are being addressed as follows:

- Developing practical techniques for the isolation of small numbers of F-RNA coliphages from large volumes of water; the molecular characterisation of serogroups of F-RNA coliphages using gene probe nucleic acid hybridisation; the extent to which local F-RNA coliphage groups can be applied to distinguish between faecal pollution of human and animal origin.

Estimated cost: R162 200
Expected term: 1998 - 2001

Protocol for surveillance and prospective epidemiological studies of gastro-intestinal health effects due to consumption of drinking water

Scientific Services, Rand Water
(WRC Reference No 1028)

When cases of diarrhoea occur in the community the public is often very quick to blame the water. Confidence in the quality of the water can then only be restored if this accusation has been investigated to the satisfaction of the public. This project is developing a handbook that provides practical guidelines on how to conduct such an investigation. This book will pull together the relevant methodology (from traditionally remote disciplines) required to find out whether cases of diarrhoea could be due to water consumption. The target audience for

this manual includes both the water supplier and the health sector.

Estimated cost: *R225 000*
Expected term *1999 - 2001*

Scope and dynamics of toxins produced by cyanophytes in the freshwaters of South Africa and the implications for human and other users

Department of Botany and Genetics, University of the Free State
(WRC Reference No 1029)

The project aims to investigate the scope and degree of toxicity of cyanophytes: Methods for growth and cultivation of toxic and non-toxic cyanophytes on a laboratory-scale are being developed to provide a constant supply of these bacteria to research laboratories to be used as standards. The project also addresses the control of pesticide synthesis as a prelude to determine genetic control of the algae.

- Gather information on the occurrence, treatment and management options to address algal blooms from all the water suppliers, agricultural sectors and DWAF for the development of a management manual that could be of benefit to both smaller rural drinking water treatment plants and the larger water suppliers.
- Investigate if microcystins modulate the immune system of mammals and whether this modulation of the immune system can be used for diagnostic and analytical purposes.

Estimated cost: *R372 000*
Expected term: *1999 - 2001*

Occurrence of emerging viral, bacterial and parasitic pathogens in source and treated water in South Africa

Division of Water, Environment and Forestry Technology, CSIR; Department of Plant Pathology and Microbiology, University of Pretoria
(WRC Reference No 1031)

Diseases caused by protozoan parasites have gained attention in the last decade, especially due to its prevalence among children, the elderly and immuno-compromised patients. There is a need to detect and quantify these emerging pathogens in order to control and minimise the risk to human health.

Aims are to:

- Establish techniques for the detection and quantification in source and treated water of the following pathogens:
  - *Campylobacter* spp. and *Heliobacter pylori*
  - *Cyclospora cayetanensis*
  - Hepatitis E and astro-virus;
- Compare environmental isolates with clinical isolates (of *Campylobacter* spp.) to establish the importance of water in the transmission of these pathogens;
- Establish known techniques in the laboratories of participating organisations;
- Monitor various source and treated waters for the presence of the above-mentioned emerging pathogens; and
- Formulate management strategies should the pathogens be found to pose a possible health risk.

Estimated cost: *R400 000*
Expected term: *1999 - 2001*

Assessing potential health risks related to the use of treated wastewater for various agricultural and aquacultural activities

Department of Environmental Sciences, Technikon Free State
(WRC Reference No 1039)

The project aims to:

- Assess the existing 1979 Department of Health guidelines based on a literature review;
- Prepare a practical guideline for the use of treated wastewater in aquaculture and agriculture, for persistent microbiological pathogens in treated water, including bacteria, viruses and parasite groups (cysts, oocysts and helminths) with regard to occurrence and risk levels. To examine specifically:
  - Organism uptake and tissue bioaccumulation of pathogens in organisms (animals or crops).
  - Residual surface fixation and survival of pathogens on contact organisms;
- Report on existing shortcomings and the feasibility of further research; and
- Report on levels of consent relating to permit applications for wastewater reuse, particularly with regard to edible cash crops (e.g. cabbages), wheat and legume crops, meat, animal feeds, dry fodder or pasture, dairy animal feeds and aquaculture.

Estimated cost: *R80 000*
Expected term: *1999*

Isolation of microbial extra-cellular enzymes for possible use in dairy cleaning-in-place applications

Department of Biochemistry and Microbiology, University of Port Elizabeth
(WRC Reference No 1040

The aims are to:

- Produce an economically viable biological cleaning system for dairy plants. The system has to be as effective as the current chemical systems used, with regard to cleaning action and anti-microbial efficacy, while significantly improving the effluent released from the plant and reducing water consumption and energy expenditure.
- Determine whether it is economically viable to produce the enzymes at an industrial scale compared to conventional chemical effluent treatment chemicals.

Estimated cost: *R82 000*
Expected term: *1999 - 2000*

Water quality monitoring programme to fulfil the needs of integrated catchment management in a densely populated rural catchment

Department of Chemistry, University of Fort Hare
(WRC Reference No 1067)

A catchment management plan is a prerequisite for integrated catchment management (ICM). Information on water quality in the catchment is needed both for the development of a sound management plan and for monitoring the outcomes of implementing ICM. The nature of the monitoring programme required will depend on land utilisation in the catchment and riparian zones, the susceptibility of the rivers

to degradation, water quality requirements of ecosystems and users, and existing sources of water quality data. The Umtata River catchment is representative of one class of river catchment where the demands of catchment planning have created associated demands for water quality monitoring. This project will design and initiate a water quality monitoring programme to meet the requirements of catchment management in the Umtata River catchment and serve as a guide for related activities in similarly impacted catchments.

Estimated cost: *R450 000*
Expected term: *1999 - 2001*

Occurrence of E. coli *0157:H7 and other pathogenic* E. coli *strains in water sources intended for direct and indirect human consumption*

Department of Medical Virology, University of Pretoria
(WRC Reference No 1068

Most *E.coli* strains are microbial inhabitants in the intestinal tract of humans and warm-blooded animals and are regarded as harmless indicator organisms for other pathogens. The presence of pathogenic *E. coli* in contaminated surface, recreational and drinking water, however, poses a human health risk and could cause an outbreak of water-borne haemorrhagic colitis such as experienced in 1992 in Switzerland. In this study a rapid identification method for potentially pathogenic *E coli* 0157:H7 in surface water used by communities is being developed. The study provides information on the health risk of direct and indirect consumption of contaminated water. Two (triplex) PCRs are used to determine the incidence of virulence factors of pathogenic *E. coli* in water collected by Rand Water in the Vaal Barrage reservoir.

Estimated cost: *R150 000*
Expected term: *1999 - 2001*

Determination of cytotoxicity and invasiveness of heterotrophic plate-count bacteria isolated from drinking water

Scientific Services, Rand Water
(WRC Reference No 1069)

The current SABS standard plate count (SPC) or heterotropic plate-count (HPC) guidelines for treated drinking water in South Africa are often exceeded by water suppliers and when this happens water suppliers add more chlorine to comply. The association between HPC bacteria in drinking water and gastroenteritis could not be proved so far. This study aims to assess the health risk posed by virulent heterotrophic bacteria with cytotoxic and invasive properties using various methods. Current microbiological water quality guidelines for South African conditions will probably need to be re-evaluated pending the findings of the study.

Estimated cost: *R500 000*
Expected term: *1999 - 2001*

Development of guidelines and a human health risk assessment for Legionella *levels in water*

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1104)

A previous WRC project on *Legionella* evaluated methods and recommended a standard method applicable for SA conditions for the detection of *Legionella* in cooling water systems. This project builds onto the needs identified in that project. It establishes guidelines for safe *Legionella* levels in cooling water systems that will assist industries to maintain acceptable *Legionella* levels and to prevent outbreaks of legionellosis.

Estimated cost: *R55 000*
Expected term: *2000 - 2001*

Development of a field kit for microbial water quality assessment in small and rural communities

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1105)

This project aims to test the proposed field kit (H_2S strip test) for screening of microbial water quality of small rural communities with environmental health officers for use in managing small water supply systems, particularly in areas where water monitoring would not normally take place; and to undertake technology transfer to students in training as well as environmental health officers in assessing water quality

Estimated cost: *R70 000*
Expected term: *2000*

Pilot study to demonstrate implementation of the National Microbial Monitoring Programme (NMMP)

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1118)

The NMMP and manual were developed in a previous project and consultancy. A pilot study to demonstrate the implementation of the NMMP was regarded as an important link between the concepts described in the manual and a full-scale implementation of the monitoring programme.

- Through the first project the implementation of the NMMP is being demonstrated in 8 high-priority health risk areas and involves the community and other stakeholders.
- The existing NMMP for surface waters also needs to be extended to include groundwaters. The specific aim of this phase is to develop a prototype manual that formally describes the detailed groundwater monitoring system design and all aspects of subsequent implementation of the programme.

Estimated cost: *R303 000*
Expected term: *2000 - 2001*

Risk of insecticide (Pyrethroid) resistance for malaria control in South Africa

Unit Pesticide Impact, Agricultural Research Council (ARC)
(WRC Reference No 1119)

Pyrethroid, an organophosphate pesticide, replaced DDT for outdoor application for the control of malaria and is used as a pesticide in agricultural areas in KwaZulu-Natal and could, therefore, be present in surface water. Recent studies have shown that mosquitoes have developed signs of resistance to organophosphates. The projects determine the patterns of use of the pyrethroid in two areas in KwaZulu-Natal and the potential residues thereof that may cause the build-up of resistance to the pesticide in malaria vector larvae. This is being done in co-ordination with the MRC mosquito resistance-screening programme. The end-product will

be a protocol for sampling, analysing and interpretation of the results whereby areas at risk can be investigated for resistance potential within a short period.

Estimated cost: *R150 000*
Expected term: *2000 - 2002*

Incidence of enteric pathogens in domestic water, water sources and stools of residents of urban and rural areas in the Venda region of the Northern Province

Department of Biochemistry and Microbiology, University of Venda
(WRC Reference No 1126)

The project aims to:

- Examine microbiological water quality in selected communities;
- Determine the extent of enteric bacterial infection and related diarrhoea and dysentery among infants in rural and urban regions of the Northern Province;
- Determine the incidence of enteric pathogens in domestic water and water sources;
- Explore the use of viruses as indicators of water quality; and
- Examine antibiotic susceptibility and plasmid profiles of the enteric bacteria (for improved health care).

Estimated cost: *R350 000*
Expected term: *2000 - 2002*

Assessment of the risk of infection associated with viruses in South African drinking water supplies

University of Pretoria, Potchefstroom Univeresity for CHE, University of Fort Hare, University of Venda, Technikon Free State, Technikon Soshanguwe, Technikon ML Sultan, Rand Water and Umgeni Water
(WRC Reference No 1164)

The aims are to:

- Develop simpler, more sensitive, more economical techniques for the detection of small numbers of viruses in large volumes of drinking water;
- Determine indicators of virological quality of drinking water supplies;
- Examine the incidence of a spectrum of enteric viruses in selected representative drinking water supplies;
- Obtain new data for guidelines on drinking water quality and monitoring programmes; and
- Transfer techniques to previously disadvantaged educational institutions.

Estimated cost: *R1 000 000*
Expected term: *2000 - 2002*

New

Effect of microcystins on the immune system using the pro-inflammatory hormone Interleukin 6 as biomarker

Department of Zoology, Stellenbosch University
(WRC Reference No 1200)

The aims of this project are to:

- Determine whether microcystins affect the immune system of animals;
- Undertake an *in vitro* assay for microcystin immuno-modulation on human whole blood; and
- Write standard operating procedures for microcystin immuno-modulatory assays (techniques, equipment and chemicals).

Estimated cost: *R84 200*
Expected term: *2001 - 2003*

Health-risk assessment in connection with the use of microbially contaminated source waters for irrigation

Department of Medical Virology, University of Pretoria; Department of Community Health, University of Stellenbosch; and Department of Microbiology, Venda University
(WRC Reference No 1226)

This project aims to:

- Assess the presence of pathogens on crops irrigated with microbially polluted water, viz. Hepatitis A, human calicivirus, human astrovirus and selected indicator organisms;
- Identify the most likely pathogens in the Plankenberg River by investigating patient records of the community of Kayamandi, Stellenbosch and analysing river water for related disease-causing organisms;
- Determine antibiotic susceptibility patterns of organisms obtained from the river water; and
- Recommend remedial actions and to guide future research.

Estimated cost: *R100 000*
Expected term: *2001*

Endocrine disrupting contaminants in South African water resources: Development, validation and implementation of bioassays to detect and characterise physiological disruption in humans and wildlife

University of Stellenbosch, University of Pretoria, MEDUNSA, Rand Water, Windhoek Municipality
(WRC Reference No 1253)

The aims of the project are to:

- Produce a review of the global and local status of EDC research;
- Prioritise South African research needs regarding EDCs;
- Develop a framework for research on endocrine disruptors in South Africa;
- Evaluate techniques for detecting EDCs in water resources in South Africa, particularly by screening a battery of bioassays for endocrine disruptors applicable to South African conditions;
- Develop and to validate biomarkers to be employed eventually in a battery of bioassays for detecting EDCs and undertaking risk assessment of EDCs in water resources;
- Screen "hot spot" areas or other problem areas in South Africa; and
- Initiate laboratory training programmes and the development of a standardised EDC monitoring programme.

Estimated cost: *R585 000*
Expected term: *2001 - 2002*

Prevalence, survival and growth of bacterial pathogens in biofilms in drinking water distribution systems

University of Pretoria, University of the Western Cape, CSIR, Umgeni Water and Free State Technikon
(WRC Reference No 1276)

In summary the project aims to determine the occurrence, survival and growth of bacterial pathogens in drinking water biofilms.

Specific aims are to:

- Determine the prevalence of pathogenic bacteria in biofilms both in drinking water distribution systems and in containers used for distribution and storage of water in informal settlements;
- Study the growth of biofilms on PVC surfaces of water storage containers;
- Assess the survival of general water quality indicator bacteria in biofilms within water distribution systems; and
- Determine the fate, survival and possible growth of specific pathogenic bacteria in:
  - Drinking water distribution systems
  - Containers used for distribution and storage of water in informal settlements.

Estimated cost: *R721 800*
Expected term: *2001 - 2003*

Extension of the South African national microbial water quality monitoring programme (NMMP) to include groundwater

Division of Water, Environment and Forestry Technology, CSIR, DWAF and the Department of Health
(WRC Reference No 1277)

The link between the concepts described in the *Manual for the National Microbial Water Quality Monitoring Programme* and a full-scale pilot implementation has been undertaken in 8 high- priority health-risk areas and involves the community and other stakeholders.

There is a need to extend the existing NMMP for surface waters to include groundwaters. The specific aim of this phase is to develop a prototype manual that formally describes the detailed groundwater monitoring system design and all aspects of subsequent implementation of the programme.

Estimated cost: *R600 000*
Expected term: *2001 - 2003*

A study of microbial communities and related water quality of the Mhlathuze River

Department of Biochemistry and Microbiology, University of Zululand
(WRC Reference No 1282)

The aims of the project are to:

- Monitor the microbial quality and the related physical and chemical variables of the Mhlathuze River;
- Combine modern technology and traditional culture to study the microbial population, and diversity, the survival and transmission of pathogens in the river and lakes in the Mhlathuze catchment;
- Improve undergraduate and postgraduate training and to develop research capacity within the Department of Biochemistry and Microbiology of the University of Zululand; and
- Help create capacity and infrastructure for the implementation of the National Microbial Water Quality Monitoring Programme (NMMP).

Estimated cost: *R316 000*
Expected term: *2001 - 2003*

Determination of the known extent of cyanobacterial problems in SA water resources and identification of South African cyanobacterial knowledge, information and research needs

Department of Biochemistry and Microbiology, University of Port Elizabeth
(WRC Reference No 1288)

This study aims at:

- Determining the current extent of, and trends in cyanobacterial-related problems in South African water resources;
- Identifying the information needs of all stakeholders, specifically of water resource management organisations;
- Identifying currently available resources for cyanobacterial problem events; and
- Determining the need for, and direction of, future cyanobacterial research.

Estimated cost: *R70 000*
Expected term: *2001*

Outcomes to Date of Current Programmes and Projects

New knowledge

Water quality and safety are issues that increasingly attract the attention of the public and health authorities. The rapid and reliable monitoring of the microbial quality of drinking water is of fundamental importance for the management and control of water-borne diseases. New and increasingly sensitive microbial detection methods have been developed in recent years.

Examples of development and use of such detection techniques include:

- The detection of *Cryptosporidium* and *Giardia*: Several detection methods have become available and technical skills developed. The various methods tested and evaluated have been used in follow-up projects to determine the removal of the pathogens in treatment plants and the occurrence of it in catchments.
- The use of F-RNA coliphages as indicators of viral pollution: This includes the development of practical techniques for the isolation of small numbers of F-RNA coliphages from large volumes of water and the characterisation of serogroups with molecular techniques to distinguish between faecal pollution of human and animal origin. These methods are simpler, economic and effective.
- Two multiplex PCR methods developed for the detection of pathogenic *E. coli* can now be used in laboratories for routine monitoring of the environment for pathogenic *E. coli* and for early detection of a clinical disease. This adds to the general knowledge on this water-borne disease-causing organism among water authorities and the general public, and will aid in determining possible health risks associated with exposure to communities.
- The selection and development of a risk assessment model and the evaluation of suitable viruses to be used as models in risk assessment studies.
- The National Microbial Monitoring Programme (NMMP) has been developed and is now being implemented on a pilot scale to test the practical application thereof. This contributes to the public understanding of water quality and protection of water sources.
- The ECD research team discovered that although the SA frog *Xenopus laevis* is used

in studies overseas, no basic knowledge existed on the natural reproduction cycle of this frog. This was needed as a baseline for the EDC studies, and was therefore investigated in their research project. The project team also developed a technique to draw blood directly from the heart of a turtle without killing it; employed X-ray methodologies to scan for oviductal eggs in the breeding season; used a sonar scan to observe and measure ovarium follicles; and studied the histology of the GAM complex in the Nile crocodile.

Benefits to South Africa

This field contributes to the health of the inhabitants of SA by developing water quality guidelines (specifically those that protect health), protocols and manuals that could be used in education and technology transfer.

Research done in this field has contributed substantially towards building the necessary capacity to monitor and assess the quality of domestic water supplies, with the goal of providing safe water to all South Africans.

Pollution of water resources and specifically the effect of organic contaminants on humans, animals and the ecosystem are of growing concern. The gradual deterioration of water quality and the growing awareness of water quality as a factor which undermines the utilisation potential of water have given rise to new research needs.

Innovation/application of knowledge

Knowledge generated through current programmes and projects is already being or will be applied in the following ways:

- Providing focus for measures to protect the quality of water in a resource;
- Preventing further deterioration of water quality which can be health threatening;
- Reducing the time, energy and funds needed for purification and disinfection of affected waters and treatment of symptoms of water-related diseases (burden of disease);
- Finding solutions to problems associated with the decreasing quality of our water resources;
- Delivering user-friendly products which make a difference to the attitude of all South Africans in caring for water sources; and
- Risk assessment and epidemiological studies.

The follow-up of the first *Cryptosporidium* projects delivered a simple, reliable and cheap method and a test kit to be used for visual screening for *Cryptosporidium* in rural areas and in the field by rural communities.

Determination of F-RNA coliphages has been established as an integral part of the routine monitoring of several drinking water suppliers (Umgeni Water, Rand Water, Windhoek). Findings and recommendations of this project are due to be included in water quality guidelines of the World Health Organisation and specifications of the International Organisation for Standardisation.

The risk assessment model resulting from the virus programme will lead to the possible upgrading of microbial drinking water quality guidelines.

A *Legionella* guideline has been developed that aims to assist industries, building managers, hospitals and other susceptible parties to prevent an outbreak of legionellosis.

Capacity/competence development

This field aims to build capacity and competence amongst the researchers and uses the approach of multi-institutional research projects. To date about 14 projects are operating in this manner. Students, lecturers and project leaders are in close contact with the collaborating institutions. Thereby they expand their capabilities and skills in methodologies used by other institutions. In one such project 7 institutions participate and combine forces and expertise, equipment and a wide variety of methodologies. Some of the institutions have developed particular expertise in methodologies and technologies that could be shared with and evaluated by one another. Skills that were developed and shared by the participants in the *Cryptosporidium* detection project (Umgeni Water and Rand Water, CSIR and the University of Pretoria) provide a good example of the benefits of mutual evaluation and validation.

The first comprehensive molecular epidemiological survey was done to determine the incidence of pathogenic *E. coli* in environmental water samples in South Africa.

Dr Brözel (biofilm specialist), University of Pretoria, pioneered the use of fluorescent *in situ* hybridisation of bacteria (FISH) in South Africa and assisted the research group of the Technikon Natal in the use of FISH to study activated sludge. Students from other institutions involved have the opportunity to work at the University of Pretoria in order to acquire the relevant skills. The mentorship takes place within an Institutional Research Development Programme of the NRF.

Capacity building in the detection of viruses has been expanding at the University of Venda which has made use of the WRC mobility fund to train 8 students in techniques at the University of Pretoria and the CSIR. Researchers at the University of Venda as well as the University of Fort Hare and the Technikon Free State, Prof L Obi, Ms N Potgieter, Dr M Momba and Prof P Jagals are on the team of the follow-up project on the health-risk assessment associated with viruses. Ms Uys and Ms Potgieter (Venda), each obtained an M.Sc. degree on work carried out as part of this project. Mr Muller (University of Pretoria), Mr Sundram (Umgeni Water) and Ms Tdou (University of Venda) registered for an M.Sc. on bacteriophages. Work done on this project was also part of the D.Tech. dissertation of Prof P Jagals, Technikon Free State. The techniques developed in the F-RNA project have been transferred as new technology to various historically disadvantaged (HD) universities that do not have the technical equipment and expertise to detect viruses.

In summary, research in this field includes the following organisations:

- 9 universities (15 departments) including 5 HD Universities (7 departments)
- 4 technikons
- 2 science councils
- 5 water suppliers
- 1 consultant.

Degrees obtained by HD individuals:

- 5 Ph.D.s
- 1 D.Tech.
- 1 post-M.Tech.
- 6 M.Sc.
- 5 B.Tech.

In addition, 1 post-M.Tech., 5 post-Docs as well as a vast number of undergraduates have been involved in studies.

Knowledge dissemination

The intention of this research field is to serve not only the research community and water suppliers, but also water resource managers and water chemists. The needs of the high-school, technikon and university educators for appropriate textbook material have been taken into account to empower the upcoming generation, which constitute the hope and guarantee our sustained well-being.

The understanding of the relationship between water quality and public health outcomes is growing. Research has focused on a range of microbial and chemical constituents of drinking water, with relevance to both urban and rural water. The occurrence of substantial changes to drinking water quality in distribution/systems, reservoirs, as well as from the tap to the consumer has been detected/studied.

Examples of knowledge dissemination:

- EDC - 9 scientific articles (3 conference papers)
- *Cryptosporidium*: 4 publications and 4 conference papers
- 7 publications and 19 conference presentations have resulted from the virus project
- 18 road-show workshops on the *Quality of Domestic Water Supplies* guides will have been held by the end of 2001 (9 funded by the WRC and 9 by the Department of Health)
- A workshop in collaboration with DWAF has been held in Umtata on the outcomes of the project on the quality of the Umtata River to inform the public of the way forward
- Workshops on: algae (3); EDCs (3); development of the strategic plan involving stakeholders (11); WISA conferences (6)
- Presentations at specialist meetings (3)
- User-friendly documents:
  - *Legionella* guidelines
  - *National Microbial Monitoring Programme Manual*
  - *The Quality of Domestic Water Supplies*, a series of 5 guidelines, are user-friendly documents developed to be used by water service developers and suppliers, workers in the health-related fields and by the communities themselves as a tool to create an understanding of the concepts behind water quality. This series has contributed a great deal to the awareness of the public towards water quality. The first one was the *Assessment Guide*. Of the 18 000 that were printed, 8 000 were distributed to all high-schools. The *Sampling Guide* (6 000 printed) and the *Analysis Guide* (4 000 printed), like the *Assessment Guide*, are being used in both secondary and tertiary educational institutions as study material for students. The *Management Guide* will be useful as educational material for tertiary institutions and will also empower communities in decision-taking regarding the management of their water supplies.

Leveraging of resources

Most of the projects are funded solely by the WRC. The Department of Health and DWAF have made in-kind contributions.

Quality of Domestic Water Supplies series: contributions towards layout and printing were received from the Department of Health - R200 000; Rand Water - R25 000; Umgeni Water - R25 000 and Lepele Water - R2 000.

International linkages

Strong linkages have been developed over the years with specialists in the microbiological, chemical and algae areas from:

- United Kingdom: Dr Colin Fricker (*Cryptosporidium*, bacteria); Dr M Duncan (water reuse)
- Australia: Dr I Falconer (EDCs and algae)
- United States of America: Prof Guillette, Univ of Florida; Dr Selzer (EDCs)
- The Netherlands: Dr Arrie Havelaar (risk assessment)
- Spain: Dr Schaper (coliphages)
- Namibia, Windhoek Municipality: Mr Menge (viruses, coliphages and EDCs).

Several international specialists in microbial water analysis have been invited over the years as guest speakers to share their experience in water-borne disease outbreaks and at meetings organised by the WRC and attended by stakeholders.

Dr Havelaar, Rijksinstituut voor Volksgezondheid en Milieu, Bilthove, the Netherlands, facilitated a workshop on risk assessment on invitation of Prof Grabow, at the University of Pretoria. Dr Havelaar is an internationally recognised leader in the field and serves on advisory panels to formulate models and strategies for WHO and the International Life Sciences Institute (ILSI).

Dr K Selzer, Selzer Laboratories, USA, Prof LJ Guillette, University of Florida, USA and Mr J Menge, Windhoek Municipality, are some of the international researchers collaborating with the project on endocrine disruptor contaminants.

Dr Falconer, Australia, was a guest speaker on an EDC and algae workshop and gave practical examples of successful interventions and problem-solving in Australia.

Dr Colin Fricker, United Kingdom, has been invited and visited South Africa on several occasions for workshops on new techniques as well as problem-solving when experiencing water-borne disease outbreaks.

Prof Grabow is the Chairman of the Health-Related Microbiology division of the International Water Association (IWA) and is involved in an ISO task-team setting up guidelines on viruses at WHO and the European Union. His team was involved in the international research on F-RNA coliphages that led to the European Union's proposal to include the technique of F-RNA characterisation for EU water quality specifications.

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Chapter 7

Municipal Wastewater Management

Mr GN Steenveld

Scope

Municipal Wastewater Management addresses the handling, treatment and disposal of domestic and industrial effluents, and associated sludges. In recent years applicable discharge and disposal standards have become more stringent, *inter alia* to allow for the beneficial reuse of treated effluents and sludges and to maintain or improve the environment. Simultaneously, the provision of water and sanitation to previously unserved communities, increased urbanisation and ongoing industrial development have contributed to an intensification of the pollutant loads received at municipal sewage works.

Taking such factors into account, the scope and application of this field have increased in recent years and the percentage of total WRC research funds utilised has varied accordingly, as shown in Table 1. Over the period covered, WRC-supported research has led to world-leading expertise in nutrient removal, low-cost ponding systems and anaerobic digestion of effluents and sludges. Strong national and international linkages have been established, involving a number of disciplines including engineering (civil, chemical and sanitary), science (aquatic chemistry, microbiology and enzymology) and, more recently, economics and urban planning. These linkages significantly include previously disadvantaged institutions.

Links to Key Strategic Areas

Municipal Wastewater Management falls within the WRC's KSA for **Water Use and Waste Management** and links with other KSAs as follows:

Water Resource Management

Good-quality (often potable) water taken in for non-consumptive domestic and industrial use is thereby degraded, treated at sewage works and then discharged to the environment. The inputs to sewage works thus result from a demand on the upstream water resource, while the outputs affect both the quality and quantity of the downstream resource.

Water-Linked Ecosystems

Aquatic ecosystems, both coastal and inland, are directly impacted by the discharges from municipal sewage works. Treated sludge disposal also has potential effects on surface water and groundwater quality, with resultant consequences for water-linked ecosystems.

Water Use and Waste Management

This KSA is the main area of activity for municipal wastewater management, in

TABLE 1
Investment in **Municipal Wastewater Management**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R1 779 292	R1 910 989	R2 587 897	R3 528 800	R4 260 900
% of research fund	4.4%	4.3%	4.9%	5.7%	7.3%

terms of water used in domestic and industrial activities and the effluents generated, including also solid waste pollutants. Moreover, the technical ability available and economics thereof for adequately treating wastewaters and sludges at municipal sewage works are important drivers in applying demand management principles to water use and waste generation in the catchments concerned.

Water Utilisation in Agriculture

Directly (by irrigation) or indirectly (by discharge to water-courses and subsequent abstraction), treated municipal effluents constitute a valuable sustainable resource for agricultural use, provided the appropriate quality requirements are met.

Objectives

Primary

The primary objective in the municipal wastewater field is the optimal management of sanitation in South Africa through effective and coordinated research, to the benefit of all communities, while building an empowered researcher manpower base at individual and institutional levels.

Secondary

- Research activities towards the primary objective are co-ordinated by a strategic research plan, in which the secondary and tertiary-level objectives are identified and prioritised. Secondary objectives are listed below:

- Technological development of wastewater treatment processes;
- Improvement of sludge management;
- Recovery of resources (from domestic and industrial effluents);
- Development of artificial wetlands;
- Revisiting of old technologies; and
- Evaluation and optimisation of emerging technologies, e.g. bioaugmentation, package plants.

Research Projects

Portfolios of completed, current and new projects, addressing the above six objectives directly and/or indirectly, are presented below.

Completed

Appropriate low-cost sewage treatment using the advanced algal high-rate oxidation pond

Department of Biochemistry, Microbiology and Biotechnology, Rhodes University
(WRC Reference No 651)

The aim of this project was to build and operate an integrated algal high-rate oxidation pond (HROP) for the treatment of domestic sewage, as a demonstration plant that would effect the transfer of currently best available technology on the design, construction and operation of these systems, with a view to application as low-cost appropriate technology for small and developing communities. Specific objectives were to evaluate the manipulation and control of algal and bacterial growth and species dominance in the HROP system, and to investigate the recovery of algal metabolites and other products of value from the biomass.

The facility was installed and operated at the Grahamstown Disposal Works. Despite strong fluctuations observed in the influent COD (range 100 mg/ℓ to > 1 000 mg/ℓ) and flow, ascribed to rainfall incidents and the ingress of stormwater into the sewerage system, good performance stability was obtained and the overall system design demonstrated good organic and nitrogen removal characteristics. Phosphate removal was adequate in terms of the General Standard but not for the Special Standard. The final effluent quality over a 25-week period of stable operation averaged 80 mg COD/ℓ, 25 TKN/ℓ, O mg NH_3/ℓ, 4 mg P/ℓ, 60 mg SS/ℓ and 1.2 x 103 coliforms/100 mℓ. Some areas for improvement were noted, particularly in the design of the gas deflector/collector in the anaerobic pit in the primary facultative pond, which was susceptible to shock loadings, affecting the formation and maintenance of a good sludge blanket.

It is significant that the good performance results were achieved in a system that has low operating and maintenance requirements. Although no costs were quantified, it is probable that both capital and operating costs would be lower than for conventional "high-tech" sewage treatment systems. The aspects of simple and relatively cheap construction and operation combined with efficient, robust performance appear attractive for implementation of the integrated algal ponding system for sewage treatment in the local "developing world" context.

Cost: *R900 700*
Term: *1994-1997*

Appropriate low-cost treatment of sewage reticulated in saline water, using the algal high-rate oxidation ponding (AHROP) system

Department of Biochemistry, Microbiology and Biotechnology, Rhodes University
(WRC Reference No 656)

The overall project aim was to evaluate the potential for integrating sewage treatment in algal ponding systems with the treatment of saline wastewaters. In response to the urgently-growing threat of the acid mine drainage (AMD) problem in the RSA, it was agreed in consultation with the WRC to focus more directly on the bio-utilisation of sewage and sewage sludge organics in the treatment of high-sulphate AMD waters. The knowledge

gained applies also to the treatment of sewage in saline (e.g. brackish) water, and therefore addresses also the original question of whether algal high-rate ponding could be successfully used in this application. The experimental study yielded a number of valuable results, summarised below:

- Accelerated rates of hydrolysis of complex carbon sources observed in a bio-sulphidogenic environment confirmed preliminary observations made previously in WRC Project No 495. Quantitative comparative studies carried out using tannery wastes, sewage solids and algal biomass as carbon substrates showed that each provided an effective electron donor source, giving sulphate reduction rates typically in the range 200 to 300 $mg.\ell^{-1}.d^{-1}$. The algal strains investigated were shown to be reasonably tolerant to high sulphide concentrations.
- The removal of heavy metals in the process scheme investigated showed that chemical precipitation (as sulphides, carbonates and hydroxides) and microbiological adsorption (directly on the algal biomass and/or by binding to extracellular polysaccharides) both play significant metal-removing roles. The overall degree of metal removal, including final polishing to very low residual levels, could be optimised by process manipulation.
- It was shown that algae could be used to neutralise (raise the pH of) acidic effluents such as AMD. *Spirulina* spp. were found to be able to effect this while maintaining active cell growth but *Dunaliella salina* growth declined rapidly under low-pH conditions. An important general result is that bicarbonate (seldom present in AMD) is required in the bio-alkalinising process and must be provided either by process modification or chemical supplementation to make the bicarbonate biologically released during sulphate reduction available for the pH-raising step.

The results obtained in this project contribute significantly to quantifying the fundamental stoichiometry and kinetics of the chemical and microbiological subprocesses operating during the biological reduction of sulphate.

Cost: *R 160 000*
Term: *1994 -1997*

Treatment of wastewaters with high nutrient (N and P) but low organic (COD) contents

Department of Civil Engineering, University of Cape Town
(WRC Reference No 692)

Wastewaters which have low organic content but high nutrient levels include septic tank effluents, activated sludge dewatering liquors, anaerobic digester supernatants (particularly from nutrient removal activated sludge systems), stabilised landfill leachates, trickling filter effluents, sludge disposal lagoon effluents and oxidation pond effluents. These wastewaters will increasingly contribute to nutrient loads on surface water resources, and so to eutrophication. Conventional activated sludge biological nutrient removal (BNR) technology is not practical for treating these wastewaters due to the imbalance between organics (low) and nutrients (high); three of the wastewater types listed are in fact generated by BNR plants. Consequently, in order to handle treatment of these wastewaters, other methods, processes and technologies are required.

Research was carried out in this project into treatment of the first four of the low organic high- nutrient wastewaters listed - the order given is also the order of priority. The four main tasks identified were to develop a fundamentally-based mathematical model which will integrate the biological, physical and chemical processes that are operative, review the literature, collect experimental data on the wastes and various treatment schemes, and evaluate and develop existing/new processes and technologies.

The outputs provide a detailed and comprehensive picture of the potential for treating high-nutrient low-carbon wastes in conventional BNR activated sludge systems. The literature review undertaken shows clearly that the P-removal requirements of the RSA situation are not met by internationally available systems. The simulation model for BNR activated sludge systems was extended to incorporate weak acid/base chemistry and pH into an integrated physical, chemical and biological process model which is kinetic- rather than only equilibrium-based. This extension and enhancement of the model specifically for high-nutrient low-carbon wastes have general application to the family of BNR activated sludge models, for improved simulation of a range of systems, and constitute a significant overall advance in this area. Good correlation was obtained between the three-phase kinetic model predictions and experimental results for all batch tests. This enabled the kinetic model to be used to gain greater insight into system behaviour in the experiments and in the evaluation of new process technologies.

Cost: *R 305 970*
Term: *1994 -1997*

Disinfection of purified effluent

Department of Microbiology, University of Pretoria
(WRC Reference No 739)

The main aims of the study were to investigate the disinfection practices of sewage treatment plants in South Africa; to produce a guide for the design and operation of disinfection facilities; and to evaluate the efficiency of monochloramine as a disinfectant for purified sewage effluent under South African conditions.

The conclusions were the following:

- The study showed that the disinfectant capability of monochloramine is not significantly affected by chlorine-demand-causing materials as is the case with free chlorine.
- The effect of pH on the disinfectant capability of monochloramine as measured in this study was not as significant as measured by Ward et al.,1984 in *Appl.Environ.Microbiol.* **48** (3) 508 - 514.
- Of the three models evaluated for accuracy in the batch inactivation experiments, the series-event kinetic model gave the best fit to the measured data.
- The fitted parameter of the series-event model displayed a more constant variation with monochloramine and pH concentration while the reaction coefficients of the other models vary in a more random fashion. This makes the series-event model the most suitable inactivation model for the water tested.
- The series-event model combined with the tanks-in-series model gives accurate predictions of the survival ratios measured in the continuous-flow systems.

- The series-event model in combination with a tracer study provides an accurate method to predict the performance of a continuous-flow CCT from batch inactivation studies using monochloramine as disinfectant.
- The study showed that the behaviour of a continuous-flow CCT can be accurately predicted from batch experiments conducted in the laboratory. This provides a method that employs data from simple batch experiments conducted in the laboratory for the design of continuous-flow monochloramine disinfection systems.

Cost: R 84 194
Term: 1996 - 1997

Development of strategies for amelioration of bulking by anoxic-aerobic filamentous organisms in nutrient removal activated sludge systems

Stewart Scott Inc.
(WRC Reference No 775)

Although the study did not address all the objectives as originally envisaged, the research findings have made a very valuable contribution to our understanding of the filamentous bulking problem. During the preliminary investigation stage, it became apparent that very few plants in Gauteng kept data on the nutrient concentrations and sludge settleability. Therefore if the research project were to be undertaken to examine the aspects specific to the hypothesis, a dedicated sampling and analytical programme would be required. The Steering Committee recommended that such a detailed analytical programme could only be done by a university research group in partnership with a wastewater treatment plant. It was agreed that certain aspects of this project could be included in WRC Project No K5/823: **Full scale demonstration of specific filamentous bulking control in a biological nutrient removal activated sludge plant at Mitchells Plain wastewater treatment plant** (University of Cape Town).

The main results were:

Evaluation of historical operating data and configurations of 7 nutrient removal activated sludge plants in Gauteng showed the following:

- The filaments that dominate in the plants are those that are classified as AA to which the AA bulking hypothesis applies.
- In comparing the sludge settleability and aerobic mass fractions of the plants, generally, plants with larger aerobic mass fractions had better overall sludge settleabilities.
- A means of significantly controlling filament proliferation in nutrient removal activated sludge plants is to ensure that they have as large an aerobic mass fraction as possible without compromising the anoxic mass fraction required for denitrification.

Cost: R 215 927
Term: 1996 - 1998

Hydrodynamic modelling of secondary settling tanks

Department of Civil Engineering, University of Cape Town
(WRC Reference No 835)

Secondary settling tanks (SSTs) in activated sludge plants (ASP) are bottlenecks which limit sewage works capacity, affected by both the settleability of the sludge and the hydraulics within the SST itself. Design usually follows the application of empirical rules such as the surface overflow rates not exceeding 1m/h at peak wet weather flow. Due to poor hydrodynamic behaviour, unacceptably high suspended solids concentrations (>30mg/ℓ) are however often discharged long before this capacity is reached, even with good settling sludges. Current design procedures give very little guidance on the design of these SST internal features and their design-effectiveness depends mainly on the design engineer's experience.

The objectives of this study were firstly to develop a publicly-owned 2-dimensional (2D) hydrodynamic SST model for the RSA to test the applicability of the widely-used 1D idealised flux theory (IFT), and secondly to improve the efficiency and numerical stability of current SST modelling algorithms by developing a finite element program for 2D hydrodynamic modelling of full-scale SSTs.

The simulation study showed that the capacity, or flux rating, of SSTs usually decreased as the flux load factor increased, as a result of either an improvement in sludge settleability and/or decrease in feed concentration, but to a variable extent affected also by the depth and shape of the SST. It was concluded that the 1D IFT should not be used to design full-scale SSTs without applying an appropriate reduction factor, ranging typically from 75-85%, and further that the depth of the SST should be designed independently of the surface area (as is usually the practice) with the appropriate flux rating then being applied to the 1D IFT estimate of the surface area.

In the second part of the project, a working 2D finite element package was produced that reasonably simulated benchmark SST data. Good results were obtained using a constant turbulent viscosity, provided that the inlet region of the tank was small compared to the main section. Uncertainty remained about diffusion effects on activated sludge behaviour in high concentration regions, and further investigation was recommended to obtain a reliable description of the interaction between flow and settling.

Cost: R415 146
Term: 1997 - 2000

The bioaugmentation of activated sludge for enhanced biological phosphorus removal

Department of Microbiology and Plant Pathology, University of Pretoria
(WRC Reference No 934)

Activated sludge systems that fail to remove phosphate (P) to the legislative discharge standards sometimes necessitate further chemical treatment of the effluents. Some research into P-removal has indicated that biomass quantity (and not only the microbial community of the biomass) is important. This project aimed to investigate the relationship between biomass quantity and P-removal and the potential for bioaugmentation and biosupplementation to boost biological P-removal.

Sludge mass experiments employing activated sludge from a typical system showed that an increase in sludge mass led to an increase in P-removal. Adenosine tri-phosphate (ATP) proved to be a more reliable indicator for biomass concentration in activated sludge than total plate count (TPC) or mixed liquor suspended solids (MLSS), due to the higher yield and a smaller standard

deviation. When calculated in terms of MLSS, return sludge performed consistently better at P-removal than either anaerobic or aerobic wet sludge. From an economic point of view it was concluded that bioaugmentation products are too expensive to increase P-removal in a full-scale activated sludge plant, as indications were 8 kg to 10 kg of product would be required per 1 000 m^3 of feed.

Cost: R 335 932
Term: 1998 - 1999

External nitrification (EN) with the aid of fixed-media trickling filters to increase the capacity of biological nutrient removal (BNR) suspended medium activated sludge (AS) systems

Department of Civil Engineering, University of Cape Town, and Water and Sanitation Services SA (Pty) Ltd (now Ondeo Services)
(WRC Reference No 970)

The concept of "external nitrification" (EN) in biological nutrient removal (BNR) activated sludge (AS) systems was investigated in this project as a process configuration aimed at providing nitrification "externally" to the AS reactor in a trickling filter and thereby allowing the sludge age in the AS reactor to be reduced, with a consequent increase in the system capacity for removing organics (COD) and nutrients (N&P). The experimental investigation carried out on laboratory-scale ENBNRAS systems showed that good COD removal was obtained (>90%) and on average about 60% less oxygen was utilised than in an equivalent "conventional" BNRAS system, high (>80 to 90%) removal of N-species was obtained with consequently low (<10 mg N/ℓ) concentrations in the treated effluent, P-removal was lower (30% less) than expected and the settleability of the sludges produced was good (90 to 100 mℓ/g). Based on these results, the ENBNRAS system generally offers some performance advantages (P-removal being the exception) over conventional BNRAS systems. The economic analysis carried out showed that this translated into a 30% capital cost-saving but only a 5 to 10% total saving when the high proportion of operating vs. capital cost is factored in. In practice though, design decisions would probably be influenced more by the performance benefits offered (better effluent quality) rather than the modest cost-saving estimated.

In this project the kinetic simulation model for all BNRAS (including ENBNRAS) systems was also extended to include anoxic P uptake and denitrification, using literature data for the growth kinetics and stoichiometry of the various organic/nutrient transformations taking place. When tested against experimental data from the project, good correlation was found between the observed and predicted values, auguring well for the use of the model for practical design and implementation of ENBNRAS systems.

Cost: R 453 625
Term: 1998 - 2000

Use of life-cycle assessments in the selection of water treatment processes

Pollution Research Group, University of Natal
(WRC Reference No 1077)

Life cycle assessment (LCA) is one of the tools of "cleaner production" used to calculate the overall environmental burden of products, processes and services and therefore to support decision-making. Water and wastewater treatment is a component of most economic activities and thus contributes to their total life cycle environmental impact. In this project LCA was used to make a comparison of membrane technology and conventional technology for the production of potable water, to assess their respective environmental impacts as a case study, and to develop local capacity in applying LCA methodology.

The study showed that the life cycle impact of each technology is dominated by the operational stage, which has the highest material and energy consumption and highest scores for all the impact categories. The single aspect most responsible for the environmental burdens in potable water production was found to be the generation of electricity required to drive the operational stage. Pollution prevention should thus target improved electrical efficiency (e.g. efficiency of pumping) to improve the overall environmental performance of the two technologies. This demonstrates how LCA prevents the shifting of environmental burdens to different geographic locations - electricity is seen as a "clean" energy source at the point of use, but at the point of generation the associated emissions are included in LCA.

The research also highlighted the shortage of local LCA data, due to the limited studies done in the RSA to date. A series of technology transfer workshops held during the project sensitised the water industry to the benefits of incorporating LCA methodologies in design and operation, contributing to capacity building and further application of LCA in the water and wastewater treatment industry.

Cost: R520 000
Term: 1999 - 2000

Current

Chemical augmentation of biological phosphate removal

Greater Johannesburg Metropolitan Council (GJMC)
(WRC Reference No 248)

This new 3-year project commenced in July 1988 and is being undertaken by the City Council of Johannesburg. Two aspects will be covered in the research project. The first of these is to investigate the supplementation of biological phosphate removal with in-plant addition of chemicals. This will be to supplement biological phosphate removal when achievement of the 1 mg/ℓ P standard is difficult. The work will be undertaken at full scale on wastewater treatment plants with different influent characteristics.

The second aspect is an investigation into phosphate precipitation from supernatant liquor from anaerobic digesters at nutrient removal wastewater treatment plants. Phosphate removed biologically in the activated sludge plant will be released under anaerobic conditions when the waste sludge undergoes anaerobic digestion. The phosphate released into the digester supernatant liquor will be precipitated out as magnesium ammonium phosphate.

Estimated cost: R 87 000
Expected term: 1988 - 1992

Activated fixed and suspended cultures for nitrification

Department of Chemical Engineering, University of Pretoria
(WRC Reference No 462)

An important factor limiting the capacity of activated sludge plants is the need for effective nitrification. As nitrifiers can only function in

the aerobic basin, the aerobic sludge age limits nitrification. The hypothesis being tested over 1 year by this research is that the maintenance of active biomass in the aerobic basin, either on a fixed bed or on suspended material, will increase the effective nitrification rate. If this can be achieved the sludge age may be reduced, allowing for a larger volume of effluent to be treated by a works.

Estimated cost: *R30 000*
Expected term: *1992 - 1993*

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

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 that address the role of individual species. The first is the extent to which EBPR depends on community structure in the activated sludge, and the second is the role of genera other than *Acinetobacter* 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.

Estimated cost: *R276 200*
Expected term: *1993 - 1995*

Limitation of convection currents in clarifiers
Department of Chemical Engineering, University of Pretoria
(WRC Reference No 555)

In the purification of drinking water and sewage the gravity separation of floc plays a decisive role. 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.

Estimated cost: *R51 750*
Expected term: *1993-1996*

Practical application of special waste co-disposal with municipal refuse at the Coastal Park landfill bioreactor *Cape Metropolitan Council*
(WRC Reference No 606)

Following on previous work in which a basic landfill was developed and constructed, in this project the co-disposal of non-toxic waste along with municipal refuse is being extended at full scale. The design developed for the landfill modules (or cells) gives good mechanical compaction properties and minimal leachate, with evaporation of the liquid fraction.

Estimated cost: *R544 000*
Expected term: *1994 - 2001*

Determination of dissolved organic loads in raw and other sewage waters and the determination of the relationship between COD and DOC
East Rand Water Care Company
(WRC Reference No 668)

The chemical oxygen demand (COD) test is currently the most widely used wastewater analysis, but the length of time required for the analysis poses a problem for real-time control of sewage treatment works operations such as aeration and recycle rates. Total organic carbon (TOC) and dissolved organic carbon (DOC) tests are rapid procedures that are being investigated here to determine whether their ratios to COD measurements are consistent enough to offer an alternative on-line determination for plant control purposes.

Estimated cost: *R100 000*
Expected term: *1995 - 1996*

Removal of algal and other biomass from treated wastewaters employing the PETRO® process
Wates, Meiring and Barnard (CE) Inc.
(WRC Reference No 713)

The PETRO® process innovatively combines the technologies of anaerobic digestion, algal oxidation ponds and trickling filters in a hybrid process scheme that produces an effluent quality comparable to that from an activated sludge plant, but with some advantages in cost and simplicity of operation. This project aims to investigate the removal of algal and other biomass from final PETRO® process effluents.

Estimated cost: *R 489 000*
Expected term: *1995 - 1997*

Development and monitoring of integrated algal high-rate oxidation pond (AHROP) technology for low-cost treatment of sewage and industrial effluent
Department of Biochemistry, Microbiology and Biotechnology, Rhodes University
(WRC Reference No 799)

This project is undertaking comprehensive monitoring of integrated algal high-rate oxidation pond (AHROP) plants previously constructed for the treatment of tannery, sewage and abattoir effluents, in order to evaluate parameters for optimised operation, quantify the value-adding potential of algal biomass produced, and determine constraints and future research needs for wide-scale application of the process.

Estimated cost: *R510 000*
Expected term: *1997 - 2001*

Full-scale demonstration of specific filamentous bulking control in a biological nutrient removal activated sludge plant at Mitchells Plain Wastewater Treatment Plant (WWTP)
Department of Civil Engineering, University of Cape Town
(WRC Reference No 823)

This study is verifying, demonstrating and evaluating on full scale the filamentous bulking model developed by this UCT team from laboratory-scale research over the past 6 years at the Mitchells Plain Wastewater Treatment

Plant in Cape Town. The intention is to encourage other municipalities with N & P removal plants to implement similar strategies for bulking control, thus leading to improved sludge settling and increased treatment capacity for these plants.

Estimated cost: *R454 000*
Expected term: *1997 - 2001*

Water Institute of Southern Africa: Operators Handbook

Philip Pybus (CE)
(WRC Reference No 848)

The *Operators Handbook*, published by the Water Institute of Southern Africa, was last revised in 1984. It reflects the technology of the time, much of which has advanced considerably since then, for example in the field of nutrient removal (biological and chemical). In addition to its use by operators on many wastewater treatment works to assist in solving day-to-day problems, the *Operators Handbook* is also widely used by Technikons and Technical Colleges and forms part of the syllabi at these institutions. This project will update the *Operators Handbook* and bring it into line with advances in wastewater treatment and modern practice.

Estimated cost: *R170 000*
Expected term: *1997 - 1997*

Investigation into optimisation of high-rate biological filtration for wastewater treatment

Water Engineering Division, Wates, Meiring and Barnard (CE) Inc.
(WRC Reference No 929)

Biofiltration is a reliable and robust wastewater treatment technology, for example in rural situations where its simplicity and ease of operation and maintenance are attractive. The research objectives here are to further refine and optimise biofiltration technology for full-scale application, including investigation into alternative biofilter media, optimisation of wastewater dosing patterns and frequency, optimisation of the recycling of biofilter effluent across the biofilter reactor, and improvement of nitrification removal performance.

Estimated cost: *R233 000*
Expected term: *1998-2001*

Investigation into transforming the PETRO® process to provide for biological nutrient removal

PGJ Meiring Konsult
(WRC Reference No 971)

The aim of this research is to develop a link-up between the PETRO® process for algae removal and the biological nutrient removal type of activated sludge plant (both developed in South Africa) to bring about, at little additional cost and with low operational requirements, an integrated facility which will reliably produce an effluent meeting stringent nutrient and other quality requirements for discharge.

Estimated cost: *R889 000*
Expected term: *1998 - 1999*

Extension of applications and optimisation of operational performance of algal integrated ponding system (AIPS) technology in appropriate low-cost treatment of industrial and domestic wastewaters

Department of Biochemistry, Microbiology and Biotechnology, Rhodes University
(WRC Reference No 1073)

Algal integrated ponding system (AIPS) technology offers a low-cost alternative wastewater treatment technology eminently suitable for South African conditions. The scope of this project is to scale up and evaluate laboratory findings relating to the improved performance of the AIPS anaerobic pit digester utilising UASB-type configurations, and to develop the application of the AIPS high-rate algal pond as a free-standing tertiary treatment unit operation for the removal of nitrates and phosphates from conventionally treated sewage effluents.

Estimated cost: *R942 000*
Expected term: *1999 - 2001*

Computational fluid dynamic support to water research projects

Pollution Research Group, University of Natal
(WRC Reference No 1075)

Computational fluid dynamics (CFD) is being used in this project as a numerical procedure for calculating the properties of moving fluids, as occurs in most water treatment processes, to provide process insights which otherwise would not have been possible. This project extends and builds on the lessons and skills obtained in a previous WRC project, with the overall aims of providing a CFD modelling and training service to water researchers, thereby promoting the use of CFD in practical applications.

Estimated cost: *R795 000*
Expected term: *1999 - 2001*

Development of a novel reactor insert to upgrade anoxic reactors in biological nutrient removal wastewater treatment plants

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1076)

In biological nutrient removal (BNR) plants, optimal recycle flows are difficult to maintain due to variations in the TKN/COD ratios of the plant feed. Nitrate entering the anaerobic unit lowers the phosphorus-removal efficiency and a lower quality effluent is released. This project is developing, building and testing a novel reactor insert that can be retrofitted to domestic wastewater treatment plants, or used in new low-capital treatment units, to ensure that recycled flows are fully denitrified.

Estimated cost: *R163 000*
Expected term: *1999 - 2001*

Intermediate scale-up evaluation of the Rhodes Process for hydrolysis and solubilisation of sewage sludges in a sulphate-reducing bacterial system

Department of Biochemistry, Microbiology and Biotechnology, Rhodes University and ERWAT
(WRC Reference No 1169)

The accelerated hydrolysis of complex carbon sources (e.g. sewage sludge), during the biological reduction of sulphate, is potentially of major interest to sewage treatment plant operators. In this project, ERWAT, in

collaboration with Rhodes University, is carrying out a pilot-scale evaluation of the process for accelerated hydrolysis (solubilisation) of primary sewage solids and their subsequent treatment in conventional aerobic treatment processes, to quantify the role of sulphur compounds as inventory reagents in the process, to derive design criteria and to evaluate application opportunities.

Estimated cost: *R700 000*
Expected term: *2000 - 2001*

Enzymology of accelerated primary sewage sludge solubilisation and digestion in sulphate-reducing systems
Department of Biochemistry, Microbiology and Biotechnology, Rhodes University
(WRC Reference No 1170)

A spin-off from WRC-funded research into the biological reduction of sulphate in high-volume sources such as acid mine drainage is the accelerated hydrolysis observed of complex carbon sources in the presence of sulphate-reducing bacterial systems. Enzymological studies are being carried out in this project to identify the bio-catalysed reactions occurring, to characterise the physico-chemical factors involved (e.g. time, temperature, pH, redox potential, sulphide concentration, etc.) and thereby to maximise the overall reaction efficiency.

Estimated cost: *R707 000*
Expected term: *2000 - 2002*

Determination of heterotrophic active bacteria in activated sludge using novel molecular techniques
Centre for Water and Wastewater Research, Technikon Natal
(WRC Reference No 1178)

This is one of three projects (WRC Reference Nos 1178, 1179 and 1191) constituting a specific subprogramme to identify and define the active fractions in the heterotrophic and autotrophic biomass populations involved in biological nutrient removal (BNR) activated sludge systems. Engineering (University of Cape Town) and scientific (Technikon Natal, University of Pretoria) disciplines are collaborating with regard to kinetic modelling and microbiological techniques towards achieving this, in order to provide a co-ordinated understanding of the microbiological processes operating in BNR activated sludge systems as defined engineering environments. Major potential benefits are security of design and operation, with all the consequences of reduced costs and improved (more reliable) effluent discharge quality.

Estimated cost: *R875 000*
Expected term: *2000 - 2000*

Measurement of heterotrophic and autotrophic organism active biomass in biological nutrient removal activated sludge systems
Department of Civil Engineering, University of Cape Town
(WRC Reference No 1179)

This is one of three projects (WRC Reference Nos 1178, 1179 and 1191) constituting a specific subprogramme to identify and define the active fractions in the heterotrophic and autotrophic biomass populations involved in biological nutrient removal (BNR) activated sludge systems. Engineering (University of Cape Town) and scientific (Technikon Natal, University of Pretoria) disciplines are collaborating with regard to kinetic modelling and microbiological techniques towards achieving this, in order to provide a co-ordinated understanding of the microbiological processes operating in BNR activated sludge systems as defined engineering environments. Major potential benefits are security of design and operation, with all the consequences of reduced costs and improved (more reliable) effluent discharge quality.

Estimated cost: *R322 600*
Expected term: *2000 - 2001*

Microbial characterisation of activated sludge mixed liquor suspended solids
Department of Microbiology and Plant Pathology, University of Pretoria
(WRC Reference No 1191)

This is one of three projects (WRC Reference Nos 1178, 1179 and 1191) constituting a specific subprogramme to identify and define the active fractions in the heterotrophic and autotrophic biomass populations involved in biological nutrient removal (BNR) activated sludge systems. Engineering (University of Cape Town) and scientific (Technikon Natal, University of Pretoria) disciplines are collaborating with regard to kinetic modelling and microbiological techniques towards achieving this, in order to provide a co-ordinated understanding of the microbiological processes operating in BNR activated sludge systems as defined engineering environments. Major potential benefits are security of design and operation, with all the consequences of reduced costs and improved (more reliable) effluent discharge quality.

Estimated cost: *R88 000*
Expected term: *2000 - 2001*

New

An evaluation of dedicated land disposal practices for sewage sludge
Institute for Soil, Climate and Water, ARC
(WRC Reference No 1209)

Most sewage sludge produced in the RSA is presently disposed of on dedicated (i.e. sacrificial) land. It is the least expensive of the available alternatives, but has several undesirable environmental consequences and is, furthermore, not viewed as sustainable. The objectives of this project are to:

- Evaluate the extent of the current practice;
- Evaluate the potential risk the practice poses to the water environment at selected sites covering the range of climatic and other conditions; and
- Estimate the potential future impact of dedicated land disposal of sewage sludge on the water environment.

Estimated cost: *R 595 000*
Expected term: *2001 - 2003*

Laboratory- and field-scale evaluation of agricultural use of sewage sludge
ERWAT, Research and Development
(WRC Reference No 1210)

The agricultural use of sewage sludge is a promising alternative use / disposal route for this product over the short-to medium-term, but several concerns currently restrict large-scale implementation. This project being carried out by a multidisciplinary team comprising researchers from ERWAT, ARC and the University of Pretoria is a laboratory- and field-scale evaluation of the agricultural use of sewage sludge to establish the:

- Extent of metal uptake in different (winter and summer) crops grown on soils amended with sewage sludge;
- Effect of soil properties on the mobility of nutrients and metals; safe sludge loadings to prevent nitrogen leaching to groundwater;
- Persistence of sludge-borne pathogens during agricultural application; and
- Perceptions of farmers, commercial markets and urban and rural communities with regard to the beneficial use of sewage sludge for edible crops.

Estimated cost: *R 570 000*
Expected term: *2001 - 2002*

Technical and financial review of sludge treatment technologies
Africon
(WRC Reference No 1240)

In the development of appropriate and practicable guidelines for the management and disposal of sewage sludges in the RSA, the wide disparity in resources available in different localities must be taken into account, with the overarching requirement of providing environmentally sustainable practice for the country. This project aims at developing an authoritative reference document, in which locally and internationally available sludge management technologies (handling, treatment and disposal), their applicability in the RSA, and their cost implications estimated for local conditions, are reviewed and evaluated.

Estimated cost: *R 275 000*
Expected term: *2001*

Evaluation of the anaerobic baffled reactor for sanitation in dense peri-urban settlements
Pollution Research Group, University of Natal
(WRC Reference No 1248)

Wastewaters from dense peri-urban settlements are low-volume high-strength (because of low domestic water use) and intermittent in terms of both organic and hydraulic load (because of diurnal population activities). The anaerobic baffled reactor (ABR) system is potentially a good treatment choice for this application because it effectively retains bio-solids, provides good sludge-liquid contact, and is cheap, easy and low-maintenance in operation. In this project the ABR process is being evaluated on pilot scale for this purpose, in collaboration with a number of other parties representing technical, funding and community inputs.

Estimated cost: *R 1 500 000*
Expected term: *2001 - 2003*

Practical implementation of external nitrification in biological nutrient removal activated sludge systems
Division of Water Quality Engineering, University of Cape Town
(WRC Reference No 1262)

In this project, full-scale trials are being run on external nitrification in biological nutrient removal activated sludge (BNRAS) systems to test the fundamental, laboratory-scale and economic studies done to date by this research group, which have shown that external nitrification in BNRAS systems can be a more efficient and cheaper (20 to 25% lower) alternative compared to other BNRAS systems covering both green-fields and retro-fitting situations. In this collaborative exercise between UCT, the Cape Metro Council, and Water and Sanitation Services SA (Pty) Ltd (the local agent for CIRSEE/Suez Lyonnaise-des-Eaux), the cash contributions by others (excluding contributions in kind) amount to about 40% of the total annual budget.

Estimated cost: *R 1 280 000*
Expected term: *2001 - 2005*

A detailed metal content survey of South African sewage sludges and an evaluation of analytical methods for metal determination
Research and Development, ERWAT
(WRC Reference No 1283)

Current sludge disposal guidelines indicate that even sludges from predominantly domestic wastewater catchments do not meet the heavy metals criteria proposed for unrestricted beneficial reuse (Class D). It is, however, difficult to be categorical about this, firstly because analytical techniques for determining metal concentrations in sludges and soils are not standardised and are expensive, and secondly because the mobilities of metals as they affect groundwater quality and absorption into the food chain are not well understood. This project addresses the first concern, by evaluating different analytical methods for metals in sludges and receiving soils, and by sampling and analysing sludges from 50 wastewater plants in 5 categories (industrial, domestic, waste activated, digested and Class D sludges).

Estimated cost: *R 524 000*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

Building in some cases on previous research, new knowledge generated in current programmes and projects is as follows:

Optimisation of activated sludge systems for sewage treatment

- A model describing filamentous bulking in BNR activated sludge plants and indicating process control measures was hypothesised and tested, and is being demonstrated on full scale.
- A novel reactor insert is being developed and tested to ensure complete denitrification in BNR activated sludge return flows.
- A novel process modification (external nitrification by trickling filters in activated sludge plants) was developed and indicated 25% reduction in operating costs. The process modification is currently being evaluated on full scale.
- In a synergistic subprogramme to determine the active fractions applicable to populations in activated sludge kinetic models, collaboration between engineering (UCT) and microbiology (Technikon Natal and UP) is indicating an innovative synergistic approach.

Other treatment systems for sewage and municipal wastes

- The PETRO® algal ponding process has received international recognition as an innovative low-cost option for sewage treatment in both the developed and developing worlds. The process is now

being extended to include biological nutrient removal.
- New insights into the behaviour and mechanisms of algal ponding systems have led to the development of simple, cheap and robust treatment processes for sewage and a variety of industrial wastewaters.
- Innovations in biological sulphate removal using sewage sludge and other complex organics as the carbon source have revealed an accelerated hydrolysis of sludge that is of major interest to sewage and sludge management operators. Aspects of the Rhodes BioSURE process have been patented.

Critical appraisal of *"Guidelines for Sewage Sludge Disposal"*

- New knowledge is being generated in respect of analytical methods for determining the concentrations of metals in sludges and soils, and in a number of aspects regarding the disposal of sewage sludges to land and beneficial use in agriculture.

Benefits to South Africa

Current research in Municipal Wastewater Management has high-level benefits to South Africa in terms of public health, quality of life, policy development in terms of national legislation and local regulation, aquatic ecosystems and public water resources. More specific benefits related to individual projects and programmes are outlined in the following section.

Innovation/application of knowledge

Knowledge generated in current programmes and projects is being applied as follows (benefits indicated in brackets):

- Full-scale implementation of processes for:
  - Treatment of wastewaters with high nutrients but low carbon levels (practicable treatment of septage, landfill leachates and anaerobic digester supernatants).
  - Co-disposal to landfill of non-toxic wastes with municipal refuse, by Cape Metro Council at Coastal Park Landfill (benefits - reduced leachates and consequent environmental impacts, upliftment of local community).
  - Removal of algae from oxidation pond effluents using the PETRO® process, by a number of local municipalities (reduced eutrophication potential in receiving waters at low cost).
  - Treatment of sewage and a variety of industrial effluents using algal high rate ponding systems, by Grahamstown Municipality, and Western Tanning Company (benefit - reduced impact on water resources, suitable for rural communities).
  - Accelerated hydrolysis of sewage sludge in association with biological sulphate reduction, by ERWAT at Ancor Sewage Works (major potential national benefits in terms of sludge disposal and water renovation for beneficial reuse).
- Application of computational fluid dynamics to the design of various wastewater treatment units (optimisation of design and operation, with low-cost enhancement of performance efficiency and resultant reduction in environmental impact).
- Life-cycle analysis is being applied to determine rational environmentally friendly design decisions for wastewater treatment (reduction of unanticipated environmental impacts).
- An **Addendum** to the 1997 *Guidelines for Sewage Sludge Disposal* will shortly be published.

Capacity/competence building

Lead academic institutions with research capacity and competence in this field include University of Cape Town (Dept of Civil Engineering, modelling and process optimisation of biological wastewater treatment systems), University of Natal (Pollution Research Group, process design and engineering of unit processes for wastewater treatment), University of Pretoria (Dept of Microbiology, microbiological aspects of activated sludge population dynamics), Technikon Natal (Centre for Water and Wastewater Research, advanced molecular techniques for microbiological population studies). Significant collaboration between these groups with mutual interchange of competencies has been set up by WRC research subprogrammes. Collaboration between PDIs and other institutions has mutually transferred skills, for example between engineers and scientists, and between academics and commercial organisations.

Knowledge dissemination

Specific knowledge dissemination activities, in terms of numbers over the past 3 years from research currently funded wholly or partially by the WRC in this field, include the following:

Articles and papers		166
Conference presentations:	International	26
	National	87
Contributions to books		3
Workshops		3
Patents registered		5

Leveraging of resources

Outside contributions to WRC research projects in this field have been received in the following categories over the last three years:

Contributions in kind	In-kind support of research projects is acknowledged but not audited by WRC at present. ERWAT has contributed approximately R2.5 m. for capital construction of a full-scale facility for accelerated sludge hydrolysis using the Rhodes BioSURE process and approximately R0.5m. for analytical and support services. Other own-institution support (infrastructure, support services, etc.) by the contracting organisations concerned has been spread over many of the projects.
NRF funding	Technikon support per identified niche area on a per project basis; these contributions are utilised by the technikons for student support and other costs.

THRIP funding	DTI have contributed R800 000 towards full-scale commercialisation of the Rhodes BioSURE process via their Technology and Human Resources for Industry Programme (THRIP).
Cash from international donor funding	The World Bank Business Partners for Development Programme has contributed approximately R100 000 for capital construction of an anaerobic baffled reactor pilot plant for dense peri-urban communities, and will fund a full-scale plant if the research findings are positive.
Cash from overseas research institutions	CIRSEE, research arm of Suez-Lyonnaise-des-Eaux, has contributed R438 000 towards research on external nitrification via trickling filters to increase the capacity of activated sludge plants.
Cash from local water industry	ERWAT has contributed R200 000 towards research on accelerated sludge hydrolysis associated with biological sulphate-reducing systems. Eskom has contributed R350 000 towards research on electrochemical treatment of sewage and industrial effluent.

Cash from licensing of patents	The WRC will receive around R3.2 m. in instalments over 12 years in terms of a licensing agreement for the PETRO process. This amount fully recoups total WRC research investment (R2.5 m.) in this technology.

International linkages

Specific current research collaborations are with CIRSEE (research arm of Suez-Lyonnaise-des-Eaux) on nitrification; University of Queensland (through Australian CCWWR) on activated sludge morphology and modelling; World Bank (Business Partners for Development) on anaerobic digestion; the Danish Institute for Product Development (IPU) and Danish Technological Institute (DTI) on cleaner production technology.

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Chapter 8

Water Quality Management

Mr HM du Plessis

Scope

Water Quality Management covers those generic issues related to improved management of water quality as well as the study of those water quality problems which are not addressed as part of other research fields. As a result of this fragmentation, research reported under this field does not provide a full picture of the investment that the WRC is making in research aimed at improved management of South Africa's water resources. Where the WRC investment in this field represented 4.3% of the total in 2000, the total of all research contributing to water quality management, amounted to approximately 30%.

Projects in the ***Water Quality Management*** field are grouped into the following programmes:

- Salinisation of surface waters
- Eutrophication of surface waters
- Contamination of water resources with micro-pollutants
- Water quality assessment studies and information systems.

Water quality aspects of direct concern to the fields of agriculture, aquatic ecosystems, groundwater, health, industry, mining, policy and potable water treatment, are mostly excluded and are dealt with in these respective fields.

The percentage of WRC research invested in this more generic field has varied as shown in Table 1. After stabilising at around 5.4% it declined by about 1% from 2000 onwards, when ***Health-Related Water Issues*** was identified and funded as a separate field. With this relatively modest investment, the WRC has contributed significantly to improved management of surface water quality and made major inputs into the way this issue is addressed in the National Water Act.

Links to Key Strategic Areas

Although not necessarily reflected in the projects listed under this field (because those water quality aspects associated with other fields are not included), ***Water Quality Management*** is inherently a strongly crosscutting field with clear links to the following of the WRC's KSAs:

Water Resource Management

Next to quantity, quality of water is the most important characteristic of water resources in need of quantification and management. Water resources cannot be managed without information on both the quality and the quantity being available for a specific purpose. The available quantity is, furthermore, often dependent on the quality requirements of the intended use.

Water-Linked Ecosystems

Being sensitive to environmental changes, ecosystems are impacted dramatically (and

TABLE 1
Investment in **Water Quality Management**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R1 623 600	R2 371 287	R2 915 700	R2 640 400	R2 658 500
% of research fund	4.0%	5.3%	5.5%	4.3%	4.5%

sometimes catastrophically) by sudden changes in water quality. They are also impacted by sustained gradual change over a period of time. Conversely, biosensors are increasingly being used as integrating indicators or measures of water quality.

Water Use and Waste Management

One concern of this KSA is to ensure that waste and other water-polluting products are managed in such a way that water quality is sustained at an acceptable level. Water quality management is thus a core component of this KSA.

Water Utilisation in Agriculture

The quality of water used for irrigation has a major influence on the crop yield and sustainability of an irrigation scheme. The quality of irrigation return flow largely determines the environmental impact of irrigation on water resources. Water quality also plays a significant role in the suitability of water used for stock watering.

Objectives

Primary

To promote the better utilisation of South Africa's limited water resources by supporting research, development and technology transfer actions aimed at improving the management (assessment, prediction, control and utilisation) of the quality of the country's surface water resources.

Secondary

- Quantify and assess the temporal and spatial variation and impacts of the quality of surface waters on water users.
- Predict and quantify the trends and spatial variation in future quality of surface waters and its impact on water users.
- Develop and evaluate management strategies for the control of water quality which address both the causes and symptoms of water quality degradation.
- Develop and evaluate management systems and techniques to enable appropriate use and increased acceptability of water that is of poorer quality than traditionally used (e.g. for irrigation).

Research Projects

Portfolios of completed, current and new projects addressing the above-mentioned objectives for specific water quality problems (salinisation, eutrophication and micro-pollutants), are presented below.

Completed

Extension of the management orientated models for eutrophication control

Division of Water, Environment and Forest Technology, CSIR
(WRC Reference No 266)

This project was initiated when it was found that the model that was at that stage used to predict reservoir eutrophication in order to evaluate potential management alternatives, could not adequately predict the impact of eutrophication control measures in reservoirs where either low levels of nitrogenous compounds or light (in highly turbid reservoirs) were the growth-limiting factors. The same approach as was used for phosphorus was also applied to the simulation of nitrogen in reservoirs. A simple rule-based model was developed to simulate the change in turbidity state of a reservoir. An expert advisor helps the user of the extended model and decision-support system to decide whether only the phosphorus module, the phosphorus and nitrogen modules or the phosphorus and turbidity modules should be run. The improvements that were introduced thus provide for assessments of eutrophication potential to be made not only for reservoirs where algal growth is limited by the availability of phosphorus, but also for systems where nitrogen and light (turbidity) limit the growth of algae.

Cost: *R224 023*
Term: *1989 - 1992*

Completion of research relating to the DISA model - A daily irrigation and salinity analysis system model

Ninham Shand (Cape) Ing.
(WRC Reference No 369)

Concern that the expected expansion of irrigation development and a concomitant increase in future saline return flows, would render certain stretches of the Breede River's main channel unusable as a supply conduit, led to the development of the DISA (Daily Irrigation and Salinity Analysis) computer model for predicting the impact that irrigation development in the Brandvlei Dam supply area could be expected to have on river flow and salinity. When budget constraints required that DWAF curtail an intensive five-year hydro-salinity field research programme to support the development of the DISA model, the WRC decided to fund aspects of the research that would enable refinements to certain aspects of the DISA model and effective technology transfer. As a result of this investment a refined version of the DISA model, including model verification and sensitivity analyses, was produced. The process routines which simulate the delivery of water and salts to the irrigated areas as well as root zone and delivery zone processes within the irrigated soil profile, provide a realistic representation of actual water and salt movement. DISA was verified at Vaalharts and in the Breede River. It was used extensively by DWAF to evaluate alternative planning scenarios and derive the water release rules used in the Breede River scheme.

Cost: *R98 999*
Term: *1991*

Detergent phosphorus in South Africa: Impact on eutrophication with specific reference to the Umgeni catchment

Department of Chemical Engineering, University of Natal and Umgeni Water
(WRC Reference No 465)

A 1986 study for the WRC indicated that detergents comprised between 30 and 50% of the total wastewater phosphorous load and were thus a significant source of phosphorus to the environment. However, the cost associated with eliminating or banning of detergent phosphorus was deemed to outweigh the benefits. This project followed up on these findings by conducting a more detailed study with specific reference to the Mgeni catchment. The contribution of detergent phosphorus to eutrophication in the catchment was determined by a quantification of rural, industrial and domestic phosphorus loadings. In addition, the relationship between soluble phosphorus loading and algal count was determined for the Inanda impoundment. The economic and water quality consequences of eliminating detergent phosphorus were determined incorporating the results of the relationship between phosphorus loading and algal count into cost-benefit analysis procedures. Although the elimination of detergent phosphorus would greatly reduce the eutrophication potential for al the scenarios that were considered, the savings would not justify the cost of reformulating detergents in any of these cases. The project has also provided a simple methodology that can be extrapolated to other catchments where further eutrophication control measures need to be considered.

Cost: *R103 142*
Term: *1992 - 1994*

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

Department of Soil and Agricultural Water Science, University of Stellenbosch
(WRC Reference No 522)

This project was undertaken against the background of deteriorating irrigation water quality in the Breede River, with the broad objective to quantify the effect this deterioration would have on grape yield and quality, and to investigate management strategies to enhance the use of saline water for irrigation purposes. The negative effects of saline irrigation water on crop yield and soil properties can, to some degree, be ameliorated by on-farm management practices. This pilot study was undertaken to specifically investigate whether alternative irrigation management strategies can be used to enhance the use of saline water for irrigation purposes. It was conducted in the same field as a separate investigation into the longer-term effects of saline water irrigation on vine yield in the Breede River Valley irrigation scheme (Project No 695). The two sections of the experiment were planted to different cultivars. The yield of *Colombar* was generally much lower than that of *Chenin blanc*, implying a different response to treatment and therefore a reduction in the number of true replications from four to two. This severely reduced opportunities for establishing statistical significance. The seasonal fluctuation in soil salinity was much greater than the differences between treatments although in general the subsurface irrigation treatment appeared to produce a greater accumulation of salts at the soil surface. The accumulation of salts in summer was much greater on the block planted to the higher yielding *Chenin blanc* cultivar, confirming the expected relationship between yield, water consumption and salt accumulation.

Cost: *R446 458*
Term: *1993 - 1995*

Development of a guide to assess non-point source pollution of surface water resources in South Africa

Sigma Beta (CE) Inc and DWAF/IWQS
(WRC Reference No 696)

Non-point sources contribute significantly and sometimes even dominantly to the degradation of water quality on a catchment scale. This project has already provided input into the water law review process and identified the policy options for non-point source management, developed a framework for implementing non-point source management under the National Water Act and developed a guide to non-point source assessment to support water quality management of surface water resources. Still to be published are test cases relating to the development and testing of the guide.

Cost: *R 840 000*
Term: *1995 - 2001*

Modelling the long-term effect of atmospheric deposition on the salinity of catchment runoff with special reference to the Vaal Dam catchment

Stewart Scott (CE) Inc.
(WRC Reference No 697)

An assessment based on readily available water quality, atmospheric emission and deposition data indicated the possibility of severe salinisation of the Vaal Dam, with potentially large economic consequences, as a result of pollutants being emitted by the burning of fossil fuels in the Mpumalanga Highveld region. This study to investigate the uncertainty introduced by catchment lag time, was undertaken when supporting investigations into other key assumptions of the initial assessment, continued to confirm the likelihood of severe salinisation of the Vaal Dam. A conceptual computer model was developed to join together the research work already undertaken by the WRC. The model also proved useful as a water quality planning and management tool. Flow and rainfall data for 1920 to 1995 and TDS and sulphate data for 1977 to 1995 were used to calibrate the model for the Klip River catchment. The results indicate that catchment storage processes play a much bigger role than originally assumed. The long-term flow-weighted TDS concentrations for the Klip River catchment were modelled to be about 111 mg/ℓ for background conditions and 135 mg/ℓ (a 22% increase) under current conditions. These concentrations are predicted to increase for the 55-year period to 2050, to 207 mg/ℓ TDS for the most likely growth scenario for power generation, and to 279 mg/ℓ TDS for the highest likely growth scenario.

Cost: *R459 681*
Term: *1995 - 1996*

Feasibility of using low-cost modelling techniques to relate river water quality and diffuse loads to a range of land uses

Stewart Scott (CE) Inc.
(WRC Reference No 796)

One of the major obstacles in quantifying and studying non-point source pollution is the high cost associated with conventional methods of monitoring diffuse source loads from different

land uses. The conventional rigorous approach calls for continuous flow gauging in conjunction with high-frequency water quality sampling, both of which are usually extremely expensive and require a high level of technical competence to maintain. This project aimed to develop a low-cost, low -technology methodology that can be used to estimate diffuse source loads and develop useful relationships between in-stream river quality and land use. A daily time-step model was used to simulate flows at monitoring sites situated at the outlet of small, ungauged study catchments that were typically dominated by relatively unique local land-use characteristics. A correction was applied to the data to make the modelled flows coincide with those observed at the outlet of the larger catchment. Spatial and temporal variations in rainfall prevented the model from accurately replicating the flows that occurred on each day on which water quality sampling took place. Useful results were nevertheless obtained.

Cost: *R617 166*
Term: *1994 - 1999*

Identification of diatoms and their use in the assessment of water quality

Department of Genetics and Botany, University of Port Elizabeth
(WRC Reference No 814)

The diatom identification database is complete and is available as a spreadsheet listing the range of characters used in diatom taxonomy and each specific combination of features is linked to electronic images of species possessing those characters. This makes the identification of most taxa relatively much quicker and easier than it has been using the traditional methods.

Diatom (epilithic and epipelic) flora surveys were done in the Eastern Cape (Swartkops seasonally for two years) and 15 other rivers (once each) in the Western Cape and Mpumalanga (Olifants River). The relationship between water quality and taxa present was limited to 'dominant' taxa, i.e. over 10% of individuals present, to give a less confusing picture. This reduced the number of taxa used from 948 to 148 epilithic and 180 epipelic taxa, making the correlation with water quality more manageable. A good relationship was found between water quality and taxa present, although the correlation was stronger for the Swartkops as there was a richer data set. The regular sampling of the Swartkops showed that the dominant taxa did not change seasonally, indicating that temperature had relatively less effect on dominant taxa than water quality. The factors shown by this study to influence diatom taxa present are pH, conductivity, total inorganic nitrogen and phosphate.

Cost: *R226 076*
Term: *1997 - 2001*

Use of Daphnia *spp. and indigenous river invertebrates in whole effluent toxicity testing in the Vaal catchment*

Institute for Water Research, Rhodes University
(WRC Reference No 815)

In collaboration with Rand Water a number of industrial effluents from the Vaal Triangle were selected for testing, all of which proved to be sublethal. In addition, an artificial effluent based on a typical metal-plating industry effluent known to be acutely toxic to *Daphnia* was used. *Daphnia* were more sensitive than the two species of indigenous insects used in the tests (a leptophlebiid and a heptageniid - both mayflies). It was also shown that receiving water increased the variability of results, indicating its variable character. *Daphnia* tests are the cheapest and most protective, although the use of indigenous organisms increases the environmental realism of the tests.

The tests used in this project used death as the end-point. However, more subtle and sublethal effects were observed in the test organisms from a range of effluents. These sublethal effects have implications for effective management of water quality in the Vaal.

A suite of test organisms should ideally be used for setting guidelines, as different organisms show different susceptibilities to toxins. However, the use of indigenous river organisms is expensive, and those tested in this project were similarly or more sensitive to toxins than *Daphnia* so it may be economically pragmatic to use only *Daphnia* for monitoring compliance to permitted effluent discharge standards.

Cost: *R410 958*
Term: *1997 - 2001*

Current

WQ90: Development of an interactive surface water quality information and evaluation system for South Africa

Stewart Scott (CE) Inc.
(WRC Reference No 950)

Development mostly leads to an increasing susceptibility to salinisation and other forms of water quality degradation of the country's water resources. Sustained development requires the early anticipation of associated water quality problems so that these effects could be rectified or obviated. This project is developing a prototype water quality planning tool for the Vaal River system (similar to *Water Resources 90* which provided assistance with water resource planning)

Estimated cost: *R775 000*
Expected term: *1999 - 2001*

Water quality information systems for integrated water resource management: The Riviersonderend-Berg River system

Department of Civil Engineering and Department of Soil and Agricultural Water Science, University of Stellenbosch
(WRC Reference No 951)

Water quality deterioration threatens to diminish the utilisable part of the runoff in many catchments. This project has developed an integrated information system specifically for water quality (WQIS) as a tool to assist water managers with managing these complexities on an integrated catchment basis. The WQIS provides diagnostic and predictive utilities to serve technical planning and operational decision-making in a river system, and at the same time also provides appropriate information to support water managers in the engagement of and communication with stakeholders and communities. The Riviersonderend-Berg River system was selected to serve as prototype for development of the WQIS approaches.

Estimated cost: *R1 367 000*
Expected term: *1998 - 2001*

Biomarker assays for the detection of chronic toxicity in the aquatic environment

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 952)

Biological toxicity tests have become an important part of water quality management in South Africa. Currently, there is a selection of aquatic toxicity tests to detect acute toxicity. However, very little attention has been given to the establishment of techniques to detect chronic toxicity. Chronic toxicity tests are very important monitoring and control tools when the toxicity of effluents is low and are also indispensable to manage ambient waters. Traditionally, these tests take very long to complete. A new approach is the use of biomarker assays which provide rapid measures of the molecular mechanisms underlying toxicity. This project endeavoured to establish biomarker assays for the detection of chronic toxicity in the aquatic environment. The techniques were evaluated by applying them to fish under laboratory conditions and in field samples collected from polluted and unpolluted aquatic environments. Test procedures were standardised. Variability in test results was still undesirably high.

Estimated cost: *R650 000*
Expected term: *1998 - 2001*

Evaluation of predictive models for pesticide behaviour in South African soils

Plant Protection Research Institute, Agricultural Research Council
(WRC Reference No 999)

Newly developed pesticides rely on microbial activity for their degradation. South African soils with their low organic matter content, thus provide conditions which are conducive to prolonged persistence of a pesticide. This project evaluates existing computer-based mathematical models in terms of their efficiency and applicability in predicting pesticide behaviour under South African conditions. The evaluation is aimed at recommending the most suitable model for use by pesticide registration authorities. This is expected to lead to reduced risk of pesticide contamination of ground- and surface waters from pesticide application.

Estimated cost: *R357 000*
Expected term: *1999 - 2001*

Cost-effective methods for monitoring pesticide pollution in water systems: Technologies and procedures for field use in rural areas

Department of Community Health, University of Cape Town
(WRC Reference No 1120)

There is emerging evidence of widespread pesticide contamination of water at relatively low concentrations. As part of a recently completed project, pesticide analytical approaches as used at the Peninsula Technikon, have become sufficiently sensitive and consistent to detect small quantities of primary and breakdown products on a regular basis. Little pesticide monitoring takes place in South Africa because of limited capacity, high costs and the dependence of local communities on distant experts. This project is evaluating two promising new technologies that could reduce the costs of, and practical obstacles to, analyses for pesticides in water. It also aims to develop monitoring guidelines for stakeholder groups and identify the training, technical support and other needs to implement monitoring.

Estimated cost: *R500 000*
Expected term: *2000 - 2001*

Integrated approach to biomonitoring of wastewater for the presence of biologically active agents

Highveld Biological Association
(WRC Reference No 1121)

Research undertaken in this project centres on the development of a rapid (<24 h) and inexpensive biochemical water quality test using human cells. It is a colorimetric test and certain aspects can be automated to speed up the process. The method of the test ensures that the results are directly applicable to human health because the test is sufficiently sensitive to detect levels at which chronic responses will occur.

Estimated cost: *R252 000*
Expected term: *2000 - 2001*

Design and development of an implementation plan for a national eutrophication monitoring programme for South Africa's water resources

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1147)

Under the National Water Act, DWAF is required to establish national monitoring networks to collect relevant information on the quality of water resources. The Minister is required to provide guidelines, procedures, standards and methods for monitoring water quality. Data have to be stored in a National Information System where they can be used for the development and implementation of the National Water Resource Strategy and Catchment Management Strategies. This project is providing the required technical and scientific support to design and implement a National Eutrophication Monitoring Programme. It will dovetail with other networks, such as the National Rivers and Reservoir Water Quality Monitoring Network, the National Microbiological Monitoring Programme and the National River Health Programme.

Estimated cost: *R724 000*
Expected term: *2000 - 2001*

New

A guideline for the selection of toxicity tests in support of the information requirements of the National Water Act

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1211)

An important implication of the National Water Act is that the introduction of both source-directed controls and resource-directed measures aimed at improving water quality, will be based on the effect of these measures on the resource. Biological toxicity tests are ideally suited to assess these effects for stressors. Toxicity assessments can be used to set the standards used in source-directed controls, or to elicit a site or situation-specific response to a stressor. A large number and variety of biological tests are available internationally for aquatic toxicity assessment. A range of toxicity tests has also been established for South African use. Most of the local tests are presently applied in hazard assessments to establish toxicity at the

source level. However, in order to implement the requirements of the National Water Act, methodologies appropriate for resource-directed measures and source-directed controls are required, as well as knowledge on how methodologies for one application relate to the other. The purpose of this project is, therefore, to establish a guideline for the selection of toxicity tests that would support the information requirements of the National Water Act. This will be compiled in a user-friendly document that will facilitate the application of toxicity assessment in water resource management.

Estimated cost: *R450 000*
Expected term: *2001 - 2002*

Development of a user-friendly model for assessing the impact of waste discharge applications on downstream water quality

Stewart Scott Water Quality
(WRC Reference No 1212)

Successful catchment management from a water quality perspective, requires inter alia an intelligent representation (modelling system) of the catchment which describes present water quality and which can be used to predict the effect that proposed new or modified impacts will have on water quality at specific points. Options that need to be incorporated in such a modelling system include applications for new discharge points, increased discharges or altered permit conditions. It is also necessary to assess the impact of current and projected water use and alternatives for managing water quality. This points to the need for a simple but robust technology that can be used to rapidly assess the impacts of applications to discharge waste and the effect of proposed management options. The purpose of this project is to develop such a tool that would not replace the more complex models, but would rather be used to sift options to determine if more complex models need to be applied. The proposed tool could also serve to standardise the approach taken by CMAs in evaluating the initial results obtained by a large variety of organisations. It will be developed in co-operation with DWAF's Directorate of Water Quality Management and its Gauteng Region.

Estimated cost: *R449 900*
Expected term: *2001 - 2002*

Survey of certain persistent organic pollutants in major South African waters

School of Environmental Sciences and Development, Potchefstroom University for CHE
(WRC Reference No 1213)

Persistent organic pollutants (POPs) are organic compounds of natural or anthropogenic origin that resist photolytic, chemical and biological degradation, and also have toxic properties. They have low water solubility, but are readily soluble in lipids and can therefore accumulate in fatty tissue of biota. Because of their long persistence times and low volatility, they can be transported in the environment in low concentrations via water and air movements, as well as with migrating animals. This means that POPs can be transported to areas where they have never been used, and can therefore affect human and environmental health globally - consequently the need for international action. In 1997 the UN Environment Programme initiated a process to develop a global, legally binding instrument to reduce the risks these compounds pose to human health and the environment. South Africa signed an international convention in this regard on 24 May 2002. This still needs to be ratified. Much is known about POPs in northern countries. Far less is known about problems in developing countries. This situation may reduce the value of the POP convention for countries such as South Africa. South Africa might in fact be committed to a convention under which it will be obliged to act, while not knowing the full extent of its own contribution to global POPs (e.g. riverine transport to oceans). This study will establish the presence and levels of important POPs in major SA water bodies and thus help to identify the risks posed by these compounds in different geographical areas, and therefore also identify where management action should be focused. Alternative cheaper analytical methods will also be investigated.

Estimated cost: *R410 000*
Expected term: *2001 - 2002*

A case study for the practical assessment of the Guide to Non-Point Source Assessment in the A23 Tertiary Drainage Region

Department of Chemical Engineering, Technikon Northern Gauteng
(WRC Reference No 1279)

Because of the difficulties involved in quantifying non-point sources of pollution and the lack of guidance on suitable tools to use for this purpose, the WRC funded a project (No 696) to develop a guide to assess non-point source pollution of surface water resources in SA. The WRC recently published the Guide to Non-Point Source Assessment, which is the main product of this project. The present project aims to evaluate the suitability of this *Guide* for identifying the main non-point sources of pollution within the Soshanguwe and Mabopane areas. These areas are also the main source of students at Technikon Northern Gauteng. The staff of the Department of Chemical Engineering will be assisted with this project by the authors of the *Guide* and ERWAT Research and Development. It is foreseen that this project will not only yield valuable insight into the pollutants and pollution sources of the area and provide a first practical field test of the *Guide*, but will also contribute significantly to capacity building within the technikon and to raising awareness about water quality degradation and its causes, within the community.

Estimated cost: *R540 000*
Expected term: *2001 - 2003*

Application of biosensors for ecotoxicity testing of water sources

Microbial Biotechnology Programme, University of Durban-Westville
(WRC Reference No 1286)

Biosensors offer a rapid and convenient way to measure acute toxicity and to determine changes associated with complex chemical mixtures undergoing bioremediation. Microbial biosensors offer advantages over other methods of ecotoxicity testing by the rapid and sensitive response they provide, ease of culturing and maintenance, and the possibility of selecting for an environmentally relevant micro-organism. Bioluminescence-based biosensors are gaining support as a sensitive method in microbial ecotoxicity assessment. Those that are commercially available are unfortunately more appropriate for marine than for terrestrial environmental applications. This project aims to clone lux genes into terrestrial bacteria, and thereby

create the opportunity for bioluminescence-based toxicity testing using biosensors relevant to the environment being tested. They will also investigate the fusion of lux reporter genes to specific catabolic gene promoters. This offers an additional, more specific technique where bioluminescence is switched on in the presence of a particular pollutant, e.g. for the detection of xenobiotics such as naphthalene and heavy metals such as mercury. A lux-based biosensor responds to the presence of toxic compounds with a decline in light production, reflecting the effect of the toxicant on bacterial metabolic activity. The project will assess the bioavailability of heavy metals in water sources using the recombinant strains that are developed.

Estimated cost: *R650 000*
Expected term: *2001 - 2003*

Outcomes to Date of Current Programmes and Projects

New knowledge

New knowledge accruing from current and recently finalised projects in this field includes:

- The availability and ability to apply models which simulate the dynamic physical processes operating in large water bodies (reservoirs, barrages) and their influence on euthropication and salinity stratification, which created new opportunities to manage these (Unfortunately most of the skills developed in this regard have left the country).
- An improved mixed reservoir model with which to compare the effect of management alternatives on the eutrophication status of reservoirs.
- An overview which sets the SA eutrophication management situation within an international perspective and which also provides guidance with respect to research needs and priorities.
- The ability to predict the salinity and quantity of irrigation return flow emanating under both summer and winter rainfall conditions.
- Improved understanding and a quantification of how perennial crops (vines) react to irrigation with high salinity water.
- An assessment of how the increased salinity of rainwater caused by coal burning, will affect the salinity of some of our water resources.
- A generic methodology to follow when determining the cost implications of increasing salinity on various sectors of the economy and a quantification of actual and add-on cost to the economy for water users in the Middle Vaal River.
- Certainty that pesticides associated with use under intensive farming occur mostly at low (safe) levels in the water environment and that the level of awareness of potential dangers by farmers and workers is high.
- The compilation of a guide to assess the magnitude of non-point source pollution. This will enable the quantification and thus management of non-point sources which are often of greater magnitude than point sources.
- Identification of the available policy options for managing non-point sources of pollution.
- The identification and development of the concept and philosophy underlying the use of economic instruments as a means to manage water pollution (in addition to the traditional command-and-control approach).

Benefits to South Africa

Benefits accruing from current and recently completed projects in this field include:

- Recognition of the fact that South Africa has lost the leading edge in eutrophication research (which it had in the 1980s) and the realisation that we need to regain aspects of this ability to deal with the worsening problem.
- Large savings which accrued to Eskom (and indirectly to electricity users), when it was found that the decision to retrofit coal-fired power stations with scrubbers, could be delayed owing to the fact that buffering by catchment soils introduces a lengthy time lag between sulphate emission/salt deposition and the appearance of salts in water bodies. Decisions can be delayed until a resulting Vaal Dam salinisation upward trend can be confirmed by actual measurements.
- The design and development of an implementation plan for a national eutrophication monitoring programme, as required by the NWA.
- Assurance for DWAF, health authorities and the public that pesticide levels in water samples of areas with high application rates (and thus suspected of having a high contamination rate) are mostly below WHO standards, and that there is already a high level of awareness among farmers and farm workers of the risks associated with pesticide use.
- The launch of a survey to determine the presence and level of certain persistent organic pollutants (POPs), which will allow SA to honour its obligations under an international convention which is due to be signed in 2002.
- A quantification of the costs water users are subjected to because of salinisation, which provides additional justification for pollution control measures and moves to internalise pollution costs.
- The establishment of a guide for the quantification of non-point source pollution which, together with enabling clauses in the NWA and the provision of guidelines to DWAF on how to manage the process, have put the management of this important source of water quality degradation on a solid base.
- Development of a prototype water quality information system which will aid DWAF and future CMAs to achieve improved public participation and management of water quality on a catchment basis.
- Development of a user-friendly model to assist regulators in achieving a higher level of decision-making regarding the allocation of waste discharge permits, by providing them with an easy means to assess the impact of additional discharges in a catchment.

Innovation/application of knowledge

Knowledge generated through current and recently completed projects is already being or will be applied in the following ways:

- Through directing and selecting research initiatives in the eutrophication field.
- In the implementation by DWAF of the national eutrophication monitoring programme that is presently being designed.
- Enabling the evaluation of alternative development scenarios in the Breede

River and the design of freshening release operating rules.

- In the management of soil salinity of vine crops and the management of irrigation water salinity.
- Through the postponement of a decision concerning the need to retrofit coal-fired power stations with scrubbers in order to remove sulphur dioxide, which will eventually affect the salinity of water resources.
- Through quantification of costs of salinisation of water resources to society, e.g. the cost to society of water released by mines in the Vaal Barrage catchment, the cost of salinity as part of the design of a wastewater discharge system and the cost-benefit of the Vaal System Model.
- Through acquiring a better perspective on the occurrence and levels of pesticides in the water environment in SA and thus their threat to water users.
- In a more focused and standardised approach to quantify and assess the importance of non-point sources of pollution.
- In providing DWAF with the options of how to manage non-point sources of pollution.
- In assessing the possible implementation of waste discharge charges to complement the traditional command-and-control approach to water pollution control.

Capacity/competence building

Department of Water Affairs and Forestry

The technical capacity and competence of participating researchers and managers in DWAF have generally been enhanced as a result of their involvement at Steering Committee level. Several projects also make provision for the involvement of specific individuals or Directorates. For example the project **Development of a guide to assess non-point source of surface water resources in SA** provided for joint project leadership and participation between the Institute for Water Quality Studies (IWQS) and the WRC contractor.

University of Cape Town

The Department of Community Health together with Peninsula Technikon have developed considerable competence in conducting field studies on pesticide contamination of water resources, in dealing with farming communities on this sensitive issue and the health implications associated with pesticides.

The Department of Civil Engineering acquired considerable expertise on hydrodynamic models as part of a planned capacity-building initiative by Ninham Shand. This expertise was largely lost when the study leader retired and the main researcher emigrated.

Details concerning the building of individual capacity through WRC projects at this institution are as follows:

Ph.D. awarded or in progress:	2 (Black male, White female)
Diploma in progress:	(White female)

University of Stellenbosch

The Department of Soil Science acquired considerable expertise in running complex field experiments involving differential treatments, electronic data capturing and a variety of field and laboratory measurements. Personnel also acquired specialised salinity-related plant physiological expertise through technology transfer from the Volcani Center (Israel), the Water Management Laboratory (USA) and via soil chemical-solute transport modelling from Cornell University.

The Department of Civil Engineering, through a strategic alliance with Ninham Shand and others, have developed into the leading centre for non-point source characterisation and water quality modelling as well as their integration into water quality information systems for use in water resource management.

Details concerning the building of individual capacity are as follows:

M.Sc./M.Sc. Ing. awarded:	7
(3 White females, 1 Black male, 3 White males)	

Peninsula Technikon

The Departments of Analytical Chemistry and Chemical Engineering have developed an enviable pesticide analytical facility as a consequence of their involvement in WRC projects on this topic. They consistently and accurately conduct analyses to levels an order of magnitude more sensitive than in earlier WRC projects. One of the researchers attended a five-week course in advanced analytical methods at Michigan University.

Details concerning the building of individual capacity are as follows:

M.Tech. awarded:	2 (1 Black male, 1 White male)
B.Tech. awarded:	1 (1 Black female)

Knowledge dissemination

Knowledge dissemination has taken place through scientific articles and conference presentations/courses/workshops/demonstrations. Numbers for the past three years are:

Articles and papers:	6
Conference presentations:	17
Courses/workshops:	4

Leveraging of resources

Outside contributions to research projects are mostly of an in-kind nature. These contributions take the form of staff at reduced or no cost, facilities and equipment. The best example of this nature is the contribution of staff and facilities provided by DWAF as part of the development of the non-point source guide. DWAF also contributed R755 000 in addition to the WRC's contribution of R708 000 to the cost of a recently completed project dealing with the determination of the cost associated with salinisation.

International linkages

Water Quality Management research programmes and projects have developed strong linkages to the following international research institutions, which have made indirect contributions to the research.

- Cornell University, USA
- Michigan State University, USA
- Water Management Laboratory, USA
- Leuven University, Belgium
- Army Corps of Engineers, USA
- Volcani Center, Israel
- CSIRO, Australia.

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Chapter 9

Groundwater

Mr K Pietersen

Scope

The overall goal of groundwater research at the WRC is to promote the optimal and sustainable utilisation of groundwater resources of South Africa (and now Africa) through various research programmes. The following key issues for groundwater research are identified:

- The complexity of the natural system (geological conditions, climate);
- Institutional and management challenges;
- Inclusion of groundwater as a beneficial component in integrated water resource management (IWRM);
- Protection of groundwater from negative land-use impacts; and
- The development/positioning of South Africa's knowledge base to address the above to offer integrated solutions.

A programme-orientated approach addressing both the short- and long-term needs of sustainable use and management of groundwater resources in South Africa has been developed. This approach allows for close integration between the groundwater field and the surface hydrology and hydroclimatology fields.

Groundwater is currently considered as one of the key research fields in the WRC, attracting the 4th largest funding allocation in the organisation. Table 1 gives an indication of the percentage of WRC funds the research field has utilised since 1997. The field has been relatively well supported, utilising approximately 7 to 8% of total project funds. Planned research for 2002/2003 will amount to 8.8% of total project funds.

Links to Key Strategic Areas

Groundwater, although often overlooked and unacknowledged, is the cornerstone for many regional economic and environmental systems. It is far more reliable as a source of supply than surface water and if protected can provide potable water of high quality. Access to groundwater is, perhaps, the most critical factor enabling many rural populations to move out of poverty. Groundwater has the following links to the WRC's key strategic areas:

Water Resource Management

The recognition of groundwater as public water (as opposed to private water) means that the integration of groundwater into the broader water resource management framework is a key strategic directive in South Africa.

Water-Linked Ecosystems

The role of groundwater in maintaining dependent ecosystems is poorly understood. There is recognition that this is an emerging new field of study,

TABLE 1
Investment in **Groundwater**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 079 390	R3 062 086	R4 370 655	R4 971 500	R4 552 670
% of research fund	7.6%	6.9%	8.2%	8.0%	7.7%

including the identification and role of invertebrates in fractured-rock systems.

Water Use and Waste Management

Groundwater, alone or in conjunction with surface water is crucial for domestic use in many rural and urban settings. Waste and effluent disposal has the potential to impact seriously on groundwater and needs to be soundly managed in order to protect the resource.

Water Utilisation in Agriculture

Groundwater sustains many agricultural activities in South Africa. The focus on emerging farmers underscores the value of groundwater in sustainable food production.

Objectives

The strategic plan for groundwater research was updated in 2000. The plan is based on the premise that finding solutions to real-world problems will require a collaborative framework. This means breaking down traditional disciplinary boundaries, designing research to support both integrated water resource management and policy-making, and communicating research output in an appropriate manner. This will require scientists and other professionals from different disciplines to work together to achieve a common goal. Recognising these challenges, a vision (serving as an overarching primary objective) for the groundwater research field has been formulated as follows:

> "The realisation, through excellence in research, of the full potential of groundwater in contributing to equitable and sustainable development in Southern Africa"

Aims for the groundwater field were developed based on identified driving forces, such as alleviation of poverty and promotion of quality of life.

The following secondary objectives (problem areas) for groundwater research to be implemented over a 5-year time-frame were identified:

- To refocus groundwater characterisation towards integrated water resource management in line with national needs and priorities.
- To manage groundwater quality with emphasis on the prevention of contamination / pollution.
- To support activities that develop appropriate professional, institutional and management practices to achieve integrated water resource management.
- To encourage innovative and imaginative research (lateral thinking) with the potential to contribute to meeting the identified vision of groundwater research.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are herewith presented.

Completed

A synthesis of the hydrogeology of the Table Mountain Group - Formation of a research strategy

Various consultancies
(WRC Reference No TT 158/01)

This document represents a status quo on current understanding of the Table Mountain Group (TMG) aquifer system. The objectives of the project were to: synthesise current knowledge of the TMG aquifer systems and formulate a research strategy to address research needs and priorities.

The document is subdivided into technical papers and appropriate case studies. This exercise resulted in an understanding that to realise the potential of this groundwater resource, many uncertainties and barriers need to be overcome, including: deficient understanding of the occurrence, attributes and dynamics of TMG aquifer systems; lack of environmental impacts of exploitation; and uncertainties about how best to manage the resource within a multi-objective/attribute environment. This document provides a state-of-the-art assessment of current knowledge and a roadmap for future research.

Cost: *R305 100*
Term: *2000 - 2001*

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

Department of Geological Sciences, University of Cape Town
(WRC Reference No 526)

Fluorine is one of a few potentially toxic trace elements whose primary path into the human body is via drinking water. Areas of Southern Africa are amongst those notable in the world as experiencing endemic fluorosis on a regional scale. The study area of approximately 45 000 km^2 is one of them. The Pilansberg and Lebowa Granites of the area were found to have high rock F contents, whilst the Nebo granite has scattered high values and the Rustenburg Layered Suite values are uniformly low. As these levels are reflected in the groundwater, much of the study area is underlain by groundwater having F concentrations above the optimum. A map of the study area was prepared which gives a detailed plot of borehole/risk value locations while another map shows a plot of Theissen polygons classified into areas with no risk (<0.7 mg/ℓ), high risk (>1.5 - 3.0 mg/ℓ) and very high risk (>3.0 mg/ℓ). Approximately 17 000 km^2 of the western Bushveld have groundwaters with an F concentration >0.7 mg/ℓ. Just over 540 of the 3 000 groundwater samples have an F concentration >1.5 mg/ℓ, and 82 000 to 109 000 people are drinking groundwater that may induce fluorosis in the long term.

Between 145 500 and 194 000 people are drinking water with F concentrations higher than optimal.

Cost: R111 500
Term: 1993 - 1995

Hydrogeological, isotopic and hydrochemical assessment of the response of a fractured multi-layered aquifer to long-term abstraction

Schonland Research Centre, University of the Witwatersrand
(WRC Reference No 565)

The aims of this project were to assess recharge to the Karoo aquifers in the Kalahari using different methods. This included a better understanding of the effective mechanism of recharge and also to assess the reliability and value of isotope measurements in groundwater studies. The aquifer was also characterised in terms of its hydraulic response by re-examining previous pumping test data.

The research used the long-term, well-documented abstraction measurements at the Orapa Mine in Botswana. The methods used to assess recharge included isotopic techniques, water balance techniques and the cumulative rainfall departure (CRD) method. Recharge estimates of 1.75 to 4.8 mm/a were obtained. The best estimate of aquifer storativity of Orapa was inferred from the revised interpretation of pump tests (s = 0.0035).

Cost: R87 450
Term: 1993 - 1996

Regional characterisation and mapping of Karoo fractured aquifer systems - An integrated approach using a geographical information system and digital image processing

Directorate of Geohydrology, DWAF, and the Council for Geoscience
(WRC Reference No 653)

The aim of this research project was to assess the potential of satellite image processing as a tool within the GIS environment for the characterisation and mapping of Karoo aquifers on a regional scale. The research complemented the DWAF groundwater mapping programme and was carried out in conjunction with the production of the Beaufort West (3222) hydrogeological map at a scale of 1:500 000. The study produced various vector-based lineament coverages from remotely sensed information. This included coverages on dolerite dykes, kimberlite fissures and master joints. An analysis of the tectonic history and present-day stress regime was done. An exploration drilling programme was aimed at providing a more scientific assessment of the water-bearing potential of various geological lineaments. Arc/Info was used to analyse the relationship between borehole productivity and geological lineaments. This resulted in the identification of the structural factors controlling the productivity of boreholes. A hydro-tectonic groundwater yield map was compiled. The study has shown that the occurrence of groundwater can be characterised on a regional scale and potential groundwater exploration targets selected from a series of optimal structural parameters.

Cost: R277 575
Term: 1994 - 1996

The preparation of a monograph on South Africa's groundwater resources

JR Vegter Esq.
(WRC Reference No 676)

The main aim of this project was the preparation of a monograph on the exploration, development and exploitation potential of the groundwater resources of South Africa which will complement the National and Regional-Scale Hydrogeological Map series. The project has produced a global background document and historical overview including a proposed classification of groundwater regions consisting of 64 areas. This was followed by detailed work on two of the recognised groundwater regions: No 1, the Makoppa Dome and No 3 Limpopo Granulite-Gneiss Belt (both in the NE of the Limpopo Province).

Cost: R227 000
Term: 1995 - 1998

Geohydrological modelling of the Richards Bay area

Department of Hydrology, University of Zululand
(WRC Reference No 720)

The objectives of this project were to:

- Develop suitable numerical models of groundwater flow for primary aquifers with emphasis on the Richards Bay area;
- Develop a conceptual model of the geohydrology of the Richards Bay area for adaptation to numerical modelling of the groundwater; and
- Establish a geohydrological database for the Zululand Coastal Belt and in particular the Richards Bay area.

A MODFLOW model has been applied on a number of case studies in the Richards Bay area. An enormous amount of data has been collected on atmospheric conditions, lake and borehole water levels and geologic formations. Various calibration methods have been investigated. In general calibration results are very positive for a number of applications. However, one of the major shortcomings is the fact that geological surveys are not carried out with geohydrological applications in mind and data interpretation is based on numerous assumptions. The models examined in this project are mathematically and theoretically sound but their applications suffer from a lack of sufficient information. The lack of information in the region is a serious constraint to the use of the numerical models for other purposes such as solute transport modelling. Clearly, the biggest limiting factor in numerical modelling is the availability of data and information about the system. However, one of the greatest assets of numerical modelling is that it identifies gaps in the information and the need for additional monitoring. This study has led to the establishment of a long- term monitoring point in the centre of the industrial area of Richards Bay.

Cost: R560 000
Term: 1995 - 1997

A groundwater supply assessment and strategy for the western Karoo, Namaqualand and Bushmanland

Department of Earth Sciences, University of the Western Cape
(WRC Reference No 721)

The main aims of the study were to:

- Provide a quantitative understanding of the region's groundwater resources in terms of quantity and quality; and
- Assess water supply needs and to formulate strategies for groundwater use as part of the overall water services framework.

The result was a conceptual representation of the hydrogeological system and the following was described:

- Groundwater flow and salinisation;
- Groundwater evolution;
- Recharge processes; and
- Carbonate and silicate weathering (i.e. specific aquifer systems, groundwater flow regime, etc.).

The report also includes coping strategies to overcome barriers to sustainable groundwater development such as adverse climatic conditions; climate variability and aquifer assessment and management.

Cost: R 1 804 600
Term: 1995 - 2002

Modelling of groundwater flow in the Table Mountain sandstone fractured aquifer in the Little Karoo region of South Africa

Steffen, Robertson and Kirsten
(WRC Reference No 729)

This study developed a conceptual understanding of Table Mountain Group (TMG) aquifers. These include aspects related to the attribute and dynamics of the system. The study also confirmed the viewpoint that TMG aquifers are to be considered regional systems as opposed to the previous paradigm of a limited aquifer system with negligible recharge and storage. The study found that fracture styles, geometry and preferred orientation of water-bearing fractures contributed significantly to groundwater flow. The inter-relationship between different lithological units is essential in aquifer conceptualisation.

The study focused on the Klein Karoo Rural Water Supply Scheme near Oudtshoorn which obtains water from boreholes located in the Kamanassie Mountains. Three scales of groundwater flow were distinguished:

- Local scale;
- Intermediate scale; and
- Regional scale representing groundwater flow along the folded bedding of the TMG aquifer.

The output of the study provided managers with information and tools to contribute to sustainable development of the aquifer system. This has been incorporated into a series of Excel spreadsheets.

Cost: R257 900
Term: 1997 - 1999

The utilisation of tracer experiments for the development of rural water supply management strategies for secondary aquifers

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 733)

This study investigated the application of artificial tracers to understand aquifer geometry. The report also focuses on the delineation of borehole protection areas in fractured aquifers. A programme called Borehole Protection Zone (BPZONE) was developed to estimate different protection zones.

Numerous tracer and dilution tests were conducted in a number of different geological units, such as Karoo sediments and granitic terrains. Using tracers the following parameters could be determined:

- Velocity estimates;
- Effective porosity; and
- Hydraulic conductivity.

Tracers were found to be invaluable in understanding groundwater flow mechanisms.

Cost: R793 000
Term: 1996 - 1999

An assessment of ambient groundwater quality on a national scale in the Republic of South Africa

Hydromedia Solutions and DWAF
(WRC Reference No 841)

The study interpreted the national groundwater quality database (QualDB) to provide a national overview of the hydrochemical development in aquifers found in South Africa. The database comprises mostly major ions with limited positional and sampling procedure data. Trace elements and organic chemical data do not exist. The mainframe database was found to be complex and programs needed to be written to answer the queries. The data were used to compile maps of all major groundwater quality variables at a scale of 1: 10 000 000. These include calcium, magnesium, sodium, potassium, alkalinity, sulphate, chloride, nitrate, nitrogen and fluoride. In addition to the major ions other derived and index parameters were also used in the study, such as carbon dioxide to give an impression on how carbonic acid may contribute to solute-forming processes.

Hydrochemical maps were also produced using the Piper classification system. Further sets of maps were generated to show compliance of groundwater for drinking water purposes.

Cost: R110 000
Term: 1999

The preparation of a handbook on the hydrogeology of the Karoo Supergroup

Toens and Partners
(WRC Reference No 860)

The Karoo basin is characterised by fractured-rock aquifers that are intersected by numerous vertical and horizontal dolerite intrusions. These conditions produce a unique and complex hydrogeological system, which complicates the study and development of groundwater. This document provides a detailed summation and collation on the hydrogeology of the main Karoo basin. It addresses issues related to the hydrogeological properties, including a detailed geological and structural description. It describes groundwater flow and behaviour, the macro-chemical constituents and water quality; including isotopes. The report further details approaches for resource development and protection. The handbook includes an inventory of all relevant published material on Karoo fractured-rock aquifers. Research priorities are also identified.

Cost: R230 000
Term: 1997 - 2000

An integrated multidisciplinary approach to groundwater development in granitic aquifers

Department of Geology, University of Pretoria
(WRC Reference No 862)

This study combined airborne geophysical techniques and ground geophysical surveys together with detailed structural geological mapping in the siting of production boreholes. The study area was the Nebo granites in the Northern Province.

Three major aquifer types were identified, viz. fractured aquifers associated with major structures, fractures associated with dykes and weathered aquifers resulting from weathering of major structures. A previously held paradigm that drilling, in the Nebo Granites, deeper than 30 m is not warranted due to the closure of fractures was disproved. Adequate water strikes were recorded at deeper depths. Using the above techniques, the boreholes that were sited were higher-yielding than traditionally obtained in the region.

Cost: *R450 000*
Term: *1997 - 2000*

Evaluation of nuclear magnetic resonance (NMR) as a new geophysical technique for groundwater exploration in fractured rocks

Environmentek, CSIR
(WRC Reference No 935)

The main aim of this study was to intensify the literatures study and the theory and application of NMR as a geohydrological tool. The report gives a detailed account of the theory of NMR, instrumentation; field procedures; resolution and limitations of the technique.

The technique was applied to fractured-rock domains, ranging from granite to Karoo sediments. The following issues were identified (lessons learnt):

- Earth magnetic field in South Africa in order to set instrument settings;
- Signal strength in South Africa - signal response is in the order of 4 times lower in Europe and Australia;
- Noise levels in South Africa, e.g. lightning causes significant noise which means that summer months are not suitable for tests;
- Instrument limitations in terms of signal strength and geology response to signal strength.

The technique has been shown to be a useful tool in the exploration of groundwater resources.

Cost: *R385 000*
Term: *1996 - 2000*

The influence of dolerite ring structures on the occurrence of groundwater in Karoo fractured aquifers: A morpho-techtonic approach

The Council for Geoscience
(WRC Reference No 937)

Dolerite structures are intruded into the Karoo sediments over an area covering approximately half of South Africa. Preliminary studies of the dolerite ring structures have shown them to be potential groundwater exploration targets. A study was started to assess the occurrence of groundwater associated with Karoo dolerite sills and ring structures.

The study resulted in the compilation of a hydro-morpho-tectonic model that highlights zones of potential "open" fracturing which are associated with the emplacement of dolerite sill and ring complexes. The Victoria West area was chosen as a pilot study. A total of 67 boreholes (total drilling depth 13 799 m) were drilled at 10 exploration sites to investigate the morpho-tectonic complexity of the dolerite ring system. There was a marked yield increase.

Cost: *R425 000*
Term: *1998 - 2001*

Groundwater development for rural water supply in complex and problematic terrain: An assessment of geological controls, geophysical exploration methods and the quantification of exploitation potential

The Council for Geoscience
(WRC Reference No 966)

The primary aim of this project was to investigate the development potential of groundwater in problematic or complex terrain where the demand for water for rural communities is expected to grow, and to develop guidelines for groundwater exploration and development. The study followed a multidisciplinary approach where structural geological mapping, tectonics, strain analysis, LANDSAT image interpretation and geophysical methods were combined to unravel the geodynamics of the region and to identify geological structures where groundwater could be located. Four traditional low- yielding hydrogeological domains were identified for investigation. All these pilot areas clearly demonstrated the role of structural geology on groundwater occurrence. Based on such analyses the geological and structural controls that distinguish high-yielding fractures from those that have low potential could be determined. As an outcome of the study guidelines for groundwater exploration in low-yielding domains were developed.

Cost: *R833 000*
Term: *1998 - 2001*

Pilot artificial recharge schemes: Testing sustainable water resource development in secondary aquifers

Water Quality Programme, CSIR
(WRC Reference No 967)

The aims of this project were to test the artificial recharge concept in South African fractured-rock aquifers, thereby demonstrating the potential of artificial recharge. Suitable test sites were identified and the concept tested. The four study sites represented widely divergent situations. Three of the sites, Windhoek, Calvinia and a small Namaqualand village, Karkams resulted in two to three seasons of injection tests. At the 4th site, Polokwane, the infiltration of treated municipal wastewater was studied to determine the impact on the hydrogeological regime. In particular, the large-scale Windhoek pilot study and the very small-scale Karkams application confirmed the wide range of situations where the technique can succeed.

The technical success of the Windhoek artificial recharge pilot studies is confirmed on the management level by the fact that the Windhoek Municipality has decided to continue with the full-scale implementation of artificial recharge.

Cost: *R1 270 000*
Term: *1998 - 2001*

Amalgamation of Munibase and WISH software into a user-friendly software package to be used by South African geohydrologists

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 968)

Development of a Windows-based interpretation system for hydrogeologists (WISH)

Institute for Groundwater Studies, University of the Free State, and DWAF
(WRC Reference No 702)

The creation and implementation of the existing groundwater database structure in South Africa has facilitated both the production of hydrogeological maps and the Department of Water Affairs and Forestry's regional groundwater characterisation programme. The aims of the project were:

- The creation of an interface for the incorporation of geohydrological data into the Microsoft Windows environment;
- The establishment of a software ensemble for groundwater data processing and interpretation to be used by the geohydrologist under the Windows environment; and
- The establishment of a user-friendly interface to the software package for use by the geohydrologist.

A Windows Interpretation System for Hydrologists (WISH) software has been developed and licensed. Mining houses use it on a regular basis. The software was developed with input from DWAF and is licensed and maintained by the Institute for Groundwater Studies.

968 Cost: R300 000
Term: 1998 - 1999
702 Cost: R795 000
Term: 1995 - 1997

Enhancement of the WISH software package to meet current requirements of geohydrologists

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1006)

WISH (Windows-based Interpretation System for Hydrogeologist) software package was developed for the WRC to assist hydrogeologists in data processing. This project enhanced WISH to ensure compatibility with spatial data sources stored in various GIS and map files in order to extend the processing capabilities of WISH to accommodate interdisciplinary processes and associated data sources, e.g. river baseflow-groundwater interactions, vegetation-groundwater interactions, irrigation requirement-assured borehole yield relationships, rainfall-groundwater recharge relationships, etc.

The following map formats are currently supported: ArcInfo shape files; AutoCAD.dxf files; Surfer.bln files; HydroCom.map files; WISH.wdg digitised files; Bitmap.bmp files; Jpeg.jpg files and Tiff.tiff files. The following datasets are supported: HydroCom; Aquabase; Munibase and Excel. WISH has been extended through the addition of an irrigation scheduling programme. WISH also incorporates the Cumulative Rainfall Departure Method for recharge estimation.

Cost: R250 000
Term: 1999

Development of a Windows-based interactive 3D visualisation computer program for geohydrological data

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1007)

Geohydrological data and model outputs produce information that needs to be visualised for management purposes; 3D visualisation software called Groundwater Explorer was developed. Groundwater Explorer is written in the C++ programming language. Results from geohydrological software such as MODFLOW, MT3DMS, PTHT3D and RT3D were used to demonstrate visualisation of important aquifer parameters.

Cost: R273 000
Term: 1999 - 2000

Protocols for assessing groundwater pollution impacts - Formulation of a research strategy

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1008)

The main aim of this project was to formulate a research strategy for groundwater protection in urban catchments. The research was based on synthesis of current state-of-the-art methodologies for determining groundwater pollution impacts from anthropogenic activities. A summary was made of current approaches used in South Africa.

The report lists a number of methods for vulnerability assessments. This included empirical, deterministic, probabilistic and stochastic methods. The report gives significant attention to soils, and the role of soils in vulnerability assessment. Research projects are identified under two programmes:

- National information programme and Aquifer Management Programme; and
- Aquifer classification programme.

Cost: R199 000
Term: 1999

Guidelines for aquifer parameter estimation with computer models

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1114)

The report presents guidelines for estimating aquifer parameters using analytical and numerical models. The three-dimensional groundwater flow model MODFLOW from the US Geological Survey and the simulation system PMWIN as well as the inverse model PEST have been used to analyse the hydraulic data numerically. The results from the numerical models are compared with those from analytical methods. Four analytical models have been used: Cooper Jacob I, Cooper Jacob II, Gringarten and Theis. The guideline for aquifer parameter estimation with computer models describes the correct way to build a numerical model and to use it for the purpose of parameter estimation.

Cost: R200 000
Term: 2000 - 2001

Manual on pumping test analysis in fractured-rock aquifers

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1116)

The development of this manual was driven by the need to establish a scientifically sound and documented approach to performing and analysing pumping tests in fractured systems. A software program entitled Test Pumping Analysis (or TPA) was developed and includes the following methods:

- Moench method for double porosity aquifers;
- Gringarten, Kazemi, Warren and Root and Stallman methods for single and vertical fractures;
- Solutions for porous aquifers; and
- Diagnostic plots.

The manual highlights the non-linear relationship between the abstraction rate and drawdown, which is most common in South African aquifers. The manual highlights many limitations involved with each of the methods discussed.

Cost: *R195 000*
Term: *2000 - 2001*

Current

Flow and transport characteristics of groundwater in Karoo formations

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 936)

Boreholes in Karoo aquifers are frequently low-yielding and have been considered to be unreliable sources of water. However, recent investigations have revealed that Karoo aquifers contain considerably more water than formerly assumed. It is becoming apparent that their physical properties in fact differ from those generally described. This project aims to use more appropriate methodologies to confirm and expand knowledge on the physical nature of Karoo aquifers.

Estimated cost: *R 598 000*
Expected term: *1998- - 2001*

Decision tool for establishing a strategy for protecting groundwater resources: Data requirements, assessment and pollution risk

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 969)

This project on the development of a decision tool for establishing local groundwater resource protection strategies includes the development of a framework for early stage risk assessment, considering both the probability and economic consequences of contamination. Such a tool is needed to guide preliminary decision-making, prior to undertaking more detailed and expensive investigations.

Estimated cost: *R650 000*
Expected term: *1999 - 2001*

Evaluation of groundwater resources in fractured rock aquifers at a catchment scale using evidence of mixing of groundwater from CFC and isotope data

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1009

Knowledge of the age of recharged groundwater and of recharge rates is important for evaluating groundwater resources in terms of sustainability and exploitability. Chlorofluoro-carbon (CFC) levels in groundwater have been shown to provide a means of accurately estimating the age of unmixed groundwater. This research develops a method of integrating and analysing groundwater age data provided by isotopes, so that groundwater mixing ratios can be determined. It further investigates the application of these mixing ratios to groundwater resource evaluations so that the reliability of these evaluations can be refined.

Estimated cost: *R354 000*
Expected term: *1999 - 2000*

Nitrate and associated groundwater hazard quantification and strategies for protecting rural water supplies

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1058

Groundwater exploitation in many respects forms the cornerstone of water supply to rural communities in South Africa. A problem frequently faced is that of high nitrate concentrations in groundwater. This project determines the extent and severity of high nitrate in groundwater (and associated anthropogenic pollution) in selected study areas in the community water supply context. It also identifies and interprets environmental conditions aggravating the situation.

Estimated cost: *R450 000*
Expected term: *1999 - 2001*

Modelling decision support system for the groundwater reserve (A component project of the Research Programme on the Determination of the Groundwater Reserve)

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1090)

This project is developing methodologies to set the groundwater component of the ecological reserve. This project aims to fulfil a need for a user-friendly decision support system, which will enable decision-makers to interact with stakeholders in reaching decisions concerning the "groundwater" reserve and the allocation of accessible groundwater resources.

Estimated cost: *R765 500*
Expected term: *1999 - 2001*

Groundwater reserve: Delineation, reference conditions and classification (a component project of the Research Programme on the Determination of the Groundwater Reserve)

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1091)

The National Water Act requires classification of water resources. In order to do this, it is first of all important to delineate geographical boundaries of regions within which groundwater conditions are relatively

homogeneous. Within such regions, it will be necessary to establish reference conditions in order to determine the un-impacted state of the resource. Based on this the resource will need to be classified to determine a management class. Accordingly a main objective of this project is to review and determine appropriate classification methods for resource-directed measures.

Estimated cost: *R627 000*
Expected term: *1999 - 2001*

Classification of critical groundwater-dependent terrestrial ecosystems (A component project of the Research Programme on the Determination of the Groundwater Reserve)

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1092)

The research examines the dynamics of water use of terrestrial ecosystems. This is providing a better understanding of the importance of the water environment and the role of groundwater in these natural ecosystems. The project also aims to establish a practicable methodology to determine groundwater requirements of selected terrestrial ecosystems.

Estimated cost: *R485 000*
Expected term: *1999 - 2001*

Groundwater recharge to basement aquifers (A component project of the Research Programme on Sustainable Groundwater Management and Utilisation in the Northern Cape)

Department of Earth Sciences, University of the Western Cape
(WRC Reference No 1093)

An important aspect of sustainable management of groundwater resources is the quantification of recharge. Investigating recharge in basement aquifers is important not only on account of the small storage of basement aquifers, but also to obtain a better understanding of the processes and quantities involved which increases knowledge of the aquifer potential. This research project will assist in developing methodologies for the estimation of recharge in basement aquifers.

Estimated cost: *R1 701 000*
Expected term: *1999 - 2003*

Fluoride in drinking water and its effects on human health and nutrition (A component project of the Research Programme on Sustainable Groundwater Management and Utilisation in the Northern Cape)

Faculty of Dentistry, University of the Western Cape
(WRC Reference No 1094)

Contributing to the poor domestic water supply and quality in the Northern Cape are high fluoride levels. This study, through systematic analysis, is investigating the impact of poor water quality, high in fluoride, and the potential for low-cost treatment.

Estimated cost: *R318 000*
Expected term: *1999 - 2001*

Impact of groundwater abstraction on ecosystems in the Kammanassie Nature Reserve and environs

Department of Applied Natural Sciences, Technikon of South Africa
(WRC Reference No 1115)

The Vermaaks River well-field established in the Kammanassie Mountain Range to the east of Oudtshoorn supplies water to the Klein Karoo rural water supply scheme. This project addresses concerns about the effects that high abstraction rates may have on the ecology of the area. This project is advancing our current understanding of the interaction between groundwater and the environment through an appropriate case study.

Estimated cost: *R200 000*
Expected term: *2000 - 2001*

Importance of groundwater in the hydrological cycle and the relationship to surface water bodies

Department of Hydrology, University of Zululand
(WRC Reference No 1168)

Understanding the processes involved in groundwater - surface water interactions is becoming increasingly more important for protecting the integrity of ecosystems. This projects aims to develop models of typical groundwater-surface processes in South Africa and also to establish compatible methods for estimating time series of surface and groundwater rates for comparative analyses.

Estimated cost: *R770 000*
Expected term: *2000 - 2002*

New

The determination of recharge and the contribution of groundwater to baseflow (Phase 1)

Environmentek, CSIR (Stellenbosch)
(WRC Reference No 1234)

The determination of groundwater recharge and the contribution of groundwater to streamflow are crucial to the implementation of resource directed measures. Implementation of these measures is a requirement of the National Water Act and in the interests of using water resources sustainably while affording them adequate protection. It is generally assumed that baseflow in surface water resources is largely derived from groundwater resources. However, the separation of the different components of the flow hydrograph is problematic and methodologies are required to determine the actual groundwater contribution to baseflow in rivers.

This study proposes to use isotopes and major ions to develop an understanding of flowpaths and the contributions of different flow paths to streamflow. Stable isotopes of water and other conservative chemicals are increasingly being used to investigate the relative sources (contributions) of water in stream discharge, determine the extent of groundwater resources and estimate residence times. Intensive sampling of rain, soil water, groundwater, baseflow and stormflow will be done. The isotopic (and chemical) signatures will be used in mixing models to resolve the size of the different fluxes. Further, the study will focus on recharge determination, through analysing the hydrograph. This study will be an additional case study to study the hydrological interaction between groundwater and surface water in a well-defined catchment.

The research aims of the study are therefore to:

- Improve process hydrological modelling in headwater catchments based on a proper understanding of flow paths, residence time and reservoir size; and
- Develop a predictive capability for aquifers of the Table Mountain Group, based on an understanding of flow

mechanisms and flow paths in headwater catchments.

Estimated cost: *R270 000*
Expected term: *2001*

Guidelines to set resource quality objectives for groundwater

Environmentek, CSIR (Stellenbosch)
(WRC Reference No 1235)

This project intends to support the implementation of the National Water Act. The setting of Resource Quality Objectives (RQOs) is an essential part of the process and also an important mechanism to protect groundwater. The "Reserve" as it is currently defined has a focus which is primarily on surface water and does not adequately protect groundwater. RQOs have a broader definition under the Act than the Reserve, and therefore have the potential to protect groundwater more effectively and extensively. The need for this project was identified at various forums, as the current WRC-funded programme on "Determining the Groundwater Component of the Reserve" does not embrace the complete suite of resource directed measures, i.e. classification, reserve setting and RQOs. This project will complement the programme and provide significant input into developing groundwater protection measures.

The project team will attempt to develop guidelines on setting RQOs for intermediate (medium term, intermediate confidence) and comprehensive (long term, high confidence) resource-directed measures. The approach will be consultative, and many key figures from DWAF, research institutions, consultancies and (proto) CMAs will be consulted. The guidelines need to be robust and applicable in a range of South African scenarios - fully covering both the biophysical and management spectra. It is envisaged that the guidelines will provide a procedural framework to select key indicators measuring the functioning of the groundwater resource.

The aims of the project are therefore:

- The establishment of guidelines on setting RQOs;
- Contribution of a representative groundwater perspective to the Resource Directed Measures Programme, particularly delineation of eco-regions, classification and monitoring requirements; and
- A worked example of setting comprehensive groundwater RQOs in a catchment.

Estimated cost: *R200 000*
Expected term: *2001*

Mapping of naturally occurring hazardous trace constituents in groundwater

Council for Geoscience
(WRC Reference No 1236)

Groundwater is normally considered a safe, viable option to untreated surface water, especially in rural areas of South Africa where funds and expertise to operate treatment facilities is limited. In some cases this can result in the supply of water of unacceptable or hazardous quality due to the presence of trace elements not detected by routine analytical procedures. Arsenic, whose origin is often geological, is an example of such an element and the cause of an environmental disaster such as is currently unfolding in West Bengal and Bangladesh.

South Africa has an "old" geology. As a result the groundwater in these formations has a large potential to assimilate trace constituents due to long residence times of groundwater. These trace constituents, which apart from arsenic, may include uranium, selenium and fluoride, may pose a health risk to the community supplied from this source.

The project will delineate potentially hazardous areas and provide decision-makers with information for planning purposes. Identification of problem areas and the awareness of risks may lead to the development of safe alternative sources and possible treatment, where no other sources are available.

The principal aims of the study will be:

- To produce a GIS map on CD-Rom informing South African experts and decision-makers of the locations of naturally occurring hazardous constituents which pose a risk to groundwater potability; and
- To identify the hydrochemical processes involving these problem constituents and the field conditions under which they remain in solution.

Estimated cost: *R190 000*
Expected term: *2001*

A strategy for future investigations of deep groundwater systems in South Africa

Directorate Geohydrology, DWAF
(WRC Reference No 1237)

Present knowledge of fractured-rock aquifers in Southern Africa is mainly restricted to the "shallow" (i.e. upper 100 m) of the earth's surface, where the ubiquitous role of erosional unloading/weathering is an important factor controlling the occurrence of groundwater. There are, however, a number of key indicators pointing to the existence of deep groundwater systems within many of these hard-rock terrains, e.g. thermal springs and artesian boreholes for example. With the shift in emphasis of groundwater resource assessment from the localised to the catchment scale, there is a need to assess the role of deep groundwater systems in the hydrological cycle.

Due to a lack of information on and the complexity of the deep groundwater flow system, as well as the requirement of a multidisciplinary approach, a strategy for conducting such research has to be formulated as a prerequisite to detailed investigations.

The results of this research will provide guidelines to the groundwater community in terms of the conceptualisation, exploration and development of deep aquifer systems, and will also identify key areas for future research.

The aims of the project are to:

- Develop a conceptual framework for assessing the significance of deep groundwater systems; and
- Increase the level of awareness and understanding of deep groundwater systems in South Africa.

Estimated cost: *R195 000*
Expected term: *2001 - 2002*

Hydrogeology of fractured aquifers and related ecosystems within dolerite ring-and-sill systems of the Eastern Cape

Council for Geoscience
(WRC Reference No 1238)

Dolerite rings and sills control most of the second-order geomorphological features and drainage systems of the Main Karoo Basin. They also control, together with dolerite dykes, the springs and seepages of the Karoo basin. On a regional scale, these features display a great degree of variability in size, geometry, shape, level of stratigraphic emplacement and structural complexity. They form an important part of the structural framework of the Karoo Basin, and outcrop over an area approximately half of South Africa.

This proposal is a follow-up submission to a project that has recently been completed. The results are promising, indicating that ring structures are potentially excellent targets for groundwater, provided that the associated hydrogeological domains are well understood. This proposal will investigate the ring structures in the Eastern Karoo in the vicinity of Queenstown and King William's Town.

The aims of the project are:

- To assess the occurrence of groundwater associated with the dolerite rings and sills in the Eastern Cape area, i.e. Queenstown and King William's Town I/250 000 sheets, using:
- Morphological and tectonic 3D analysis
  - Drainage systems
  - Detailed investigation of the dolerite ring structures on a local scale for explorative drilling and selection of springs for detailed studies of their ecosystems; and
- To define hydrogeological domains and the effects on ecosystems, spring recharge and water quality:
  - By compiling ecosystem maps from available data and remote sensing on a regional scale
  - By completing specific fieldwork on a detailed study area
  - By selecting a specific spring for a detailed study parallel to the drilling programme.

Estimated cost: *R485 000*
Expected term: *2001 - 2003*

Deep artesian groundwater exploration for Oudtshoorn (Dageos) municipal supply

Umvoto Africa (Pty) Ltd
(WRC Reference No 1254)

The thick orthoquartzitic sandstone formations of the Table Mountain Group (TMG) in South Africa constitute a significant aquifer (aquifer volume of at least 200 000 km^3). Aquifer permeability is due to a pervasive set of fractures, including bedding-parallel and bedding-normal fractures, as well as jointing and faulting at various scales.

Traditionally boreholes have been drilled to maximum depths in the range of 90 to 150 m. Over the past few years, limited deep drilling below 150 m has resulted in boreholes yielding >32ℓ/s. This implies a deep circulation of groundwater within the TMG fractured-rock aquifer.

This study will use a multidisciplinary approach (remote sensing and geophysics and structural geology) for optimal site selection. This will be followed by groundwater verification of selected targets and finally deep drilling and pump-testing. The wells will be utilised by Oudtshoorn Municipality.

The aims of the project are:

- To explore and quantify the deep artesian groundwater resource potential in confined fractured-rock aquifers of the Table Mountain Group (TMG) within a water-stressed catchment through the integrated application and further enhancement of structural-geological and remote-sensing/ geophysical methods;
- To develop and prove the technical capacity for drilling deep (>350 to 400 m) wells at selected sites of potentially high water resource yield (>35 ℓ/s);
- To complete and pump-test at optimum yield an experimental deep groundwater well at two or more target sites for the purpose of constraining the aquifer parameters (e.g. permeability and storativity) and proving a sustainable and environmentally acceptable augmentation of the Oudtshoorn municipal water supply; and
- To develop and implement modern methods of technical and financial risk assessment as a scientific-technical guide and decision-making tool, and to determine the overall project financial risk.

Estimated cost: *R550 000*
Expected term: *2001 - 2002*

Groundwater in the Olifants River basin: Assessing viable alternatives for small-scale irrigation

University of Venda (School of Environmental Sciences)
(WRC Reference No 1278)

The development of viable small-scale farming operations is considered a means to alleviate poverty and contribute to sustainable rural livelihoods (rather than the focus only on subsistence production). The government's objectives in the agricultural sector are to:

- Make the sector more efficient and internationally competitive;
- Support the production and stimulate an increase in the number of new small-scale and medium-scale farmers; and
- Conserve agricultural natural resources.

This proposal focuses on the second objective and aims to explore the potential and sustainability of small-scale irrigation using groundwater in the Olifants River basin. Groundwater presents a cost-effective means of implementing small-scale irrigation systems. However, to use the resource in an efficient and effective manner requires:

- Quantification of available groundwater and more realistic recharge estimations;
- Quantification of the demand of water by smallholder agriculture from groundwater and the assessment of the impact of such abstraction on overall water resources in the basin;
- Development and application of conceptual recharge-runoff models for the typical aquifers in the basin; and
- Development of abstraction baseflow rate relationships in order to establish impact of groundwater development and use for small-scale irrigation, and assess sustainability.

The aims of the research project are as follows:

- To explore the potential and sustainability of small-scale irrigation

using groundwater in the Olifants River basin; and
- To develop decision support tools, including guidelines, for sustainable use of groundwater for small-scale irrigation, and for policy makers, which address the problems and needs of smallholders.

Estimated cost: *R420 000*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

Understanding of the environmental functions of groundwater is increasingly improved through involvement of projects supporting mainly the implementation of the National Water Act. By addressing the following issues a new body of knowledge in connection with the integration of groundwater in the broader water management framework is being created:

- Development of integrated classification systems to protect water resources by linking delineated hydrogeological systems with eco-region classification systems;
- Approaches to establish reference conditions (conditions prior to impact) in order to determine management protection classes as required by the National Water Act;
- Approaches to identify and map groundwater-dependent ecosystems in South Africa;
- Understanding groundwater/surface water linkages; and
- Establishing appropriate RQOs and adequate monitoring systems, addressing ecosystem and groundwater resource integrity.

New knowledge created in assessing fractured-rock aquifers is steadily growing. This includes the improvement of conceptual understanding of groundwater occurrence in fractured rock aquifers, i.e. greater validity of theoretical assumptions and sounder data interpretation techniques (pump- testing and modelling).

Knowledge concerning application of artificial recharge in fractured rock aquifers has been acquired through pilot-case studies that the WRC has funded, most notably in Windhoek. A full-scale artificial recharge system will be developed by the city in the next few years, thereby creating security of water supply, especially during drought conditions. Knowledge on how to integrate techniques such as geophysics, remote sensing, GIS and structural geology has resulted in significant successes in targeting groundwater in what have traditionally been considered low-yielding aquifers. The integration of existing structural and hydrogeological knowledge base and petroleum technologies offers further exciting opportunities for assessment of fractured rock aquifers.

A WRC project on nitrates has further demonstrated the dangers that may exist as a result of ingesting water that contains high nitrate concentrations. This may now include the spontaneous abortion of foetuses.

Benefits to South Africa

Benefits accruing from projects in this field include:

- Enhanced capacity to implement national legislation, e.g. groundwater resource-directed measures;
- Better understanding of environmental impacts (or non-impacts) associated with groundwater abstraction in sensitive areas;
- Enhanced supplies to large towns as well as to rural communities through the application of artificial recharge techniques; and
- Establishment of methodologies to cost-effectively locate groundwater resources in traditionally low-yielding aquifers.

Innovation/application of knowledge

Knowledge generated through current programmes and projects is already being or will be applied in the following ways:

- The methodologies developed to support the implementation of the National Water Act are in the process of being used to set resource-directed measures in priority catchments.
- As a result of the pilot studies performed in Windhoek a fully commissioned artificial scheme will be operationalised in the next few years.
- A soon-to-be-published guideline document on pumping test methods in fractured-rock aquifers will assist practitioners in sustainable groundwater utilisation.

Capacity/competence building

Department of Water Affairs and Forestry
The following approaches (or strategies) for achieving capacity development objectives in the groundwater research field were utilised:

- The identification of "talented" designated persons located at various institutions (e.g. science councils) and providing research opportunities through mentorship.
- The fostering of groundwater (and related) research capabilities at universities and technikons.
- The formation of partnerships between institutions and individuals.
- Advocating research opportunities to Black-owned SMMEs.

Outcomes of these strategies within the context of the groundwater research programmes are as follows:

A number of projects have capacity development outputs, through the involvement of "young" designated (gender considerations included) researchers in the project teams. A number of senior hydrogeologists will be due for retirement in the foreseeable future. Currently there is not an adequate resource base to replace these competencies. This resource base needs to be built through the development of high-level capabilities.

There are currently three Black universities (Universities of Venda (UNIVEN), Western (UWC) Cape and Zululand (UZ)) involved in groundwater education and research. Technikon SA is involved through research on determining the ecological impact of groundwater abstraction. The focus of most of the programmes at these institutions is on the training and development of designated persons. The WRC, through research funding, has contributed to development of both human resources and much needed infrastructure at these institutions. The outcome of this process is that UWC in the groundwater field is no more regarded as a capacity-building centre but as an institution

with the capabilities to assist with capacity-building initiatives in the country. As a result of similar initiatives at the Universities of Venda and Zululand, the post-graduate students in the groundwater field for 2001 at these specific institutions (UWC, UNIVEN and UZ) are:

5 Ph.D. students
9 M.Sc. students
16 Honours students

Most of the Black scientists currently employed in the groundwater sector graduated from these institutions. Too often, government officials and the established consulting companies equate experience as a prerequisite for success in terms of building capacity. The Black institutions are not seen as vehicles for capacity development, and resources are directed towards traditional institutions. At the WRC we as yet have not made this paradigm shift. The above statistics clearly indicate that capacity-building of designated persons predominantly occurs within the specific institutions mentioned above, despite limited resources.
In the groundwater field partnerships have been created between organisations such as UWC, UFS, CSIR, University of Venda and the International Water Management Institute (IWMI). This strategy has not been broadened sufficiently to be effective at this stage.

Knowledge dissemination

Dissemination of knowledge from this field is summarised as follows:

Articles and papers	69
Theses	2
Courses/workshops/demonstrations	3

Leveraging of resources

Outside contributions to research projects are mainly of an in-kind nature. For example, in certain projects DWAF provides drilling support which can amount to a substantial benefit if converted to monetary inputs. This also applies to municipalities such as Windhoek and Calvinia. In a number of projects the NRF has made significant contributions in terms of student support.

Direct financial contributions have been made to the following projects:

R900 000	DACST (**Nitrate and associated groundwater hazard quantification and strategies for protecting rural water supplies**)
R2 000 000	DBSA (**Deep artesian groundwater exploration for Oudtshoorn municipal supply**)
R140 000	DWAF (**to a consultancy on Institutional Arrangements for Groundwater Management in Dolomitic Terrains**)

International linkages

Groundwater research programmes and projects have developed strong linkages to the following international research institutions, which have made considerable indirect contributions to the research.

- CSIRO, Australia
- ITC, Netherlands
- IAEA, Austria
- University of Missouri, USA.

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Chapter 10

Agricultural Water Management

Dr GR Backeberg

Scope

Utilisation and development of water resources in agriculture must be analysed in relation to the needs of people. People involved with water management in agriculture comprise a diverse group of subsistence, emerging and commercial farmers, and permanent and seasonal labourers, with their dependants. All these water users are the clients or target groups of the research output. According to the Strategic Research Plan for ***Agricultural Water Management***, the point of departure of applied research is the real-life problems experienced by water users for irrigated and rain-fed crop production as well as livestock watering. The problems which may be experienced in practice for any aspect of water management on the farm, irrigation scheme or river catchment vary from non-existence of knowledge, doubt regarding the applicability of existing knowledge, deviation of empirical observations from some relevant theoretical optimum, to an unclear outcome of possible alternative directions of decisions and actions.

Research as a problem-solving process must provide information and technologies and models, which can be applied by water users. The overall objectives are to utilise scarce water resources efficiently and beneficially, to increase household food security and farming profitability, and thereby increase economic and social welfare, i.e. efficient growth and equitable distribution of wealth on a farming, local community and regional level. These objectives must be achieved through creation of knowledge by means of research and transfer of technology, training and extension. Traditionally contributions are made by scientists in applied disciplines or focus areas of soils, crops, engineering, climatology, economics and sociology. Increasingly, however, the complexity of the information needs of water users requires a multidisciplinary or interdisciplinary research effort. In all instances the priorities are enhancement of management abilities in order to improve the efficiency of water utilisation for food and fibre production.

In terms of the percentage of WRC research funds allocated to this field, funding has remained relatively stable at between 8.4 and 9.5%, as shown in Table 1.

Links to Key Strategic Areas

The current research field on ***Agricultural Water Management*** has direct and indirect links with two new KSAs:

Water Utilisation in Agriculture

All current programmes and projects in the field of ***Agricultural Water Management*** will be incorporated in this KSA.

TABLE 1
Investment in **Agricultural Water Management**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 599 400	R4 058 152	R5 012 129	R5 779 100	R5 240 180
% of research fund	8.90%	9.1%	9.46%	9.31%	8.9%

Water-Linked Ecosystems

Links exist with this KSA, since water use for agricultural production has an impact on the natural environment and precautions have to be taken to prevent ecosystem degradation.

Objectives

Primary

To increase household food security, farming profitability, efficient growth and equitable distribution of wealth on a farming, community and regional level through efficient and sustainable utilisation and development of water resources.

Secondary

- To increase biological, technical and economic efficiency of water use;
- To alleviate and reduce poverty amongst rural people through water-based agricultural activities;
- To protect and reclaim water resources; and
- To refine methodologies and improve the database in respect of climatic, soil, crop, engineering and financial parameters.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

Assessing the impacts of varying rainfall conditions on vegetation dynamics, production and certain hydrological properties of natural grassland, using a system modelling approach

Department of Plant and Soil Sciences, Potchefstroom University for CHE
(WRC Reference No 372)

This project aimed to synthesise grassland ecosystem dynamics information into systems models which could be used to predict the likely impact of an altered rainfall regime (as might be expected from operational cloud seeding or global climate change) on the species composition and production of natural grassland. Software previously developed by the research team was shown to be useful in describing species behaviour and composition along a grassland degradation gradient associated with different veld management and utilisation practices. By comparing species compositions at comparable locations along such degradation gradients in different rainfall regimes, the long-term rainfall impact on species composition could be ascertained. Unfortunately, the assessment of biomass production using available agrohydrological models was not successful, which meant that the combined impact of rainfall on grassland composition and production could not be satisfactorily simulated.

Cost: *R496 700*
Term: *1991 - 2001*

Computerised weather-based irrigation water management system

Department of Agrometeorology, University of the Free State
(WRC Reference No 581)

The overall aims of this research project were the design, development and establishment of an effective automatic weather station (AWS) network and computerised irrigation decision support system (IDSS). Essentially this entailed establishing a computer-aided system for the provision of information upon which to base decisions related to irrigation planning, scheduling and water distribution management.

It was shown that efficient scheduling of irrigation can be achieved using the Putu-IDSS based upon automatic weather station data and crop growth models. Water-efficient irrigation scheduling advice was transmitted from central computing centres linked by telecommunication network to distant AWSs and farm managers located in other provinces and countries.

Automatic weather stations were connected in a computerised network. Weather data were collected and used in mathematical models to compute crop water-use and recommended irrigation amounts. This information was then disseminated in sufficient time to allow irrigators to act before crop water stress was induced, with concomitant yield reductions.

The technology devised, is suited to extensive commercial as well as low-input small-scale operations and the major advantage of the system stems from the use of data from a single weather station and its application to numerous neighbouring farms. This has significant cost and logistic benefits.

The installation and maintenance of AWSs were investigated and applied. The most necessary precautions are detailed in the report. While Putu-IDSS does advocate a standardised format for information dissemination, this was, however, not always found to be desirable, because of varying client facilities and requirements. Radio, short-haul modem, direct cable and telephonic links all proved successful for the exchange of data and timing of recommendations.

Cost: *R810 000*
Term: *1993 - 1996*

Optimal management of uncertain water availability at farm and regional level with due allowance for risk and the environment

Department of Agricultural Economics, University of the Free State
(WRC Reference No 645)

The research was done in the catchment area of the Little Tugela River near Winterton which comprises a total of almost 7 000 ha irrigation land of some 100 land owners.

The following objectives were achieved:

- The impact of irrigation agriculture on the environment was demonstrated by developing procedures that can calculate the economic cost for irrigation farming if water is allocated away from irrigation agriculture for the conservation of biodiversity of river ecosystems.
- The environment was fully taken into account by means of certain safety boundaries, which guarantee that the instream flow requirement (IFR) will be maintained.
- An important contribution was made by the development of the **C**hance **C**onstrained **O**ptimising **D**eficit **I**rrigation (CCODI) model, which can be used to economically evaluate alternative water management strategies and to indicate the impact thereof on the environment via the change in return-flow.
- The impact of alternative water management strategies at regional level was also evaluated by developing a mixed integer non-linear optimising model that optimises the effect of water transfers taking into account the interaction between catchment areas.

The research results not only showed that the developed procedures are suitable to analyse the effect of uncertain water availability on the economic efficiency of irrigation farming taking into account risk, the environment and possible negative externalities, but the results also contain important policy implications:

- A water conservation policy with the aim of increasing water application efficiency can only create the illusion that water is being conserved as an increase in water application efficiency, although being economically advantageous, can detrimentally affect streamflow by decreased return-flow.
- Deficit irrigation would only conserve water if irrigation farmers were not able to irrigate larger areas with conserved water.
- The detrimental negative externalities of water transfers can be decreased by basing the tradable rights on actual water usage.

It is concluded that the best approach for the optimal management of water resources at catchment level is the interactive use of an agrohydrological model such as ACRU, a whole-farm simulation model such as FARMS, and economic optimising models such as CCODI to take into account the interaction between alternative water management strategies on farms, water policy administration, water legislation and hydrology. It can be stated that more reliable and realistic feasibility studies of irrigation farming will be possible in future by means of the models, procedures and instruments which were developed.

Cost: *R1 765 415*
Term: *1998 - 2001*

Maximisation of economic water-use efficiency of processing tomatoes

Department of Plant Production, University of Pretoria
(WRC Reference No 646)

It is clear from numerous reports that irrigation management is the most important factor contributing towards economic optimisation of processing tomato production. The most crucial decision about irrigation management for processing tomatoes is to decide on when and to what extent irrigation should be reduced in order to apply the right amount of stress. This "right" amount of stress is not only a function of the physical situation, but is determined to a great extent by the economic situation as far as expected costs and benefits are concerned. In order to optimise economic water use efficiency for the processing tomato industry, the total cost of the whole process (production as well as processing) should be minimised.

A modelling approach seemed to be the only practical way of integrating all the different variables into a single decision-making process. Therefore, in order to facilitate this integration, a management tool in the form of a computer program was developed. The TOM-MAN program integrates the TOMYIELD crop growth model, which is based on SWB and an economic optimisation model, TOM-ECON, which was developed during this project.

The function of TOM-ECON is to establish the optimum irrigation strategy for processing tomatoes for application by TOM-MAN during routine scheduling. The user can define a set of potential irrigation strategies in terms of the allowable depletion levels of soil water during the different growth stages of the tomato crop. For each of these strategies a simulation of required irrigation and the resulting yield and quality are simulated by TOM-MAN.

Cost: *R440 000*
Term: *1994 - 1995*

Establishing effects of saline irrigation water and managerial options on soil properties and plant performance

Department of Soil and Agricultural Water Science, University of Stellenbosch
(WRC Reference No 695)

This project was undertaken against the background of deteriorating irrigation water quality in the Breede River, with the broad objective to quantify the effect this deterioration would have on grape yield and quality. It followed on a previous study where the effects of moderate salinity treatments were not yet sufficiently consistent to permit salinity tolerance criteria to be firmly established. Trends indicated that it would take a few more seasons for the full treatment effects to be revealed. It emerged from the newer results that, irrespective of whether the inhibitory effect of the saline irrigation treatments on yield is an osmotic one, a toxic one (Na and/or Cl), or both, the yield threshold level remains the same over a number of seasons of irrigation, but that the sensitivity of the crop to levels beyond the threshold, increases with the number of seasons of exposure. This result may have very important management implications because it suggests that even moderately acceptable water by current standards may, in the longer term and not necessarily because of soil deterioration, have a cumulative, debilitating effect, leading to premature failure of the vineyard. All of the wines produced from the experimental vineyards lacked the typical character of the cultivar, while those made from the most saline treatment, were judged to have a salty taste.

Cost: *R837 158*
Term: *1995 - 1998*

A quantitative evaluation of the hydraulic properties of stony soils by means of laboratory simulations

Department of Plant and Soil Science, Potchefstroom University for CHE
(WRC Reference No 725)

The hydraulic conductivity of the soil used in this investigation, decreased with increasing stone contents until it reached a specific threshold stone content and then increased for higher stone contents due to the formation of preferential flow paths around the stones. Because of the limited number of tests (21) of this study, the stone contents where preferential flow started to become important was ill-defined (between 40 and 70%). Therefore it was suggested that the threshold value can be taken at a stone content of about 50%.

The water retention of the experimental soil decreased with an increase in stone content. The pore sizes did not decrease proportionally with the stone content, in fact the ratio between large and small pores actually increased with stone content. The relatively good hydraulic conductivity of stony soils compared to their low porosity can be attributed to a higher percentage of large pores. However, the absence of small pores, especially in the range 10µm to 0.6µm, reduces the water-holding capacity of stony soils.

The soil matrix used in this study had a strong crusting tendency and surface crusting largely controlled the infiltration rate. For any given stone content crusting was prevented at slope angles steeper than 25°, through the combined effect of less effective rainfall and the dissipation of raindrop energy by the stones. For a constant slope angle (10°) the infiltration rate decreased rapidly for stone contents higher than 30% by volume.

This study once again confirmed that stones have an ambivalent effect on runoff generation. Stones promote runoff by concentrating rainwater or reducing the infiltration of the soil but it can also dissipate raindrop energy and thereby protecting the soil from forming crusts. The major effect of stones was the reduction of infiltration and thereby increasing runoff. Stones can play a role in erosion control but the decision to use stones or not should be based on other factors as well.

Cost: *R85 700*
Term: *1995 - 1999*

Extension to and further refinement of a water quality guideline index system for livestock watering

Department of Animal and Wildlife Sciences, University of Pretoria
(WRC Reference No 857)

This project dealt with water quality requirements for animal production and set out to incorporate two new models into the original water quality guideline index system developed previously through WRC research support. The software program, CIRRA (Constituent Ingestion Rate Risk Assessment) was updated to include four facets, i.e.:

- Rural communal livestock production systems;
- Wildlife production systems;
- Poultry production systems; and
- Ostrich production in the Oudtshoorn district.

As a result, knowledge was generated pertaining to the above production systems to alleviate water quality induced trace element imbalances, deficiencies and toxicity. Solutions were developed by linking water palatability, design and placement of watering points to the supplementation of licks.

Cost: *R1 199 920*
Term: *1997 - 1999*

Two-dimensional water balance and energy interception model for fruit trees

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 945)

Two types of model, both predicting crop water requirements on a daily time step, were developed for hedgerow tree crops. These models were incorporated into the Soil Water Balance (SWB) model. The models are:

- A mechanistic two-dimensional energy interception and finite difference, Richards' equation based soil water balance model; and
- An FAO-based crop factor model, with a quasi 2-D cascading soil water balance model.

The two-dimensional model for hedgerow crops calculates the two-dimensional energy interception, based on solar and row orientation, tree size and shape as well as leaf area density. Inputs required to run the two-dimensional canopy interception model are: day of year, latitude, standard median, longitude, daily solar radiation, row width and orientation, canopy height and width, skirting height and width, extinction coefficient, absorptivity and leaf area density.

For the two-dimensional soil water balance model, the input required included starting and planting dates, altitude, rainfall and irrigation water amounts, as well as maximum and minimum daily temperature.

To run the FAO-type crop factor model, the required input included planting date, latitude, altitude, maximum and minimum daily air temperatures, FAO crop factors and duration of crop stages.

The two-dimensional SWB model evaluation consisted of checking internal consistency and units used, comparison of model output with independent data sets of real life observations and sensitivity analysis. Inspection of the qualitative behaviour of the model and its implementation was done by checking whether the response of the model output to changing values of a parameter conforms to theoretical insights.

There was good agreement between predicted and measured daily soil water deficit for water-stressed and non-stressed treatments. Field measurements indicated that in hedgerow plantations the whole area across the row must be borne in mind when assessing soil water content. The reason for this is the effect of irrigation distribution and rain interception by the canopy, the variation in radiation interception by the canopy across the row, the irradiance reaching the soil surface as the season progresses, the presence of a grass sod or bare soil in the inter-row region and the root density across the row. It was found that there are significant amounts of roots in the inter-row region and thus this portion of the rooting volume must not be ignored when assessing the water balance.

A linear correlation between accumulated energy interception and daily evaporation was found for the first two days. After two

days, the correlation was lost - indicating that evaporation began to be limited by soil water supply and was no longer directly correlated to energy interception.

The contribution to crop water uptake from the inter-row volume of soil can be high, particularly under high atmospheric evaporative demand, and thus needs to be accounted for in irrigation management in order to maximise rainfall use efficiency.

Cost: *R827 000*
Term: *1998 - 2001*

Current

Water-use efficiency of cultivated subtropical forage and pasture crops

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 573)

The primary aim of the project is to develop irrigation standards for cultivated subtropical forage and pasture crops as well as to develop concomitant water production functions. The results emerging from this project, together with those of a completed project on temperate forage and pasture species, will lead to the establishment of scientific irrigation standards for the entire forage and pasture crop spectrum.

Estimated cost: *R677 600*
Expected term: *1994 - 2001*

Effect of the introduction of agroforestry species on the soil moisture regime of traditional cropping systems in rural areas

Environmentek, CSIR
(WRC Reference No 780)

The majority of farmers in SA still practise mixed farming. Usually, cattle are used for land preparation in spring, while stover is used for fodder in winter. While crops are growing in summer, rainfall becomes a major source to satisfy crop water needs. In winter, however, fodder becomes limited. As such, livestock does not get enough fodder. This necessitates the supplementation of fodder sources through the introduction of forestry species. Such species, on the other hand, will compete with crops for rainwater. This requires some balance - whereby introduction of forestry species serves its purpose (as fodder supplement) without negatively impacting on crop water availability. This project aims to develop agroforestry systems and management practices that minimise competition for water between trees and crops. It will also determine the comparative water use of multi-purpose trees in agroforestry systems in the Upper Thukela region (KZN) for making recommendations on appropriate species.

Estimated cost: *R363 000*
Expected term: *1997 - 2001*

Quantification of the water balance on rehabilitated mine soils under rain-fed pastures on the Highveld of Mpumalanga

ISCW, ARC
(WRC Reference No 798)

Water which infiltrates through the surface of land which has been rehabilitated following opencast mining, artificially recharges the groundwater storage compartment which was created when coal was extracted. This water mostly becomes acid and/or saline as a result of the oxidation of pyrite present in the backfilled waste material. Depending on the seepage rate, it may take decades before the groundwater compartment fills up and the polluted water starts to decant into surface streams. One of the big uncertainties from a water quality management perspective is how much of rainfall infiltrates to recharge the groundwater compartment, and thus how soon the compartment will fill up and start decanting. This project is to determine the water balance of rehabilitated land under pasture at three sites over three growing seasons, and use the results to calibrate an existing mathematical model, which can be used to make long-term water balance predictions.

Estimated cost: *R363 000*
Expected term: *1997 - 2002*

Use of triploid grass carp for the biological control of excessive growth of water weeds in irrigation schemes

Department of Zoology, Rand Afrikaans University
(WRC Reference No 816)

This is one of a suite of projects focusing on the control of filamentous algae in canals. In this project, the ability of triploid (sterile) Chinese grass carp to control the growth of filamentous algae is being investigated and if cost-effective, recommendations will be made on their use in this situation.

Estimated cost: *R371 000*
Expected term: *1997 - 2001*

Influence of irrigation with gypsiferous mine water on soil properties and drainage water in Mpumalanga

(Chamber of Mines)
(WRC Reference No 858)

Huge quantities of acid mine drainage are presently being produced as a result of mining activities. These waters are mostly neutralised, either inadvertently, as a result of seepage through neutralising geological strata, or artificially, by the addition of lime. Mine drainage is, therefore, often saturated with gypsum. When released into the surface water environment, their high salinities are frequently responsible for unacceptable water quality degradation. On the other hand, irrigation provides for a novel approach to the utilisation and disposal of gypsum-rich water as demonstrated in a recently completed WRC project. Irrigation of neutralised acid mine water holds promise to significantly reduce the salt load emanating from mine drainage while at the same time extracting value from a water which would otherwise be a polluting agent. This project aims to ascertain on a semi-operational scale whether gypsiferous mine water can be used on a sustainable basis for the irrigation of crops and/or the amelioration of acidic soils.

Expected cost: *R1 307 000*
Estimated term: *1997 - 2001*

The evaluation of a model for water use in deciduous fruit orchards and scheduling of irrigation with the aid of meteorological data

Infruitec, ARC
(WRC Reference No 892)

In this project a mathematical model is being developed in order to predict water use by deciduous fruit trees with the help of

meteorological data. The model will also be integrated with other existing models in a GIS-based farm-management system. Ultimately, the model will serve as guide for irrigation scheduling of deciduous fruit trees. The deciduous fruit industry contributes immensely to the GDP of SA - and improved water use within the industry will enhance economic growth.

Expected cost: *R371 000*
Estimated term: *1998 - 2001*

Implementation of the FARMS (firm-level agricultural risk management simulator) system for management decision-making in irrigated farming

Department of Agricultural Economics, University of the Free State
(WRC Reference No 894)

Procedures and methods have been developed for economic evaluation of irrigation scheduling strategies, analysis of the cost of irrigation equipment, and assessment of the business and financial risks on a whole-farming level. Successful implementation of the above-mentioned models in practice mainly depends on linking of various submodels to provide decision support for management of the farming business unit. The modelling system must be flexible and make provision for evaluation of various management alternatives. The main aim of this research project is to integrate available computerised tools into a modelling system in support of irrigation management on a farm level. This project on the FARMS modelling system was undertaken simultaneously with the project on the integrated information system (No 946), mentioned below.

Expected cost: *R358 000*
Estimated term: *1998 - 2001*

An investigation into the use of pathogenic organisms for the biological control of the troublesome alga Cladophora glomerata

PPRI, ARC
(WRC Reference No 918)

The efficacy of organisms selected during the previous project was tested under laboratory conditions, and the host range of the selected organisms was tested. No field trials or mass production of spores was undertaken as none of the organisms isolated were sufficiently highly pathogenic to warrant this.

Two groups of pathogenic fungi were commonly found in the canals. One of these, the Chytridiomycete, are known to be obligate pathogens which are currently impossible to culture *in vitro*. This means that it is currently not possible to produce fungal biocontrol formulations using chytrids. As a result, work on the chytrids was taken no further. The other group, genus *Pythium*, was studied. Some *Pythium* species are known to be pathogenic on other algae, and the previous project indicated that some of the *Pythium* isolates were pathogenic on *Cladophora*.

Environmental conditions (temperature, pH and copper) affecting growth and zoospore production by *Pythium* isolates, and factors influencing the integration of the use of *Pythium* with other existing or potential control methods were also investigated. Preliminary studies on the use of *Acacia mearnsii* (black wattle) bark for the control of algal growth were also carried out.

The pathogenicity of the 15 *Pythium* isolates showing potential pathogenicity to *Cladophora* was tested on a range of crop plants. Blue lupin, normally very susceptible to *Pythium*, showed little effect. Three isolates were pathogenic to maize, wheat, tomato, brinjal, pepper and cabbage seedlings, but not to blue lupin, sunflower or lettuce seedlings. Otherwise, pathogenicity was absent or slight.

Expected cost: *R279 400*
Estimated term: *1998 - 2001*

The selection for drought tolerance in the germplasm of Vigna unguiculata (cowpea), Vigna subterranea (bambara groundnut) and Amaranthus spp. (marog)

VOPI, ARC
(WRC Reference No 944)

Food security at household level is one of the primary goals of the government. Other than staple food (maize), a number of other summer crops are used by the rural poor as a supplement. Most of these crops have become a way of life for such communities. However, water stress has a severe effect on the production of such crops. This project focuses on the selection of cowpea, marog and bambara for drought tolerance, particularly for dryland production. This means that drought-tolerant lines are screened and propagated, thus ensuring production (yield) even under adverse water supply conditions

Estimated cost: R735 000
Expected term: 1998 - 2002

Development of an integrated information system using the WAS, SWB and FARMS computer models

NB Systems
(WRC Reference No 946)

Based on two completed and one ongoing research project funded by the WRC in the past, the water administration system (WAS), soil water balance (SWB) and firm-level agricultural risk management simulator (FARMS) computerised models have been developed. This project combines these tools to be used for integrated water management, creates a uniform database and links crop and whole-farming models on the demand side with canal flow models on the supply side. The aim of this project is to develop an integrated information system to efficiently manage irrigation water use on a field, farm and scheme level. The geographic information system is implemented on a computer network for irrigation schemes where it can be used by different stakeholders to capture data, generate reports, calculate water releases, advise farmers on irrigation scheduling and efficient water use for irrigation.

Expected cost: *R636 000*
Estimated term: *1998 - 2001*

Economic impact of changing water quality on irrigation farming in the Lower Vaal River

Department of Agricultural Economics, University of the Free State
(WRC Reference No 947)

The causes and consequences of deteriorating water quality can be managed by adapting on-farm production practices and by introducing policy instruments such as pollution charges. In this project an analysis is done to determine the short-term economic viability of irrigation farming under conditions of variable water quality. It investigates whether benefits can be generated which at least cover private costs

and internalised external costs. Models are being developed and applied to determine the financial and economic viability of irrigation farming with reference to the Lower Vaal River area.

Expected cost: *R417 000*
Estimated term: *1998 - 2001*

The economic efficiency of irrigation systems for large- and small-scale farming enterprises

Department of Agricultural Economics, University of the Free State
(WRC Reference No 974)

With the implementation of the new land and water reform initiatives, the need for financial analyses with regard to the viability of irrigation on small-scale farms has become very important. The economic analysis of small-farm irrigation is also a logical continuation of completed WRC projects on the technical aspects of irrigation. The objectives of the project are, *inter alia* a critical analysis of irrigation systems and methods in relation to each other and in terms of efficiency of water use and energy use, as well as economic and financial feasibility. Guidelines will be formulated on how to economically compare different irrigation systems to make correct investment decisions.

Expected cost: *R750 000*
Estimated term: *1998 - 2001*

An investigation into the factors affecting the performance of drip irrigation systems in South Africa

IAE, ARC
(WRC Reference No 1036)

Drip irrigation is arguably the most efficient system available to irrigators at present. As a result, various suppliers of irrigation equipment have targeted the irrigation sector - and have a wide range of specifications and performances for their products - sometimes making it difficult to choose. Technical guidance, as a result, is needed. Such guidance, however, has to be based on unbiased research, which this project undertakes, in order to provide guidance for future introduction of new and better products.

Expected cost: *R459 000*
Estimated term: *1999 - 2001*

Quantification of the water use of four tree crops in the Lowveld of Mpumalanga

ITSC, ARC
(WRC Reference No 1046)

Various fruit tree species (high value crops) have different water needs. These needs also change with growth stages - and are subject to climatic and edaphic factors. Where water becomes limiting, a decision tool becomes paramount so that farmers can decide beforehand what crops to produce (based on the efficiency of water use and economic benefits). Such a tool will also enable authorities to plan future development/ expansions better, based on sound water budgeting. The aim of this research is to provide information on plant water use at various stages of growth. Water use by mango, avocado, litchi and macadamia nuts will be measured. Trees between one and twenty years old will be used. This information will be used to develop guidelines for water budgeting within the fruit industry.

Expected cost: *R459 000*
Estimated term: *1999 - 2003*

Water use efficiency of multicrop agroforestry systems, with particular reference to small-scale farmers in semi-arid areas

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 1047)

Multicroping is common among small-holder farmers. In most cases field crops are grown around fruit trees. In some cases, fodder is also planted along contours, then used as animal feed or windbreaks instead of fruit trees. Limited information is available about competition for water that takes place among crops. Although benefits of multicropping are obvious, yield reduction, particularly of poor competitors or drought-sensitive crops, may occur. Since farmers usually grow intercrops on the headlands or contour-lines, there is a need for understanding the optimum distances between the various crops. The hydraulic conductivity of the soil, the water content, and the root distribution of different crops influence their performance. This project evaluates locally adapted crops that may be incorporated into an agroforestry system, with emphasis on water requirements. This information will be used to develop a model that would predict the productivity and water-use efficiency of different agroforestry systems.

Expected cost: *R1 001 000*
Estimated term: *1999 - 2003*

An analysis of the social, economic and environmental direct and indirect costs and benefits of water use in the irrigated agriculture and forestry sectors

Environmentek, CSIR
(WRC Reference No 1048)

The concept of "best possible use" of water involves more than productive use of water since it explicitly provides for weighing up of social, economic, and environmental objectives to promote equity, efficiency and sustainability. It is important to quantify direct and indirect benefits and costs to allow a fair comparison of water use between water-use sectors. It is also necessary to determine backward and forward linkages in the economic activity of different water users within and outside the boundaries of catchment areas. The findings will therefore provide decision support for private and public management of water allocation within river catchments.

Expected cost: *R558 000*
Estimated term: *1999 - 2001*

Application of rainfall intensity-runoff relationships to water harvesting from micro-catchments to stabilise food production in rural and peri-urban settlements

Department of Agrometeorology, University of the Free State
(WRC Reference No 1049)

The low and erratic rainfall in South Africa contributes to limited cultivation of a number of food crops. Stormwater and runoff, however, can be used for crop production if harvested. This water can be channelled to adjacent high-potential land for beneficial use. Runoff and rainfall intensity data and their relationships

are not readily available. The beneficial manipulation of runoff is fundamental to the success of water-harvesting techniques, and rainfall intensity data are a major factor in this respect. The project aims to generate and analyse rainfall intensity and runoff data - in order to conduct a risk analysis for water harvesting techniques. Existing climate-crop models will also be incorporated in the analysis.

Expected cost: *R521 000*
Estimated term: *1999 - 2001*

Sustainable local management of smallholder irrigation

Faculty of Agriculture, University of the North
(WRC Reference No 1050)

Most "upliftment" irrigation schemes in South Africa are not viable. A few schemes that are in operation are under-performing. There are a number of reasons for this. The main reason, however, is that beneficiaries have never been involved in the management of the schemes. It is only recently that the government and other stakeholders realised a need to hand management over to the beneficiaries. In this way, the end-users will be responsible and accountable. However, other technical and social problems need to be identified and addressed. Once this happens, the potential of the smallholder irrigation schemes in this country will be unlocked. This project identifies economic, social, institutional and policy issues affecting small-holder irrigation water use. It will also determine the extent to which poverty alleviation and empowerment of smallholder farmers can be achieved through self-management of smallholder irrigation schemes.

Expected cost: *R863 500*
Estimated term: *1999 - 2001*

Contribution of root-accessible water tables towards the irrigation requirements of crops

Department of Soil Science, University of the Free State
(WRC Reference No 1089)

The water requirements of crops, particularly in areas with high water tables, can be augmented through capillary movement of water. In dryland areas, capillary contribution can account for the bulk of crop water needs. Even under proper irrigation, this contribution (particularly during /after normal rain seasons) can be significant. Such contribution has to be quantified - and taken into account during irrigation water budgeting or when estimating water use efficiency for irrigated or dryland cropping. This project aims to develop methods of quantifying the contribution of water tables to satisfying crop water requirements.

Expected cost: *R498 000*
Estimated term: *2000 - 2002*

Cheap and simple irrigation scheduling using wetting front detectors

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 1135)

Scheduling of irrigation does not only ensure that adequate volumes of water are applied. It also ensures that many people who rely on the limited water resource can share it because of the curtailment of over-irrigation. Much as irrigators are aware of the importance of scheduling, very few practice it. A wide range of reasons for not scheduling exists, the common ones being the high level of management required and the costs involved. With simple and cheap scheduling tools, water savings will be achieved and farmers will soon realise the importance of irrigation scheduling and its benefits. The project is aimed at improving adoption of irrigation scheduling through the introduction of a cheap and simple technique of detecting the position of the wetting front in soil following irrigation. It will also evaluate factors affecting the acceptability of this irrigation scheduling technology by resource-poor and commercial farmers.

Expected cost: *R961 000*
Estimated term: *2000 - 2002*

Optimisation of irrigation management in subtropical fruit trees by determination of water and carbon demands to improve water-use efficiency and fruit quality

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 1136)

Adequate irrigation improves crop yield. In turn carbon demand (formation of fruits/ harvested plant organ) influences water needs of crops, more so at specific times of the season (particularly with fruits). This supply and demand water-dependency system has often been used for manipulating ripening and quality of fruits. It allows a farmer to regulate water applications in order to promote/induce certain physiological processes without compromising crop yield. Regulated deficit irrigation (RDI), if better understood, can improve water-use efficiency (WUE), the quality of fruits as well as economic benefits through timing of harvesting. This project aims to determine optimum levels of RDI for mango, their effects on yield, ripening and fruit quality. The research is testing a model, developed for peach, which will be adapted in order to be used by the mango producers.

Expected cost: *R984 000*
Estimated term: *2000 - 2002*

An investigation of the range and distribution of irrigation scheduling models in South Africa in general, with specific reference to the application of selected models

Department of Agricultural Engineering, University of Pretoria
(WRC Reference No 1137)

Much research has been done on the physical principles underlying irrigation scheduling and a range of techniques and methods have been developed. Nonetheless, available evidence shows that these tools are not widely applied in practice. The need has been highlighted to shift the emphasis in research from the technological (hardware and software) tools to the human and managerial factors which play a pivotal role in the application of irrigation scheduling technology. Apart from an audit of irrigation scheduling, it is important to determine under which circumstances and how effectively irrigation scheduling has been adopted and applied. Consequently the reasons for discontinuation or application of scheduling methods will be investigated and recommendations will be made to improve effective implementation of irrigation scheduling advisory services.

Expected cost: *R586 000*
Estimated term: *2000 - 2002*

An investigation into the potential of sustainable irrigation in black developing communities of two sub-catchments of the Pongola and Thukela Rivers

Sineke Development
(WRC Reference No 1138)

When government "upliftment" irrigation schemes started some decades ago, little or no attention was placed on the potential for the success of such initiatives. The government and farmers alike are aware that this should not have happened - or alternative processes and approaches should have been followed. It also implies that such development should not only be based upon economic evaluation or feasibility studies (using climatic data). Socio-political evaluation should also be done in order to ensure the success of the project. The main aim of this project is to define the socio-economic aspects and their importance for developing sustainable water-driven farming systems in rural communities. The project aims at analysing farming systems and identifying institutional arrangements within such systems. This will lead to the identification of processes to transform present irrigation farming systems among small-scale farmers. The project will further develop action plans for the development of irrigation farming systems among black communities.

Expected cost: *R995 000*
Estimated term: *2000 - 2001*

Application of risk assessment modelling in groundwater for humans and livestock in rural communal systems

NCE cc
(WRC Reference No 1175)

This project concerns itself with quantifying the risk assessment to humans and livestock in communal areas through ingestion of poor natural water quality, and investigating means of applying solutions that will benefit the user groups. It is addressing the formulation of alleviatory treatments of a lower dosage and different chemical compositions that will still serve to significantly mitigate adverse impacts on livestock production, whilst making the water fit for human consumption.

Expected cost: *R1 500 000*
Estimated term: *2000 - 2002*

Water conservation techniques on small plots in semi-arid areas to enhance rainfall use efficiency, food security and sustainable crop production

ISCW, ARC
(WRC Reference No 1176)

Food production/security under dryland cropping depends on the amount and the distribution (time and space) of rain. Both the rainfall amount and distribution are erratic in South Africa. Conservation of rainwater, particularly in arid areas is therefore paramount. This project aims to identify conservation techniques, their economic benefits and social acceptabilities. Yield improvements and water use efficiency for various common crops will also be established.

Expected cost: *R1 000 000*
Estimated term: *2000 - 2002*

Subsurface drip irrigation

IAE, ARC
(WRC Reference No 1189)

The major factor in irrigation-water loss is evaporation. This can occur before the fine water droplets reach the ground or on the soil surface. Depending on the evaporative demand of the atmosphere as well as the soil type, up to 50% of the water application can be lost through evaporation. Subsurface drip irrigation is the best system of by-passing evaporation problems. However, subsurface drip irrigation is very "sensitive" to clogging of driplines. Crop type, emitter type, depth of dripline and water quality are factors that determine the beneficial use of subsurface drip systems. These necessitate thorough investigation. The project, therefore, aims to investigate the occurrence of root penetration in terms of depth of dripline installation, type of drippers and the influence of the application of various chemicals (during fertigation or disease control). Such information will allow better management and maintenance of subsurface drip system.

Expected cost: *R343 000*
Estimated term: *2000 - 2002*

New

Technology transfer and development actions to promote and facilitate the use of SWB as an irrigation scheduling tool

Department of Plant Production and Soil Science, University of Pretoria
(WRC Reference No 1203)

There is general agreement that correct irrigation scheduling is essential for efficient water use. Most farmers decide when and how much to irrigate based on acquired knowledge and experience. In the past the WRC has funded research to develop irrigation scheduling tools, either for planning and design, or for real-time application. Although most of these irrigation scheduling tools have so far not been widely used, this position is now rapidly changing due to, amongst others, increasing water tariffs. A survey amongst farmers at the end of 1999 found that the biggest need for training was in the use of simple and practical irrigation scheduling methods. Clearly, the emphasis must now shift from research to technology transfer.

For the purpose of real-time scheduling, the most recently completed project is the Soil Water Balance (SWB) Model (WRC Report No 753/1/99). The research has validated parameters for a wide range of crops which are grown on different soils and under varying climatic conditions. The model follows a scientifically based, mechanistic approach, but has a user-friendly interface, which makes it accessible to any person with basic computer skills.

Since the release of the SWB model, feedback from users has indicated several difficulties regarding e.g. data capture. Only a small number of people are using the model for irrigation scheduling, and potential users have experienced problems with installing it and adapting it to their specific farming situation. Obviously there is presently a different perception between researchers and users regarding "user friendliness" of the model. It follows that further refinement of the model and formal training courses are required. The intention is to present training sessions in all provinces. The target audience will be:

- Irrigation advisors and extension staff;
- Irrigation farmers; and
- Final year or honours level students.

Care will specifically be taken to involve advisors who are serving subsistence farmers on irrigation schemes in the Northern, KwaZulu- Natal and Eastern Cape Provinces, which are the focus of the Presidential Initiative on Rural Development.

The main aims of this technology transfer project are therefore to:

- Further refine and, where necessary, upgrade the SWB model as a user-friendly irrigation scheduling tool; and
- Promote the adoption and application of the SWB model for irrigation scheduling in practice, through training sessions.

Expected cost: *R587 200*
Estimated term: *2001 - 2003*

Market risk, water management and the multiplier effects of irrigation agriculture with reference to the Northern Cape

Department of Agricultural Economics, University of the Free State
(WRC Reference No 1250)

An important aim of the Water Conservation and Demand Management Strategy for the agricultural sector is to provide a regulatory support and incentive framework to improve irrigation efficiency. This can be achieved by firstly ensuring that volumetric water tariffs reflect the financial cost of supply and, secondly, by promoting voluntary reallocation of water resources from lower valued to higher valued uses on farms and between farms within agriculture. For irrigation farming this means that farming operations must be restructured. However, production of e.g. high-value perennial crops also involves higher financial and business risks. This is caused by the high capital outlay and the time lag before full production is reached as well as variable export prices and changing consumer preferences over time. Although risk management through e.g. crop diversification or market forecasts and price hedging can be implemented, the question is how far the shift to higher valued crops can be taken.

Presently it is not known what the financial boundaries are within which water reallocations can be managed sustainably on a farm level and what the potential impact is on a regional economic level. Knowledge of these issues is of particular importance for irrigation areas in provinces such as the Northern Cape where agriculture is the dominant economic sector. Instability influences not only employment and income on farms, but also processing and input supplying industries through forward and backward linkages. This is emphasised by the recent turmoil in the global market of deciduous fruit, which has also affected table grape production in the lower Orange River.

The proposed project will analyse the related production and marketing risks and develop models which link economic activities on a farming level to the regional level. The model will be tested in the particular study area but will be applicable in any area.

The main aim of this project is to quantify the impact of market risk on the efficient use of irrigation water and to determine the multiplier effects of irrigation farming accompanied by a shift in production patterns.

Expected cost: *R1 333 700*
Estimated term: *2001 - 2005*

Irrigation water measurement: The application of flow meters in irrigation water management

Department of Agricultural and Food Engineering, University of Pretoria
(WRC Reference No 1265)

Effective management of water resources can be vastly improved if water use is measured accurately. This applies in particular to efforts to influence the quantity of water demanded by levying tariffs on the volume of water actually consumed. However, on most irrigation schemes water flow is not measured and water tariffs are presently still levied on an area and not a volumetric basis. It is not surprising, therefore, that a survey at the end of 1999 found that 72.3% of farmers do not measure water use. This practically rules out using water tariffs as an economic policy instrument to implement a water conservation strategy.

In contrast, a range of water metering technologies is available which vary in cost and effectiveness. The determining factors are:

- Accuracy and durability over time;
- Resistance against tampering; and
- Ease of recording of readings.

This situation calls for a comprehensive study of water measurement in irrigation and this research proposal was, therefore, initiated by the WRC. Firstly, the technical, financial and social reasons for non-measurement of water use will have to be determined. Secondly, the appropriate water meters (hydraulic, mechanical or electrical) for different distribution networks (pipelines, canals or rivers) and depending on the physical, biological and chemical quality of water will have to be identified. It will also require both laboratory testing and field evaluation. For this purpose active participation of the major manufacturers of water meters, representatives of farmers on different irrigation schemes and officials of DWAF will be obtained.

The aims of this research project are to:

- Identify the methods and technologies for water flow measurement used in different water distribution systems on irrigation schemes under South African conditions;
- Investigate the effectiveness of the various flow measuring methods and technologies through laboratory and field evaluations;
- Determine the reasons for not measuring water use in practice by means of a field survey amongst farmers; and
- Establish directives for the correct choice and management of water flow meters for irrigation systems under different circumstances.

Expected cost: *R914 300*
Estimated term: *2001 - 2004*

Socio-economic impact study on water conservation cultivation techniques in semi-arid areas

Department of Agricultural Economics, University of the Free State
(WRC Reference No 1267)

Food production is fundamentally a product of the atmosphere-plant-soil system with water the main factor limiting productivity, especially in semi-arid regions. To promote sustainable crop production, rainfall use efficiency, therefore, needs to be optimised. In a previous WRC-funded project which

terminated in 1999 (entitled **Optimising rainfall use efficiency for developing farmers with limited access to irrigation water**) an in-depth study was made of all the relevant production techniques, and identification of the most appropriate techniques for long-term implementation. In order to further evaluate these techniques (i.e. specific cultivation practices, water harvesting by means of runoff manipulation and certain water conservation practices) the Board, during 1999, approved a follow-up research project by the Institute for Soil, Climate and Water of the ARC. In addition to evaluation of the water conservation techniques, land and human power requirements, and technology transfer, the new project also intends to evaluate the socio-economic implications of these conservation techniques.

At the first meeting of the new project's steering committee, however, the importance of the latter aim was emphasised. The argument was that since the practical sustainability of and the extent to which these conservation practices will be supported and recommended by the relevant authorities, depend on the socio-economic acceptability thereof, this aim needs to be investigated in greater detail and to a wider extent. Consequently, a strong recommendation in this regard was submitted to the WRC.

In view of their experience in socio-economic evaluations, the research team consisting of the Departments of Agricultural Economy and of Sociology of the Free State University was approached to submit a project proposal concerning this need. The aims they intend to address in this project, are the following:

- Develop an appropriate methodology for the determination of the socio-economic implications of water conservation cultivation techniques;
- Develop a simulation model to integrate biological productivity, entrenchment of risks, management of natural resources and social acceptability with economic sustainability;
- Determine the socio-economic implications of employing water conservation cultivation techniques on small plots in semi-arid areas; and
- Determine the area of land needed to provide an average-sized rural family with food security, as well as the human power required for these cultivation practices.

It needs to be mentioned that the Free State Provincial Department of Agriculture, after a visit to the ARC experimental sites, is very keen to launch a programme for the implementation of the water conservation cultivation techniques. They also agreed that the proposed socio-economic evaluation is a necessary intermediate step before embarking on this programme. In addition to in-kind support for both the ARC and the proposed project, two departmental extension officers of the previously disadvantaged section of the community, will also be involved in the project. Capacity development will, therefore, be attended to from a research and an implementation point of view.

Expected cost: *R425 800*
Estimated term: *2001 - 2004*

Outcomes to Date of Current Programmes and Projects

New knowledge

Valuable knowledge has been generated. This knowledge is also being validated on various soils, crops, climatic conditions, economic scales and social aspects.

- Irrigation scheduling has been improved dramatically through ongoing research over the past decade. A number of computer programs have been developed for various crops. These include BEWAB, which can be used for planning and management of irrigation at farm level. BEWAB has been extended and refined, to also manage irrigation under controlled water-stress conditions.

  The soil-water balance (SWB) model is a mechanistic, real-time generic crop irrigation scheduling model. It interprets the soil-plant-atmosphere water continuum, making use of weather, soil and crop management data. The model, however, requires parameters specific to a crop before water requirements are determined.

  Integration of solar, edaphic and other meteorological data in irrigation scheduling and the modelling thereof makes it possible to estimate and even predict crop water requirements without even taking soil samples or going to the field.

  Attempts have been made to test and validate these models *in situ*. End-users, based on their experience with the models, maintain that irrigation scheduling is important as it can save water and money.
- Computerisation of irrigation design, particularly drip and sprinkler systems, has occurred. Design procedures for flood and furrow systems have also been evaluated, computerised and tested *in situ*. Some models (foreign origin) have been tested and found to be unacceptable for South African conditions. However, those models that proved to be useful have been developed further - and have led to the OPTIVLOED 2.2 design approach, which incorporates all the capabilities identified.
- Some computer programs have been created that estimate crop water requirements. SAPWAT, a planning tool, enables irrigators, planners and designers to obtain realistic estimates of irrigation requirements for a wide range of crops throughout South Africa. SAPWAT incorporates crop and climate databases and maintains flexibility to accept "other" input if necessary. It is compatible with FAO procedures. Currently, SAPWAT is being used for water budgeting in the establishment of WUAs countrywide.

  Water stress and drought tolerance have been investigated extensively in the past decade. Certain crops and cultivars can tolerate some levels of water stress and drought. In other crops, drought tolerance is seasonal. Most crops, including maize and potatoes, have been found to be very sensitive to water stress during formation of economic yield (grain and tuber, respectively).

  The correlation between water stress/drought tolerance and climatic

factors has been highlighted. The adaptability of various crops and genotypes to water stress has also been determined (potatoes, cowpea, bambara and marog).

- The RDI (regulated deficit irrigation), although having been used in citrus, is becoming more popular and of benefit to the deciduous fruit and subtropical growers as well. In fact, the technique, once understood, is more useful to the latter. Fruit quality, ripening and export timing can be manipulated through RDI.
- Accurate comparison of the water stored in the soil with the expected crop-water deficit, requires knowledge of the soil-water balance in order to lower the risk of crop failure. Estimation procedures for the quantification of each component of the soil water balance were developed and linked in a single computer program. This software package under the title Soil-Water Management Program (SWAMP) is available to farmers and agricultural advisors to estimate the obtainable crop yield and decide whether to plant or not.
- An exploratory investigation in the Lower Vaal River found that the trend for water quality deterioration was less pronounced than anticipated and was influenced by annual and multi-year wet and dry cycles. However, long-term model predictions indicate that all **undrained soils** could become unsuitable for crop production as a result of excessive salt accumulation over the next 50 years. This means that timely precautions will have to be taken and by adapting on-farm production practices. The economic viability of these alternative practices on a farming level is currently being investigated.
- In previous research projects, separate models were developed for calculating the cost of irrigation, assessing the risk attached to variable water supply and crop yield and doing short-term whole-farm planning for irrigation farming. These sub-models have now been successfully linked under the FARMS model (firm-level agricultural risk management simulator) system, user-friendly adjustments have been made and the practical applications have been demonstrated through interactions with farmers on a case-study basis.
- Research geared towards social and technical considerations within a poverty-reduction programme has empowered the poor. Scientifically based improvements of traditional production systems guarantee adoption of technology.
- The involvement of the end-users of technology in the early stages of the project has added value to interventions. This ensures that research receives guidance - which ensures applicable and beneficial outcomes.
- In multicropping, there is competition for soil water. Crop rows adjacent to the forestry species tend to yield less than the rows further away. However, the yield reduction is far less than the gains through fodder production. No yield reduction has been observed for shade-tolerant crop species such as sweet potatoes.
- The in situ research on irrigation schemes and the management thereof has indicated that it is not only technical difficulties that lead to poor performance of the schemes. Social and economic factors are probably the most influential reasons for non-performance. Political factors also have effects on the low productivity of the "upliftment" irrigation schemes.
- The dynamics underlying the establishment of government "upliftment" irrigation schemes have been investigated. The institutional development and management of irrigation schemes, poverty levels and productivity have also been investigated.
- Research results have indicated that an increase in the size of land holdings tends to be accompanied by a shift in the objectives of farmers from subsistence to market-oriented production. This "shift" exposes farmers to a number of other challenges, including production practices, marketing, finance and management.

Investigation has shown that food plots are not recommended for settlement schemes. The size of food plots is just too small to make irrigated farming a viable livelihood option. At least 2 ha is the minimum plot size required for irrigated farming to become the source of income for farming households.

- Irrigation techniques commonly used by smallholder irrigation farmers have been evaluated for appropriateness. Guidelines for on-scheme water distribution design (flood and furrow), including the layout of plots and secondary canals, have been compiled.

Sprinkler irrigation can be surprisingly flexible, but its design for the specific circumstances encountered in small-scale farmer irrigation requires refinement and the application of basic principles.

Benefits to South Africa

All current projects contribute to improvement of the quality of life and wealth creation in agriculture. The efficient use of water does not only maximise economic benefits from dryland and irrigated agriculture, it also ensures sustainable use of other natural resources.

Some particular benefits from current programmes are as follows:

- Water savings are achieved - which also imply savings in pumping (electricity) costs. Irrigation models have also allowed irrigators to benefit from other service providers and experts. For example, duplication of services is eliminated at farm level - thus improving profits for most farming operations.
- Regulated deficit irrigation (RDI) has been used to control both fruit quality and harvesting of mangoes, particularly for the export market. Water-use efficiency in terms of quality and income is also enhanced by RDI.
- The availability of SAPWAT makes it possible to move away from the ambiguous levy system whereby payment for water is based on the potential land under irrigation to a system in which payment is based on actual volume of water used for irrigation.
- The problems caused by blackfly (*Simulium* spp.) stem from the fact that water resources along the Orange River are increasingly regulated as they are developed, and the natural flow variation which existed previously and exerted a degree of control, has been removed. Initial research investigated

the use of the microbial larvicide *Bacillus thuringiensis* var. *israelensis* (B.t.i.) and an organophosphate larvicide. While these were found to be effective, control was costly. Further ways of increasing the efficiency of integrated control of blackflies were investigated by studying the relationship between population dynamics and variations in the ecosystem. A model was developed to assist in the decision of when to apply larvicide to achieve effective control at lowest cost. Although this project has been completed, research is being taken further in the field of ***Conservation of Water Ecosystems.***

- Two problem species of filamentous algae have been identified. *Oedogonium capillare* occurs in the lower pH water in the canals of the Breede River system, and *Cladophora glomerata* occurs in alkaline waters elsewhere in the country. A satisfactory method of monitoring the time and rate of algal invasions has been developed. A technique has also been developed to allow laboratory work on basic growth requirements of algae, as well as determining the relationship between copper uptake and environmental variables. This, in turn, has enabled specific recommendations to be made regarding the use of copper sulphate in the control of the algae.
- The majority of farmers have been exposed to the real causes of their low productivity. They also understand the possible ways of improving production. In cases where improvements are not likely, farmers are now informed about other possible options.
- The rehabilitation of smallholder irrigation schemes in South Africa, a multimillion Rand programme, is based on the WRC guidelines. The schemes, despite huge investments, previously fell far short of the expectations of all stakeholders. Some of the schemes even collapsed.
- The handing-over of the management of irrigation schemes needs better planning. Guidelines are being developed and evaluated to guide the process of handing over.
- Guidelines have been developed for trainers and extension officials involved in small-scale irrigation. These guidelines supplement the efforts by the National Department of Agriculture to improve the skills within their extension services. The extension services have been identified as the poor link in the irrigation sector throughout South Africa. With well-trained extension officers and development facilitators, irrigated farming in South Africa stands a better chance to improve even further.

Innovation/application of knowledge

The involvement of the end-users at all stages of research has improved the application of new knowledge and adoption of technologies resulting from current research in this field. Some specific examples are the following:

- The fruit industry of South Africa is achieving direct benefits from the use of regulated deficit irrigation for enhancing fruit quality and timing of harvesting.
- The research on developing models for water management at farm and catchment levels taking risk into account, involved multidisciplinary interaction between hydrologists and agricultural economists. This resulted in improvements in the ACRU hydrological simulation model and linking it with economic simulation models which optimise water use. The chance-constrained optimisation model which was developed, represents a breakthrough regarding modelling work in South Africa. Through this modelling approach, decision support is being provided for evaluating alternative risky water-use strategies on a farm level while at the same time taking into account return-flow and instream flow requirements of the river system or catchment.
- Relevant research aimed at improvement of traditional production systems has enhanced the participation of farmers and their scientific technical understanding of their practices. Establishment of optimum combinations of species for multicropping and the spacing thereof enables the producer to obtain better yields.
- The availability of the SAPWAT program has made it possible to do water budgeting for planning, and for the establishment of WUAs by DWAF. The tool is also being used effectively for the purposes of registration of lawful water use by irrigators (farmers).
- Decision-support for integrated water management has been achieved by linking the SWB model, FARMS model and WAS model while using a uniform database and recording information on a GIS. By integrating the three models, the potential benefits are to maximise crop water-use efficiency, optimise crop combinations with the desired exposure to risk and minimise water distribution losses. Possibilities are currently being investigated to implement the models as part of the water-conservation and demand-management strategy pilot projects undertaken by DWAF.
- Traditional cropping systems have been improved through introduction of efficient and practical technologies resulting from research projects. In this way poverty and food security are being addressed effectively.

Capacity/competence development

Capacity development in this research field occurs at the individual, organisational and community level.

Individual capacity development

Nineteen of the 33 current projects are being undertaken by universities.

After the last project by the University of Fort Hare was completed in 1998, regular follow-up discussions have been held, explaining the priorities for research according to the Strategic Plan. Although submission of proposals has been encouraged, no response has so far been obtained.

In 7 projects of the ARC and 4 projects of the CSIR, the competency of mainly young researchers is being developed. One project of the ARC involves collaborative research with the University of Zululand as does one project of the CSIR with the University of Natal.

Organisational capacity development

Three current projects are being undertaken by private consultants. One of these is an emerging consultancy group which has received research funding for the first time. In this particular project 3 post-graduate students from the University of Zululand are undergoing further training.

Community capacity development

Ongoing efforts are being made to undertake participatory action research projects where farmers benefit directly while the research is being done. At least 27% of the current projects involve some form of on-farm research in previously disadvantaged communities which enables project-related education and training of farmers. More concerted focus on this type of research is envisaged for new projects in future years.

Knowledge dissemination

The research output is mainly published in the form of manuals, guidelines and standard reports. In recent years a special effort has been made to ensure that research results actually reach farmers and their advisors. Discussions have been held with Agri SA and NAFU and the most effective communication channels are continuously being sought. As part of this effort 5 Discussion Forums have been organised during 2000 and 2001 in different Provinces to explain the Strategic Research Plan, gain a better understanding of the problems experienced by farmers and obtain an indication of priorities for research and technology transfer. A further 4 Discussion Forums are planned for 2002.

In addition the following information dissemination has taken place since 1997, mainly based on research projects undertaken by Universities:

Articles	Papers	M.Sc.	Ph.D.	Workshops
17	85	6	3	5

Leveraging of resources

In all projects undertaken by Universities, the ARC and CSIR, contributions are made by those organisations in the form of salaries of project leaders, office and research infrastructure.

International linkages

Through project-related research, links have been established or student exchange has taken place with the Virginia Polytechnic Institute in the USA regarding modelling work for management of risk and water quality.

Respectively, the University of California (LA), Washington State University, and the CSIRO (Australia) are participating in WRC projects on: **Optimisation of irrigation management in subtropical fruit trees by determination of water and carbon demand to improve water use efficiency and fruit quality; Two-dimensional water balance and energy interception model for fruit tree irrigation systems in SA;** and **Determining plantation water use and growth from integrated remote sensing, water-use models, geographic information systems (GIS) and field data**.

The use of agroforestry species for intercropping is predominant in Asia and elsewhere in Africa. Research being conducted here in South Africa takes into account what has been successful elsewhere in the world.

Water harvesting has been used successfully in Morocco and in Egypt. However, no direct linkages have been made yet internationally. Respectively, the CSIRO, IWMI and SADC countries (through certain individuals and organisations) are involved in WRC projects on: **Cheap and simple irrigation scheduling using wetting front detectors; Sustainable local management of smallholder irrigation;** and **Water conservation techniques on small plots in semi-arid areas to enhance rainfall use efficiency, food security, and sustainable crop production**.

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Chapter 11

Industrial Water Management

Mr GN Steenveld

Scope

Industrial Water Management deals with water use and the wastes (liquid and solid) generated during industrial processing activities. The industrial sector uses a relatively small proportion (nominally 10%) of national water use, but, in the process, good-quality (often potable) water is rapidly degraded. The effluents produced have a much higher pollutant load than domestic wastewater, are therefore expensive to treat, and moreover contain components which are recalcitrant, inhibitory or even toxic to conventional wastewater treatment and to the receiving aquatic environment. The modern focus in industrial water management is thus to demand-manage water use and to prevent pollution at source (cleaner production), rather than relying on end-of-pipe treatment (clean-up technology).

Water used by urban-based industry is normally supplied by the local municipality and the resultant effluents are then discharged to municipal sewer systems, sometimes after on-site pretreatment. Industrial effluents thus affect treatment operations at municipal works and the qualities of the treated effluent and sludges produced. The fields of ***Industrial Water Management and Municipal Wastewater Management*** are thus strongly linked, reflecting also the economic importance of industrial activity in terms of municipal resource management and revenue.

Industrial Water Management also links with the ***Mine-Water Management*** field, in that certain treatment processes are being developed and applied in both the industrial and mining sectors. The research activities in this regard in the industrial field, however, concentrate on process development, fundamental mechanistic understanding and kinetic modelling, as support to application and implementation in the mining industry.

Table 1 shows that, on average over the past 5 years, around 7% of WRC total research funding has been committed to this field. Annual expenditure on research in the field varies, for example with sectoral needs, in the wide range of industries covered. Actual expenditure has, however, steadily increased, partly as a reflection of the importance of industry to the national economy and the government's GEAR strategy. Sustainability of South African "wet" industries in various sectors depends on an adequate supply of suitable-quality water. International cost-competitiveness and exporting now include the requirement of adequate environmental performance by local industry. Such factors strongly influence the strategic scope and direction of research in this field, to assist local industry in using water and other resources conservatively, in reducing the wastes produced and consequent

TABLE 1
Research Funding Investment in **Industrial Water Management (IWM)**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R2 391 210	R2 800 900	R3 569 920	R3 962 900	R4 761 100
% of research fund	5.9%	6.3%	6.7%	6.5%	8.1%

environmental impacts, and generally being internationally competitive in terms of production and environmental performance.

Links to Key Strategic Areas

Industrial Water Management falls within the WRC's key strategic area (KSA) for ***Water Use and Waste Management***, and links to other KSAs as indicated below:

Water Resource Management

Good-quality (often potable) water is taken in by industry for consumptive use (a net loss from the national water resource, e.g. evaporative losses) and non-consumptive use (available for return but at a degraded quality, e.g. treated effluent).

Water-Linked Ecosystems

Industrial wastes (liquid and solid) impact on aquatic ecosystems, usually indirectly (via discharge to sewage works, treatment and then return to water bodies) but sometimes directly (discharges to receiving water bodies after some degree of on-site treatment). Of special concern are components of industrial wastes that are resistant to conventional treatment but are toxic to the aquatic environment.

Water Use and Waste Management

The ***Industrial Water Management (IWM)*** field falls wholly within this KSA. Industry takes in raw materials, water and energy (in varying degrees) to carry out the processing activities concerned and generates effluents and wastes which often require extensive pretreatment before being acceptable for discharge to municipal sewers or directly to watercourses. The approach adopted is reduction at source. Life-cycle considerations applied to industrial resource management indicate the far-reaching implications of industrial process activities.

Water Utilisation in Agriculture

Industrial Water Management links to this KSA mainly in respect of the potential deleterious effect of industrial effluent components on the fitness of water for agriculture (inhibitory or toxic effects on crop growth, for example by salinity or heavy metals).

Objectives

Primary

The overall objective in the ***IWM*** field is the optimal management of the water used and wastes generated by industry during production/processing, to the national, sectoral and community-level benefit.

Secondary

The widely divergent nature and needs of particular industrial sectors have in the past mitigated against the development of a rigorous co-ordinated strategic research plan in this field. Research activities continue to reflect both historical end-of-pipe treatment requirements which vary greatly between different sectors, and, increasingly, pro-active intervention at the production/processing stage to reduce water use, energy consumption and waste generation at source. Such aspects of cleaner production are organising principles around which strategic research is co-ordinated. Current secondary-level research objectives in this field are as follows:

- Treatment of effluents from agro-industry processing including forestry (pulp and paper) and livestock production;
- Co-treatment of mining/industrial and sewage effluents;
- Treatment of effluents containing heavy metals;
- Sulphate-removal processes;
- Tools for cleaner production in industry;
- Training in wastewater treatment plant operation; and
- Treatment of concentrated and/or toxic organic effluents.

Research Projects

Completed, current and new projects addressing the above objectives directly and/or indirectly, are outlined below.

Completed

Improved oxygen transfer for high biosludge concentrations

Dept of Chemical Engineering, University of Pretoria
(WRC Reference No 331)

In the design of bioreactors utilising concentrated fungal or other organisms for the treatment of effluents, sometimes with simultaneous protein production, there is a lack of knowledge relating to the oxygen transfer aspects of the aeration or oxygenation technology used. The aims of the project were to redress this knowledge gap, by carrying out experimental studies to determine the optimum arrangement of aeration equipment for maximum aeration (oxygenation) and mixing efficiency of concentrated filamentous fungal biomass sludges, and to develop guidelines for the treatment of suitable effluents by means of organisms such as *Geotrichum* or *Aspergillus*

The main empirical results found were that maximum oxygen transfer rates of about 1 100 mg O/h could be achieved, but that there are lower practical limits that should not be exceeded. These limits are that the concentration of filamentous biomass should be controlled at less than 8 000 mg/ℓ (oxygen transfer is limited exponentially with further increases in biomass concentration), that the maximum aeration rate should be limited to about 1 m^3 air/m^3 liquid.min (higher aeration rates were found to cause severe foaming), that there was an optimum number of mechanical air bubble breakers (usually two) and that a linear relationship exists between the submergence depth of the diffuser and the rate of oxygen transfer (although energy requirements for pumping air through the diffusers would eventually limit practical aeration depths).

The results obtained provide guidelines to a very uncertain area of design, which will be useful to the biochemical engineering fraternity in the design of bioreactors. The technology is being applied for the first time in a demonstration plant erected by a sugar mill for the biological treatment of a furfural stream with simultaneous production of single cell protein.

Cost: *R 75 000*
Term: *1990 - 1996*

Anaerobic digestion of dairy factory effluents

Irene Animal Production Institute, ARC
(WRC Reference No 455)

The objectives of this project were to:

- Survey the SA dairy industry to determine the present effluent treatment situation;
- Investigate the use of anaerobic digestion for dairy wastewater;
- Investigate the use of the anaerobic digestion-ultrafiltration (ADUF) system for the treatment of dairy wastewater; and
- Investigate the possible development of the ADUF system into an efficient process for the treatment of wastewater produced by dairy factories in South Africa.

The findings of this study provide a starting point from which the dairy industry can proceed to make an informed decision, based on viable effluent treatment options. When anaerobic digestion is considered as an option for the on-site treatment of dairy effluents, the results of this study will hopefully remove many fundamental uncertainties.

The application of the results from this study, in an on-site pilot-scale setup, will provide practical information that will help to ensure the successful design and operation of a full-scale treatment plant. Since the quality of the final effluent, after anaerobic digestion, does not allow its direct disposal to rivers and waterways, further research will have to include an investigation of secondary, "polishing" steps, such as ultrafiltration, a chemical treatment step or a secondary biological treatment step.

Cost: *R 142 000*
Term: *1992-1994*

Current

Biotechnological approach to the removal of organics from saline effluents

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 495)

Based on the findings of a previous WRC project (Reference No 410), this research is evaluating the potential of integrated algal biotechnological systems to remove organics and heavy metals from saline wastewaters on a scale appropriate to large water impoundments. The specific aims include the development of an appropriate saline high rate algal pond (HRAP) process based on halophilic algae which could produce products of value and in turn thus improve the economic incentive for environmentally sound disposal of such wastes.

Estimated cost: *R 998 200*
Expected term: *1992-1996*

Evaluation of the potential quantity of methane gas from 85 anaerobic household digesters

BE La Trobe
(WRC Reference No 551)

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.

Estimated cost: *R 58 900*
Expected term: *1993-1995*

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

Department of Chemistry, University of Stellenbosch
(WRC Reference No 552)

Raw surface water and groundwater can contain a wide range of compounds that are detrimental to human health, including natural organic materials (NOM) such as humic acid arising from the vegetation in a catchment area, and a variety of organic molecules of industrial and agricultural origin. Traditional flocculation/coagulation processes are not completely efficient in removing all the combinations of material that can occur. This project is assessing the effectiveness of titanium oxide photo-catalysis for the oxidative removal of such organic compounds from raw water, leading to the development of photo-catalytic reactors.

Estimated cost: *R 95 400*
Expected term: *1993-1994*

Purification of abattoir effluents by means of the protein reclamation process

Abakor Ltd.
(WRC Reference No 652)

One of the major problems confronting abattoirs is coping with the effluent. Physical-chemical techniques, as well as biological processes, are normally employed to treat the effluent. Both types of processes, however, suffer from the drawback of being either relatively expensive or of still discharging a pollution load to the environment.

An alternative treatment process is the culture of single-cell protein in the effluent. This process has the advantage of being environment-friendly, of relieving the pollution load to existing municipal sewage treatment plants and of being an additional source of protein.

The purpose of this project is to transfer single-cell protein technology to a full-scale plant at the Johannesburg Abattoir.

Estimated cost: *R 300 000*
Expected term: *1994*

Algal high-rate oxidation ponding for the treatment of abattoir effluents

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 658)

Abattoir effluents present significant problems with high levels of COD, protein, nitrogen and phosphate. The research objectives of this project are to develop a low-cost Algal High Rate Oxidation Ponding treatment process for effluents from small to large country abattoirs, potentially with the conversion of waste into an algal product of value, and to install a industrial-scale demonstration plant at a suitable site.

Estimated cost: *R 571 300*
Expected term: *1995-1996*

On-site evaluation of an anion-free flocculant for industrial cooling systems

Pollution Research Group, University of Natal and Eskom
(WRC Reference No 674)

At present ferric chloride is added to power-station cooling water to effect removal of organic and inorganic contaminants. The resultant build-up of chloride ions in the cooling-water circuit results in corrosion of the condenser tubules, which are expensive to replace. Bleed-off from the cooling-water circuit, to control corrosion, constitutes the largest source, both in volume and salt mass, of liquid effluent from a wet-cooled power station. An alternative approach is to use an anion?free flocculant, such as iron hydroxide, which is produced electrolytically. This would not only decrease corrosion but would also significantly reduce the effluent produced at a power station and hence the impact on the receiving water environment. The objectives of the project are thus to:

- Use the information gained from a preceding laboratory study to design and erect a pilot plant for the electrochemical production of iron hydroxide at a power station; and
- Effect on-site evaluation of its effectiveness to treat the different water circuits in a power station, and to establish how this is affected by variations in water quality.

Estimated cost: *R 130 000*
Expected term: *1995*

Biotechnological approach to the management of effluents from the pulp and paper industry

Department of Microbiology and Biochemistry, University of the Free State
(WRC Reference No 763)

Bleach plant effluents from the pulp and paper industry are highly coloured and contain chlorinated organic materials and high concentrations of chlorides. The pulp and paper industry is making efforts to reduce the chloro-organic/chloride discharges by using more environmentally-benign bleaching methods. Work carried out in a previous WRC project made considerable progress in establishing viable bio-bleaching, bio-decolorisation, bio-degradation and bio-remediation as alternatives to the use of chlorine. This project aims at furthering this work towards practical implementation, and also expanding this into the production of commercially exploitable enzymes from pulp and paper effluents.

Estimated cost: *R400 000*
Expected term: *1999-2001*

Development of bioreactor systems for the treatment of heavy metal containing effluents

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 845)

Heavy metal contamination of wastewaters is a major source of environmental pollution and represents a vital resource loss in terms of water availability and quality. Biotechnological processes such as biosorption may provide an effective and inexpensive means of removing heavy metals from water when compared to more traditional methods. This study, focused primarily on mine effluents as one of the major sources of metal contamination of waters in South Africa, aims to evaluate the potential of algae and the water fern, *Azolla*, to accumulate heavy metals from effluents, to exploit exopolysaccharide production by a number of algae as a means of enhancing metal removal efficiencies, and to optimise bioreactor design including biomass retention and separation systems for direct on-site application of the technology.

Estimated cost: *R598 000*
Expected term: *1997-1999*

Application of pinch technology as a strategic tool in the rational management of water and effluent in an industrial complex

Pollution Research Group, University of Natal
(WRC Reference No 851)

Pinch technology is a technique that was first used for assessing the overall interrelated energy needs of a complex industrial plant or cluster of such plants. The project objectives here are to apply and assess pinch technology as an approach for minimising water use and effluent generation in large industrial complexes; develop procedures for integrating water quantity and quality requirements of individual unit operations; establish guidelines for the use of pinch technology as a planning tool for water management; and transfer the technology for application in water conservation.

Estimated cost: *R907 000*
Expected term: *1998-2001*

Assessment of a baffled (compart-mentalised) anaerobic digester for the treatment of high-strength and toxic organic industrial effluents

Pollution Research Group, University of Natal
(WRC Reference No 853)

Organic effluents from the agri-industrial sector are generally problematic in terms of their concentrated, variable, intermittent and sometimes toxic nature. Many streams would be amenable to treatment by anaerobic digestion if the toxicity of the particular components is identified at an early stage so that the microbial populations can be acclimated to the constituents concerned in a suitable reactor. The anaerobic baffled reactor (ABR) offers good separation between hydraulic and solids retention times, good solids retention, and the

potential for selecting acclimated microbial biomass fractions in a series configuration. The objective in this project is to develop and apply an ABR for treating dyeing effluents from the textile industry.

Estimated cost: *R1 218 000*
Expected term: *1998-2001*

Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the algal integrated ponding system (AIPS)

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 869)

Effluents containing heavy metals and high sulphate levels present urgent and intractable environmental impact problems both in the RSA and abroad, and also represent a large untapped resource of water. WRC-sponsored research on algal ponding technologies, undertaken over a number of years, has resulted in the development and patenting of a novel process for effecting the linked removal of heavy metals and sulphate from such wastewaters, providing both high-rate sulphate reduction and photosynthetic conversion of sulphide to elemental sulphur. The broad objective of this project is to develop the fundamental design principles necessary for rationalising process development and functional performance optimisation.

Estimated cost: *R922 000*
Expected term: *1998-2001*

Development of bioreactor systems for the conversion of organic compounds in industrial effluents to useful products

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 939)

Toxic organic compounds in industrial wastewaters are an environmental hazard to the community and an expensive material waste to the producer. The fields of bio-transformation and bioremediation offer the potential both for limiting or neutralising such toxic effects and possibly of converting some of these compounds to economically valuable by-products. The project aims at developing oxidative enzymatic processes for bio-convertage of toxic organic pollutants in selected major industrial effluents to saleable products and applying this fundamental knowledge to the design of practical bioreactor systems.

Estimated cost: *R595 000*
Expected term: *1998-2001*

Electrochemical treatment removal of phosphates and sulphates from sewage and acid mine drainage respectively

Anglo Coal, Anglo Operations Ltd.
(WRC Reference No 940)

Electrochemical (EC) treatment of wastewaters has some significant technical advantages over chemical dosing methods, particularly in that counter-ions e.g. chloride are not produced while generating cations e.g. ferric ions for flocculation. Such benefits have previously been negated by the high cost of EC processes. The project aims to revisit EC treatment of wastewater, using modern electric, electronic and control technology. The approach proposed is to employ sacrificial scrap-electrodes, which could make the process cost-competitive. Further cost advantages could be derived by developing a generic EC-reactor using scrap metal.

Estimated cost: *R670 000*
Expected term: *1999-2001*

Process development and system optimisation of the integrated algal trench reactor process for sulphate biodesalination and heavy metal precipitation in mining and industrial effluents

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 972)

Effluents containing heavy metals and high sulphate levels present urgent and intractable environmental impact problems both in the RSA and abroad, and also represent a large untapped resource of low-grade water. WRC-sponsored research on algal ponding technologies, undertaken over a number of years, has resulted in the development and patenting of a novel process for effecting the linked removal of heavy metals and sulphate from such wastewaters, providing both high-rate sulphate reduction and bio-conversion of sulphide to elemental sulphur. The broad objective of this project is to develop the fundamental design principles necessary for rationalising process development and functional performance optimisation.

Estimated cost: *R922 000*
Expected term: *1998-2001*

Waste minimisation and effluent treatment clubs - Phase 1: Initial assessment and pilot study

Pollution Research Group, University of Natal
(WRC Reference No 973)

Industrial small-, medium- and micro-enterprises (ISMMEs) are a strategic growth sector in the RSA but cumulatively are significant sources of pollutants which detrimentally affect sewage treatment. The overall objective of the project is the development of regional waste minimisation clubs, in which cleaner production practices can be cost-effectively established as a contribution to the sustainability in South Africa of ISSMEs that are both competitive and environmentally responsible.

Estimated cost: *R1 062 000*
Expected term: *1998-2001*

Mass culturing of granules for use in upflow anaerobic sludge blanket bioreactors (UASB) by process induction and microbial stimulation

Department of Food Science, University of Stellenbosch
(WRC Reference No 1022)

In a previous WRC-funded project the biogranulation process was successfully enhanced in a small batch reactor. In this study, microbial consortia within granules cultured in larger batch reactors are being analysed, to increase understanding of the microbial metabolic processes that are responsible for enhancing biogranulation. The study is also evaluating the use of different synthetic media and wastewaters as carbon sources for granulation. The successful cultivation of granules on a large scale has important economic implications

for biological treatment in the RSA in terms of faster start-up; independence of local industries from importation of granules; and the potential for developing an export industry.

Estimated cost: *R231 000*
Expected term: *1999-2001*

Caustic management and reuse in the beverage bottling industry

Department of Chemical Engineering, ML Sultan Technikon
(WRC Reference No 1033)

Sodium hydroxide solution (caustic) is widely employed as a cleaning agent in the food industry, with a high proportion of the water that enters bottling plants being discharged as a caustic effluent. The industry is now giving serious consideration to caustic management and reuse/recycling. The aims of the project are to develop a viable membrane-based process for the reuse and/or recovery of sodium hydroxide; demonstrate the process to potential users; develop a commercialisation strategy for the proposed process; and develop a human resource skills base that is capable of implementing such processes in industry.

Estimated cost: *R370 000*
Expected term: *1999-2001*

Optimisation of protein recovery in treatment of organic effluents: Feeding trials on biomass from pilot plant

DB Thermal (Pty) Ltd.
(WRC Reference No 1081)

In previous work funded by the WRC, replacement of the conventional settling tank in an activated sludge system with a fine screen resulted in the possibility of growing filamentous organisms (mainly fungi) as a near-monoculture in an open reactor, without any sterilisation, while simultaneously purifying the water. In order to finalise the work, in this project animal feeding trials are being carried out on the biomass to assess its applicability as animal protein and its commercial value.

Estimated cost: *R196 000*
Expected term: *1999-2001*

Further development of a bio-technological approach to the management of effluents from the pulp and paper industry

SAPPI Biotechnology Laboratory, University of the Free State
(WRC Reference No 1082)

Bleach plant effluents from the pulp and paper industry are highly coloured and contain chlorinated organic materials and high concentrations of chlorides. The pulp and paper industry is making efforts to reduce the chloro-organic / chloride discharges by using more environmentally-benign bleaching methods. Work carried out in a previous WRC project made considerable progress in establishing viable bio-bleaching, bio-decolorisation, bio-degradation and bio-remediation as alternatives to the use of chlorine. This project aims at furthering this work towards practical implementation, and also expanding this into the production of commercially exploitable enzymes from pulp and paper effluents.

Estimated cost: *R400 000*
Expected term: *1999-2001*

Assessment and application of the latest technology available for the bioremediation of heavy metal effluents

Centre for Water and Wastewater Research, Technikon Natal
(WRC Reference No 1083)

Inadequately treated metal-laden effluents from mining and industry are toxic to the aquatic environment, thereafter to informal settlements using rivers for potable purposes, and affect the efficient functioning of wastewater works. The overall aim of the project is to conduct a comprehensive global search to identify effective biosorbents for metals and to test these in laboratory- and pilot-scale trials so that guidelines for their appropriate application can be developed for local industrial users. The latest bioremediation technology for treatment of heavy metal effluents will be transferred to postgraduate students and personnel from industry.

Estimated cost: *R350 000*
Expected term: *1999-2001*

Development of biological treatment technology for the remediation of edible oil effluent

Centre for Water and Wastewater Research, Technikon Natal
(WRC Reference No 1084)

Effluents from the South African vegetable oil industry generally have a high pollutant profile based on their pH and high concentrations of COD, greases and phosphates. The aim of the project is to develop multi-stage anaerobic/aerobic processes to remove COD anaerobically with minimum bio-mass (waste) production, and to remove phosphates aerobically, so as to produce a treated effluent of acceptable quality.

Estimated cost: *R350 000*
Expected term: *1999-2001*

Survey of pesticide wastes in the RSA and a preliminary study of their biodegradation

School of Chemical Engineering, Pollution Research Group, University of Natal
(WRC Reference No 1128)

The increasing use of chemical pesticides poses an ever-growing threat to the aquatic environment, from production, distribution, storage, use and runoff of the toxic compounds concerned. No national database exists in terms of current or potential pollutant discharges to the environment or their aquatic impacts. Disposal methods such as incineration transfer the problem from a solid/liquid context to the atmospheric environment. Diffuse discharges are not quantified, and the life-cycle fate/efficiency of pesticide breakdown in engineered treatment processes or natural ecosystems is not known. This scoping project aims to develop a national schedule of pesticide production, distribution, storage and use and a comprehensive survey of existing technologies providing treatment options for pesticide and associated waste products.

Estimated cost: *R125 000*
Expected term: *2000 - 2001*

Further application and development of pinch analysis for water and effluent management

School of Chemical Engineering, Pollution Research Group, University of Natal
(WRC Reference No 1158)

The City of Durban is proposing a scheme to provide reclaimed wastewater to industrial areas. However, pollutants from certain factories in the area may prejudice the reuse of water by other participating factories. Pinch analysis of the water use of the entire industrial community could make such a scheme workable and beneficial to the whole community by identifying the optimal technical decisions and targets. The expertise developed in this project will be transferred to the wider South African water industry, as a neutral tool that can be used by industry to set targets and to indicate their environmental performance to the public and the authorities.

Estimated cost: *R1 603 000*
Expected term: *2000 - 2002*

Establishment of a methodology for initiating and managing waste minimisation clubs

School of Chemical Engineering, Pollution Research Group, University of Natal
(WRC Reference No 1171)

Waste minimisation (wastemin) clubs are very successful as a model for achieving significant improvements in local environmental performance by industry. In this multi-stakeholder approach, the interests of industry, regulatory authorities and affected communities are constructively combined. The main aim of this follow-up project is to develop a sustainable method of promoting and managing wastemin clubs, by producing, *inter alia*, a guide for effectively establishing and managing wastemin clubs, specific sectoral self-assessment guides, and training for wastemin consultants in a quality-controlled operation.

Estimated cost: *R882 000*
Expected term: *2000-2002*

Effective design of woven fabric microfiltration and tubular filter press technologies for different process applications in South Africa

Umgeni Water
(WRC Reference No 1172)

In this project long-term performance and operating/maintenance considerations of woven fibre-cross-flow microfiltration technology are being evaluated in critical comparative assessment studies being carried out by Umgeni Water and ML Sultan Technikon according to agreed task activities. The programme aims to optimise the tubular filter press (TFP) process and provide least-cost data from pilot-scale studies for dewatering of waterworks sludges on an existing TFP plant, and to compare the results to other full-scale dewatering technologies.

Estimated cost: *R587 000*
Expected term: *2000-2002*

Purification of wastewater with crown ethers and other macrocycles bound to water-soluble and/or elastomeric polymers

Department of Chemistry, University of the Free State
(WRC Reference No 1173)

The technology being investigated involves the development of a ligand system which can be tailored to selectively trap and then release the contaminant ions in high-concentration/low-volume and low-concentration high-volume industrial effluents. The ligand system, consisting of macrocyclic crown ethers, is anchored on a mobile polymer support. Specific technical aims are to modify crown ethers and other macrocycles to permit polymer anchoring; develop a suitable polymeric anchoring carrier; evaluate the polymer-bound macrocycles as cation and anion scavengers of wastewater contaminants; and develop techniques for regeneration of the ligand/polymer matrix.

Estimated cost: *R702 000*
Expected term: *2000 - 2002*

New

Effects of sulphate and pH on hydrolysis of sewage sludge for use in the treatment of acid-mine drainage waters

Dept of Civil Engineering, University of Cape Town
(WRC Reference No 1216)

The Rhodes BioSURE process utilises complex substrates (sewage sludge) as the carbon source for sulphate-reducing bacteria in the treatment of low-pH, high-sulphate, high-volume wastewaters from acid mine drainage (AMD). An essential rate-defining step is the bio-hydrolysis of the complex carbon source to render it available for subsequent bio-reactions. Sulphate, sulphide and pH conditions significantly affect the solids hydrolysis rates obtained. In this project, a systematic experimental protocol is being carried out to quantify and simulate these effects in terms of a calibrated mathematical (differential equation) model.

Estimated cost: *R 250 000*
Expected term: *2001-2002*

Process development and mechanical design to construct and commission a 100 to 1 000 kg industrial bioreactor for mass culturing of UASB

Department of Chemical Engineering, University of Stellenbosch
(WRC Reference No 1239)

Biogranulation (also known as pelletisation) is an important feature of upflow anaerobic sludge blanket (UASB) bioreactors. The physical properties of the biogranules allow a greater upflow velocity, more even substrate distribution, more stable bio-reaction behaviour, and the potential for tailoring bio-processes to produce value-added products from wastewater components. In this project the biogranulation enhancement system established in previous WRC projects is being developed to a larger industrial scale. A direct national economic benefit is to reduce or eliminate the expensive importation of biogranules with possibilities of establishing an export market.

Estimated cost: *R 235 000*
Expected term: *2001 - 2002*

Application of pinch technology in water resource management to reduce water use and wastewater generation for an area

Process Technology Division, CSIR
(WRC Reference No 1241)

The overall objective of this project is to identify and optimise external (inter-operator) water use and reuse-possibilities in a multi-operator study area using pinch technology. Previous studies into pinch have shown that this systematic methodology for optimising the quality-quantity requirements and outputs from a series of water-using

processes on a single site can achieve very meaningful water-saving and economic benefits. This project extends this to a regional scenario incorporating power stations, a petrochemical complex, mining operations, local towns and farms. It is noted that a specific catchment can be targeted which would facilitate the implementation of the catchment management agency approach of the National Water Act.

Estimated cost: *R 281 800*
Expected term: *2001 - 2002*

Simultaneous water recovery and utilisation of two harmful effluents, fly-ash leachate and acid mine drainage, for production of high-capacity inorganic ion-exchange material useful for water beneficiation

Department of Chemistry, University of the Western Cape
(WRC Reference No 1242)

An innovative process scheme is being investigated to recover water and co-dispose of alkaline fly-ash leachate and acid mine drainage (AMD) effluents and produce high-capacity inorganic ion-exchange adsorbate materials. The neutralised water after co-disposal of the fly-ash leachate and AMD is to be recovered by electrodialysis reversal, with recovery also of metal ions, and stoichiometric regeneration of the ion-exchange material by non-chemical means, i.e. without the use of strong acids and bases.

Estimated cost: R 580 000
Expected term: 2001 - 2003

Development of integrated biosorption systems for the removal and/or recovery of heavy metals from mining and other industrial wastewaters, and determination of the toxicity of metals to bioremediation processes

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 1243)

Microbial biosorption of metals and metal toxicology (including inhibition kinetics) in biological treatment systems are of specific relevance to both active and passive bio-treatment processes. These aspects are being investigated in this project, in close collaboration with other research groups studying biological desalination and metal removal processes.

Estimated cost: *R 97 000*
Expected term: *2001*

Novel method for removal of metal ions from acid mine drainage waters and development of a passive aeration system for sulphide and ferrous bio-oxidation

Department of Civil Engineering, University of Cape Town
(WRC Reference No 1244)

This project aims to remove heavy metals from acid mine drainage by precipitation of ferrous and ferric ions as a stable fast-settling ferrous sulphato-hydroxide complex at pH > 6,5 followed by the addition of small amounts of sulphide to form stable metal colloids which can be removed by further precipitation as a well-settling floc which can be easily separated and concentrated (dewatered). A second aspect is to investigate the bio-oxidation of ferrous and sulphate ions using a novel passive aeration / oxidation system to recover sulphur and ferric ions where the latter is employed in sulphur recovery.

Estimated cost: *R 520 000*
Expected term: 2001 - 2002

An investigation of the mechanism and kinetics of bacterial sulphate reduction

Department of Chemical Engineering, University of Cape Town
(WRC Reference No 1251)

In a previous WRC project a basic kinetic model was developed for the use of complex (sewage sludge) organics as carbon substrates for sulphate-reducing bacteria (SRBs) in the remediation of acid mine drainage (AMD) wastes, metal precipitation by the pH-raising properties of algal high-rate ponding systems, and the accelerated hydrolysis of sewage sludge by SRB activity in an integrated process scheme. The present project aims at completing the anaerobic dynamic simulation model to incorporate sulphate / sulphide inhibition and sulphate reduction, and at developing a model for metal precipitation (as sulphides, carbonates and hydroxides) resulting from sulphide and carbonate production in the biological sulphate-reducing process.

Estimated cost: *R 1 146 000*
Expected term: 2001 - 2003

A life-cycle assessment of a secondary water supply

Department of Chemical Engineering, University of Natal
(WRC Reference No 1252)

Life-cycle assessment (LCA) methodology provides a holistic basis for policy-making and decision- taking. In this project, previous work carried out into developing a customised RSA database for various industrial processing activities is being applied to investigate a rational (LCA) approach to options for water supply and wastewater disposal in a coastal RSA city, using Durban as the case study. LCA comparisons are being made of the environmental trade-offs involved in providing secondary (reclaimed) wastewater rather than potable water to industry for processing purposes, and the treatment of wastewater at conventional land-based sewage treatment works as opposed to direct marine disposal.

Estimated cost: *R 1 239 000*
Expected term: *2001 - 2003*

Removal of heavy metals from water by use of biomaterials

Department of Chemical Engineering, Cape Technikon
(WRC Reference No 1259)

This project investigates a technology that seeks to take advantage of the "natural" propensity of certain biological materials (algae, yeast, fungi, etc.) to absorb or otherwise temporarily take up heavy metals at levels much greater than their metabolic requirements for trace elements. The biotechnology "trick" is that the toxic heavy metals can thus be concentrated into a relatively small biomass which can be much more effectively managed in terms of ultimate disposal or even recovery of the heavy metal component(s), thereby reducing the toxic potential threat to receiving water bodies.

Estimated cost: *R 105 000*
Expected term: *2001*

Outcomes to Date of Current Programmes and Projects

New knowledge

Building in some cases on previous research, new knowledge has been generated in the following programmes and projects:

- Algal high-rate oxidation pond technology has been further developed for low-cost treatment of a number of industrial, mining and domestic wastewaters.
- A biological sulphate reduction process (BioSURE®) incorporating also metal precipitation and sulphur recovery, has been developed for treatment of both high-concentration/low-volume industrial effluents and high-volume/low-concentration acid mine drainage. A number of patents have been registered.
- Innovative biotechnological alternatives for bleaching and pulping of wood products have been developed to reduce the harsh chemical use in this industry.
- Techniques for enhancing and accelerating biogranulation (pelletisation) in anaerobic reactors have been developed, with important economic implications for the application of anaerobic treatment in the RSA.
- Bioreactor systems have been developed for converting organic components of toxic industrial wastes to commercially useful products.
- A novel low-cost method for recovering elemental sulphur from high-sulphate industrial and mining effluents has been developed.
- Entrapment and release of cations and anions in macrocyclic ligand systems offers a potentially "clean" treatment / recovery process.
- Pinch technology has been successfully adapted from thermal pinch theory to water pinch in the water-scarce South African situation, offering a powerful demand-management tool.
- The development of life-cycle assessment methodology for application in the South African situation promises to be very valuable in formulating policy and making design decisions.
- Development of the concept and establishment of regional waste minimisation clubs is proving to be a major success story for promoting multi-stakeholder interests in cleaner production in the RSA.

Benefits to South Africa

National benefits deriving from research activities in this field include:

- Technologies and techniques for managing water and waste will assist in economic growth of South African industry in terms of improved cost-competitiveness, environmental performance and sustainability.
- Inputs to national policy development regarding water and waste management and consequent impacts on public health, economic sustainability of industry and legislation/regulation developed at national/local level.
- Reductions in effluents and wastes from industry contribute to an improved quality of life in terms of public health and the aqueous environment.
- Public water resources can potentially be supplemented by renovation of currently unusable effluents from industry and mining for beneficial use.

Innovation/application of knowledge

Knowledge generated through current programmes and projects is already being or will be applied as follows with technical support from the relevant WRC projects:

- The National Waste Management Strategy (DWAF/DEAT) incorporates waste minimisation as a principle and encourages waste minimisation clubs as a vehicle for sustainable cleaner production.
- Four other waste minimisation clubs are being established, three regional (Durban, Johannesburg, Cape Town) and one sectoral (textiles).
- Pinch technology is being progressively applied by industry to optimise water and effluent management (current users include Sasol, AECI, Polyfin).
- Life-cycle assessments are being accepted and adopted by industry, regulators and community organisations as a comprehensive neutral tool for environmental decision-making (current initiatives are City of Durban, SAPPI, Mondi).
- An anaerobic baffled reactor developed for treating toxic high-strength industrial effluent is being evaluated by Business Partners for Development to serve dense informal settlements.
- Biodesalination technology developed in the industrial field is being applied on full scale by ERWAT (accelerated sludge hydrolysis at Ancor Sewage Works) and is under ongoing consideration by the mining industry.
- Biotechnology (bio-pulping and bio-bleaching) alternatives are being considered by the pulp and paper industry for full-scale trial implementation.

Capacity/competence development

Research capacity and competencies have been developed during current WRC-funded projects in the following areas at PDIs:

Technikon Natal	Biosorption (metal-containing effluents); biotreatment (edible oil effluents); molecular biology (activated sludge); modelling (nutrient removal systems)
ML Sultan Technikon	Membrane technology (microfiltration)
Cape Technikon	Biosorption (metal-containing effluents)
University of the Western Cape	Ion exchange; electrodialysis (power generation and mining)

Capacity and competence in this field have also been developed by designated individuals at the following institutions in the research areas indicated:

University of Cape Town	Kinetic modelling, sulphur chemistry, aqueous chemistry, metal precipitation (biological sulphate removal, activated sludge)

University of Natal	Pinch analysis; waste minimisation; life-cycle assessment; anaerobic treatment processes and microbiology; toxicology
Rhodes University	Microbiology, enzymology and process kinetics (biological sulphate reduction); genetic transformations; biosorption of metals; toxicology
University of Stellenbosch	Microbiology and process development of anaerobic treatment processes
University of the Free State	Ligand chemistry; biotechnology for lignin hydrolysis
CSIR, Environmentek	Pinch analysis

Collaborative research activities and skills interchange have been promoted by the WRC among most of the PD and other institutions indicated above. This also extends to the involvement of designated individuals from several commercial organisations engaged in joint research.

Knowledge dissemination

Specific knowledge dissemination activities, in terms of numbers over the last three years from research funded wholly or partially by the WRC in this field, include the following:

Articles		97
Conference presentations:	National International	6 58
Workshops		5
Patents registered	A number of patents have been registered for aspects of the BioSURE® process	

Leveraging of resources

In this field WRC actively encourages the involvement of stakeholders including regulators (national and local), end-users (local industry) and practitioners (consultants, service companies) in research projects. In addition to the technical, funding and in-kind support given towards project execution, a major strategic benefit is technology transfer and ground-truthing during projects.

Over the last three years, local and international contributors of in-kind and funding resources to projects in this field include DWAF; DACST (Innovation Fund); NRF (niche area funding); DTI (THRIP funding); SAPPI; Mondi; Eskom; Anglo Coal; Sasol; ERWAT; Durban Metro; Umgeni Water Board; Linnhoff-March (UK); March Consulting (UK); Paques (Netherlands); DANCED (Denmark); Thermie (EEC).

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Chapter 12

Membrane Technology

Dr G Offringa

Scope

Membrane technology is the application of a positive barrier or film in the separation of unwanted particles, micro-organisms and substances from water and effluents. Also covered in this research field are other technologies for the removal of salts from water, such as ion-exchange and evaporation. Membrane and desalination technologies are increasingly being accepted as cost-effective unit processes for a wide range of applications, including desalination of seawater and brackish water, the purification of surface- and groundwaters for potable use, and for the treatment and reuse of industrial and domestic wastewaters. The scope of the research is aimed at the improvement and application of membranes and desalination technologies from the largest factory to single households. Both technical and social components of research are supported. Multidisciplinary, inter-institutional research and the establishment of an empowered manpower base are assigned high priority. This research field has a high innovation component and both research management style and funding strategy are adapted to accommodate this.

In recognition of its future potential benefits, WRC investment in this, basically single-technology, field of research has been relatively high in the past, as portrayed in Table 1. However, support for this high innovation-oriented sphere of research seems to have been justified. The WRC succeeded in establishing a viable South African membrane-manufacturing and-supply industry, as well as research and development capabilities - also at previously disadvantaged institutions - which can hold its own against the best in the world, while providing for the needs of all of the communities in South Africa.

Links to Key Strategic Areas (KSAs)

Being a technology research field, ***Membrane Technology*** is a crosscutting field, with the following linkages to the WRC's KSAs:

Water Resource Management

The ability of membranes to potentially supplement depleted conventional water sources by supplying coastal cities with desalinated sea water, and to supply communities with potable water from saline and polluted groundwater, impact positively on the management of these sources. Strategic planning is therefore also linked to this KSA.

Water-Linked Ecosystems

Membranes are increasingly being used as best available technology for the removal of toxic and recalcitrant compounds from effluents. Linkages therefore exist with

TABLE 1
Research Funding Investment in **Membrane Technology**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R1 222 800	R1 712 000	R2 634 692	R3 036 700	R3 553 800
% of research fund	3.02%	3.9%	5.0%	4.9%	6.0%

ecological aspects in terms of receiving water quality improvement and integration of related strategic planning.

Water Use and Waste Management

The main application of membrane and desalination technologies falls within this KSA. Strong linkages exist with water and wastewater treatment, community water supply from groundwater and surface water, health-related aspects of water, and the treatment of toxic waste such as leachates from waste dumps.

Water Utilisation in Agriculture

Solar-powered membrane and evaporative-condensing systems are paving the way for increased use of these technologies in the desalination of brackish and seawater for small-scale food production. The reject water from reverse osmosis systems may under certain circumstances be used for irrigation or stock watering. Linkages are still low at present but a significant future requirement is envisaged.

Objectives

The overall goal of research on membranes and desalination technology is to facilitate the development, implementation and use of cost-effective membranes and desalination technologies to purify or treat water for potable use, industrial reuse or the abatement of environmental pollution, to the benefit of all communities, while building an empowered researcher manpower base country-wide.

Main objectives through research include the following:

- The supply of potable water to emerging and established communities;
- Promotion of innovative and technology-driven developments;
- Prevention of environmental pollution, and reuse of water and by-products;
- Development of human resources and research infrastructure; and
- Promotion of the use of membrane and desalination technology.

Research Projects

Completed, current and new projects address the above five objectives directly or indirectly, as outlined below.

Completed

Development of a fabrication protocol for the production of capillary membranes and special modules for the low-cost treatment of contaminated water

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 769)

In this project, the narrow-bore membrane production facilities at the Institute of Polymer Science were extended to include hollow fine-fibre production. A variety of novel developments resulted from the research. A new polysulphone membrane with a spongy structure, and superior strength compared to the previous membrane, was developed and tested. An improved high-speed spinning technique for the production of dense-porous capillary membranes was developed. Further, an adsorptive coating layer was developed which will potentially allow the binding and removal of selected substances from water and effluents when suitable ligands are employed. This principle was demonstrated by the selective removal of bovine serum albumin from abattoir effluent. Module design was improved to allow lower-cost manufacture and simplified maintenance of the modules. In improving the local membrane systems to this extent, this project contributed to the future application of local membranes for affordable community water supply and effluent treatment.

Cost: *R1 407 000*
Term: *1997 - 2000*

Development of a continuous flow membrane bioreactor catalysing the solubilisation of hydrophobic pollutants by rhamnolipid-producing bacteria

Department of Microbiology, University of the Western Cape
(WRC Reference No 846)

The aim of the project was to develop technology for the biodegradation of hydrophobic pollutants by emulsification using a membrane-supported biofilm producing the surfactant rhamnolipid produced by *Pseudomonas aeruginosa*. A number of *P. aeruginosa* producing rhamnolipids were isolated and characterised. Whereas *P. aeruginosa* does grow to some extent on the capillary membranes, growth was not satisfactory. The amount of rhamnolipids produced by biofilm-growing cells was higher than that produced by cells growing in suspension. Attempts at constructing a genetically modified strain over-producing rhamnolipids have not succeeded to date. Production of rhamnolipids by suspended batch culture was successful, and does not require intricate technology or expensive substrates. Although not all aims could be achieved, the project was successful in that methodology developed to immobilise cell cultures onto membranes are currently being used successfully in a number of membrane bioreactor studies in other institutions in the country.

Cost: *R176 000*
Term: *1997 - 1999*

The use of tolerant membranes for preparing drinking water as well as for water reuse, using solar power and electro-induced driving forces

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 852)

The project aimed to design and prepare novel electrode materials for the electrocatalytic oxidation of recalcitrant organic pollutants in water, by optimising the .OH radical production electrochemically. This included the preparation of novel coated SnO_2 sol-gel layers and the development of a solid polymer electrolyte (SPE) reactor. Good progress was made in improving on the current electro-combustion technology for the electrolytic oxidation - and thus removal - of pollutants in water and effluents. Novel coating materials were implemented and a solid polymer electrode was successfully developed (which allows electrolytic combustion of pollutants without needing to add conductive salts to the water or effluent). The research performed to date is still fundamental and scale-up and engineering studies still need to be performed in follow-up studies.

Cost: *R928 000*
Term: *1997 - 2000*

Transverse-flow module fabrication technology development

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 931)

The aim of this project was to develop transverse-flow membrane bioreactors useful for the small-scale point-source treatment of biodegradable effluents, the production of enzymes for the treatment of non-biodegradable obnoxious effluents or contaminated soil, or the biotransformation of objectionable species in effluents into useful products. The project managed to develop various experimental membrane contactors for use in bioreactor application studies. Most of the work concentrated on the development of suitable membranes and techniques to improve gas transport into and out of water. A series of mass transport correlations were established to quantify oxygen transport into and out of water as well as carbon dioxide transport into and out of water. A centrifugal casting technique was developed to produce transverse-flow membrane modules. Double-skinned polysulphone capillary membranes were developed and found to yield better gas transfer than skinless membranes. By using an ethanol-based drying technique, the mass transfer capability of the membranes could be improved further. As part of the project, a cross-flow membrane configuration was also developed, which included the development of new materials required for the reactor.

Cost: *R308 000*
Term: *1998 - 2000*

Implementation of membrane cleaning and pretreatment techniques for membranes fouled during the filtration of pulp and paper effluent

Department of Biochemistry, University of Stellenbosch
(WRC Reference No 1035)

The project aimed to evaluate the feasibility of membrane pretreatment techniques in the treatment of pulp and paper effluent in parallel to an existing membrane treatment plant. This research project contributed to the understanding of organic fouling of hydrophobic membranes. A number of fundamental laboratory analyses and other techniques were developed or refined. A step forward was made in understanding and solving the very difficult problem experienced with the fouling of membranes used in pulp and paper mills to assist in the closing of their water cycles. For this specific paper mill the study ensured that their membranes could be utilised more effectively and that the goal of a zero effluent discharge will now be reachable within the next few years.

Cost: *R123 000*
Term: *1999 - 2001*

Current

Designed functionalised polymers by anionic macromolecular engineering for membrane development

Department of Chemistry, Vista University (Port Elizabeth Campus)
(WRC Reference No 723)

In order to render the locally developed ultrafiltration membranes less fouling, the surface of the membrane has to be made more hydrophilic. Hydrophilic surface active groups have been grafted onto the membrane surface in a patented process and initial studies prove to be a significant improvement in hydrophilicity.

Estimated cost: *R476 335*
Expected term: *1995 - 2001*

Water desalination and clarification by electronically enhanced membrane defouling

Mineral Water Development (Pty) Ltd.
(WRC Reference No 930)

Monitoring of fouling and cleaning of membranes using non-invasive techniques are being investigated, using a novel South African membrane system. Ultrasonic wave deflections from the fouling layer are showing some success in both monitoring of fouling as well as removal thereof.

Estimated cost: *R405 209*
Expected term: *1998 - 2002*

Development of a "defouling on demand" strategy for the operation of bio-active membranes

Department of Biochemistry, Rhodes University
(WRC Reference No 932)

An inactive enzymatic oxidant is coated onto a clean membrane surface. After some fouling, the oxidant is activated, thereby breaking up the fouling layer from the inside and restoring membrane flux. Application is seen in both potable water and effluent purification.

Estimated cost: *R389 000*
Expected term: *1998 - 2000*

Electromembrane reactors for desalination and disinfection of aqueous solutions

Department of Chemistry, University of the Western Cape
(WRC Reference No 964)

Novel catalyst-impregnated ceramic membranes are used to break down pollutants

electrocatalytically. A flat-sheet format bench-scale unit is showing considerable success on polluted surface waters containing recalcitrant organic compounds.

Estimated cost: *R834 786*
Expected term: *1998 - 2000*

Capillary ultrafiltration membrane process systems R & D

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 965)

Improvements are being made to the membrane materials and system hardware of the locally-developed capillary membranes as precursor for both potable water production to small communities and for effluent treatment. Both efficiency of treatment and cost factors are being addressed in order to make the systems even more cost-effective.

Estimated cost: *R1 245 000*
Expected term: *1998 - 2001*

Microbiological assessment of membrane technology in water treatment

Biological Sciences, ML Sultan Technikon
(WRC Reference No 1034)

The integrity of locally manufactured membranes is being evaluated for the rejection of micro-organisms in potable water production for small communities. A protocol for the correct operation to safeguard end water supply in terms of microbiological quality is also being compiled.

Estimated cost: *R683 000*
Expected term: *1999 - 2001*

Electrochemical generation of high-concentration ozone in compact integrated membrane systems

Department of Chemistry, University of Stellenbosch, and Dinax Technologies cc
(WRC Reference No 1071)

Membranes which have been impregnated with metals and other conducting materials are being used to manufacture high-concentration ozone for the disinfection and treatment of water and effluent. Ozone of double the concentration of current systems is being produced, which will increase the efficiency of oxidation of recalcitrant organic substances significantly.

Estimated cost: *R809 000*
Expected term: *1999 - 2001*

Development of environmentally friendly bio-polymeric heavy metal adsorbing membrane materials for industrial wastewater treatment

Department of Chemical and Mineral Engineering, Potchefstroom University for CHE
(WRC Reference No 1072)

Chitosan, derived from chitin (e.g. from crayfish shells) is being formed into pellets or membranes for the adsorption and removal of heavy metals from effluents. Sourcing of local shells and the local manufacturing of chitosan is part of the scope of the project.

Estimated cost: *R894 000*
Expected term: *1999 - 2002*

Development of a novel membrane photobioreactor for the production of algal toxins

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 1103)

A locally developed capillary membrane system is employed to cultivate algal toxins using a patented "gradostat" technique. In the membrane reactor, algae are put under varying degrees of stress to ensure the production of algal toxins. Algal toxins are required world-wide for water treatment and health-related experimentation purposes but are not freely available because of inadequacies of current production methods and concomitant high price.

Estimated cost: *R81 000*
Expected term: *2000*

Development of a membrane bioreactor system using the white-rot fungus Trametes versicolor for bioremediation of industrial wastewater

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 1129)

The use of a white-rot fungus in combination with a membrane is being investigated for the breakdown of phenolic organics in petroleum and pulp and paper effluents. These effluents are difficult to treat with conventional methods. The scale-up of a laboratory unit and technology transfer to the relevant industries are included in the scope of the project.

Estimated cost: *R533 000*
Expected term: *2000 - 2002*

Effluent harvesting and detection of steroidogenic agents by affinity separation

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 1165)

Chemical groups are being grafted (reversibly) onto existing locally manufactured membranes. These chemical groups ("ligands") are chosen such that various wanted or unwanted components could be removed from the water or effluent selectively. A part of the project is aimed at producing an analytic tool for the analysis of oestrogenic compounds in water making use of this principle.

Estimated cost: *R1 560 000*
Expected term: *2000 - 2002*

Visualising the effects of electro-magnetic and turbulence defouling techniques in membrane modules

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 1166)

Mathematically-manipulated ultrasonic wave deflection is being utilised to "visualise" the fouling layer thickness and character on the surface of a membrane. Simultaneously, membrane cleaning effects of ultrasonication are being investigated. This technology is showing significant potential and will be the subject of international co-operative research under the Penta-party agreement with America, Germany, The Netherlands and Australia.

Estimated cost: *R992 000*
Expected term: *2000 - 2002*

Development of electrodialysis and reverse osmosis process technology for the treatment of hazardous municipal leachates

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1167)

The study evaluates the use of nanofiltration and reverse osmosis membranes in conjunction with electrodialysis for the treatment of varying concentrations of leachates from municipal waste sites. Pretreatment options are included and the novel South African anti-fouling membrane is also being assessed.

Estimated cost: *R630 000*
Expected term: *2000 - 2001*

New

Technical and social acceptance evaluation of a novel microfiltration and ultrafiltration membrane system for potable water supply to rural and remote communities

Chris Swartz Water Utilization Engineers
(WRC Reference No 1227)

The project entails the evaluation of locally developed membrane systems for the production of potable water for small communities from a variety of surface water qualities found in South Africa. The evaluation will be performed using both ultrafiltration and microfiltration mobile treatment systems. Guidelines for the application of these membrane systems to specific surface water qualities will be drafted. The project scope includes operational guidelines for potential users as well as the establishment of social acceptance factors of the technology with rural communities.

Estimated cost: *R556 000*
Expected term: *2001 - 2004*

Guidebook for alternative small-scale desalination technologies for potable household water augmentation in South Africa

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 1228)

This project aims to evaluate small-scale water purification technologies for potable water supply to farms, schools, clinics and small communities from brackish surface water sources. The report will be produced in the form of a guide to assist decision makers in the selection of these technologies. Both membrane-and distillation-based technologies are being assessed, mostly in terms of a desk study. Recently developed local innovations will be included into this guide.

Expected term: *2001 - 2003*
Estimated cost: *R215 000*

On-line removal of organic foulants from membranes by use of ultrasonication

Department of Chemical Engineering, University of Stellenbosch
(WRC Reference No 1229)

The fouling of membranes treating water which contains organic pollutants remains a serious problem limiting the free use of membranes in these applications. The aim of the project is to study the feasibility of the use of ultrasonic waves for the on-line prevention and/or removal of organic foulants from membranes used in various potable water and industrial effluent treatment applications. The study will mostly deal with fundamental aspects on a laboratory scale, but configurations for the best use of ultrasound energy in membrane defouling and the use of novel, simple and effective ultrasound generators will also be investigated.

Estimated cost: *R286 500*
Expected term: *2001 - 2003*

Evaluation of nanofiltration for the treatment of rural groundwater for potable use

Department of Chemistry, Potchefstroom University for CHE
(WRC Reference No 1230)

High nitrate concentrations are prevalent in groundwater from various parts of the country. High nitrate-containing groundwater which is consumed by babies can lead to a blood illness methemoglobinaemia, or so-called "blue baby" syndrome. This project aims to evaluate various nanofiltration membranes for the removal of nitrates (and other unwanted salts, such as sulphates and bromides) from groundwater used for community water supplies in the North West Province.

Estimated cost: *R178 000*
Expected term: *2001 - 2002*

Membrane reactor for the electrocatalytic minimisation of organic matter in water and effluents

Department of Chemistry, University of the Western Cape
(WRC Reference No 1231)

Novel proton-conducting ceramic membranes for the oxidation of recalcitrant organic material in water have been developed at the University of the Western Cape. Initial laboratory studies show good promise. The aim of this project is the further development and improvement of these membranes. Prototype membranes will be evaluated on organics removal from a selection of possible effluents, such as Cape surface water, textile, power station and petroleum effluents. The scope includes the construction of a small pilot plant from which large plants could be upscaled.

Estimated cost: *R422 000*
Expected term: *2001 - 2003*

Development of a reverse-flow microfilter

Department of Chemical Engineering, ML Sultan Technikon
(WRC Reference No 1232)

A novel idea is being evaluated whereby the woven fibre "fire hose" microfilter, previously developed by the University of Natal, is being modified to allow sucking water and effluents from the outside inward in the purification process. This simple microfiltration system could be much more cost-effective than similar current systems. Studies up to bench-scale level on high-turbidity water, low-turbidity water and a gelatinous effluent are being performed. Preliminary costs are to be estimated.

Estimated cost: R194 000
Expected term: 2001 - 2003

Hydrophilisation of hydrophobic ultrafiltration membranes

Institute for Polymer Science, University of Stellenbosch
(WRC Reference No 1268)

The locally manufactured polysulphone capillary membranes are normally hydrophobic in nature. Although these membranes are very inert, they are also prone to fouling. The aim of this project is to improve these membranes with regard to their fouling propensity. Various techniques are being followed to modify the membrane surface characteristics in order to make this membrane less fouling and more competitive internationally in both water and effluent purification applications.

Estimated cost: *R650 000*
Expected term: *2001 - 2004*

Outcomes to Date of Current Projects

New knowledge

The following new knowledge has been generated to date by the current projects portfolio:

- A simple and robust "fire hose" type of microfilter has been developed for the filtration of water and effluents and for the dewatering of sludge. A new innovation (patent pending) will allow these tubes to be simply immersed in surface water or effluent dams and purify the water or effluents at low cost.
- A new method has been developed to make polysulphone membranes more hydrophilic and therefore less fouling. The method has been patented.
- Both polymeric and ceramic membranes have been developed for the electrocatalytic breakdown of organic pollutants in water. This technology has also been patented.
- An ultrasonic-based method has been developed to monitor the fouling layers on the surface of a membrane in a non-invasive way. A patent is pending. Ultrasonication combined with backflushing has shown considerable promise in cleaning fouled membranes.
- A new, enzymatic, method has been developed and patented to break up fouling layers on a membrane from the inside, as and when required.
- Numerous improvements have been made to the locally developed capillary membrane materials and systems to enable the successful commercialisation of these systems for water and effluent treatment.
- Solar-powered membrane and distillation systems have been shown to be viable possibilities for water supply of small communities from salty water sources
- Microbiological integrity evaluations of the locally produced capillary membranes provided important information on shortcomings of the membrane systems and led to necessary improvements to ensure safe potable water production.
- Computational fluid dynamics analyses of membranes resulted in improved cost efficiency of locally produced membrane systems.
- A novel membrane bioreactor system, containing tailor-made membranes, has been developed which utilises micro-organisms for the production of valuable compounds, such as water treatment oxidants, enzymes, algal toxins for experimental purposes, etc. The principle has been patented.
- Valuable information has been obtained on the efficacy of membranes for the removal of contaminants such as nitrates, fluorides and sulphates from groundwater used for potable water supply.
- Knowledge gathered on the possible purification and reuse of caustic effluent in industry using membranes is showing good potential.
- Invaluable knowledge was also obtained on the prevention of fouling of membranes used in the treatment of paper effluent and the enzymatic cleaning of these membranes.
- A method has been developed to graft active groups onto a membrane system with the potential to "catch" specific wanted or unwanted substances from the water or effluent being filtered. Although the application is novel, the method could not be patented since it is being used in certain analyses.
- Membrane treatment methodology is being developed which may lead to solving the problem of disposal of hazardous leachates from municipal waste sites.

Benefits to South Africa

Benefits accruing to South Africa from projects in this field include the following:

- Improved capabilities to manufacture local membrane materials and systems, leading to significant future import replacement and export possibilities;
- Improved health of communities through both improved water treatment as well as effluent treatment and pollution prevention; and
- Savings of water through internal reuse and the recycling of wastewater.

Innovation/application of knowledge

Application of knowledge from projects in this field includes the following:

- The capability to supply safe water to rural and small communities is being established through a number of innovative and cost-effective membrane and desalination technologies developed under WRC funding. These technologies are already able to supply potable water from microbiologically and chemically contaminated groundwater and surface water. A few membrane and distillation plants have been constructed and are producing water for small communities.
- Novel membrane bioreactors, utilising a variety of possible micro-organisms, are being developed which have the capabilities to:
  - Treat toxic and recalcitrant effluents;
  - Treat contaminated surface waters to potable quality; and
  - Produce useful products (a licence has recently been granted by the WRC to a private company for the manufacture of high-value enzymes for export).

  However, the developments are currently only at bench-scale and pilot-plant stage and demonstration and full-scale applications have yet to take place.
- Research on membrane fouling prevention and de-fouling techniques is being applied at the paper mill where the investigations were done and results will also be made available for other paper mills. The study resulted in the virtual closing of the water cycle of this mill and

a significant lowering of the pollution load to the environment.

- The innovative ultrasonic monitoring and cleaning techniques being developed show good potential to expand the practical use of membranes to a range of new applications - especially for wastewater treatment. Capital costs will be lowered significantly because of the higher fluxes achievable. Practical application is, however, some years away.
- The application of membranes for the removal of contaminants such as nitrates, fluorides and sulphates from groundwater used for potable water supply has been established. Two reverse osmosis pilot plants purifying non-potable groundwater to potable standards for water supply to small communities in the Northern Province have demonstrated the sustainability of these systems. Such plants will contribute significantly in lowering deaths by "blue baby" syndrome (methemoglobinaemia), as well as reducing teeth and bone fluoridosis.
- Patents registered: 12, nine of which are owned by the WRC.
  Three patents on membrane materials, systems and a new membrane bioreactor configuration were registered by IPS, Stellenbosch University. A patent on the modification of membrane surfaces to reduce fouling was registered by UNISA. Three patents on functionalised ceramic electromembranes were registered by the University of the Western Cape. Two patents on operation and cleaning of membrane bioreactors were registered by Rhodes University. One patent on the use of powdered activated carbon with the local hose-type microfilter has been registered by ML Sultan Technikon. Two patents have been provisionally registered on a new immersed membrane system developed by IPS, Stellenbosch.
- Licensing of patent: A licence was granted to a private organisation, Helix Biotechnology, to produce high-value enzymes using a WRC patent on membrane biotechnology developed at the Universities of Rhodes and Stellenbosch. A potential exists for an income to the WRC of a few hundred thousand Rands per year within the next four years.

Capacity/competence building

One of the more significant benefits achieved from this research is the capacity and multidisciplinary team-building which resulted from the multi-institutional co-operation during research execution. Under this current suite of projects capacity and competency in membrane and desalination technologies are being built at 13 tertiary and other research institutions. In close co-operation with the Eskom Tertiary Education fund for membrane bioreactors, the WRC funding in this field succeeded in bringing new researchers from the Cape Peninsula, Northern Gauteng, ML Sultan and Vaal Technikons into contact with various aspects of membrane research at established institutions.

Details concerning the building of individual capacity are as follows:

ML Sultan Technikon	M.Tech. awarded or in progress (6 Black/Indian males;2 females)	8
	B.Tech. awarded or in progress (11 Black/Indian males; 5 females)	16
University of Potchefstroom	M.Sc. awarded or in progress (1 Black male;1 White female)	2
	Ph.D. (1 White male)	1
Rhodes University	M.Sc. awarded or in progress (1 Black female; 1 White female)	2
	Ph.D. awarded or in progress (1 Coloured male)	1
Univ of Stellenbosch	M.Sc. awarded or in progress (1Coloured male;1Black female; 2 White males)	4
	Ph.D awarded or in progress (1 Coloured female;1Black male; 1 White male)	3
Univ of the Western Cape	M.Sc awarded or in progress (2 Black females;1Black male)	3
	Ph.D. awarded or in progress (1Black male and 1White male)	2
UNISA	M.Sc. awarded or in progress (4 Black males)	4
	Ph.D. awarded or in progress (2 Black males)	2
Technikon N. Gauteng	B.Tech. awarded or in progress (2 Black males)	2
Vaal Triangle Technikon	B.Tech awarded or in progress (1 Black male)	1
Cape Technikon	B.Tech. awarded or in progress (4 Coloured males)	4

Knowledge dissemination and patents

Specific knowledge dissemination, in terms of numbers over the last three years, includes the following:

Articles and papers	Peer-reviewed:	29
	Not peer-reviewed:	7
Conference presentations	International	*28*
	National	43

Leveraging of resources

- R590 000 from Eskom over the past three years for membrane research on ceramic membranes at the University of the Western Cape. The money feeds into the research programme being executed for the WRC but the money is paid directly to the project leader.
- R300 000 from various industries towards membrane development at ML Sultan Technikon.
- R160 000 from McCracken Solar Stills as their contribution toward a project being funded by the WRC to the value of R215 000.
- NRF funding is also received for some projects, R700 000 for ML Sultan Technikon and approximately R300 000 estimated for the membrane projects at all of the other institutions.

International linkages

A formal agreement has been signed in Berlin recently between water research institutions of five countries to perform co-operative research on membrane development for potable water production. This “Penta-party” agreement was signed between the WRC and the American Water Works Association Research foundation, the German Technologiezentrum Wasser, the Australian Cooperative Research Centre for Water Quality and Treatment, and KIWA Research and Consultancy from The Netherlands. The objective of the agreement is to promote the planning and execution of co-ordinated water research on selected issues.

Links have also been established with acknowledged Spanish, Finnish and French membrane research institutions who will assist with equipment building and student training, whereas joint research is planned between South Africa and the French institution.

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Chapter 13

Hydroclimatology

Dr GC Green

Scope

Hydroclimatology is defined by the WRC as an atmosphere-related science and technology in service of the water industry and the community of water users. To accomplish this, hydroclimatological research is programmed to contribute to the more efficient, effective and economical assessment, management, augmentation and utilisation of water resources. Together with its sister disciplines, geohydrology and surface hydrology, which similarly aim to serve the water industry and the community, hydroclimatology completes the list of disciplines needed for characterising the all-important hydrological cycle and quantifying associated water budgets at regional, country, catchment and field scales.

The scope of the field in terms of the percentage of WRC research funds utilised has varied, as shown in Table 1. In 1997, during the final year of the rainfall enhancement research programme, expenditure was a relatively high 7.8%. It subsequently declined sharply to 4.4%, whereafter there has been steady growth to the current stable level of around 6%, which currently supports 18 projects. Despite this relatively modest investment, the WRC has emerged as a major supporter of atmospheric science in South Africa, as shown in the most recent South African report to the world's earth science community. While small in number, researchers in this field in South Africa have strong international links, which is to be expected in bringing an essentially global science to bear on national concerns relating to climate and water resources.

Links to Key Strategic Areas (KSAs)

Hydroclimatology is a strongly crosscutting field with clear links to the following of the WRC's key strategic areas (KSAs):

Water Resource Management

With rainfall being the primary input into South Africa's water budget, the ability to monitor, characterise, predict and, when necessary, to augment rainfall, with sufficient precision and at appropriate space and time scales, is crucial for water resources assessment and decision-making.

Water-Linked Ecosystems

Being sensitive to environmental changes, ecosystems can be expected to be impacted severely by extreme climate events as well as systematic trends in climate. Many fundamental ecosystem processes are weather- and climate-dependent and could not be adequately modelled without an understanding of

TABLE 1
Research Funding Investment in **Hydroclimatology**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 170 023	R2 136 985	R2 309 400	R3 314 000	R3 643 800
% of research fund	7.8%	4.8%	4.4%	5.3%	6.2%

the relationships and dependencies on the atmospheric/environmental energy and water balances.

Water Use and Waste Management

All water uses in which atmospheric-driven evaporation and transpiration processes are significant factors (most consumptive uses) can only be managed adequately if these processes and how to manipulate them beneficially are properly understood.

Water Utilisation in Agriculture

With climate both governing water supply and dictating water demand in agricultural and forestry production, most sound management decisions are compelled to incorporate hydroclimatic considerations.

Objectives

Primary

To acquire adequate understanding of atmospheric processes and develop appropriate atmosphere-based technologies needed for the satisfactory assessment, management and augmentation of South Africa's water resources.

Secondary

- The acquisition of adequate understanding of:
  - The statistical nature of climate variability (especially precipitation variability) over space and time; including inter-scale relationships;
  - Mechanisms governing climate variability;
  - Human influences on atmospheric processes and climate change; and
  - Mechanisms associated with precipitation and evaporation.
- Development of appropriate techniques, technologies and systems for:
  - Climate monitoring (mainly precipitation and evaporation monitoring);
  - Climate information management (both real-time and archived information);
  - Expressing space-time characteristics of precipitation;
  - Inferring past and predicting future climate variability and change; and
  - Sourcing additional quantities of atmospheric water (e.g. precipitation enhancement and fog collection).
- Integration of atmosphere-based technologies into specific procedures or programmes for water resource assessment and management.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

An integrated radar-based precipitation observing system for the Vaal Dam catchment to facilitate water resource operations and research

METSYS, SA Weather Bureau, Department of Environmental Affairs and Tourism
(WRC Reference No 954)

Real-time access to appropriate data is necessary for many water resource management applications. Data on areal rainfall data have traditionally not been available in real time, either in the Vaal catchment or anywhere else in South Africa, where rainfall has been monitored primarily using widely-spaced rain gauges. The Vaal Dam catchment, having three meteorological radars in addition to the conventional rain-gauge network, lent itself to an investigation into the feasibility of establishing a real-time rainfall monitoring and reporting system which, if successful, could serve as a prototype for country-wide application. To accomplish this, it was necessary to refine radar-based techniques for areal rainfall measurement previously developed using the MRL-5 S-band radar and other infrastructure at Bethlehem and to extend the techniques to other radars (SAWB Enterprise C-band radars at Bethlehem and Ermelo) in the catchment. Further objectives were to develop communication systems for real-time transmission of radar data to a central location (Bethlehem) and to standardise data-formatting systems and storm-tracking (TITAN) software, to facilitate radar networking and merging of radar data. Numerous radar rain-gauge comparative studies revealed strengths and weakness of the respective measuring systems in relation to rainfall types (convective, stratiform) and spatial distribution. Refinements in radar signal processing methodologies (e.g. distinction between hail and rain, overcoming bright-band distortions, etc) were made and protocols developed for optimal merging of rain gauge and radar data and providing rainfall maps on the Internet in real time.

Cost: *R1 662 341*
Term: *1998 - 2001*

Real-time flood forecasting model using radar and satellite data

School of Civil Engineering, University of Natal
(WRC Reference No 1005)

This project was undertaken in response to an urgent need to put in place improved, efficient and easily-calibrated flood forecasting systems in order to anticipate serious, life and property-threatening flooding. These improved systems need to have the capacity to use powerful new data sources (radar, satellite) to supplement rain-gauge data. This proposal aimed to provide a model shell which can be used for testing model constituents and training hydrologists in the area of flood forecasting, using modern technology and new data sources. To facilitate automation and ease of calibration, faster running and real-time use in flood forecasting, the focus was on the transfer type of model rather than the conceptual/physical type. The project succeeded in this aim. It

delivered such a computer-based streamflow forecasting model shell, together with a linear transfer function model which, in operation, is very fast, readily updateable using real-time streamflow data, robust in calibration and exploits the data-dense information from weather radar measurements to maximise the advantage of forecasting future flows in problem rivers. The model shell has been installed in the offices of Umgeni Water and in Durban Metro's Flood Management Centre.

Cost: *R200 000*
Term: *1999 - 2001*

Space-time modelling of rainfall using the string of beads model: integration of radar and rain gauge data

School of Civil Engineering, University of Natal
(WRC Reference No 1010)

The manner in which rainfall gets distributed in time and space is a complex process, as observers of thunderstorm behaviour will know. Previous research had utilised radar images of rain-fields to show that within this apparently chaotic, turbulent behaviour, there exists a simplifying structure which can be exploited to model the main features of rain falling over space and time. A preliminary space-time rainfall model was consequently developed to produce simulated, sequential, radar-images for a given area of land. This project aimed to further develop the model (String-of-Beads) to fulfil a pronounced need for such a tool in flood management as well as in land-use planning and hydraulic engineering design. This aim was achieved, with considerable refinement in model parameterisation and calibration procedures. For example, calibration is possible using radar alone, rain gauges alone, or a combination of these measuring systems. The model may be used to statistically summarise large numbers of radar-rainfall images to produce a radar-rainfall climatology of an area and to stochastically generate (simulate) valid long sequences of spatially distributed rainfall for water resource studies. Short-term rainfall forecasts (one to two hours ahead) for use in real-time flood management is a further possible application.

Cost: *R200 000*
Term: *1999 - 2001*

Current

Acquisition of off-shore marine sediment samples for palaeoclimatic and hydrological record reconstruction

Climatology Research Group, University of the Witwatersrand
(WRC Reference No 804)

Core samples of marine off-shore sediments have been obtained and are undergoing analyses with the objective of reconstructing SA hydroclimatological records for the period preceding historical observations. Extension of records in this way is necessary to develop a realistic perspective on issues of climate change and climate variability as they might impact on South Africa's water resources in future decades.

Estimated cost: *R140 000*
Expected term: *1997 - 2001*

Modelling variability in the Agulhas Current system and its influence on South Africa's climate

Department of Oceanography, University of Cape Town
(WRC Reference No 868)

Globally and regionally, ocean processes have an enormous impact on local weather and climate through exchanges of heat and water vapour. The Agulhas Current, being one of the world's major boundary current systems, is being investigated with the assistance of ocean circulation models to establish its sensitivity to various forcing factors and its influence on atmospheric circulation with a view to better understanding and predicting its impact on rainfall conditions over the SA subcontinent.

Estimated cost: *R621 000*
Expected term: *1997 - 2002*

Development of optimum statistical long-range forecast models of summer climate and hydrological resources over Southern Africa

Department of Geography, University of Zululand
(WRC Reference No 903)

The final stage in the development of statistical forecast models for predicting summer rainfall and streamflow using optimally selected atmospheric and oceanic predictors is the subject of this project. It is simultaneously evaluating such models and strengthening competencies in their use.

Estimated cost: *R560 000*
Expected term: *1998 - 2002*

Seasonal climate predictions with a coupled atmosphere/ocean general circulation model: A contribution to water resource management over Southern Africa

Department of Civil Engineering, University of Pretoria
(WRC Reference No 904)

Ultimately, the key to better seasonal climate forecasts for management purposes lies in an improved understanding of coupled ocean-atmosphere processes as captured in models, operating at the global scale, which interactively drive nested models cascading through regional and ultimately catchment scales. This project represents a major collaborative initiative with the CSIRO in Australia aimed at coupling leading global atmospheric and ocean models, with the emphasis on those ocean areas which are meaningful for Southern Hemisphere climate; and using the model outputs to improve forecasting skills.

Estimated cost: *R252 000*
Expected term: *1998 - 2001*

Aerosols, recirculation and rainfall experiment (ARREX)

Climatology Research Group, University of the Witwatersrand
(WRC Reference No 938)

Through a programme of airborne sampling various seasonal and atmospheric chemical and microphysical data have been collected which are now being analysed with a view to establishing whether transport and recirculation of long-lived, fine-fraction atmospheric aerosols, over South Africa and adjacent areas, may create conditions

favouring a long-term diminution of rainfall over the region.

Estimated cost: *R1 390 000*
Expected term: *1998 - 2002*

The ocean's role in South Africa's rainfall
Department of Oceanography, University of Cape Town
(WRC Reference No 953)

The investigation of ocean processes impacting on South Africa's rainfall is being assisted through development of satellite-remote-sensing methodologies, firstly to observe, study and monitor the hydrological cycle from ocean evaporation to advection of water vapour over South Africa and secondly to further elucidate mechanisms causing sea surface temperature (SST) variability in those regions where SST anomalies are linked to drought in South Africa.

Estimated cost: *R1 395 000*
Expected term: *1998 - 2002*

Short-term weather forecasting techniques dedicated to flood management systems
Chair of Meteorology, University of Pretoria
(WRC Reference No 1011)

Short-term river flow forecasting is crucial for flood management, but to be useful, river flow models need to be driven by accurate, quantitative rainfall forecasts up to 2 days ahead, continuously verified by areal rainfall measurement in the catchment. This project examines the feasibility of producing quantitative rainfall forecasts for introduction into comprehensive real-time river flow forecasting systems.

Estimated cost: *R239 000*
Expected term: *1999 - 2002*

Climatology of water vapour sources, sinks and transport in Southern Africa
Department of Environmental and Geographical Sciences, University of Cape Town
(WRC Reference No 1012)

To be relevant and useful within the context of climate forecasting, atmospheric models have to be able to accurately represent (simulate) flows of water vapour over Southern Africa. This project uses all available data and especially developed trajectory models to establish a unique and important climatology of water vapour sources, sinks and pathways which will be used to further elucidate rainfall processes over Southern Africa and to serve as a diagnostic frame of reference for analysing the performance of regional atmospheric models.

Estimated cost: *R562 000*
Expected term: *1999 - 2002*

Reconstruction of long-term, high-resolution records of summer rainfall and its variability on South Africa from cave speleothems
Department of Archaeology, University of Cape Town
(WRC Reference No 1013)

As a further contribution to climatic record reconstruction, cave speleothems in the Northern Province have been sampled and are being analysed in order to establish long-term changes in moisture availability, temperature, rainfall and vegetation responses. Unprecedented temporal resolution (subdecadal or 5-year time scales) appears achievable using this technique.

Estimated cost: *R 375 000*
Expected term: *1999 - 2002*

Spatial interpolation and mapping of rainfall: Maintenance and upgrading of radar and rain-gauge infrastructure
SA Weather Services
(WRC Ref No 1151)

This project addresses the needs for the upgrading, networking, maintenance and operation of existing weather radars in order to render them suitable for routine, precision rainfall measurement in addition to their intended usage for severe weather warning purposes. The project also addresses the need for supporting rain-gauge networks required for radar calibration.

Estimated cost: *R1 647 000*
Expected term: *2000 - 2002*

Spatial interpolation and mapping of rainfall: Radar and satellite products
Meteorological and Technology Systems, SA Weather Bureau
(WRC Reference No 1152)

This project contributes to the programme by refining and extending procedures whereby radar and satellite signals are converted into best possible rainfall measurements in areas of radar and satellite coverage. Special procedures and algorithms are being developed in order to reduce the effects of "noise" superimposed on the rainfall signals, thereby enhancing data reliability.

Estimated cost: *R318 000*
Expected term: *2000 - 2002*

Spatial interpolation and mapping of rainfall: Optimal integration of rain-gauge, radar and satellite-derived data in the production of daily rainfall maps
Department of Civil Engineering, University of Natal
(WRC Reference No 1153)

This project optimises the merging of data from different rainfall data sources (point data from rain gauges and spatially distributed data from radars and satellites). Merging (integration) procedures take into account that there will be instances where availability and/or reliability of data from some sources are greater than from others, and that data selection should be preferentially based on reliability and requirements for best spatial and temporal resolution.

Estimated cost: *R270 000*
Expected term: *2000 - 2002*

Dynamical modelling of present and future climate system variability at inter-annual and inter-decadal time scales
Department of Environmental and Geographical Sciences, University of Cape Town
(WRC Reference No 1154)

Outputs from general atmospheric circulation or global climate models must be "downscaled" before results can be meaningful for prediction of impacts of climate change at regional or catchment scale. This project continues to investigate, and build capacity in the nested use of global and regional-scale dynamic atmospheric models for downscaling purposes in order to complement and refine empirical techniques already developed and in use. It does not

attempt to refine regional models, developed overseas, for South African conditions.

Estimated cost: *R1 616 000*
Expected term: *2000 - 2003*

Development of an improved gridded database of annual, monthly and daily rainfall

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1156)

The gridded (one minute by one minute) database of monthly and daily rainfall produced in 1987 is being updated to accommodate all recent data. In the process, refined methods of data infilling and extension are being used, revised maps of rainfall statistics are being produced and automated input into simulation models is being provided for.

Estimated cost: *R 2 277 600*
Expected term: *2000 - 2002*

New

Caledon River catchment rainfall data linked with streamflow data

Eskom
(WRC Reference No 1199)

An existing research programme on real-time spatial interpolation and mapping of rainfall addresses the infrastructural needs of a national real-time daily rainfall monitoring and mapping system, the refinement of radar and satellite rainfall-estimation technologies, and the merging of rain-gauge, radar and satellite data to provide the best possible integrated product from the point of view of resolution (both spatial and temporal) and reliability. The programme also makes provision for pilot applications of the real-time spatial rainfall outputs, in order to test and demonstrate their efficacy and promote technology transfer. Use of digital rainfall products from the mapping programme is being tested and promoted through this small pilot implementation project which aims to link areal rainfall data in the Caledon River catchment to streamflow, thereby fulfilling a need for inflow prediction into the Gariep Dam for optimising water releases for hydropower generation by Eskom.

Estimated cost: *R76 000*
Expected term: *2001 - 2002*

Umgeni flood nowcasting using radar - An integrated pilot study

Department of Civil Engineering, University of Natal
(WRC Reference No 1217)

An existing research programme on real-time spatial interpolation and mapping of rainfall addresses the infrastructural needs of a national real-time daily rainfall monitoring and mapping system, the refinement of radar and satellite rainfall-estimation technologies, and the merging of rain-gauge, radar and satellite data to provide the best possible integrated product from the point of view of resolution (both spatial and temporal) and reliability. The programme also makes provision for pilot applications of the real-time spatial rainfall outputs, in order to test and demonstrate their efficacy and promote technology transfer.

This project, which addresses the issue of early flood warning as an aid to disaster management, is not only a pilot study linked to the above-mentioned research programme, but is also an extension of WRC-sponsored research on the development of a real-time flood forecasting model undertaken in the Department of Civil Engineering at the University of Natal. Umgeni Water and Durban Metro will participate, with a view to immediate implementation of the research products.

The aims of the project, therefore, are to:

- Draw together new rainfall data sources and flood forecasting methodologies resulting from recent WRC-sponsored research and demonstrate their usefulness within the context of flood management.
- Provide decision-makers in Umgeni Water and Durban Metro with tools which will allow them to be more pro-active and effective within the same context.

Estimated cost: *R350 000*
Expected term: *2001 - 2002*

Regional model development for simulating atmospheric behaviour and rainfall over Southern Africa

Department of Earth Sciences, University of Pretoria
(WRC Reference No 1261)

There is an increasing demand by hydrologists, the agricultural community, disaster managers and the public for more accurate spatial projections of anomalous rainfall.

The complex distribution of surface characteristics over Southern Africa such as topography, coastlines, inland water bodies and vegetation, induces atmospheric circulation and rainfall patterns unique to the region. To better simulate local circulation patterns and rainfall over the Southern African region, it is necessary to develop or adapt a regional atmospheric model to suitably capture the unique surface characteristics of the region. An issue as important as the development of a regional atmospheric model for Southern Africa, is the broadening of the skills base needed for continuous refinement and use of such models. It is intended to use this project to create opportunities for interested scientists and students from various institutions to familiarise themselves with atmospheric modelling concepts and practices.

The aims of this project, therefore, are to:

- Modify the dynamical formulation and physical parameterisation schemes of an internationally competitive regional atmospheric circulation model (DARLAM from Australia) in order to improve the simulation of water-related atmospheric variables over Southern Africa.
- Equip scientists and prospective students from the Southern African community with the necessary knowledge and skills to develop, maintain and use such regional atmospheric models.

Estimated cost: *R678 000*
Expected term: *2001 - 2003*

Outcomes to Date of Current Projects

New knowledge

Knowledge concerning past and potential future climate change is being expanded significantly. Previously palaeoflood research revealed Orange River floods greatly in excess

of those experienced during the period of observational record. Current palaeoclimate projects, particularly the one focusing on cave speleothems, are promising to reveal pre-record hydroclimatic variations with unprecedented temporal resolution, possibly better than 5 years.

Empirical methods for downscaling general circulation model predictions of global change in order to generate regional climate change scenarios have been developed, and knowledge on how to bring about refinement of these scenarios using dynamic modelling approaches is being acquired.

Projects focusing on the role of the oceans have, through direct measurements above the ocean surface, provided insight into the magnitude of heat and water vapour transfer between ocean and atmosphere in those areas of ocean to which South Africa's hydroclimate is particularly sensitive. Such measurements also provide ground truth, for satellite remote sensing, used to obtain more extensive data to clarify key ocean processes and employ ocean models needed to elucidate the manner in which oceans regulate rainfall processes over Southern Africa.

Research on the forecasting of hydroclimate variation from daily to seasonal time scales has progressed through a series of phases: recognition of best statistical predictors of hydroclimatic variation and development of statistical modelling capabilities for climate prediction in Southern Africa; elucidation of the physical basis for statistical relationships; and use of physically-based dynamic models to progress beyond limitations of statistical models and provide far more generally applicable hydroclimate forecasting methods.

Building on previous projects, current projects relating to the development of an integrated rainfall monitoring system to replace the declining rain-gauge network in South Africa have produced the following new knowledge and skills:

- Fundamental understanding of radar-rainfall relationships and advances in the theory of quantitative rainfall measurement by radar;
- An understanding of hardware, software and signal processing requirements for transforming meteorological radars from severe weather warning devices to "areal rain gauges", each sampling an area of up to 10 000 km^2 with a spatial resolution of 1 km^2;
- A growing ability to network radars and use them to produce merged digital maps of real-time, areal, radar-derived rainfall over large parts of South Africa;
- An understanding of how best to integrate radar and rain-gauge measurements in the interests of intercalibration and greatest reliability of data;
- Preliminary understanding of the integration of satellite information to further enhance coverage;
- Ability to track and forecast short-term behaviour of rain-bearing systems;
- An appreciation of network running costs and maintenance requirements; and
- Initial experience in the use of data products for real-time applications in river flow prediction and flood warning.

In studying the potential impacts of pollution on rainfall, conveyor-belt-like behaviour of the Southern African atmosphere in relation to the transport and recirculation of pollutants and aerosols of local origin has been confirmed and dynamic chemical and microphysical properties established. Knowledge of particle characteristics has confirmed that they can impact on local cloud and rainfall processes in various ways, depending also on ambient atmospheric conditions. Data analysis is still under way to confirm and extend initial findings.

Concerning fog as a potential source of water supply, conditions (meteorological, locational and structural characteristics) required for high yields from fog-collector structures have been elucidated. Sites with high fog-water yield potential along the West Coast and north-eastern escarpment have been identified, typical yields determined and the feasibility of the technology established.

Benefits to South Africa

Benefits accruing from projects in this field include:

- The ability to generate and provide SA planners with climate-change scenarios at the regional, country and local (catchment) scales;
- Access to, and ability to use, satellite information relating to key ocean areas needed for the utilisation of ocean models in schemes for predicting rainfall;
- Steady improvement in schemes for generating rainfall forecasts for use in disaster mitigation and water resource management;
- A national rainfall monitoring system meeting all requirements of water resource managers with regard to spatial coverage and both spatial and temporal resolution;
- Knowledge needed to assist in decisions as to whether and how potential impacts of pollution on rainfall in South Africa need to be managed;
- The capability to exploit fog as a water resource where possible and where needed; and
- Improved rainfall databases and statistical techniques for characterising rainfall variability in space and time.

Innovation/application of knowledge

Knowledge generated through current projects is already being or will be applied in the following ways:

- In generating climate change scenarios for analysing potential impacts and risks to South African and Southern African water resources as a result of climate change;
- In the production of operational forecasts (at this stage mainly at the seasonal scale) being coordinated and issued by the SA Weather Service on behalf of a consortium which includes WRC-sponsored researchers;
- In the building of an integrated radar/rain-gauge satellite-based rainfall monitoring network for South Africa;
- In the production and web-based dissemination of daily radar/rain-gauge-generated rainfall maps to all users and the general public;
- In the pilot operational use of a fog-collecting screen to satisfy water requirements of a rural school in the Northern Province; and
- In basing water resource planning on better assessments of risks associated with rainfall spatial and temporal variability.

Capacity/competence building

Capacity and competence developed through current WRC programmes resides in the following institutions:

The SA Weather Service (SAWS)
Capacity of certain researchers and forecasters in the area of short-term and long-term rainfall forecasting is constantly being enhanced as a result of both self-supported research and research collaboration with universities in WRC-sponsored projects. Within the context of research into the development of integrated rainfall monitoring technology, however, remarkable capacity development has derived directly from the WRC-sponsored programme. This capacity/competence development has encompassed radar meteorology, engineering and technology; signal processing, hard and software development, signal processing and communications technology. Most of the capacity development has been in-house, with some support from the University of Natal.

Details concerning the building of individual capacity are as follows:

- 6 technologists trained in radar maintenance and upgrading (out of a total of 12) are from previously disadvantaged backgrounds; and
- 2 final-year meteorology students (one from disadvantaged background) are completing final year projects on radar-rainfall estimation as an integral part of the WRC-sponsored research.

Universities

Pretoria
The Chair of Meteorology in the School of Earth Sciences has developed its own capacity in the areas of global atmospheric/oceanic model sampling, regional atmospheric model development, dynamic model application for seasonal rainfall forecasting and short-term quantitative rainfall forecasting for flood warning purposes. Projects actively attempt to extend the capacity/competency base further afield through creating links to other universities (notably Venda) and the SAWS and by providing for training courses for outside scientists and practitioners in Southern Africa.

Details concerning the building of individual capacity are as follows:

Ph.D. awarded:	1
(White male)	
M.Sc. awarded or in progress:	5
(1 White male, 1 Black male, 3 White females)	
Honours:	1
(White female)	
Final year B.Sc. projects:	2
(White female, Black male)	

Cape Town
Research capacity has been developed in the Department of Oceanography (observing, understanding and modelling ocean processes and their links to South African rainfall) and in the Department of Environmental Sciences (understanding and investigating the nature of climate variability at various time scales and the ability of general circulation models to accurately represent this variability from South Africa's perspective; development of empirical and dynamic techniques for downscaling GCM predictions of climate change to regional and local scales for purposes of impact analysis). In these instances also, most recent projects are structured in a manner which ensures that through collaboration, capacity built is shared with other institutions (notably Zululand) in South Africa.

Details concerning the building of individual capacity are as follows:

Ph.D. awarded or in progress:	11
(3 White males, 5 White females (SA), 2 Black males (Zambia), 1 Black male (Zimbabwe)).	
M.Sc. awarded or in progress:	8
(1 White male, 1 White female, 1 Black female (SA), 3 Black males (SA), 1 Black male (Zambia), 1 Black female (Botswana)).	
Honours:	1
female (Namibia).	

Zululand
Capacity in climatological analysis leading to identification of process-based predictors (both atmospheric and oceanic) of seasonal rainfall and hydrological variables has been developed as a result of WRC funding.

Details concerning the building of individual capacity are as follows:

Ph.D. awarded or in progress:	2
(Black Males from Tanzania, Ethiopia)	
M.Sc. awarded or in progress:	5
(Black Males from Tanzania (2), Malawi (2) and SA (1)).	

Witwatersrand
Until 2 to 3 years ago the Climatology Research Group (CRG) at Wits commanded a wide range of research skills with climate variability being the main research thrust. Loss of skilled researchers through emigration, however, has reduced the competence base to one main area of specialisation of current interest to the WRC, namely the regional transport of anthropogenic aerosols and their impact on the region's climate. The project initiated in this regard by the WRC takes place in close collaboration with the SAWS.

Details concerning the building of individual capacity are as follows:

Ph.D. awarded or in progress:	2
(White male, White female)	
M.Sc. awarded or in progress:	2
(Black male, White female)	
Honours awarded:	1
(Black male)	

Natal
The Department of Civil Engineering (Durban), in close collaboration with the SAWS, has developed cutting-edge skills in the spatial modelling of rainfall processes, which have proved indispensable in the development of procedures for the merging of point (rain gauge) and spatial (radar) measurements of rainfall as part of the national integrated rainfall monitoring system. The School of Bioresources Engineering and Environmental Hydrology (Pietermaritzburg) has acquired advanced competencies in rainfall database management and data interpretation for water resource engineering applications.

Details concerning the building of individual capacity are as follows:

Ph.D. awarded or in progress:	2
(White Males)	
M.Sc. (Eng) awarded or in progress:	2
(White Male, White Female)	
B.Sc. Honours awarded:	1
(Black Female)	

More than 50% of current final year and Honours students are from disadvantaged background; these have been receiving direct exposure to or hands-on experience with WRC projects. Of 4 final year/Honours students who have recently gained hands-on experience, 3 are females (2 White, 1 Black) and 1 male (White).

General

The involvement of previously disadvantaged South Africans in this field has not yet reached satisfactory levels. By contrast, the demand for post-graduate training from among SADC countries is large. It is apparently perceived that national funding levels are inadequate to sustain meaningful career opportunities. Retention of developed capacity has at times been a problem, as illustrated by the loss of capacity at the Wits CRG and more recently at the University of the North.

Knowledge dissemination

Knowledge dissemination has taken place through scientific articles, conference presentations/courses/workshops/demonstrations and via the Internet.

Scientific articles:	56
Conference proceedings:	114
Courses/workshops/ demonstrations:	14
Internet:	Forecasts published Continuous display of products

Leveraging of resources

Outside contributions to research projects are mainly of an in-kind nature. The most notable example of these relates to the development of the national integrated rainfall monitoring system. In the initial phases of this programme, the WRC contributed the largest proportion of the funding, but this has now diminished to an estimated 20% of the cost of the programme, with the SAWS bearing the brunt of the cost and small contributions coming from Eskom, Umgeni Water and Durban Metro. DWAF has made R280 000 available through the WRC for rainfall monitoring in inaccessible mountainous areas.

Direct financial contributions have been made by Eskom to the WRC for the following programmes:

R534 000:	Aerosol impacts on rainfall
R100 000:	GCM downscaling for climate change scenarios
R140 000:	Prediction of seasonal hydro-climatic variations.

The linkages to international research institutions (next section) have resulted in significant indirect contributions by such institutions to WRC research.

International linkages

Hydroclimatic research programmes and projects have developed strong linkages to the following international research institutions, which have made considerable indirect contributions to the research:

- Penn-State University, USA
- CSIRO, Australia
- University of Melbourne, Australia
- French Oceanographic Institute
- UK Meteorological Office
- National Centre for Atmospheric Research, USA
- National Aeronautics and Space Administration (NASA), USA
- Max Planck Institute, Germany.

In particular, through the WRC's ARREX project, the multimillion dollar SAFARI 2000 programme was launched by NASA.

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Chapter 14

Integrated Water Resource Management (IWRM)

Mr H Maaren
(† 28 August 2002)

Scope

This field has two main legs: On the one hand a better understanding of the goods and services provided by water resources throughout the hydrological cycle is needed and on the other hand there is a need to develop better ways of making stakeholder participation more effective. Research on hydrological, socio-economic and environmental issues needs to merge into one or other form of multicriteria decision analysis (MCDA) in order to improve the quality of South Africa's water management decision-making.

The main reason for the seemingly variable investment in the field of ***Integrated Water Resource Management*** is the somewhat arbitrary distinction between this field and several other research fields. A major portion of the funding has gone into community participation in catchment management and the development of MCDA to accommodate stakeholder participation. Fruits of both research investments have started to achieve recognition in the structuring of water user associations (WUAs) and strategic environmental assessment (SEA) in DWAF.

Links to Key Strategic Areas (KSAs)

Integrated Water Resource Management is a strongly overarching field, as the nature of integration necessitates roots in each of the KSAs. It mainly addresses various aspects of managing water resources using fundamental knowledge, generated in other fields, in some integrated way.

Water Resource Management

The ***Integrated Water Resource Management*** field falls entirely within this KSA, together with a wide range of institutional and policy issues.

Water-Linked Ecosystems

The integrated nature of ecosystems and especially the dynamic impacts of land and water processes makes ecosystems vulnerable to what people actually do with water. The value attached to water-linked ecosystems is crucial in the water management process.

Water Use and Waste Management

Water abstraction for urban and industrial use and the associated return flows play a vital role in managing water resources on a catchment basis. Although this component of the hydrological cycle, as modified by man, can be rather localised, it still has a significant impact on the whole cycle.

TABLE 1
Research Funding Investment in **Integrated Water Resource Management**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R2 905 057	R4 623 709	R4 486 491	R5 051 000	R3 691 500
% of research fund	7.18%	10.4%	8.46%	8.14%	6.28%

Water Utilisation in Agriculture

Irrigation and rain-fed agriculture, including forestry, woodland and grazing land, cover by far the greatest portion of South Africa's land surface. The impact of this land management on our resource base therefore is critical.

Objectives

Primary

To develop a systems approach, supported by the necessary management tools and institutions, to integrate all environmental, economic and social issues within a catchment or water management area into an overall management philosophy, process and plan.

Secondary

- To develop a quantitative understanding of how a disturbance (usually man-made) at one place in the system will be translated to other parts of the system; and
- To develop management tools and institutional arrangements, policies and organisational structures to ensure the sustainable use of the water resource for the benefit of all stakeholders.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

Development of a water information management database system for data capture and processing at local authority level

Institute for Groundwater Studies and DWAF, University of the Free State
(WRC Reference No 642)

The project supports the overall objectives of DWAF's MuniWater programme:

- To provide a platform for systematic data collection storage and utilisation in support of water management at local level; and
- To link MuniBase to the National Information System of DWAF in order to capture selected local data for the national and intermediate levels and to provide access by the local level to the National Information System.

The scope of data to be captured will satisfy the requirements of water resource management programs.

In principle, the proposed goals have been achieved. Not all modules proposed for consideration have been approved, for instance a surface water module. On the other hand a Water Resource Module has been included. Those modules that have been allocated to the IGS, have now been completed.

One determining factor has been that database analysis for the DWAF Hydrological Information System (HIS) has led to changes in the PC-MuniWater modules, and specifications have frequently been altered. Although this has caused some organisational and timing problems, it had, in the opinion of IGS, the advantage of increased compatibility between PC-MuniWater and the HIS databases. The creation of a MuniWater Project Committee at DWAF (on which IGS was represented), and the parallel development of PC- and mainframe systems, have also led to a more uniform approach with consolidated chemical databases.

The response of the municipalities selected for co-operation in the testing of the software has been slower than expected. Especially during the last two years these were the main reasons for retarded debugging and failure to create additional specialised processing and management tools for use by local authorities. Most of the search for bugs had to be done by the project team. In addition the Geohydrology Division of the Namibian Department of Water Affairs, which tested the groundwater module, has made some useful contributions.

Cost: *R705 000*
Term: *1994 - 1996*

Development of group decision-support methods to facilitate participative water resource management

Department of Statistical Sciences, University of Cape Town
(WRC Reference No 863)

The aim of the project was to develop a general framework for the design of such systems, as well as a decision-support "shell" which could be used for rapid development of specific DSSs.

This is the 3rd project in a sequence, following K5/296 and K5/512. One of the major obstacles in this research has been the lack of real-life case studies that would allow the methodology to be tested more realistically. In this project 4 case studies have been completed and in general the results have led to useful recommendations that are being followed up by important stakeholders such as the Forestry Review Panel in the Eastern Cape, World Wildlife Fund and the DWAF Resource Directed Measures initiative.

The project team also developed 5 important guiding principles concerning the following:

- Role of the facilitator/decision analyst.
- Discipline of the multicriteria decision analysis process in identifying critical information needs.
- Consistency checks and feedback to participants.
- Allowance of adequate time for the process.
- Use of appropriate technology (software).

Considerable progress has been made in the use and development of software, including the link to spreadsheets and GIS.

Cost: *R628 000*
Term: *1997 - 1999*

Integrated catchment management in an urban context: The Great and Little Lotus Rivers, Cape Town

Abbott Grobicki (Pty) Ltd
(WRC Reference No 864)

The objective of this project was to provide a blueprint for urban catchment management in South Africa. In particular, the approach developed in this project focused on water quality and on rehabilitation strategies, as well as on the involvement of the local communities in the catchment area.

The Lotus River project focused from its inception upon creating a positive working relationship with the local authority structures. At all stages, "buy-in" to the project on the part of the local authority was considered to be essential. This was necessary in order to ensure the sustainability of the project objectives in the long term. The work can be summarised under the following categories:

- **The development of GIS-based methodologies for urban catchment management**
  The primary objective of the GIS component of the Lotus River project was to integrate existing and acquired geo-spatial data on the catchment onto a single platform. The data collation process was carried out in such a manner as to include data from as many of the key role-players in the ICM process as possible.
- **Catchment characteristics**
  In the short term the Lotus River catchment makes an excellent case study of a highly impacted urban system, demonstrating the whole spectrum of land uses, socio-economic variations and housing types found in South African cities. It also exhibits acute ecological stress, highly polluted water bodies and significant loss of biodiversity.
- **Hydrological and water quality studies**
  The Great Lotus River now exists as a multistage channel with concrete-lined trapezoidal low-flow sections and a grass-lined high-flow section. The sections flowing through the Philippi Horticultural Area are an enlarged earth-lined canal, permitting groundwater interaction. Throughout the redesign and upgrading work carried out historically, no flow measurements were ever undertaken to verify the event-based stormwater model for the catchment.

A once-off analysis for protozoan parasites detected *Giardia* oocysts in the samples, but no *Cryptosporidium*.

The Great Lotus River catchment is characterised by few industries and no wastewater treatment plants discharging into the canal. Most pollution contributions are therefore from "non-point" or diffuse sources, i.e. highway runoff, urban residential pollution entering the canal through the stormwater network and dumping, and the agricultural area contributing groundwater and surface water from drainage ditches.

The Great Lotus River is characterised by very poor water quality, with high nutrient loading, as well as very high faecal coliform counts. This is due to raw sewage effluent overflowing from blocked sewers into the stormwater drains, occasional sewer pump overflows, as well as the inadequate or non-existent sanitation characteristic of the informal settlement areas.

- **Ecological management of the catchment**
  The Lotus River catchment is a highly modified environment. It has recently become intensively urbanised, and even the remaining vegetated areas and wetlands are very disturbed.

Cost: *R1 000 000*
Term: *1997 - 1999*

Community-based integrated catchment management programme with special reference to sustainable resource use in the Mlazi catchment

Farmer Support Group, University of Natal
(WRC Reference No 866)

The project aimed to develop a framework for community participation in integrated catchment management. As a concrete measure of success the community participation over a period of five years grew from virtually zero to 18 communal vegetable gardens, 5 craft groups using natural products, 20 environmental school-clubs and extensive liaison with other important stakeholders. A scale model of the Mlazi catchment has played a major role in building a sense of identity for the catchment community.

Close co-operation has been achieved with the previous Mlazi Irrigation Board, Mondi Forest and the Hammarsdale Industrial Conservancy. The project also made a considerable contribution to the development of the Environmental Management System for the Durban Metropolitan Area and the Durban Outer West Local Council's integrated development plan. A local newsletter, Mlazi River Catchment News, is appearing quarterly and has assisted greatly in the growing awareness around water in the area. DWAF has very positively engaged in several aspects of the project.

The critical steps in establishing community participation in integrated catchment management are thus:

- Set up networks at subcatchment level, to exchange information and to manage conflict; this process needs careful facilitation.
- Provide examples of good practice in a way which helps local people to discover for themselves that this is better than what they do - they will only change their management practices if they are convinced that the new practices are more beneficial to them than the old ones.
- Make visible the problems of the catchment and the systems of the catchment, thus building a sense of catchment identity.
- Monitor the river qualitatively and quantitatively, involving locals in the process.
- Through supporting joint activities, help conflict management to evolve into collective resource management.

Cost: *R1 700 000*
Term: *1997 - 1999*

Aids for flood damage assessment and flood damage control planning in irrigation and urban areas

Dept of Agricultural Economics, University of the Free State
(WRC Reference No 889)

During this third and final research phase, the refinement of models and the loss functions

on which they are based has been concluded to such an extent that they can be applied in practical circumstances. These models form part of a continuous pro-active, reactive and post-disaster management system. This is necessary to give effect to the new policy on disaster management as is described in the Bill on Disaster Management that was published during January 2000. As part of the flood damage management aids, a computer questionnaire FLODCAL has been developed which can be used for ex post flood damage assessment and to provide information for calibrating the loss functions of the FLODSIM and TEWA models.

User manuals

To guide potential users of FLODSIM, TEWA and FLODCAL in applying these computer programs, user manuals have been prepared, which are included as separate **Annexures** to the report. The manuals are not technical manuals but are constructed in such a way that they will enable potential users with some basic background knowledge of flood damage assessment and flood control planning, to run the programs with limited or no assistance from the model developers.

Demonstration software of FLODSIM, TEWA and FLODCAL is made available on a CD that is obtainable from the Department of Agricultural Economics, University of the Free State.

Cost: *R551 470*
Term: *1998 - 2000*

The development of a decision-support system for the Mhlatuze catchment in Zululand

Hydrological Research Unit, University of Zululand
(WRC Reference No 906)

The aim of this project was to develop a decision support system (DSS) for Integrated Environmental Management (IEM) of the Mhlatuze catchment in Zululand. The DSS has been created around two principle areas of development; information and communications technology (ICT). This is a very dynamic sector that will change much of our present management style. It is imperative that these developments are incorporated into decision-making tools for effective and informed management.

The DSS is a collection of existing systems that have been configured and applied in a local area network (LAN). The concept can be deployed or adapted in any ICT environment. It supports both freely and commercially recognized systems that are being extensively deployed in the commercial sector. Consequently, it can function as a low cost, entry-level system that can be progressively developed for very large enterprises. Generally, it does not require major changes in existing IT systems as it supports Windows, Linux and Unix operating systems. This can be a suitable system for the management of water resources by the emerging catchment management agencies (CMA).

Term: *1998 - 2001*
Cost: *R502 000*

A technique for modelling scenarios for alien plant control

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 907)

The aim of this project was to develop modelling techniques for estimating:

- The financial requirement for achieving effective control of water-using invasive plants in the different provinces and South Africa;
- The time required to achieve significant reductions in water lost due to alien invasion resulting from varying rates of expenditure on control; and
- The impact of introducing biocontrol methods on long-term costs.

Investigations focused on KwaZulu-Natal and the Western Cape as good data on alien plant distributions and densities are available for the Western Cape and could be obtained for KwaZulu-Natal.

The study produced the scenarios in terms of future descriptions and issues and a simulation model dealing with various rates of vegetation invasion, linked to a cost estimate of control measures.

Key conclusions that arose from the study are:

- A coherent set of laws, policies and regulations that control the import and distribution of invasive species needs to be rigorously and comprehensively implemented.
- Biological counter-measures can offer a very cost-effective solution to continuing invasion, but other methods of control also need to be investigated.
- Control measures should not be delayed because of the cost implications.
- Projects for clearing alien plant invaders should use rate of spread as a means of prioritisation.
- The ecology and economics of invasions are not well understood and the subjects need investment.

Both scenario development and simulation modelling offer powerful analytical techniques for better understanding of alien invasion and the strategies necessary to combat invasion.

Cost: *R298 000*
Term: *1998 - 2000*

The development and co-ordination of catchment forums (CFs) through empowerment of rural communities

Geography Department, Rhodes University
(WRC Reference No 1014)

The objective of this project was to contribute to the development of important institutional structures within the integrated catchment framework. Hopefully, lessons learnt through this pilot attempt to develop a water user association (WUA) in the Kat River valley will be of value in drawing other rural communities into the integrated water resource management process.

Research into community empowerment in the Kat Valley had been ongoing for five years prior to the start of the current WRC project. The focus had been on raising environmental awareness and building capacity to manage the water resource at the local scale of two villages (Fairbairn and Hertzog).

The research findings demonstrate that there are no 'recipe book' methods that can be

applied to developing CFs and WUAs in a participatory manner. There are, however, guiding principles that will help the practitioner to avoid falling into traps which weaken the sustainability of the project. These include using extractive methods, imposing external beliefs and systems to the detriment of local ownership, not appreciating the centrality of local stakeholders' needs, and avoiding dual accountability.

In the National Water Act, responsibility for water resource management is closely tied to DWAF and the CMA. Currently, DWAF sees CFs as structures that enable communication with stakeholders and as valuable tools for facilitating the consultation process. It is crucial, however, to appreciate that sustainable resource management will not be realised if CFs are merely seen as consultative bodies.

Ultimately, the integrity and efficacy of catchment management plans (CMPs) depend on their adherence to ethics, participatory principles, self-awareness and honesty. Without these traits, CMPs cannot be built within communities, with stakeholders. Only then will they be sustainable.

Cost: *R417 000*
Term: *1999 - 2001*

Current

Modelling benefits of integrated catchment management

Department of Agricultural Engineering, University of Natal
(WRC Reference No 749)

In many water management areas we will find that present water resources have been over-allocated and some form of compulsory licensing and re-allocation of water use will have to be implemented. Based on 7 case studies, the trade-off between various water uses and associated socio-economic benefits is being investigated. This will make a science-based contribution to negotiating the best possible solution to problems of allocation of a limiting water resource and optimisation of land use.

Estimated cost: *R3 360 000*
Expected term: *1996 - 2001*

Operational model of the Orange River

BKS (Pty) Ltd.
(WRC Reference No 865)

Most of the Orange River's runoff is generated in the eastern high rainfall catchments. In the 1 400 km below the Vanderkloof Dam, before flow reaches the river mouth, evaporation losses amount to about 960 million m^3/a which is more than the MAR of the Mgeni River. Previous research has indicated that evaporation losses can possibly be reduced if dam operating rules are optimised to reduce water surface areas in the river. This research uses an operational model to evaluate this potential.

Estimated cost: *R968 000*
Expected term: *1997 - 2001*

The development of a hydrological economic model based on the Mvoti catchment

Umgeni Water
(WRC Reference No 890)

Currently, sophisticated hydrological models are being used to predict the effects of current and expected levels of catchment development on the quantity and reliability of available water. Economic evaluations usually enter the picture only at the end stage, such as in the cost-benefit analysis of water infrastructure. This project focuses on the development of integrated ecological-economic modelling approach, in which the complex dynamic interdependencies between the economic and natural systems can be taken into account when making decisions on resource management. The research findings will make it possible to assess the potential of using an integrated hydrological economic model as a tool for guiding integrated catchment management in other important catchments.

Estimated cost: *R159 000*
Expected term: *1998 - 2001*

The model for water demand management planning and monitoring

BKS (Pty) Ltd.
(WRC Reference No 905)

Water demand forecasting is a critical element in medium- to long-term planning. In the past projections were mainly based on extrapolations of broad historical data on actual water use. This project combines population growth and service level considerations to provide a more accurate and verifiable methodology of demand forecasting in urban-industrial complexes.

Estimated cost: *R456 000*
Expected term: *1998 - 1999*

Framework for state of the catchment report for developing a catchment management plan using as a basis the Palmiet River, Western Cape

Palmiet CMP
(WRC Reference No 913)

This project aims to develop the catchment management strategy (CMS) for the Palmiet River, at the same time developing generic guidelines for CMSs. The Palmiet specifically addresses biodiversity, water quality, equitable resource use (including the estuary), land-use management and sanitation. It also ensures that there is active and informed stakeholder participation to encourage collective ownership and responsibility for the CMS.

Estimated cost: *R250 000*
Expected term: *1998 - 2001*

Use of grass species for rehabilitation after wattle control

Agricultural Research Council
(WRC Reference No 1016)

The Working for Water Programme removes alien vegetation from riparian zones. This leaves many river-banks vulnerable to erosion and this project develops guidelines for the establishment of a suitable grass cover after wattle removal. The WRC is a co-funder of the project, together with the National Department of Agriculture and the SA Wattle

Growers Union. This project is linked to the ***Conservation of Water Ecosystems*** field.

Estimated cost: *R214 000*
Expected term: *1999 - 2001*

Water resource systems analysis: Training and transfer of technology

BKS (Pty) Ltd.
(WRC Reference No 1038)

DWAF uses several water resource systems models. Some of the research on evaporation losses will be incorporated in these models and this project contributes to preparing suitable training material which will also be exported to the SADC region. The emphasis in this project is therefore on technology transfer.

Estimated cost: *R40 000*
Expected term: *1999 - 2001*

Development of models for economic evaluation of the integrated management of quantity and quality of irrigation water within river catchments

Department of Agricultural Economics, University of the Free State
(WRC Reference No 1043)

Legislative prescriptions have been specified in the National Water Act to protect aquatic ecosystems as part of the reserve, regulate streamflow reduction activities and prevent pollution. Information on and tools to manage the quantity and quality of water are now clearly required to ensure sustainable use of water for irrigation in relation to all other use sectors. User-friendly adaptation of available models in order to provide practical decision-support, will furthermore assist with the implementation of water policy. The aims of this research are to develop decision-making tools and evaluate the economic impact of policy strategies on the control of non-point pollution and to apply agro-hydrological and economic models for integrated water resource management.

Estimated cost: *R683 000*
Expected term: *1999 - 2001*

Predicting the impact of farming systems on sediment yields in context of integrated catchment management

Institute for Soil, Climate and Water, ARC
(WRC Reference No 1059)

Erosion and sediment delivery is one of the major land-use impacts in South Africa. The WEPP model was developed in the USA and this project is testing the model against field observation data in several trial areas both in commercial and traditional farming systems. The adequacy of the required input data is being evaluated for South African conditions. If successful the model can make a major contribution in better land-use management to curtail erosion losses.

Estimated cost: *R843 000*
Expected term: *1999 - 2002*

Developing protocols for integrated catchment management (ICM) based on current initiatives and techniques

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1062)

This project, being undertaken in close cooperation with the DWAF Regional Director in Mpumalanga, seeks to develop protocols for defining the present state of the environment and the desired state of the environment. The required management actions will be formulated and monitoring procedures will be designed. The Sabie catchment is being used as a test case. Stakeholder participation is an important aspect of the protocol and the outcome of this project should be widely applicable in South Africa.

Estimated cost: *R1 500 000*
Expected term: *1999 - 2001*

Estimation of the value of water in the commercial forestry sector for selected areas in SA

Department of Economics, University of Natal
(WRC Reference No 1133)

Information on the value of water is essential for private investment and production decisions, of e.g. forestry companies. Similarly, government authorities on a national level need to weigh up different social, economic and environmental values in order to determine the "optimum use" of water. Better information on water values will, therefore, provide a sound basis for application of demand management. The economic modelling that is being undertaken in this project, relies on available data and forestry growth models. The major aim of the project is to estimate the value of water use for commercial forestry.

Estimated cost: *R276 000*
Expected term: *2001 - 2001*

Effective local management of water resources with reference to the Middle and Lower Orange River

Department of Agricultural Economics, University of the Free State
(WRC Reference No 1134)

A computer-based decision-support model based on the institutional arrangement of capacity-sharing, is available for application in off-stream and in-stream water use management under conditions of uncertainty. This project evaluates the usefulness of this innovative approach under South African circumstances. This must be done within the context of the National Water Act, information requirements on the quantity and quality of water available, levying of water charges and tariffs in relation to water values for different uses and regulations for the performance of functions by the to-be-established WUAs. It is envisaged that the model will provide an appropriate tool for water management by irrigation farmers and other water users.

Estimated cost: *R949 000*
Expected term: *2000 - 2002*

Design and testing of an installed hydrological modelling system

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1155)

One of the main needs in integrated water management on a catchment basis is the requirement to achieve vertical integrity between the detail of the individual field scale and the broader view of the larger catchment scale. It is believed that a GIS-based installed modelling system covering a catchment or entire water management area is one of the tools required in this regard. Together with DWAF and BKS Inc. the ACRU modelling system is being tested in the upper Olifants River catchment. DWAF has made additional funds available in excess of R1 million.

Estimated cost: *R2 104 000*
Expected term: *2000 - 2002*

Towards integrated catchment management in the Mlazi River: A model for participation in the South African context

Farmer Support Group, University of Natal
(WRC Reference No 1157)

In a previous WRC-funded study a structure for community participation in integrated catchment management in the Mlazi catchment was explored. Considerable progress over a wide front of rural water related activities was achieved. This project serves to develop a transfer policy to ensure that community participation brought about by external intervention is sustainable and that lessons learned can be translocated to other rural areas.

Estimated cost: *R1 000 000*
Expected term: *2000 - 2001*

Decision support of stakeholder involvement in reserve determination and other catchment management agency responsibilities

Department of Statistical Sciences, University of Cape Town
(WRC Reference No 1186)

There is a growing recognition that some form of multicriteria decision analysis (MCDA) can make a solid contribution to improving various water management decisions. This project builds upon previous experience and lessons learned in applying the MCDA methodology in the field of setting management classes for rivers (contributes also to ***Conservation of Water Ecosystems*** field).

Estimated cost: *R578 000*
Expected term: *2000 - 2001*

Integrated socio-economic and cultural values as additional components of the criteria for estimating and managing the reserve

Institute for Natural Resources
(WRC Reference No 1195)

The National Water Act of 1998 aims to achieve sustainable use of water for the benefit of all users. It also guarantees the protection of aquatic ecosystems. Historically, the evaluation of the importance of river systems has been largely based on ecological importance, while ignoring social and cultural aspects. This study is establishing the importance of integrating ecological, socio-economic and cultural values in the estimation and management of the reserve. It is also providing information on the dependency of rural households on river system resources (contributes also to ***Conservation of Water Ecosystems*** field).

Estimated cost: *R300 000*
Expected term: *2000 - 2001*

New

Development of guidelines for the treatment of scale and resolution in assessing the streamflow reduction impacts of and commercial afforestation in integrated water resource management in South Africa

Ninham Shand Inc
(WRC Reference No 1221)

In South Africa, methods for estimation of streamflow reduction (SFR) impacts of both afforestation and alien infestations have adopted either of two different approaches: relatively simple free-standing empirical relationships; or component modules in the physically-based, land-use sensitive ACRU daily rainfall-runoff catchment model.

The CSIR has used sets of empirical curves to prepare national overviews of potential impacts on mean annual runoff, on a quaternary basis, for both commercial afforestation and alien infestations. It should be noted that these studies did not assess potential impacts on "utilisable" runoff, e.g. on reservoir yield-reliability characteristics, or on water supplies from run-of-river schemes. This limits the usefulness of these studies, e.g. the Working for Water planners could not easily use the latter for alien clearing project prioritisation. Similarly, the National Water Situation Assessment Model (MWSAM) of DWAF finds it difficult to incorporate impacts in a consistent manner.

Currently, a collaborative research project between the CSIR and Natal University's School of Bioresources Engineering and Environmental Hydrology is under way to use the two different quantification approaches for afforestation-related SFRs conjunctively to provide an improved predictive tool for widespread use. However, with the exception of a few *ad hoc* studies, there has been no systematic research into SFR impacts in terms of "utilisable water", as expressed in terms of reliability of reservoir/ system yield, or of water supplies from run-of-river situations, which are common in rural communities.

The aims are to:

- Develop generic guidelines for the treatment of scale and resolution in assessment of streamflow reductions due to alien infestation and commercial afforestation in integrated water resource management (IWRM) in South Africa;
- Quantify streamflow reduction impacts caused by alien vegetation and commercial afforestation on reservoir and system yield-reliability characteristics, as well as for run-of-river water supplies for a range of South African river systems; and
- Assess and reconcile streamflow reduction impacts caused by alien vegetation and commercial afforestation, modelled at different levels of scale and resolution and over a range of bio-climatic regions.

Estimated cost: *R599 700*
Expected term: *2001 - 2002*

Developing and trialing guidelines for participatory water resource management at catchment and water management area scales

Geography Department, Rhodes University
(WRC Reference No 1233)

In a previous WRC-funded study the establishment of a WUA in the Kat River valley, Eastern Cape was used to formalise community participation. A considerable number of valuable lessons were learned in the process. In this project guidelines for participatory water resource management are being developed that can be used throughout South Africa. The project leader is working closely with Australian counterparts.

Estimated cost: *R764 000*
Expected term: *2001 - 2002*

Statistically based regionalised flood frequency estimation study for SA, using systematic, historical and palaeoflood data

SRK (CE) Inc

(WRC Reference No 1260)

The need for flood management and flood protection planning has intensified within the context of the Government's Disaster Management Policy. This project will compile a regionalised flood frequency estimation based on observed flood data in a key water management area in the Eastern Cape. If successful the study can be extended into the rest of South Africa

Estimated cost: *R773 200*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

Integrated water resource management (IWRM) is a philosophy accepted and incorporated in the National Water Act. Research projects on MCDA carried out over the past six years have gradually moved from a highly theoretical approach towards assisting various other initiatives to come to grips with many aspects and issues in water resource management.

MCDA approaches developed by Prof Stewart of UCT are currently under consideration in a DFID-funded project with DWAF on Strategic Environmental Assessment (SEA). In projects on the ecological reserve determination, MCDA is being used to develop manageable scenarios. An increasing number of water resource experts see MCDA as the ideal vehicle to improve our water management process.

Many current research projects have provided data and information on socio-economic aspects of water use; it has been learnt that goods and services derived from resource use provide crucial management focus.

In the project on modelling the benefits of integrated catchment management, 7 case studies on real-life catchment situations are providing new information on water use efficiency under different cropping and management systems. Information such as this will be most useful for considering alternative management options within the context of compulsory licensing of water use.

Research on community participation in the IWRM process has shown that the building of platforms or community organisations is essential for the wide variety of stakeholders to be empowered to participate. In the Mlazi catchment, it has been learnt, for example, how the use of reeds from wetlands for crafts can provide communities with cash incomes and at the same time ensure the sustainable management of wetlands.

Different phases of flood management assessment in South Africa have caused the management perspective to change from a monetary cost/physical damage perspective to a more acceptable one of socio-economic and environmental impact assessment. The MCDA approach, including other criteria besides economic efficiency, is now being applied. This approach will, for instance, fully capture the knowledge, information, wisdom and needs of local riparian communities, allowing for more comprehensive flood management.

In the Kat River valley it has been learnt how previously disadvantaged communities can work together with citrus farmers and small municipalities to start an effective WUA. One of the main lessons was that a certain level of professionalism is needed in dealing with community interests, otherwise sustainable solutions may not be achieved. Professionalism in this regard refers to the standards and personal commitment of facilitators, attributes which are often absent from so-called stakeholder participation projects in South Africa.

On the biophysical side, research has highlighted the different aspects of the resource that need to be managed as a whole. The improved use of grass species to combat erosion on river banks after the removal of wattle trees is a good example.

Work in the Orange River has shown how the operation of large reservoirs can be fine-tuned to reduce losses.

Benefits to South Africa

- The National Water Act and its underlying principles require a totally new, balanced, approach to water resource management. WRC-funded research is assisting in achieving this balance by harnessing and giving due prominence to social and economic sciences as well as to more traditional natural sciences and engineering.
- Models which have been developed are able to predict a wide range of impacts of human interventions on water resources.
- A systematic approach to management decision-making, that will go a long way to satisfying the requirements of the Promotion of Administrative Justice Act, has been developed.
- Research projects have contributed to more efficient and equitable resource management in South Africa, one of the cornerstones of democracy.
- A more complete picture is emerging of how existing capacity at different levels of society can be mobilised to contribute effectively to water management under the National Water Act.

Innovation/application of knowledge

- The research on the Kat River in the Eastern Cape has made a highly significant contribution, not only towards establishing a viable WUA but also to providing input into the DWAF guidelines and policies for the establishment of WUAs and CFs.
- The water demand management and planning tool is regarded as a significant step towards better water demand forecasting.

Web-based MCDA software is now being used by a variety of stakeholders.

Capacity/competence development

In this field, capacity-building takes place in several spheres. At university level higher degrees are being obtained as part of WRC research projects. Graduates are often employed by DWAF, consulting firms and water boards, transferring theory into practice. In several projects in the Kat River, Mlazi River and Sabie-Sand River, DWAF officials have become closely co-operating partners in the research, and a sound exchange between scientists and regulators is taking place.

A quite different sphere is the community level, where stakeholders learn to take part in

water resource management projects. These stakeholder communities consist of people with a wide range of educational backgrounds, but the concept of catchment management is new to most of them. The *modus operandi* of good projects in this field are participative action with an emphasis on learning by doing.

Capacity has, and is being, built at the following academic institutions:

University of Natal

Capacity building at the School of BEEH at the University of Natal has been mentioned also under the research field of ***Catchment Hydrology***. The utilisation of this capacity is strongly felt in the ***Integrated Water Resource Management*** research field and is therefore repeated here:

By far the dominant capacity for catchment hydrology research has become established at the University of Natal in the School of Bioresources Engineering and Environmental Hydrology (School of BEEH). The CSIR (Environmentek) has established a separate office on the University campus in Pietermaritzburg that enables the BEEH and CSIR groups to work together. So far the co-operation has been very productive.

The School of BEEH is very strong on hydrological modelling and hydrological process studies as well as on the use of soil physics and soil-water hydraulics in understanding hill-slope hydrology.

SAPPI has given recognition to this centre of expertise by providing the funding for a 5-year contract at senior lecturer level (Dr G Jewitt).

As a centre of expertise largely supported by the WRC, the School of BEEH has and continues to contribute graduates for the hydrological and water-resource job markets, as follows:

- Ph.D.s in hydrology topics:
  6 completed
  3 candidates currently doing Ph.D.s
  (Lecler, Rivers-Moore, Taylor)
- Masters in hydrology topics:
  38 completed (24 M.Sc., 14 M.Sc.Eng)
  9 currently registered, of whom 4 are from disadvantaged communities
- B.Sc. Honours in Hydrology:
  Approximately 80 students graduated since 1984
  Currently (1999/2000/2001) 60 to 67% are from disadvantaged backgrounds
- B.Sc. in hydrology
  Approximately 230 students graduated since 1982

Currently (1999/2000/2001) 65 to 76% of 3rd year students are from disadvantaged backgrounds

At the INR of the University of Natal, Christian Tham and Sandile Zeka are studying for M.Sc. degrees using WRC-funded work.

University of Cape Town

- Ms Alison Joubert will do a Ph.D. on MCDA in water management.
- Prof T Stewart is expanding his recognition as a world authority on MCDA and operational research.

Knowledge dissemination

- Training material has been developed for a course in the use of water resource systems modelling.
- A two-day course on MCDA was given to the Defense Research Centre staff. The course will also be presented at the "Science at Work" seminar at UCT.
- MCDA thinking has been brought directly into the SEA process and indirectly into the development of catchment management strategies.
- Workshops were held with the Cape Metropolitan Council to use MCDA to develop water supply and demand management options.

Publications	1998	1999	2000
WRC Reports	2	3	4
Scientific papers		1	3
Presentations	6	12	23
Web-pages	0	1	0
Thesis (Ph.D.)	1	1	0

Existing information indicates that the number of conference presentations based on projects in this field is growing continuously.

Leveraging of resources

DWAF is making major financial contributions in this research field. In the Mlazi catchment DWAF has paid for the printing of newsletters. In the Kat River project DWAF paid for poor people to attend workshops. In the Olifants River the utility of the ACRU model has been evaluated at a cost of more than R800 000.

Research on the development of philosophy and guidelines for integrated catchment management was co-funded by DWAF.

The UNESCO/IHP-sponsored HELP-programme may contribute major funding in research on the Upper Olifants and Tugela catchments (see also under **New Projects**).

Many of the WRC-funded project leaders are making contributions to the DANCED-funded project with DWAF through which the establishment of CMAs in three water management areas is being initiated.

International linkages

Dr R Auerbach obtained his Ph.D. at Wageningen University in the Netherlands on WRC-funded research in the Mlazi catchment.

Prof N Röling, an internationally recognised development expert, has visited the WRC's Mlazi project several times. Dutch students, paid by the Netherlands, have made valuable contributions.

Ms N Motteux is working closely with Dr J Fargher, an internationally recognised Australian expert, on institutional development for resource management. Dr Fargher has worked in South Africa for several months and will continue to do so in 2002.

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Chapter 15

Catchment Hydrology

Mr H Maaren
(† 28 August 2002)

Scope

This field strongly overlaps with the bio-physical programme in the ***Integrated Water Resource Management*** field. The main distinction is that in catchment hydrology the emphasis is on the science of hydrology while in integrated water resource management the emphasis is on management application.

Of South Africa's rainfall only a relatively small portion (national average < 10%) lands up in our rivers as streamflow. An even smaller portion filters through to our groundwater. The catchment is the primary landscape unit in which the hydrological process can be studied as a whole. At the heart of this process is the atmosphere-soil-plant interaction; relatively small changes in this process can have major impacts on our rivers and groundwater. Hydrological modelling supported by sound and well-focused field studies, is central to this activity.

The understanding of hillslope hydrology and its precise impact on seasonal low flows in our rivers are essential. In this regard the connectivity between surface water and groundwater needs to be better understood. The impact of various land uses and vegetation changes such as afforestation, alien invading plants and grazing regimes on our water resources remains an important domain for research.

The investment in this field has declined somewhat as funds have been redirected towards hydrological applications in more applied fields, notably that of ***Integrated Water Resource Management.***

Links to Key Strategic Areas (KSAs)

Water Resource Management

This entire field will be absorbed into this new KSA, probably under a new thrust on water resource assessment. Catchment hydrology focuses on the land phase of the whole hydrological cycle and as such forms the base of all our available water resource assessments. In this respect the field also links closely to the fields of ***Hydroclimatology*** and ***Groundwater***, especially recharge aspects.

Water-Linked Ecosystems

The management of aquatic ecosystems in rivers and wetlands is very much dependent on the management of the surrounding land and its impact on the hydrological cycle.

Water Use and Waste Management

Catchment hydrology determines the quantity and quality of surface water which

TABLE 1
Research Funding Investment in **Catchment Hydrology**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 754 725	R3 289 946	R2 906 207	R3 328 400	R2 829 200
% of research fund	9.28%	7.40%	5.48%	5.4%	4.7%

can be abstracted for use and, in turn, is impacted by return flows, effluent discharges and waste disposal.

Water Utilisation in Agriculture

The vast majority of our catchments are under one or other form of agricultural land use.

Objectives

Primary

Research on catchment hydrology is to provide a scientific explanation and adequate quantitative understanding of the soil-water balance dynamics and streamflow generating mechanisms for any spatial and temporal scale and their relationships with the physical and chemical transport of matter and with ecology.

Secondary

- To determine baseline hydrological characteristics of the South African landscapes;
- To assess the impacts of different land uses on hydrological characteristics;
- Evaluating the interaction between surface- and groundwater;
- Integration of research methodology at different scales of time and space; and
- Development of a national water resource information system.

Research Projects

Portfolios of completed, current and new projects, which directly address the above-mentioned objectives, are presented below.

Completed

Hydrological systems modelling research programme: Hydrological process research

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 637)

During the project certain key catchments were studied and a valuable database of soil physical data was established. The data and data analysis are being used in conjunction with hydrological models to assess the capability of such models to simulate the appropriate hydrological processes. The Cedara, Ntabamhlope and Weatherly catchments form the bulk of the work; in the first two catchments some datasets extend back to 1964.

Of particular importance in the newly collected data is that not only the traditional rainfall and runoff are measured but also the associated data on subsurface soil water dynamics. Hillslope hydrology in particular has been intensively studied at the Weatherly catchments in the NE Cape with major inputs from NE Cape Forests (Mondi). This research catchment was initially established in 1995 and since has been developed in a truly multidisciplinary action programme on land-use hydrology. Mondi has agreed to hold back on planting forests until such time as enough quantitative understanding of the hillslope and the impact thereof will be studied.

Soil physical process studies have also been used to assess small-scale irrigation of market gardens. For instance, in Willowfontein it was found that furrow irrigation was too infrequent and too long, causing excessive drainage below the root zone. Local market-garden farmers could use the monitoring equipment and achieve considerable water savings.

Cost: *R 2 593 400*
Term: *1993 -1998*

Development of a hydrological model of the Upper and Middle Limpopo River

Department of Civil Engineering, University of Stellenbosch
(WRC Reference No 746)
and

The Limpopo River main-stem hydrological model: Update of existing model and installation in the co-basin states

Ninham Shand (Pty) Ltd
(WRC Reference No 1113)

These two projects are treated as one, because Project 1113 was fundamentally an extension of Project 746. They were kept separate for tactical reasons. Because the anticipated total basin studies did not materialise, the objective of carrying out a yield assessment at the confluence with the Olifants River could not be achieved.

The achievements are:

- Completion of a monthly hydrological model of the complete main-stem of the Limpopo from the Marico/Crocodile confluence to Chokwe in Mozambique;
- Sets of short- and long-term recommendations relating to the improvement of the hydrometric monitoring systems in the Limpopo in those parts of the basin shared by the four countries. A report summarising these recommendations was submitted to the four co-basin states. Most of the short-term recommendations are already being implemented. The long-term ones are being investigated;
- Establishment of improved lines of communication and relatively free exchange of data and information between the project team and each of the co-basin states' relevant government departments;
- An agreed process of reconciliation of Beit Bridge flow data between Zimbabwe and South Africa;
- An active international Steering Committee with representation by all four countries which meets regularly in the Northern Province; and
- Technology transfer to a hydrologist from Mozambique and Zimbabwe by the hands-on training in model configuration and implementation at the University of Stellenbosch.

Usefulness of the hydrological model
As it stands, the hydrological model has the following applications:

- It has allowed understanding of the flow balance components of the Limpopo main-stem and can be used to refine these estimates, once the data problems that have been experienced during this study are ameliorated. These comprise the paucity of a range of relevant data in some tributary catchments and the discrepancies in flow records at check points.
- It has allowed identification of river reaches where flow monitoring needs to be augmented or, at least, improved.
- The model can serve as the backbone of the hydrological component of the Limpopo Basin Study. The model can be adjusted to simulate naturalised flows once the flows of the tributaries are also naturalised. Long records of rainfall data starting from as far as 1921 have been prepared where possible. Similar records can be prepared if the relevant data are made available. Long periods can then easily be simulated for the entire Limpopo Basin and different main-stem development scenarios tested.
- In its current form, the model is set up with historical flows from tributaries and historical water use abstractions along the main stem for the post 1970-period. As such, it can already directly serve to answer "what-if" questions about the relevant impacts of different main stem or tributary development scenarios.

Conclusions
The following conclusions emerged from the study:

- The study has strengthened the understanding of the magnitude of transmission losses. The task under completion will shed more light on this aspect and the related processes.
- The implementation of the recommendations formulated for the improvement of streamflow gauging is crucial. It will provide a more reliable and complete set of flow records for future studies of the water resources of the Limpopo River.
- Various problems were encountered, mainly the paucity of data on land use, on the geophysical channel characteristics and on rainfall in some tributary catchments. The hydrological model has, however, been improved with a better definition of the geomorphological characterisation of the main stem.
- The hydrological model has proved to be useful in providing the components of the flow balance and it will benefit the hydrological component of the Limpopo Basin Study.

A synergy of collaboration among the co-basin states and with the project team has emerged from the strong commitment of all parties involved in this study. It is hoped that this synergy will lead to successful planning and execution of the Limpopo Basin Study.

No. 746
Cost: *R346 000*
Term: *1996 -1999*

No. 1113
Cost: *R140 000*
Term: *2000*

Comparison of the water use of selected invasive and indigenous riparian plant communities

Environmentek, CSIR
(WRC Reference No 808)

A riparian fynbos site was chosen in the upper reaches of the Jonkershoek valley, close to the Eerste River that flows past Stellenbosch. A 12-month record of 20 min evaporation rates from this site was recorded using the Bowen ratio energy balance (BREB) technique. A closed-canopy, mature stand of self-established wattle in the Wellington area of the Western Cape was selected to provide comparative water use data. The heat pulse velocity technique was used to record hourly sap-flow rates in six sample trees representing the range of tree sizes in the thicket. Total daily sap-flow in all sample trees was closely correlated to a daily air humidity index defined as the product of mean daily vapour pressure deficit (VPD) of the air and the number of daylight hours. A fire destroyed the sample trees after seven months of data collection. However, the daily sap-flow/VPD index relation was found to be constant over the entire data record, which spanned both wet conditions in late winter, and very hot and dry conditions in late summer, indicating an absence of stress due to soil-water deficits. It was assumed therefore that the same relationship would hold throughout an entire year, and could be used to predict wattle transpiration at the Jonkershoek site using the VPD data recorded there by the BREB system.

A replacement *A. mearnsii* riparian site was chosen on the slopes of the Groot Drakenstein mountains close to Pniel in the Stellenbosch district. Hourly sap-flow was monitored in six sample trees over a period of seven months, until the experiment was terminated by another fire. Daily sap-flow over the entire period of measurement showed a distinct and progressive reduction over the second half of the dry summer, which is shown to be caused by stress due to soil-water deficits. Sap-flow rates recorded over the period prior to the commencement of transpiration reduction were found to be very similar to those recorded at the Wellington site. Both data sets were used to develop a simple model of daily sap-flow (under conditions of no water stress) for this species on the basis of tree diameter at breast height (DBH) and the product of mean daily VPD and the number of daylight hours.

Conclusions
- Reduction in annual ET following removal of *A. mearnsii* from riparian zones is potentially large, but is also highly variable, depending on the characteristics of the pre- and post-clearing plant communities, and climate regime. The results of this research cannot be extrapolated to other sites without taking careful account of these factors.
- Assuming that soil-water availability remains high throughout the year in riparian habitats, annual ET will be greatest in vegetation that maintains a high state of physiological activity and green-leaf area throughout the year, and lowest where water use is curtailed by seasonal dormancy or any other cause of low green-leaf area.
- The impact on catchment water yield of clearing *A. mearnsii* from riparian zones will vary in proportion to the area of riparian zone present in the catchment.
- Where *A. mearnsii* is present in non-riparian areas of a catchment, the potential for streamflow enhancement following clearing is greatly magnified.

However, the hydrological effects of clearing these areas will depend on the annual ET characteristic of the pre- and post-clearing plant communities. The more constrained this is by soil-water deficits, the less scope there is for large differences in annual ET between pre- and post-clearing vegetation.

- Clearing alien invasive trees in different parts of the country will lead to different catchment yield responses. Local assessments of such responses are required for prioritising clearing efforts and evaluating the cost-benefit of such actions. Simple predictive models are required to make such assessments.
- This study has demonstrated that annual water use of diverse plant communities may be adequately modelled on the basis of the factors most limiting ET rates. This is the basis of the "Alimits concept" propounded by Calder (1999). Models described in this report for predicting the water use of riparian *A.mearnsii*, grassland and fynbos are examples of such models.

Cost: *R421 000*
Term: *1997 - 2001*

Feasibility of using trunk growth increments to estimate water use of* Eucalyptus grandis *plantations

Environmentek, CSIR
(WRC Reference No 809)

The data were analysed together with water-use efficiency (WUE) data obtained in five previous studies. The combined plot of data points displays a more variable and curvilinear trend than suggested by the original Kruisfontein data, and physiological reasons for the non-linearity and variable WUE are reviewed. These results support some recent physiological evidence that the relation between above-ground growth and amount of water transpired may be significantly affected by altered patterns of carbon allocation by trees, with a greater proportion allocated to roots in trees that are stressed. Data reported here have yielded particularly clear evidence that the WUE of forest plantations is influenced by rainfall distribution. *Eucalyptus* clones sampled in the Kwambonambi district showed a distinctly lower WUE than the remaining sample trees, and this difference is attributed to a severe growing-season drought during the period of measurement.

Cost: *R302 000*
Term: *1997 - 1998*

Afforestation effects: A re-analysis of the South African catchment afforestation experimental data

Environmentek, CSIR
(WRC Reference No 810)

For each successfully analysed experiment the estimated effects on total and low flows are standardised to a 10% level of planting or clearing and plotted against time in two figures. The seasonal effects are illustrated by plotting the mean flow reductions or increases for each month of the year, generated over many years while the plantations were mature. The results are also tabulated.

The initiation of flow reductions (onset of significant reductions after planting) varies widely depending on the stature of the competing native vegetation and the rate at which catchments are dominated by the plantation crop. The pine plantations in tall fynbos in the Western Cape and in high-altitude grasslands in the Drakensberg usually took several years to have a clear impact on streamflow (up to 6 years). However, some pine crops, e.g. Lambrechtsbos-A in Jonkershoek and Mokobulaan B in Mpumalanga had an early effect on streamflows (within 3 years). *Eucalyptus* have an earlier impact on streamflows, within 2 to 3 years. Under drier conditions this was still true, though here (Ntabamhlope) the timber crop also had the benefit of full site preparation prior to planting.

Once reductions are significant they generally become larger quite quickly, reaching peak or near- peak reductions fairly early in the rotation. Peak reductions under pine are reached around 15 years of age and at least 5 years earlier under *Eucalyptus*. At the drier Ntabamhlope site, flows ceased completely in the 4th year after planting, which was also a dry hydrological year. It seems to be generally true that dry conditions will accelerate the desiccation of the catchment after planting.

A new finding from this up-to-date analysis is that flow reductions are definitely diminished towards the end of longer timber rotations, and this is true of both pines and at least one *Eucalyptus* experiment. Obviously this trend is clearest in the longer-term experiments. The diminution of final flow reductions (mean over last 5 years measured) compared to the highest 5-year mean reductions ranges from zero (no change over time, usually in short-term experiments) to 60% and 50% less, for absolute and relative measures respectively. The single *Eucalyptus* experiment in which this trend was observed was confounded by a partial clearing (~10% cleared along the stream) prior to the restoration of streamflows. However, the small area that was cleared is not likely to account for the large change in flow reductions (48%).

Cost: R400 000
Term: 1997 - 1999

Development of models to quantify streamflow reductions caused by commercial afforestation in South Africa

Environmentek, CSIR
(WRC Reference No 1110)

The main objective of this project was to verify the ACRU model on available streamflow data from experimental or research afforested catchments and thereafter to run the model for all regions with forestry potential with the goal of producing regional look-up tables that will provide site-specific streamflow reduction estimates that are acceptable to a wide group of stakeholders.

The modelling results are based on the following assumptions:

- For each QC a single quality-controlled daily rainfall data set was used for the period of 1950 - 1994 with associated QC information on temperature and potential evaporation.
- For each QC three alternative depths (shallow, medium and deep) of a uniform sandy clay- loam soil were used and the SFR for each depth was simulated.
- Three genera of trees were included in the study: *Eucalyptus*, pines and wattles.
- While individual trees go through a

growth cycle, a large plantation usually has a mosaic of tree ages from seedlings to mature trees. For this study, a normalised single representative age of trees was therefore assumed to mimic the average situation on a typical large forestry estate, catering for planting and felling simultaneously. The ages used were 4 years for *Eucalyptus*, 7 years for pines and 4 years for wattles.

- The water use and streamflow under this forest cover was compared with those associated with a baseline land cover equivalent to the dominant Acocks veld type within a QC.
- Because the QC database was already in place at the University of Natal at the start of the project, a standard ACRU model run was done on the Acocks veld type base-line. After an initial model run it was realised that the manner in which the Acocks veld type was characterised differed from the manner in which the forest canopy was characterised. Therefore, a second model run on the Acocks base-line was undertaken to ensure a consistent comparison of the two vegetation covers.
- In all the model verification runs and model adjustments accurate records of all modifications were logged, and have been included in the scientific project report to be published by the WRC.
- A set of confidence limit classes was developed which allows the linking of a confidence limit to each QC's SFR values, for both total flows and low flows.

The following recommendations are made as to the advised use of the SFR look-up tables:

- To avoid confusion with regard to the influence of soil depth, it is recommended that the SFR values simulated for the medium soil-depth case be used to best represent the average South African forestry situation.
- Therefore, the values are mainly suitable for broad preliminary national or regional planning.
- The SFR table values should be used to improve the SFR estimates in the Water Situation Assessment Model (WSAM).
- If used with due consideration of the confidence limit classes, the SFR values can provide a fairly consistent basis for identification of regions where the detail required by forestry licensing procedures may indicate a need for more site-specific study.
- It is not recommended that the SFR values for individual QCs be used for water pricing and catchment management charges. It would be more prudent to devise three or four classes of SFR impacts in combination with some regionalised smoothing between QCs.

Cost: *R303 000*
Term: *2000 - 2001*

Current

Flood forecasting system for Vaal Dam

DWAF
(WRC Reference No 908)

As a result of the Gore-Mbeki Binational Commission, South Africa received an offer of a flood forecasting system based on USA technology. At the time the WRC decided, together with DWAF, to accept the offer rather than invest in costly development locally. The system has been installed for the Vaal system. The WRC contribution is to be towards meeting training and installation costs.

Estimated cost: *R 150 000*
Expected term: *1998 - 2001*

Monthly multiple site streamflow model

BKS (Pty) Ltd.
(WRC Reference No 909)

Stochastic streamflow generation to deal with South African's variable flow regimes has been in use since 1985. The existing model is not user-friendly and runs under DOS. It cannot handle records of variable length. This project will develop, restructure and rewrite a more user-friendly streamflow generator software under Windows that can accommodate variable record lengths.

Estimated cost: R300 000
Expected term: 1998 - 2001

Modelling the impacts of land cover and land management practices on streamflow reduction

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1015)

This project is a refinement of the ACRU modelling system specifically highlighting best management practices for optimal water-use efficiency in rain-fed agriculture and catchment water balances. Since the early 80s the impact of land use on streamflow has been recognised as an important issue. Hydrological modelling based on physical concepts is the accepted way of quantifying such impacts under different environmental conditions. This project not only studies the vegetation cover or plants used, but specifically studies the level of land management that is employed, such as contour walls, swales, mulches, etc. as it is believed that these management practices have significant impacts.

Estimated cost: *R571 800*
Expected term: *1999 - 2001*

Regionalisation of rainfall statistics for design flood estimation

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1060)

Most design rainfall methodologies of the past were based on individual stations' records. The regionalisation approach, being addressed in this project, will allow us a more robust processing of all observations of different record length and observation period. Since the last comprehensive processing of data on flood-producing rainfall took place in the mid 1980s, the project also presents the opportunity for a much-needed update.

Estimated cost: *R1 072 700*
Expected term: *1999 - 2001*

A field study of two- and three-dimensional processes in hillslope hydrology for better management of wetlands and riparian zones

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1061)

Most high rainfall and runoff producing areas in South Africa are characterised by relatively shallow soils over more or less weathered bedrock with variable topography. This project addresses the lateral movement of infiltrated rainfall on the hillslope as a key element of the rainfall-runoff process that needs quantitative

understanding for the management of wetlands and base flows in rivers.

Estimated cost: *R1 809 000*
Expected term: *1999 - 2002*

Experimental and laboratory measurements of soil hydraulic properties for improved modelling of catchment processes

School of Bioresources Engineering and Environmental Hydrology, University of Natal
(WRC Reference No 1086)

The movement of water in the soil mantle of the earth plays an important role in many aspects of catchment management. Soil hydraulics is important when investigating waste sites, irrigation and drainage and water infiltration of natural surfaces in general. This project is to develop robust field and laboratory measurement techniques to characterise soil hydraulic properties on a consistent and scientifically sound basis as an input into modelling.

Estimated cost: *R646 300*
Expected term: *1999 - 2002*

Development of terms of reference for a long-term study to quantify the surface water resources of Southern Africa

Institute for Water Research, Rhodes University
(WRC Reference No 1112)

As part of the SADC/UNDP Water Round Table Programme, an SADC regional strategic action plan (RSAP) has been formulated. One of the proposed projects in this action plan is entitled: **Assessment of Water Resources**, and will be executed in three phases, preceded by a mobilisation phase.
Inadequacies in information-gathering and -sharing were identified as a constraint to the trans-boundary development of water resources and serve as prime motivating factors for undertaking this project.

The purpose of the long-term RSAP project is to produce and make accessible an SADC-wide surface water resources assessment in a manner that builds capacity in participating institutions, promotes confidence in products amongst member states and which ensures that the assessment supports equity amongst stakeholders through equitable sharing of water within international river basins. The project is of strategic importance for contributing to the development in the Southern African region.

In this project, which constitutes the mobilisation phase of the larger RSAP project, consideration will be given to the following factors:

- Not all SADC countries have undertaken national assessments, notably Angola and DRC and, therefore, a full regional assessment cannot be constructed by aggregation.
- In many countries the assessment is of residual flow due to a lack of data and estimation procedures to account for abstractions and other reductions (afforestation for example).
- Significant variations exist among the data-transfer methods adopted in national assessments. Such variations can introduce regional concerns regarding methodological rigour and consistency.
- For various reasons only very limited consistency exists between countries in methodological approaches.
- There are different methods of river flow estimation and measurement. The project will face significant challenges if it attempts to accommodate all prior work.

Estimated cost: *R300 000*
Expected term: *2000*

Analysis of streamflow generation mechanisms in a wide range of catchments

Environmentek, CSIR
(WRC Reference No 1193)

In modern catchment management it is increasingly necessary to pay attention to detail on how any human intervention impacts on river flow regimes. Although each catchment is almost unique in this regard, this project will provide some general principles applicable for South African landscapes as a basis for improved modelling and management.

Estimated cost: *R496 000*
Expected term: *2000 - 2001*

New

The use of isotope (13C) techniques to define the riparian zone in commercially afforested catchments

Environmentek, CSIR
(WRC Reference No 1218)

Trees growing in riparian zones have continuous and free access to water. Because they are not restricted in their use of water, they make a disproportionate contribution to streamflow reduction. As a matter of policy, afforestation in riparian zones is therefore prohibited. A major difficulty, however, in implementing what is a sound policy, is the problem of delineating riparian zones. In this project, an isotopic (13C) technique is being investigated for riparian zone delineation.

Estimated cost: *R200 000*
Expected term: *2001*

Improving the basis for predicting evapotranspiration from dry land crops and veld types in South African hydrological models

Environmentek, CSIR
(WRC Reference No 1219)

Evapotranspiration or "green water" represents between 50 and 99 % of our natural water balance in South Africa. Hydrology, rain-fed agriculture and irrigation have in the past followed somewhat different methods to estimate evapotranspiration of plants and plant covers. This project aims at building a common base from which the integration of various catchment management activities (afforestation; wetland rehabilitation and alien vegetation control) can be quantitatively understood and prioritised.

Cost: R530 600
Term: 2001 - 2003

Can effective management of riparian zone vegetation significantly reduce the cost of catchment management and enable greater productivity of land resources

Environmentek, CSIR
(WRC Reference No 1284)

Riparian zone management has become an important issue in water conservation in South Africa and water resource managers are under increasing pressure to assess the impacts of different land uses and

management practices on catchment water yield. This has been exacerbated by the introduction of the new Water Act, which has prompted DWAF to develop a framework for managing the use of water by streamflow reduction activities (SFRAs). This calls for the ability to predict and monitor the impacts of SFRAs on water and on the protection of water resources within each water management area.

The forestry industry has a particular concern over the management of riparian zones, which through effective management may significantly reduce the impacts of forest plantations on catchment water yield. The need to exclude plantation trees from riparian zones is widely accepted within the industry, but there is also recognition of the fact that not all riparian zones in a catchment are equally effective in influencing catchment yields.

The Working for Water Programme managed by DWAF is a multimillion Rand project aimed at clearing alien invasives from South African river courses. The rationale behind this Programme is that the clear-felling of invasives will help to restore the water balance and biological diversity in many of South Africa's most important water-yielding catchments. Of particular interest is the difference in impacts of trees close to streams and those further away from streams.

Re-colonisation of cleared areas with natural vegetation will also have an impact on water yield. In order to quantify the long-term effects of clear-felling invasives, one has to compare streamflow responses following clear-felling with those after re-colonisation has taken place. In addition, clearing riparian areas of weeds is very costly for land-owners and they need to know what the return is in terms of water.

Since riparian soils are mostly the wettest and most fertile within a catchment, and are therefore the most productive, there is great interest in moving away from the use of a standard width throughout the catchment, and rather to identify the required limits to the riparian zones on the basis of more objective criteria. What is unclear is the size and significance of this moderating influence. This project will therefore investigate how effective management of riparian zone vegetation can reduce the cost of catchment management and enable greater productivity of land resources.

The aim of this research project will be to investigate the links among vegetation, saturated zone dynamics, and runoff generation for the different classes of riparian zone, and to test the hypothesis that riparian zone vegetation has a significantly variable effect on catchment water yields.

Estimated cost: R727 500
Expected term: 2001 - 2003

Outcomes to Date of Current Programmes and Projects

New knowledge

It has become apparent that hydrological processes at scales with which new water legislation is concerned are rather site specific. Consequently, it has been necessary to give more attention to detail concerning spatial variability of soils, slopes and rainfall and climate distributions in the context of process and modelling studies.

Furthermore, with the change in emphasis from a supply-management approach (building new reservoirs) to a demand-management approach and the fundamental role given to the ecological reserve, there has been a move away from monthly time-series modelling to higher-resolution physical-conceptual modelling based on daily data. Such a move demands much better quality input data, and shortcomings in existing rainfall and soil data have been identified. This new knowledge is crucial for redirecting hydrological research.

As a result of the WRC's scientific support for the Working for Water Programme, it has become apparent that existing knowledge about the extent and dynamic nature of alien plant invasion is inadequate and that further research is needed. It has also been clearly established that riparian zones are particularly vulnerable to additional water losses through alien vegetation.

It has been learnt that hillslope hydrology is a key process affecting the interplay between surface water and groundwater in our catchments. The optimal management of many of South Africa's wetland types depends on this knowledge.

Benefits to South Africa

This field provides the scientific hydrological basis for catchment management in South Africa. Not only does it contribute to better measurement of river flow but it also provides the knowledge to interpret observed changes in flow regimes. The understanding of the difference between natural and present-day flow regimes is crucial to resource management.

The main benefit to South Africa is therefore an enhanced capability to manage land and water resources in a more integrated manner. This integration requires consistent approaches over vertical scales that will allow the broad national picture to be soundly aggregated up from the more detailed local situation. The ACRU hydrological modelling system is based on South African data and allows aggregated and cumulative impacts of land-use changes, varying from the individual land or farm to the primary catchment, to be predicted.

Innovation/application of knowledge

Knowledge generated through the current ACRU model, in combination with results from a limited number of paired catchment experiments, is presently being used to provide DWAF with a national information base of the impacts of commercial afforestation. The data are at the quaternary catchment scale and will allow the resource managers to make the following decisions:

- Identify how commercial forestry reduces streamflow;
- Develop a consistent method for licensing afforestation; and
- Develop an acceptable pricing strategy for catchment management.

The ACRU model is increasingly being used to provide consultants, farmers and government agencies with answers to a number of land and water questions.

Capacity/competence development

Capacity and competence developed through WRC-funded research resides in the following institutions:

University of Natal

By far the dominant capacity for catchment hydrology research has become established at the University of Natal in the School of Bioresources Engineerng and Environmental Hydrology (School of BEEH). The CSIR (Environmentek) has established a separate office on the University campus in Pietermaritzbrug that enables the BEEH and CSIR groups to work together. So far the co-operation has been very productive.

The School of BEEH is very strong on hydrology modelling and hydrological studies as well as the use of soil physics and soil water hydraulics in understanding hillslope hydrology.

SAPPI has given recognition to this centre of expertise by providing the funding for a 5-year contract at senior lecturer level (Dr G Jewitt).

As a centre of expertise, the School of BEEH, has produced capacity, i.e. skilled people for the hydrological job market in SA, as follows:

- Ph.D.s in hydrology topics
  6 completed
  3 candidates currently doing Ph.D.s (Lecler, Rivers-Moore, Taylor)
- Masters in hydrological topics
  38 completed (24 M.Sc., 14 M.Sc.Eng)
  9 currently registered, of whom 4 are from disadvantaged communities
- B.Sc. Honours in hydrology
  Approximately 80 students graduated since 1984
  Currently (1999/2000/2001), 60 to 67% are from disadvantaged backgrounds
- B.Sc. in hydrology
  Approximately 230 students graduated since 1982
  Currently (1999/2000/2001), 65 to 76% of third-year students are from disadvantaged backgrounds

CSIR (Environmentek)

The CSIR-Environmentek has two main centres, Pietermaritzburg and Stellenbosch. The group is very strong in high technology measurements of plant water use. This group does considerable research for the Working for Water Programme, the Land-Care Programme, DWAF and many other organisations. The fact that a major office was established on the Pietermaritzburg campus of the University of Natal has created a very effective critical mass in various hydrological disciplines.

Two members of the Pietermaritzburg team are about to obtain higher degrees based on WRC projects:

- Marilyn Royappen: M.Sc. based on the WRC project: **An analysis of streamflow generation mechanisms in a wide range of small catchments**
- Mark Gush: M.Sc. based on the WRC project: **The development of models to quantify streamflow reductions caused by commercial afforestation in South Africa**

IWR at Rhodes University

In the early 1990s the WRC decided to move away from arid zone catchment hydrology and concentrate more on national priorities with regard to the integration of hydrology and aquatic sciences. The IWR has subsequently become a national centre that serves South Africa well in this regard. Development of students which takes place through the Department of Geography, has been as follows:

1998	1 White female and 1 White male doing Honours on hydrological aspects of reserve determinations
1999	1 White female working as a post-Honours trainee on hydrological aspects of reserve determinations
2000	No courses offered by IWR as there were no students in hydrological aspects of geography.
2001	2 Black females, 2 White Females and 1 White male doing Honours water resource management, a course partly given by IWR members 1 Black female from Zambia registered as an M.Sc. student 2 Black females and 2 Black males attended a short course on hydrological aspects of reserve determination 12 Black males and females (mostly Zimbabwean) attended a 1-week course on environmental flows at the University of Zimbabwe as part of a regional Masters course

Civil Engineering at University of Stellenbosch

Profs Rooseboom and Basson are national leaders in dealing with sedimentation problems. Prof Görgens plays a vital role in promoting land-use hydrology and hydrological modelling.

Recent qualifications resulting from WRC projects are the following:

White Male:	Ph.D. - 3 graduated; 2 In progress M.Sc. or M.Eng - 2 graduated
Black Male:	Ph.D. - 1 In progress M.Sc or M.Eng - 2 graduated
White Female:	M.Sc. or M.Eng - 2 graduated
Black Female:	M.Eng -1 In progress

University of Zululand, Department of Hydrology

Through the years the research catchments near the University of Zululand have made important contributions to process hydrology. The integration between surface water and groundwater is strongly supported by this group.

WRC-funded projects have provided opportunities for work towards higher degrees (completed or in progress) to the following individuals:

- Mrs Snyman, Mrs Germishuyse and Mr Nomquphu have completed M.Sc. degrees;
- Mr Mbatha and Mr Mthembu are presently doing an M.Sc. in hydrology;
- After completing his B.Sc. Honours at Zululand, Mr Magagula completed his M.Sc. at ITC Cuschede, Holland and is now doing his Ph.D. in hydrology in Zululand. He will work together with Dr Simon Lorentz on the hillslope hydrology project.

Knowledge dissemination

At the last SANCIAHS Symposium held in Pietermaritzburg, attended by about 85 hydrologists there were 44 presentations. Of these 35 acknowledged WRC funding. This has been a fairly consistent pattern over the last six years.

Courses on using the ACRU modelling system have been attended by several of the prominent consultants and staff from DWAF.

Publications:

	1998	1999	2000
WRC reports	2	4	5
Scientific papers	1	6	1
Other reports	5	5	3

Presentations	16	18	12
Web pages	0	3	0
Theses (M.Sc.+Ph.D.)	2	2	0

Leveraging of resources

WRC-sponsored research has benefited from outside contributions, as follows:

- The USA has contributed an estimated R1 million towards the development of a flood model for DWAF.
- The School of BEEH was funded by the EU to the tune of R 500 000 over a 3-year period to use the ACRU model for modelling the hydrology of the Muture catchment in Zambia and the Mbuluzi catchment in Swaziland.
- NOAA contributed about R 120 000 to a project on using the ACRU model to develop climate change scenarios in South African hydrology.
- The School of BEEH is doing work for DFID to develop a water-poverty index in the Tugela catchment (R 100 000).
- The USA country studies programme contributed R 60 000 towards buying field equipment for the NE Cape hillslope hydrology project.
- Under the SA-UK research agreement, the UK contributed R 60 000 for work on ecohydrology in the Kruger National Park.
- Eskom contracted the ACRU modelling team at a cost of about R 60 000 to produce water resource scenarios for climate change.
- DWAF's Water Resource Management Directorate has contributed about R800 000 to evaluate the ACRU model in the Upper Olifants River catchments. As a direct result of this study DWAF and the Weather Bureau have initiated discussions on the need to maintain an adequate national rainfall monitoring network.
- The Working for Water Programme, costing over R300 m./a maintains direct links with WRC projects for assistance in developing its national and regional strategic plans.

International linkages

Several of the WRC-funded researchers are guest lecturers at foreign universities. Prof Schulze of the University of Natal lectures at the Hydrology Programme at the University of Delft in the Netherlands. Prof Hughes of IWR at Rhodes University is a guest lecturer at the University of Zimbabwe in Harare.

The WRC has funded a South African contribution to the UNESCO's FRIEND (Flow Regimes from International Experimental and Network Data) programme for Southern Africa, specifically highlighting the impacts of land use on water resources and hydrological modelling in semi-arid regions. As a result the 4th International Conference on FRIEND was held in Cape Town in March 2002.

The SADC Water Sector has developed a regional action plan for water. The WRC has funded the development of the TOR for a US $16m. project on assessment of surface water resources in Southern Africa. This project included comprehensive consultation with national water sector representatives. The TOR has been approved by the national ministers of Water Affairs. The WRC is in line to become the "implementing agent" for this project and will have to assist in finding the required funding.

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Chapter 16

Conservation of Water Ecosystems

Dr SA Mitchell

Scope

This field focuses on the protection and sustainable utilisation of the aquatic environment (abiotic and biotic). It addresses national research needs (strategic and shorter term) as well as those of international conventions on environmental management (e.g. Wetland Conservation [Ramsar] and Biodiversity). Work done within this field has contributed to the development of the National Water Act (NWA) and associated policies, an example being the ecological reserve. This has meant that work within this field has not only addressed the strategic needs of the country which have increased in line with the increased global recognition of the importance of the role of sustainable environmental management, but also has addressed some of the immediate research needs related to the NWA and its implementation. As a result, funding in this field has expanded substantially in recent years (Table 1). What people require of the environment is an area of increasing importance in the field, and the building of capacity amongst the country's citizens (managers and the various user groups) to manage the environment sustainably is of cardinal importance.

Links to Key Strategic Areas (KSAs)

The ***Conservation of Water Ecosystems*** field is central to the KSA for **Water-Linked Ecosystems** as much of the research being funded in this field addresses the topics to be included in this KSA.

Water Resource Management

Ecosystem health provides a cost-effective monitor of the condition of the resource and links closely to integrated water resource management.

Water Use and Waste Management

Water abstraction and waste discharge both exert direct influence on the goods and services provided by ecosystems. Costs for treatment of waste which are externalised by human activity are registered in a decline in the quality and quantity of goods and services provided by the environment, specifically the links between groundwater and surface water and integrated catchment management.

Water Utilisation in Agriculture

Alterations in water quantity and quality through agricultural activities will influence ecosystem health.

TABLE 1
Investment in **Conservation of Water Ecosystems**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 423 500	R4 143 928	R 5 262 048	R6 528 800	R 5 993 550
% of research fund	8.46%	9.3%	9.92%	10.52%	10.1%

Objectives

Primary

The provision of knowledge to enable the utilisation and sustainable management of the aquatic ecosystem in a water-scarce country in a time of demographic and climate change.

Secondary

- Develop understanding of the ecological processes underlying the delivery of goods and services;
- Develop the knowledge to sustainably manage the aquatic ecosystem for ecosystem protection and ecosystem utilisation;
- Transfer the knowledge to appropriate end-users; and
- Build capacity in both research and management to sustainably manage aquatic ecosystems.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

Linking abiotic and biotic data on South African rivers

Department of Zoology, University of Cape Town
(WRC Reference No 754)

The assumption that rivers in the same region with same abiotic features will have the same fauna, used in many countries as a basis for river management, has been challenged by the results of this project. The project set out to investigate whether the geomorphological classification developed by Rowntree and Wadeson (WRC Report No 497/1/99) is an ecologically valid classification system. To do this, 28 sample sites were selected, and at each the substrate and flow type were mapped and up to 12 samples of the invertebrate fauna were taken, 1 from each of the physical conditions represented at the site.

It was shown that the geomorphology is not a good surrogate for the ecological aspects in management decisions. While hydraulic biotopes can be differentiated into 11 categories geomorphologically, ecologically only four were shown to be relevant, simplifying classification.

The hydraulic conditions under which each taxon was found has been defined, and a technique has been developed for mapping flow types.

Cost: *R1 305 546*
Term: *1996 - 1999*

The tolerances of selected macro-invertebrates from the Buffalo River

Institute for Water Research, Rhodes University
(WRC Reference No 783)

This project examined the toxicity of kraft and textile effluents on indigenous riverine invertebrates. The experimental approach selected was acute 96 hour toxicity tests following an unreplicated regression design, using mayfly nymphs as the test organisms, and river water as diluent and control. Test organisms were collected from unimpacted, flowing-water riffle areas, and were exposed in recirculating artificial streams (or channels) to a range of effluent concentrations. Mortality was selected as end-point and observed twice daily. The experimental results showed the variability and acute toxicity of both kraft and textile mill effluents. In both cases effluent that had been irrigated was less toxic than that direct from the factories.

Toxicity test data indicated the GKE, IKE and GTE should not enter the aquatic environment without treatment, as these are toxic to aquatic biota. Both kraft and textile effluents must therefore be treated before discharge. The use of indigenous organisms, and not a standard laboratory organism, could have contributed to the variability observed. A hazard-based approach would provide a consistent basis for deciding on the acceptability of impacts, while allowing natural site-specific differences to be taken into account.

Cost: *R35 000*
Term: *1996 - 1998*

The botanical importance rating of estuaries in former Ciskei and Transkei

Botany Department, University of Port Elizabeth
(WRC Reference No 812)

Ninety-two estuaries in the former Ciskei and Transkei regions of the Eastern Cape were surveyed during this project to determine their botanical importance as well as their habitat integrity.

Mangroves were also incorporated into the botanical rating system, the southern limit of mangrove distribution being in the southern Transkei. In addition, swamp forest and micro-algae were included in the Botanical Importance Rating (BIR), thereby extending the BIR to include nine estuarine plant communities. In its current form, the BIR can now be applied to all South African estuaries, and forms a standard part of estuarine freshwater requirement (EFR) estimates in the environmental reserve determinations. Information gained from this project has been incorporated into estuary management protocols, both for the use of the BIR and specifically for the management of mangroves. It was found that the habitat integrity (HI) could be applied to aerial photographs to determine the change in score with time. Using this technique it was found that the HI in the case of the Swartkops Estuary had decreased by 50% during the latter half of the 20th Century.

Estuaries from the study area were shown to be among the best preserved in the country.

Specifically, the Mgazana Estuary is important because of its unique flood plain and the fact that it supports the third largest (after St Lucia and Kosi) mangrove area in the country, although the current rate of exploitation of these is not sustainable. Of concern is the future of the Nxaxo Estuary, rating high in importance but under threat from proposed dune mining at Wavecrest.

Cost: *R165 000*
Term: *1997 - 1999*

The regional implementation of the Department of Water Affairs and Forestry's biomonitoring programme

Environmentek, CSIR
(WRC Reference No 850)

The River Health Programme (RHP) has been designed to address specific information needs, and these are spelt out to ensure that all have the same understanding of what the RHP will and will not do. The overall aim of this project entailed the co-ordinated development of a number of facets of the programme and is published in three volumes. The quality control and assurance (QC/QA) framework developed is in accordance with the requirements of the National Water Act and covers all aspects of the RHP. In recognition of the part resource users play in sustainable management of the resource, 3 case studies involving local communities were undertaken. Recommendations are made on bridging the very wide knowledge differential between resource managers and less sophisticated communities. The procedure for strategic adaptive management has been developed with the specific aim of optimising the balance between utilising and protecting aquatic ecosystems. The RHP has been established as a statutory national monitoring system in terms of the National Water Act of 1998, but the procedures and mechanisms to integrate the programme into the decision-making procedure must still be developed. The process of developing the RHP from an idea to a national initiative is explained, and a business plan for the RHP developed.

Volume **2** details the sites selected, to enable future changes to be recognised against these descriptions, and Volume **3** describes the riparian vegetation index.

Cost: *R976 000*
Term: *1997 - 1999*

Interaction of reed distribution, hydraulics and geomorphology in semi-arid rivers

Department of Civil Engineering, University of the Witwatersrand
(WRC Reference No 856)

The aspects of reed life history characteristics that influence hydraulics and sedimentation by documenting stem characteristics and their variations with season and age of reedbed are described. The hydraulically relevant characteristics of reedbeds were also documented and used to guide the laboratory investigations on hydraulics of partially reeded channels. The experiments on the basic resistance of reeds established that resistance depends on stem density and drag coefficient, but not independently on stem diameter or channel slope. The velocity profile amongst the stems under unsubmerged conditions was found to be essentially uniform. For submerged flow the velocity distribution is mostly uniform below the stem tops, and similar to boundary resisted flow above the tops.

Manning's *n* was shown to vary significantly with flow condition, so a theoretically sound alternative equation form is proposed which accounts for all influences of vegetation on flow resistance. Experimental work demonstrated the influence of partially reeded channels on the flow distribution pattern of the reedbeds. The important variables for ecologically relevant and sediment-related hydraulic conditions are shown to be flow depth, velocity and boundary shear stress.

For both ecological and sediment dynamics purposes, the distribution of velocity and boundary shear stress also needs to be described. The effectiveness of vegetation strips on trapping and stabilising sediment was clearly demonstrated. A modelling framework for simulating the interaction of water flow, reedbed dynamics and sediment movement was developed to enable reedbed and channel morphology changes to be predicted under modified hydrological regimes.

Cost: *R793 224*
Term: *1997 - 1999*

Verification of estimates of water use by riverine vegetation on the Sabie River in the Kruger National Park

Environmentek, CSIR
(WRC Reference No 877)

Bowen ratio evapotranspiration data provided direct, reliable estimates of evapotranspiration rates for the two dominant riparian communities growing along the Sabie River in the Kruger National Park. The results showed that regardless of season, the evapotranspiration flux was a significant term in the energy balance of both sites, accounting for more than 50% of the available energy. Evapotranspiration accounted for summer daily averages of 4.8 $mm.d^{-1}$ and 3.1 $mm.d^{-1}$ at the reed and forest sites respectively. This is approximately 1 $mm.d^{-1}$ higher than the winter values for reeds and 0.6 $mm.d^{-1}$ for the forest site.

The dominant control on evapotranspiration rates was available energy. Water was available to the reeds at all times except late winter.

The highest evapotranspiration rates recorded for the reeds (approximately 9.5 $mm.d^{-1}$) were likely to be the maximum evapotranspiration rates for this community, The highest rates of evapotranspiration for the trees (approximately 4.5 $mm.d^{-1}$) were recorded in mid-October and may not represent the highest rates possible.

This study emphasised the complex interactions that underlie the evapotranspiration process, and highlighted the importance of using models that are able to account for these complex physical processes.

Cost: *R600 000*
Term: *1997 - 1999*

Hydrological modelling to manage the environmental reserve within the Kruger National Park

Department of Agricultural Engineering, University of Natal
(WRC Reference No 884)

During the projects 130 subcatchments covering IFR sites, abstraction and transfer sites, areas of irrigation, geomorphological and aquatic sampling sites and land cover were considered. Information on rainfall, streamflow, land cover, soils and irrigation

was collated for inclusion in the predictions. The benefit of this modelling framework is that it is dynamic in that it can be updated on a regular basis as more accurate information pertaining to activities such as abstractions and irrigation becomes available. Various options regarding water quality modelling in the Sabie River were also investigated. Based on this work, DWAF have commissioned BKS Consulting Engineers to undertake an independent investigation into the feasibility of installing the ACRU modelling system in the Olifants catchment.

It appears that a physically-based conceptual hydrological model could be an invaluable asset in assisting authorities to make decisions regarding allocation of water both for the reserve and other allocations. However, it is anticipated that physical-conceptual hydrological models will play an increasingly prominent role in ensuring that the scarce water resources in Southern Africa are managed in an equitable and sustainable manner in the future scenario of a "bottom-up" approach to allocations and catchment management as envisaged by the National Water Act (1998), where these models will provide decision makers and affected parties in a catchment with opportunities to evaluate the future consequences of their current decisions.

Cost: *R200 000*
Term: *1997 - 1999*

The impact of herbicides used in water hyacinth control on natural enemies released against the weed for biological control

PPRI, Agricultural Research Council
(WRC Reference No 915)

Water hyacinth has resisted the development of a sustainable control strategy. The possibility of using an integrated approach based on a combination of biological and chemical methods, with nutrient and mechanical/manual control playing a lesser role was investigated.

This project aimed to investigate the assumption that the herbicides used on hyacinth are non-toxic to two biocontrol agents, the weevil *Neochetina eichorniae* and the bug *Eccritotarsus catarinensis*. The chemical companies manufacturing the herbicides supplied their proprietary formulations (active ingredients diquat, glyphosate and 2,4-D amine), and in one case supplied the active ingredient and surfactant separately for testing. Diquat caused high mortality in both biocontrol organisms. Glyphosate was non-toxic to *N. eichorniae* but slightly toxic to *E. catarinensis*. 2,4-D was slightly toxic to both organisms, and the surfactant was moderately toxic to both organisms. However, biocontrol moved from treated to untreated plants when given the opportunity.

The implication for integrated control is that each site should be investigated thoroughly and a management plan drawn up for each site, taking into account the biocontrol agents and the herbicide to be used. This would enable the most effective control strategy to be developed.

Cost: *R107 000*
Term: *1998 - 1999*

The invertebrates of South Africa - Identification keys

Albany Museum
(WRC Reference No 916)

The third and fourth volumes of the ten volume series were published during 2001. Volume **3** (Crustacea II) covers the Ostracoda, Copepoda and Branchiura, and Volume **4** (Crustacea III) covers the Bathynellacea, Amphipoda, Isopoda, Spelaeogriphacea, Tanaidacea and Decapoda. This brings to a conclusion the series on the Crustacea. A training course was held on the use of these guides which was attended by 15 delegates.

Cost: *R348 000*
Term: *1998 - 2002*

Promotion of scientifically based estuaries management through the development of an estuaries management handbook

Institute of Natural Resources
(WRC Reference No 917)

This book was written with the express intention of empowering people to manage, or make informed input into the management of, estuaries. The six chapters were each written by experts in that specific field, and the document was then edited for language and style by the overall editor. The first three chapters deal with the estuaries themselves, and cover the following topics: the value of estuaries, their structure and functioning and the influence of human activities. The next three chapters explain estuary management, explaining how to become involved in estuary management, how to assess the state of an estuary and the final chapter covers the policies and legislation affecting estuaries. In addition, there is a list of the organisations where expertise in estuary management and research resides.

Cost: *R250 000*
Term: *1998 - 1999*

Ecological risk assessment in water resource management: Research priorities, process development and underpinning technologies

Environmentek, CSIR
(WRC Reference No 957)

Ecological risk assessment (ERA) is a relatively new process to inform decision making for effective resource management. The process is used widely in the developed world. In South Africa its use is implicit in the implementation of the ecological reserve and once available the process will be recommended for use in environmental impact assessments conducted within the framework of the Department of Environmental Affairs and Tourism's legislation and policies.

This ERA guideline document resulting from the project takes the user step-by-step through the process clearly and logically with the philosophy and actions printed on opposite pages for ease of reference. The main steps of the process (colour-coded in the guide for ease of reference) lead the user logically and clearly through the process to the point where a decision can be made. In addition there are three case studies illustrating the functioning of the process.

Cost: *R854 709*
Term: *1998 - 2000*

Development of management policies, procedures and structures for Eastern Cape estuaries

Institute for Natural Resources, University of Natal
(WRC Reference No 1018)

Overall the Phase One of the Eastern Cape Estuaries Management Programme has been successful with some notable highlights. An Estuary Management Forum was successfully formed for the Bushmans-Kariega complex, and the process has been initiated at the Tyolomnqa Estuary. Estuary management planning processes have been initiated at the Kowie, Bushmans-Kariega, Tyolomnqa and Mtentu Estuaries. Building on the latter, additional funds have been secured to train community members in natural resource management and business skills and to support the expansion of community-based tourism enterprises at the Mtentu Estuary.

In addition to the above, a large database of stakeholders has been established and a programme newsletter has been regularly published.

Cost: *R264 000*
Term: *1999 - 2001*

Current

Decision support for the management and conservation of estuarine systems: Phase 2

Institute for Natural Resources, University of Natal
(WRC Reference No 756)

South Africa's ability to sustainably manage its estuaries is hampered by a lack of knowledge. The aim of the project is to maximise co-ordination of estuary research in the country to produce a DSS on integrated management and conservation of estuaries based on sound scientific and socio-economic principles. This is done by developing operational and management capabilities and by formulating appropriate policy guidelines.

Estimated cost: *R1 000 000*
Expected term: *1996 - 2001*

Geomorphological research for the conservation and management of Southern African rivers

Department of Geography, Rhodes University
(WRC Reference No 849)

Fluvial geomorphology is an essential discipline in the determination of environmental flow requirements. Geomorphologists are able to make input both in the form of long-term predictions of the effect of altered flow patterns and defining the habitats available to stream-dwelling organisms. The broad aim of this project is to integrate geomorphology into the conservation of Southern African river systems. Specifically, it will refine the geomorphological input into the determination of instream flows, develop indices and monitoring procedures for the assessment of channel conditions and refine the hydraulic biotope concept.

Estimated cost: *R738 000*
Expected term: *1997 - 2001*

Development of a classification system for rivers of the KNP, and a model for analysing trends in the condition of these rivers

Institute for Water Research, Rhodes University
(WRC Reference No 881)

In spite of the wealth of information on the rivers in the Kruger National Park (KNP), particularly the Sabie, it is not clear how this information can be extrapolated to other rivers in the area. During Phase 3 of the KNPRRP comparable data has been collected from all the rivers in the KNP, and a classification system is required to enable comparisons and predictions to be made. While a proposed national classification system lacks sufficient definition, it provides guidelines for the development of a more specific system which should be based on physical structure, ecological integrity and desired future state. The classification system being developed through this project is based on a geomorphological template with habitat overlay.

Estimated cost: *R113 000*
Expected term: *1997 - 2001*

Use of indigenous riverine organisms in applied toxicology and water-resource quality management

Institute for Water Research, Rhodes University
(WRC Reference No 955)

Lack of knowledge on the water quality tolerances of indigenous aquatic invertebrates motivated the inception of this project. The approach used has proved itself in the setting of site-specific water quality guidelines for protection of aquatic ecosystems within the framework of the ecological reserve. Data generated will also inform the process of development of guidelines on complex effluents as well as that of biomonitoring. This project links to that entitled **The applied aquatic ecotoxicology: Sublethal methods: Whole effluent toxicity (wet) testing and communication.**

Estimated cost: *R963 600*
Expected term: *1998 - 2001*

Development of numerical methods for assessing water quality in rivers, with particular reference to the "instream flow requirements" process

Department of Zoology, University of Cape Town
(WRC Reference No 956)

The management of water quality in the environmental reserve is more complex than that of water quantity. The principal aim of this project is to examine the relationship between water quality and water quantity with particular reference to instream flow requirement assessments, and to produce a framework for the assessment of water quality in IFR studies. Secondary aims are to investigate how the Biobase database may be used in the assessment of water quality guidelines.

Estimated cost: *R800 000*
Expected term: *1998 - 2001*

Assessment of the implications of inter-basin water transfers for the genetic integrity of donor and recipient river basins using selected taxa

Department of Zoology, University of Cape Town
(WRC Reference No 975)

South Africa has many inter-basin transfer (IBT) schemes, but has not considered the faunal or genetic integrity of the systems involved. Of concern is not only the transfer of species, but also individuals of the same species, between basins. Using selected taxa, the project will assess the implications for the conservation of river ecosystem functioning and biodiversity to develop a management protocol for the assessment of IBTs on both the donor and recipient rivers.

Estimated cost: *R115 000*
Expected term: *1998 - 2001*

The Orange River blackfly,* Simulium chutteri*: Investigations into the physiology of the aquatic and non-aquatic stages so as to adjust the existing control programme to overcome summer outbreaks

Onderstepoort Veterinary Institute, Agricultural Research Council
(WRC Reference No 1019)

This is the third in a series of projects aimed at developing cost-effective control of the blackfly. The project aims to investigate the effect of temperature on larval size, and link this to the physiological condition of newly emerged adults. The effect of certain key environmental variables on the adults will also be investigated and the control programme adjusted accordingly.

Estimated cost: *R512 000*
Expected term: *1999 - 2001*

Evaluating the environmental use of water - Selected case studies in the Eastern and Southern Cape

Department of Economics, University of Port Elizabeth
(WRC Reference No 1045)

In the Working for Water Programme, considerable capital and operating expenditure have already been incurred on the project to eradicate alien vegetation. The potential saving of water and appeal of reintroducing indigenous vegetation are generally accepted. However, a comprehensive identification, quantification and valuation of benefits and costs have so far not been undertaken. This information is essential to retrospectively justify expenditure for public funds and to ensure the economic and ecological sustainability of alien plant removal in different catchments.

Estimated cost: *R143 000*
Expected term: *1999 - 2002*

Rule-based modelling of riparian vegetation and technology transfer to enable strategic adaptive management of Kruger National Park rivers

Department of Botany, University of the Witwatersrand
(WRC Reference No 1063)

Research, prediction and monitoring through rule based modelling of riparian vegetation for strategic adaptive management of KNP rivers is important. This enables effective management of riparian system response to changes in flow regime and geomorphology of rivers. The project is also being used to develop a protocol of technology transfer for use in strategic river management by other river managers or catchment user groups. This project is developing a technology transfer product.

Estimated cost: *R710 500*
Expected term: *1999 - 2001*

Decision-support system for rehabilitation and management of riparian systems

Institute for Natural Resources, University of Natal
(WRC Reference No 1064

Only recently have efforts been made to prevent the degradation of riparian areas. There are a number of techniques available for use for the purpose of prevention of degradation, but there is a lack of experience and guidelines for integrating the concepts of biodiversity conservation and habitat rehabilitation in a way that can be implemented. This project is providing a vehicle to develop both guidelines and experienced people in a field by piloting a rehabilitation exercise in the Mhlatuze catchment using students from designated groups.

Estimated cost: *R600 000*
Expected term: *1999 - 2001*

Rule-based modelling of fish: Facilitating strategic adaptive management of the Kruger National Park rivers through model development and technology transfer

Institute for Water Research, Rhodes University
(WRC Reference No 1065)

A management model based on fish was developed for the country's East-flowing rivers early in the 1990s, but not along the lines of strategic adaptive management (SAM), the highly effective and currently accepted method. This project specifically aims to express the problems surrounding fish biodiversity within the context of SAM, and to develop appropriate thresholds of probable concern to inform the process. This project is developing a technology transfer product.

Estimated cost: *R552 000*
Expected term: *1999 - 2001*

Information management and facilitation in the Kruger National Park Rivers Research Programme (KNPRRP)

Computing Centre for Water Research, University of Natal
(WRC Reference No 1096)

This continuation of the KNPRRP information management system project is aimed specifically at handing over the software developed during the programme to SA National Parks at the end of Phase III of the Programme. This project is developing a technology transfer product.

Estimated cost: *R344 000*
Expected term: *1998 - 2001*

Multi-party strategic adaptive management (SAM) of the Sabie River

Centre for Water in the Environment, University of the Witwatersrand
(WRC Reference No 1097)

The availability of strategic adaptive management alone will not ensure its successful application. This project will ensure that SAM will be operationalised in the Sabie River basin in a way that CMAs will be able to respond appropriately to modelling or monitoring results to ensure that the desired state will be met.

Estimated cost: *R98 600*
Expected term: *1999 - 2001*

Development of monitoring methods for the ecological reserve (quantity) for rivers

Institute for Water Research, Rhodes University
(WRC Reference No 1101)

The National Water Act requires that the Minister ensure that monitoring is performed. However, although a number of reserve determinations have been done, very few have been implemented and there is no monitoring protocol to ensure that the required flow is being delivered and that it is achieving what it was intended to achieve. This project has developed a protocol to address these two aims and discussions are underway with DWAF officials to implement this as a monitoring programme.

Estimated cost: *R538 000*
Expected term: *1999 - 2002*

Benthic diatoms in the rivers and estuaries of South Africa

SAB Institute for Coastal Resource Management, University of Port Elizabeth
(WRC Reference No 1107)

This follow-on project (from the project entitled Identification of diatoms and their use in the assessment of water quality) will address 3 aspects of the use of diatoms in monitoring for water quality. The determination of the relationship between dominant diatom assemblages and freshwater quality will continue. The same will be done for estuarine diatoms, where the relationship between water quality and dominant assemblages will be defined. Thirdly, a manual of South African diatoms will be produced. The product of this project will enable the use of diatoms, long recognised as being sensitive indicators, in water quality management at the technician level, not achieved elsewhere before.

Estimated cost: *R415 000*
Expected term: *2000 - 2002*

Integration of water quality tools for the ecological reserve into a risk-based DSS

Institute for Water Research, Rhodes University
(WRC Reference No 1108)

The relative complexity of water quality has meant that it has received less attention than water quantity in the reserve methodology. This project seeks to link water quality firmly into the DSS being developed (Development of a computer based decision support system for quantifying the components of the ecological reserve) to express flow in terms of invertebrate stress, using a risk-based framework.

Estimated cost: *R278 000*
Expected term: *2000 - 2001*

Removal of marine sediment in South African estuaries with specific application to Eastern Cape estuaries

SAB Institute for Coastal Resource Management, University of Port Elizabeth
(WRC Reference No 1109)

Although sedimentation in estuaries is a natural process, long-term anthropogenic changes to river flow have caused an increase in sedimentation in many estuaries. An increase in the sediment in an estuary curtails certain activities, detracting from the value of the estuary experience. This project seeks short-term ways of controlling the sediment in the estuaries while the longer term interventions of integrated catchment management are being implemented. Longer term sediment management is being addressed in the project entitled **Dealing with estuarine sedimentation-assessment of the hydraulics of estuarine sediment transport processes and the development of water reserve management guidelines.**

Estimated cost: *R266 000*
Expected term: *2000 - 2001*

Development of DRIFT, a second-generation methodology for instream flow assessments

Southern Water Research and Ecological Consulting cc
(WRC Reference No 1159)

DRIFT, first tested in the World Bank funded study in the Lesotho Highlands, addresses the shortcomings identified in the building block methodology by adopting an approach to the process of flow determination which allows the assessment of the importance of individual components to the ecological integrity of the river. This project seeks to develop this methodology to ensure that it addresses the needs of managers, compile guidelines for its use and transfer the methodology to the management milieu.

Estimated cost: *R 848 000*
Expected term: *2000 - 2002*

Development of a computer-based decision-support system for quantifying the components of the ecological reserve

Institute for Water Research, Rhodes University
(WRC Reference No 1160)

The objective of this project is to develop a consistent protocol for the quantification of the ecological reserve within a risk-based framework. This will be incorporated within a DSS which will accommodate all the steps and procedures required to quantify the reserve. It will also develop a risk-based process for the biotic flow requirements by combining their stress/response relationships with flow time series.

Estimated cost: *R1 089 000*
Expected term: *2000 - 2002*

Ecological and geomorphological principles for river rehabilitation

Department of Zoology, University of Cape Town
(WRC Reference No 1161)

Decades of poor catchment management, over-abstraction of water, use of rivers as waste disposal systems, destruction of riparian buffer strips and river beds have contributed to the toll of badly degraded rivers. The costs of poorly functioning rivers are largely externalised in any development activities, and so unknown. At present, there is not a developed science to deal with this in South Africa. There are no guidelines for, or even general principles, guiding such rehabilitation. The aim of this project is to pilot river rehabilitation in the Western Cape and to develop generic guidelines for rehabilitation, while at the same time building capacity for the science in 2 students

Estimated cost: *R1 190 000*
Expected term: *2000 - 2002*

Ecological and economic evaluation of wetlands in the upper Olifants River catchment, with reference to their functions in the catchment and their management

Afridev (Pty) Ltd.
(WRC Reference No 1162)

The upper Olifants Basin (Mpumalanga) has a number of wetlands which play a role in the hydrology and conservation value of the area. The region is, however, underlain by coal, and this leads to conflict between industry and wetland conservation. The project will survey the wetlands and provide information on their ecological and economic value to the catchment.

Estimated cost: *R585 000*
Expected term: *2000 - 2001*

Development of an estuarine water quality index for implementation in estuarine water quality management in Southern Africa

Department of Zoology, University of Zululand
(WRC Reference No 1163)

Methodologies for the determination of water quality and quantity, as required by the NWA, are less well developed for estuaries than rivers. The aim of this project is to develop a water quality index based on rating curves for selected water quality determinants, to enable the interpretation of variables in terms of ecological resource protection. It includes elements of similar indices developed elsewhere, but is applicable to South African estuaries, and will take the form of a decision support system. This links to the water quality component of the project titled **Information requirements for the implementation of resource directed measures for estuaries.**

Estimated cost: *R515 000*
Expected term: *2000 - 2001*

Hydraulic analyses for the determination of the ecological reserve for rivers

Department of Civil Engineering, University of the Witwatersrand
(WRC Reference No 1174)

The determination of the ecological reserve depends heavily on hydraulics to translate managed flows into aquatic habitat. Current application of river hydraulics is, however, based to a large degree on principles that are more appropriate to high flows and flood analysis. Also, hydraulics are usually determined for cross-sections. This project aims to provide hydraulic methods to link low flow hydrology and aquatic habitat and develop an index of hydraulic characteristics for quantifying the habitat available, as well as to develop 3-dimensional habitat modelling to assist in the determination of the ecological reserve for rivers.

Estimated cost: *R1 050 000*
Expected term: *2000 - 2003*

Importance and role of water resources in the environment - A training course for social facilitators

Institute for Water Research, Rhodes University
(WRC Reference No 1180)

Social facilitators are central to rural upliftment and development projects. However, they often have limited ecological background and are therefore ill equipped to educate rural communities on the implications of South Africa's limited water resources. The course being developed aims to give social facilitators an understanding of the role of goods and services provided by the environment and the importance of the water resource, thus empowering them to pass this knowledge on to people in the communities amongst which they work.

Estimated cost: *R680 000*
Expected term: *2000*

Refinement of geomorphological tools for sustainable management of the river environment

Department of Geography, Rhodes University
(WRC Reference No 1181)

Existing riparian habitat assessment protocols do not directly address the relationship between habitat and the adjacent landscape. Given the values of riparian areas in the landscape, the objectives of habitat rehabilitation should include the reinstatement of such values and functions. This project will develop appropriate protocols.

Estimated cost: *R 99 0000*
Expected term: *2000*

Suspended sediment concentration and its implications on macro-invertebrates in the Umzimvubu River, Eastern Cape

Department of Zoology, University of Transkei
(WRC Reference No 1182)

The project which this follows (**Water quality and aquatic faunal studies in the Umzimvubu catchment, Eastern Cape, with particular emphasis on species as indicators of environmental change**) indicated that the Umzimvubu River transports an enormous sediment load, but only preliminary investigations were undertaken on the effect of this on instream biota. This project seeks to quantify this effect as well as to attempt to measure the sediment load actually carried (above the bed) by floods.

Estimated cost: *R90 000*
Expected term: *2000 - 2002*

Managing rivers in rural regions through community involvement and community awareness programmes. Phase One: Determining the influences and interactions of the factors affecting biotic integrity through an investigation of habitat requirements

Department of Zoology, University of Venda
(WRC Reference No 1197)

Rural communities with low *per capita* income, such as those on the Luvhuhu and its tributaries, depend heavily on the natural resources provided by a river and its catchment. The aims of this project are to firstly identify the factors leading to the loss of biodiversity. Secondly, a draft management plan will be prepared based on the principle of strategic adaptive management as developed for the Kruger National Park.

Estimated cost: *R100 000*
Expected term: *2000 - 2001*

River system research in South Africa: A strategic analysis

Institute of Natural Resources, University of Natal
(WRC Reference No 1198)

The incorporation of social, economic and environmental processes into water resource management poses a challenge to managers.

The aims of this project are to develop a strategic analysis, aligned with the "foresight project", to provide insight and direction for research and management in river systems, together with a training programme for river systems management.

Estimated cost: *R197 000*
Expected term: *2000 - 2001*

New

Applied aquatic ecotoxicology: sub-lethal methods; whole effluent toxicity (wet) testing; course development and communication
Institute for Water Research, Rhodes University
(WRC Reference No 1245)

The release of harmful and potentially harmful substances into the environment has caused water quality problems worldwide. Toxicology offers a cost-effective way of measuring the likely impact of an effluent on the environment, in that it will identify whether the effluent is toxic, including any synergistic and antagonistic effects. This will allow for both the determination of the suitability of the effluent for discharge to be determined for licensing purposes, and for specific industries to monitor their compliance with licence conditions.

Most toxicity tests measure acute effects and the chronic values are calculated empirically. The measurement of sublethal methods will, thus, provide accurate values on which to base decisions, so enhancing the capacity of managers to protect the water resource.

During this project new methods will be developed for quantifying the chronic effects of toxic effluents at sublethal concentrations.

Estimated cost: *R1 397 000*
Expected term: *2001 - 2004*

Directed estuary research programme to facilitate and enhance management for the sustainable use of Eastern Cape estuaries (Phase III)
Institute of Natural Resources
(WRC Reference No 1246)

Approximately 50% of the country's estuaries are in the Eastern Cape, but very little is known about these compared to those on other coastlines of South Africa. Many are thought to be in near pristine condition, relatively free from the catchment disturbances which have resulted in degradation of many of the nation's estuaries in other areas. Estuaries are important resources for adjacent communities, but form the focus of coastal development and ecotourism opportunities as well. They are also very sensitive to disturbance, and so can easily be degraded. The Eastern Cape has a high unemployment rate, and it is likely that the natural resources in the region will be exploited to provide for the regional population. If these resources are managed sustainably, then they will continue to provide wealth generation and employment opportunities. If the management is not sustainable, however, the pressure on the resources is likely to damage them to the point where they have little value, even to the rural poor living beside the estuaries themselves.

Considerable progress has been made during the previous phase (Phase II) of this programme in terms of its articulated goals and this has generated a good deal of momentum in the region. In addition to ongoing capacity building in estuary management, co-operative governance was identified as a specific problem which will be addressed, with the aim to create the capacity and protocols to enable sustainable estuary management.

Estimated cost: *R1 920 000*
Expected term: *2001 - 2003*

Information requirements for the implementation of resource directed measures for estuaries
Department of Zoology and Botany, University of Port Elizabeth
(WRC Reference No 1247)

The National Water Act requires that aquatic ecosystems be protected (the Reserve) to ensure sustainable development. The implementation of the ecological reserve through the resource directed measures strategy of DWAF is well advanced in rivers, but currently behind in estuaries. Where estuaries are involved, though, their needs are likely to influence the decision on the reserve, as the estuarine environment is fragile and easily disturbed. The process currently being followed to develop policies for the sustainable management of estuarine ecosystems within this context has indicated that there are gaps in knowledge that need to be addressed.

Through the overall aim of providing data and understanding to support the estuarine component of the resource directed measures programme of DWAF, the following specific aspects will be investigated: the response to flow variation in temporarily open/closed estuaries, the response of biota to water quality and to devise an overall index of importance rating for South African estuaries.

Estimated cost: *R1 125 000*
Expected term: *2001 - 2003*

Phytoplankton primary production and community structure in two temporarily closed estuaries
Department of Zoology and Botany, University of Port Elizabeth
(WRC Reference No 1255)

Estuaries are fragile systems which are important to both those living adjacent to the estuaries (for the goods and services they provide) as well as others (for the recreation opportunities provided). Their fragility results in part from their geographical position as final integrator of activities in the catchment and the sea. Increasing water abstraction inland means that more of the nation's estuaries will be closed for longer periods than previously.

The major energy pathways of open-mouthed estuaries have been worked on, but those of estuaries that are closed for varying periods are less well known. In addition, these periods of closure result in a build-up of pollutants which would otherwise be washed out to sea.

Through addressing the following aims this project will contribute to the national ability to manage these estuaries in terms of the requirements of the National Water Act.

Through this project understanding will be generated on the major energy pathways that are driven by phytoplankton production of various size fractions during periods of month breaching and closure, shifts in

phytoplankton community structure following nutrient enrichment, the spatio-temporal distribution and influence of fluctuating water level on phytoplankton, and to use this knowledge in the estuarine reserve determination process.

Estimated cost: *R597 000*
Expected term: *2001 - 2002*

Evaluation of the fish assemblage integrity index to assess river health, and its refinement to ensure high levels of accuracy

ECOSUN
(WRC Reference No 1256)

Worldwide there is a trend towards biomonitoring for the initial monitoring of water quality. Some of the reasons for this are that it would be virtually impossible to monitor chemically for all the substances released into the environment, and biomonitoring offers a cost-effective way of ascertaining the water quality and alerting authorities to the existence of problems. The South African River Health programme, a biomonitoring programme using a suite of methods, has been piloted in Mpumalanga and is in the process of becoming institutionalised in several provinces in the country.

The prototype Fish Assemblage Integrity Index (FAII), one of the indices used in this programme, has been developed over a number of years in Mpumalanga and the Northern Province, and has been used elsewhere in the country. It has proved its value within the River Health Programme, but its application has identified additional work that needs to be done to make it the robust and universally applicable tool that is required by the River Health Programme. With this in mind, the aims of the project are to relate fish distribution to the ecoregions, evaluate the suitability of the FAII in assessing levels of site specific impairment for rivers, to amend and standardise techniques used as part of the FAII to ensure acceptable levels of accuracy, precision and representativeness and to develop guidelines for the use of the FAII to enable the evaluation of the levels of site specific impairment.

Estimated cost: *R593 000*
Expected term: *2001 - 2002*

Dealing with estuarine sedimentation - Assessment of the hydraulics of estuarine sediment transport processes and the development of water reserve management guidelines

Department of Civil Engineering, University of Stellenbosch:
(WRC Reference No 1257)

River flow reduction resulting from increasing abstraction combined with the increased erosion caused by unsustainable veld management, has negatively impacted on the sediment transport dynamics in estuaries. This results in both an increase in the accumulation of fine sand derived sediments, which are often cohesive, as well as an ingress of marine sediments which may or may not result in mouth closure. The accumulation of sediments in estuaries has negative economic impacts for the region (commercial fishing and recreation), as well as negative impacts for ecosystem stability (reduction of habitat by sediment accumulation and reduced tidal prism). The cohesiveness of the fine sediments makes this trend effectively irreversible, as they do not erode at all easily. This project aims to generate knowledge on the sediment transport and flushing processes of estuaries, and then to develop guidelines on how to management he ecological reserve of the estuaries to ensure the maintenance of a long term equilibrium.

Estimated cost: *R950 500*
Expected term: *2001 - 2003*

A biophysical framework for the sustainable management of wetlands in the Northern Province with Nylsvlei as a reference model

University of the North in conjunction with Rand Afrikaans University
(WRC Reference No 1258

Wetlands are internationally poorly understood and large areas are drained annually for development of one form or another. South Africa is no different, in that we do not understand or appreciate the role that wetlands play in river ecosystems. In spite of South Africa being signatory to the Ramsar Convention, it has been estimated that by 1998 over half of the country's wetlands had been destroyed. Wetlands deliver a number of goods and services such as flood attenuation, raised dry season baseflow, improvement of water quality and increase in biodiversity. Although the value of these has not been fully quantified, there is a growing awareness in certain quarters that this value justifies maintaining the wetlands intact as may be seen from the funds committed to wetland rehabilitation nationally by Working for Wetlands and in Seekoeivlei by Rand Water.

There are a number of wetlands in the Waterberg area of the Northern Province, Nylsvlei is not only the largest but is also a proclaimed Ramsar site. The wetlands of this area are subject to the same destructive influences as elsewhere, and as is the case elsewhere, the knowledge and understanding of the systems are not available to allow us to manage and restore them optimally. This project aims to lay the foundation for this by compiling a draft sustainable management programme for Nylsvlei which would include guidelines for water quality and biomonitoring, and to propose a strategic management plan for the sustainable use of wetlands in the Waterberg region of the Northern Province.

Estimated cost: *R745 000*
Expected term: *2001 - 2003*

The derivation of ecological reference conditions for aquatic invertebrates and factors affecting the utility of such reference conditions within a National Biomonitoring Programme

Southern Waters Ecological Research and Consulting cc
(WRC Reference No K8/404)

One of the main components of the River Health Programme is the South African Scoring System (SASS). SASS also forms one of the key tools used in generating aquatic invertebrate information for the Intermediate and Comprehensive Ecological Reserve for rivers. In both instances, interpretation of SASS results is dependent on an appropriate reference condition. To date, such reference conditions are theoretical and a protocol has yet to be established for the derivation of ecological reference conditions for riverine invertebrates.

It is essential that any protocol developed for national application be suitable for all geographic regions. As such, validation and testing of this protocol in other regions will be undertaken. It has been acknowledged that

any monitoring programme should remain dynamic and allow for modification as, for example, new findings become available. This project will facilitate the overall increased utility of SASS by examining aspects of the SASS4 protocol, such as the incorporation of invertebrate abundances and verification of sensitivity/tolerance scores.

Estimated cost: *R85 364*
Expected term: *2001*

Biological control of* Myriophyllum aquaticum *(parrots feather)

ARC (Plant Protection Research Institute)
(WRC Reference No K8/405

The parrot's feather (*Myriophyllum aquaticum*) is one of the five aquatic weeds in South Africa (all of which originate from South America) which is a declared weed and, by law, should be controlled.

The negative impact of parrot's feather in an aquatic ecosystem includes a reduction of biodiversity, increased water loss, reduction in the value of irrigated crops (e.g. tobacco) and interference with water used for recreational and domestic use through the clogging of pumps and reduction in stream flow. The threat posed by *M. aquaticum*, was already noted in the 1960s when it was considered to be of greater importance than *E. crassipes*. It is envisaged that as the other weeds come under control *M. aquaticum* may again increase in importance.

Presently there are no herbicides registered for use on parrot's feather. Those unregistered herbicides that are used only give temporary relief as only the top growth (emergent, above water) of the weed is killed.

One agent (the beetle *Lysathia* sp.) has been released and monitored in the field. It has shown distinct population peaks and initial patchy distribution, but does retard growth of the weed when the population numbers were high. A second agent with more consistent effects is necessary. To this end another beetle, *Listronotus marginicollis* has been imported from Brasil and is in quarantine. This beetle is stem-boring and supplements the effect the leaf feeding *Lysathia* sp. has on the weed.

The biological control of parrot's feather is not only important, but is a realistic goal, and through this project the agent will be screened prior to release if suitable.

Estimated cost: *R98 000*
Expected term: *2001*

Outcomes to Date of Current Projects

New knowledge/understanding

New knowledge generated through current projects includes the following:

- The understanding of the links between the technical, social and economic aspects of environmental management is being developed to enable more effective communication between scientists, managers and the wider public. This unique understanding will pave the way to improved capacity-building in these groups in the future.
- The knowledge generated by research in the area of the ecological reserve first allowed this concept to be incorporated in the National Water Act of 1998 and has developed and is continuing to develop the scientific and management competence to implement the Act. This has also led to the World Bank recommending this as its chosen methodology for environmental flow determination.
- The Kruger National Park Rivers Research Programme has developed new knowledge in several main areas. The understanding of the riverine and riparian ecosystem processes was very substantially deepened during this programme. In addition, a lot of effort was put into transferring this into the management arena, and the framework for strategic adaptive management, together with its implementation, was developed during this programme.
- Strategic adaptive management has been comprehensively implemented in the Kruger National Park. When looking for a model to implement in Australia, developments made in the South African use of SAM were seen as the most successful practical implementation globally of this new way of management.
- New methods for the testing of water quality at both the acute and chronic levels have been developed during research done within the Toxicology Programme. These include methods for the setting of site-specific water quality guidelines using indigenous organisms, and methods for detecting low levels of pollutants using physiological techniques.
- A new way of classifying wetlands, based on their functions, is in the process of being developed.
- The implication of inter-basin transfers (IBT) on biodiversity is being explored in this project, and initial results show substantially greater biodiversity at the genetic level than initially anticipated, implying that the IBTs have potentially serious consequences to biodiversity.

Knowledge dissemination

	1998	1999	2000
Articles, papers and Conference presentations:	50	35	36
Workshops	5	2	3
Reports, theses	14	-	15

Benefits to South Africa

The outputs of this field are well acknowledged and utilised by government and industry. These include:

- The competence to include the concept of the ecological reserve in the NWA with the understanding to enable its implementation;
- Sufficient understanding of estuarine processes to enable informed decisions to be made on the management of these fragile and sought-after areas;
- Capacity-building in estuary management at the levels of provincial and local government as well as the rural communities living beside estuaries;
- Coherent policy developed on the use of toxicity testing in effluent discharge permits;
- Development of site-specific water quality guidelines using indigenous organisms;
- A widely implemented river health programme with national support that is used by both government and industry.
- Implementation of strategic adaptive management; and
- The implementation of a new interface between science on the one hand and

management and the wider public on the other, to improve communication and understanding between the two groups.

Innovation/application of knowledge

Knowledge generated through current projects is already being used or will be applied in the following ways:

- The methodology for the determination of environmental flows (the ecological reserve in the NWA) in addition to being widely applied in South Africa, is the chosen methodology for use in World Bank Projects. The methodology has been implemented in Lesotho (on World Bank funding), and is being implemented in Zimbabwe and Australia. It is shortly to be introduced into the Mekong Basin, SE Asia and has been discussed in various European and far eastern countries.
- The estuary management programme has enabled the development of the scientific and management competence to sustainably use and conserve South Africa's estuaries. The development of management competence has centered on the estuaries of the Eastern Cape.
- Estuary management has been successfully implemented at the local community level on two estuaries so far (workshops and courses given in English and Xhosa), and is being implemented on others. National DEAT have commissioned similar work to be done on additional South African estuaries by the same group.
- Toxicity testing has been included in DWAF policy on effluent discharge.
- Ecotoxicology using indigenous organisms has enabled the development of site-specific water quality data, used in the ecological reserve determination.
- A coherent biomonitoring programme (the River Health Programme), developed in conjunction with DWAF and DEAT, has been nationally implemented by government and industry.
- Strategic Adaptive Management has been successfully implemented in the Kruger National Park (with SA National Parks), and is being implemented with stakeholder groups in the Sabie River basin to enable them to interact successfully with the Nkomati Catchment Management Agency.
- The project **"River System Research ..."** is making an important contribution to the interface between science and management in that it is proposing and testing the use of ecosystem goods and services as a way of communicating ecosystem health to managers and the wider public.

Capacity/competence development

Projects in this field which include universities all employ students, often more than one and in one case (Directed Estuary Research Programme to Facilitate and Enhance Management for the Sustainable Use of Eastern Cape Estuaries), eight students. In line with WRC policy to select students from designated groups, Black students have been employed on projects wherever possible. This longer-term focused exposure to research methodology develops competence in a way that cannot be done with brief contact between researchers and stakeholders. In addition to full-time postgraduate students, a range of short courses are held by certain institutions which cover the application / implementation of technologies developed during WRC-funded research.

There are several ways in which the capacity of institutions is being built. In some projects new institutions or departments are being involved as partners in research projects. The development of guidelines usually involves piloting these with representatives of the target institutions or groups.

Technologies such as the ecological reserve and strategic adaptive management have in all cases been developed in close co-operation with the people who will be the first to use them. In this way, not only are users empowered to use them but there is continual feedback to the researchers on what is and is not understood.

Communities are specifically addressed by two programmes, that on estuary management and that on river health. In both cases there are people from disadvantaged backgrounds centrally involved in communication, courseware development and delivery.

The technology transfer process is started in workshops, such as that held recently to introduce the first three volumes of the invertebrate keys. With less complex technologies this may be sufficient, but in other cases and where practical people are encouraged to work directly with the researchers to complete the technology transfer.

In addition, there were workshops organised by DWAF on the Reserve Determination and River Health Programme. Researchers have addressed the World Bank during their in-house workshops, and invited keynote addresses at international conferences have been given by four researchers during this period.

Leveraging of resources

DWAF has contributed substantially to the development of the ecological reserve, not by putting funds into the research but by implementing the research on a number of catchments. The implementation teams are headed by consultants who work closely with the researchers in this field, so there is thorough and immediate exchange of problems and technologies. This catapulting of the technology into implementation has had the effect of creating effective problem solving as well as a robust technology. This has occurred for all the researchers and institutions involved with the environmental reserve.

The estuary management programme run by the Institute of Natural Resources in Pietermaritzburg has been successful in sourcing additional funds. Both South African Breweries (R225 000) and the Tony and Lizette Lewis Foundation (R355 000) have contributed funds to the research, and the indication is that SAB will continue to contribute to the process. In addition, Anglo Gold (R48 000) made a grant to assist towards the publication of the *Estuary Management Handbook*, although the bulk of the publication cost of this WRC-funded handbook was carried by Marine and Coastal Management (M&CM) of DEAT.

M&CM are involved in the estuary programme at steering committee level, and have commissioned the researchers to take the process that has been developed within the programme further afield and so have, in fact leveraged the WRC-funded work by providing resources to give the work wider exposure than otherwise possible.

The suite of WRC-funded projects at the Institute for Water Research has been leveraged by funds from DWAF (R662 000), Lever Ponds (R450 000) and Eskom (R150 000).

International linkages

Each of the researchers brings a network of international linkages to their WRC-funded projects. While these are important to the progress of individual projects and programmes, only those linkages which have made signal contributions to the advancement of a WRC-initiated technology will be considered here.

One of the groups of researchers in the ecological reserve programme has a firm linkage with the World Bank, which is now funding the implementation of the methodology internationally. This has also been introduced into Australia on Australian Government funding. Experience gained during these exercises is brought back into the South African arena.

Prof Rogers (Department of Botany, Wits) is being funded by the Melon Foundation from the USA. The research being done with this funding, while not directly linked to WRC projects, is working within his arena of expertise, so the WRC-funded research is benefiting from this exposure.

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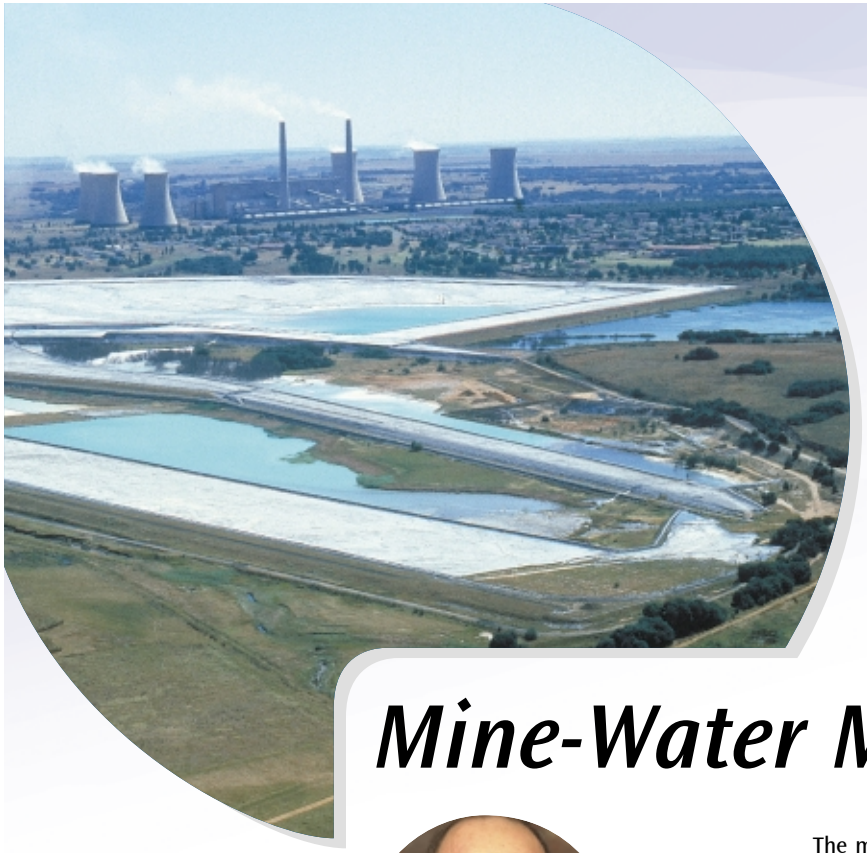

Chapter 17

Mine-Water Management

Mr HM du Plessis

Scope

Mine-water management covers those water quality and use issues which are related to the mining industry specifically. Since mining activities use a relatively small fraction of the country's stored water, but mostly have a major impact on the quality of South Africa's water resources, the WRC devotes most of its efforts in this field to addressing water quality issues.

The mineral pyrite is associated with all of South Africa's gold ore and coal deposits. When these deposits are exposed to oxygen and water during the mining process, pyrite is oxidised under bacterial action to yield sulphuric acid, giving rise to what is commonly known as acid mine drainage (AMD). AMD is associated with increased metal (Fe, Al, Mn, etc.) concentrations, low pH and high salinity and thus has and will have, for many centuries to come, a major impact on the quality of water resources in most mining areas unless the problem can be successfully addressed. AMD has been identified as the main water-related problem associated with mining and is thus the main focus of research in this field.

Mine-Water Management was identified as a separate research field in 1993 by the WRC. This was shortly after the regulating authorities (through the Department of Minerals and Energy) started to require mines to submit Environmental Management Plans (EMPs), which had to indicate the projected environmental impact of a mine and how this would be minimised. The introduction of EMPs created the need for accelerated and focused research on this topic, which had previously been dealt with as groundwater or salinity-related issues.

The percentage of WRC research funds invested in this field has varied as shown in Table 1. With the exception of significant increases during 1997 and 1999, funding fluctuated around 6 to 7%. With this investment the WRC has contributed significantly to raising the awareness of the industry and the regulating authorities about the present and potential future impact of mining activities on water quality and how this can be managed.

Links to Key Strategic Areas (KSAs)

Mine-Water Management is a field with clear links to the following of the WRC's KSAs:

Water Resource Management

Mine-water impacts on both the quantity and quality of our water resources. On the one hand mining activities create large underground reservoirs which can be used for storage (without being subject to evaporation losses), while on the other hand, the stored water may be heavily

TABLE 1
Investment in **Mine-water Management**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R3 089 800	R2 863 675	R 4 371 700	R4 109 800	R3 371 000
% of research fund	7.6%	6.4%	8.2%	6.6%	5.7%

polluted, thereby threatening the quality of other sources. (At present more than double the Witbank Dam capacity of 100 million m3 is stored underground in its catchment and this quantity may eventually increase to more than thirty times the capacity of Witbank Dam. In the Vaal River catchment, mines contribute approximately 35% of the salt load entering the Vaal Barrage in approximately 6% of the flow). Mining also often interferes with the occurrence of groundwater. Dolomitic compartments on the West Rand were e.g. dewatered by the mining activities beneath.

Water-Linked Ecosystems

Changes in water quality and quantity brought about in subcatchments dominated by mining activities impact dramatically on ecosystems which are sensitive to environmental changes. This effect is to a lesser degree also felt further downstream.

Water Use and Waste Management

The mine-water management research field falls wholly within this KSA which, *inter alia*, aims to ensure that waste and other polluting products (*inter alia* from mining) are managed in such a way that water quality is sustained at an acceptable level. Although mining is not a major water user, its activities have a major impact on water quality.

Water Utilisation in Agriculture

Mining is expected to contribute to the deteriorating quality of water in those subcatchments dominated by mining activities. Mining will thus aggravate the situation in irrigated agriculture, which is expected to be increasingly constrained by a combination of deteriorating water quality and diminishing quantities. On the other hand, the gypsiferous nature of neutralised AMD also presents opportunities to be utilised as a source of irrigation water. By precipitating gypsum within the soil profile, irrigation could be instrumental in the removal of salinity from the water environment.

Objectives

Primary

To promote the sustainable utilisation of South Africa's limited water resources by supporting research and development and technology transfer actions aimed at improving water use and quality as affected by management practices (which include assessment, prediction, control and mitigation) within the mining industry.

Secondary

The secondary objectives of this field are captured in the following problem-orientated categories, which also serve as programme areas:

- Prevention of mine-water pollution;
- Mine-water situation assessment studies;
- Improved ability to predict mine-water pollution and quantity;
- Improved options for the management of AMD; and
- Rehabilitation studies.

Research Projects

Portfolios of completed, current and new projects which address the above-mentioned objectives, are presented below.

Completed

Application of isotope chemistry to quantify the contribution of gold- and coal-mines to salt pollution load in groundwater and rivers

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 647)

This project investigated the feasibility of using isotopes common in acid mine drainage (AMD) to distinguish between different sources of pollution and where possible, to quantify the proportion of contaminant supplied by each source at some point downstream. The techniques developed were applied to coal- and gold-mining situations.

The coal-mining case study was in the Witbank area. Strontium isotopes could distinguish between water derived from different lithologies. Iron isotopic ratios could distinguish between AMD and non-AMD waters. Isotope studies for the gold mining component of the project were conducted in the Central Rand and concentrated on mine dumps, particularly ones being reworked. Using isotopes, a distinction could be made between different sources of water. To quantitatively source apportionment of different contributions to pollution was complex. In the coal-mining example it was concluded by the researchers that the Klipspruit and Blekbokspruit contribute 50% of the dissolved solids load to the Orange River. For the gold-mining example, it was more difficult to model the results due to the inability to determine end-members.

Cost: *R114 833*
Term: *1994 - 1996*

Prediction techniques and preventative measures relating to the post-operational impact of underground mines on the quality and quantity of groundwater resources

Institute for Groundwater Studies, University of the Free State, Chamber of Mines of South Africa, and DWAF
(WRC Reference No 699)

The progressive flooding of defunct underground workings usually results in an accumulation of inferior quality water that impacts negatively on the ground- and surface water environments. This project developed a risk assessment procedure to evaluate the risk of groundwater pollution from mining operations. The evaluation determines the combined risk associated with

surface disposal, the mine-water character and the aquifer character. Three issues were investigated in greater detail, based on the outcome of using the risk assessment procedure to classify mines and mining activities. Based on these investigations, the project:

- Produced a summary of the *status quo* of groundwater in underground high-extraction mining of coal, used modelling to investigate the recovery and decanting phases after mining has ceased and provided recommendations into ways and means to minimise the impact of underground high extraction of coal;
- Concluded that very little remains that can be done to improve the long-term chemistry of the mine water in the coal-mining industry in outcrop areas of KwaZulu-Natal. The mining methods that resulted in the collapse of the overlying strata, are the main causes of the current situation. It was recommended that in new mining areas of a similar nature pillar extraction should not be allowed and access to underground workings should be from the highest topographic position, with the mine floor sloping away from the entrance; and
- Investigated the post-operative hydrogeological impacts of the two gold-mining areas west of Johannesburg, referred to as the West Rand and West Wits Line. The investigation focused on estimating the time that would be required for the rewatering of the dolomitic compartments after cessation of mining, how sinkhole development would be affected, assessing the impact of various sources of contamination and modelling of pollution from surface sources as a result of rewatering.

Cost: *R1 989 954*
Term: *1995 - 1999*

Pilot-scale development of integrated passive water treatment systems for mine effluent streams

Pulles, Howard and de Lange Inc., Chamber of Mines of South Africa, Eskom and Sasol Coal
(WRC Reference No 700)

There is an urgent need to develop low cost, self-sustaining, low maintenance passive treatment systems to address the problems of acidification and salinisation (in terms of sulphate) associated with acid mine drainage (AMD) at operating, defunct and closed mines. All the known experts in South Africa formed part of the project team who utilised the most up-to-date information available internationally to design and construct pilot-scale passive treatment systems at three sites which had different AMD qualities. Unforeseen practical and other problems such as leaky units, problems with horizontal and upward flow and the unsustained removal of sulphate made it difficult to adequately test the designs and develop management guidelines for use by the gold and coal mining industries. Nevertheless, preliminary design guidelines were prepared based on the design philosophy that has evolved during the research project and a computerised mechanistic model of the utilisation of carbon within a passive sulphate removal reactor. Based on a rough estimate of construction costs, the researchers believe that in order for passive sulphate removal technology to be economically feasible, it will be necessary to develop the technology to a point where sulphate load removal of the order of 60 g/m^3.d or higher, can be sustained. The experience gained as a result of this project enabled the project leader to motivate successfully for a follow-up study funded by the Innovation Fund.

Cost: *R1 200 00 (WRC),*
R1 048 680 (Chamber of Mines),
R102 000 (Eskom) and R110 920 (Sasol)
Term: *1995 - 1999*

Suitability and impact of power station fly ash in mining rehabilitation

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 745)

In co-operation with Eskom and the relevant mines, this project investigated ways in which power station fly ash can be applied for mine rehabilitation, without a risk to the environment. The in-pit application of ash below the water table, application above the water table and the introduction of ash water, were considered as possible application scenarios. The base potential of fly ash was found to be relatively low (50 to 140 kg/t) as the fly ash leaves the power station and to be lowered by an order of magnitude in the ash dams by carbon dioxide fixation from the air. Extensive chemical and leaching tests on both spoil and fly ash demonstrated that placing fly ash below water in pits introduces a high risk of metal leaching. This practice is thus not recommended. On the other hand, application of fly ash as a cover will minimise water and oxygen ingress, and in so doing, improve the pit water quality and minimise the volume of seepage (cement or bentonite could be added to the fly ash to further reduce water and oxygen ingress). The application of ash water will improve the pit water quality by raising the pH and precipitating sulphate in the pit. The alkalinity to be released from an ash cover is, however, insufficient to neutralise acid production in the spoils below.

Cost: *R498 322*
Term: *1996 - 1999*

Preliminary assessment of pollution contained in the unsaturated and saturated zones beneath reclaimed mine dumps

Geo-Hydro Technologies
(WRC Reference No 797)

This project investigated the pollution that remains in the footprint of mine dumps once these dumps have been removed for reprocessing or other reasons. A complete GIS-based mine residue deposit register for South Africa was compiled from various information sources. An investigation of 11 case study sites indicated that the soil underneath reclaimed tailings dams was contaminated with pollutants such as Co, Cr, Cu, Ni, S, U and Zn, which typically originate from acid mine drainage (AMD) seeping from tailings dams. The acidic conditions (pH 3 to 4) encountered in soils at surface, improved to slightly acidic to fairly neutral pH conditions at depths of about 2.4 m. The future contamination impact was assessed on seven sites by using a geochemical load index, which classifies pollution levels into six classes. One case study site was classified as excessively polluted with regard to U (100 fold higher than background), whereas three case study sites were highly polluted with respect to heavy metals such as Co, Pb, U and V. The three remaining case study sites were moderately to highly polluted (pollution

classes II to III) with respect to trace elements such as As, Co, Cr, Cu, Fe, Mn, Ni, Pb, Th, U and V.

Cost: R 333 026
Term: 1997 - 1999

Compilation of a generic water balance for the South African coal-mining industry

Pulles, Howard and de Lange Inc.
(WRC Reference No 801)

A total of 41 mines, representing 66% of the operating coal mines and 88% of the total coal production in South Africa, have been included in the database used in this investigation. The available data were used to prepare an overall summary water balance for the survey mines and generic water balances for the different categories of mining. The overall water balance indicates that on average, 133ℓ of water is used for each ton of coal that is mined. Beneficiation plants consumed the largest portion, i.e. 36.1%, of the water used by the industry, compared to mining operations that used 25% of the water and road wetting for which 6% was used. Approximately 31% of the available potable water is used for domestic purposes, with 18.8% of the latter volume actually being consumed. In general terms, the state of recorded water balances at coal mines was found to be poor with insufficient detail being provided to enable a proper assessment of the status of water management at these mines. The primary problems with the water balances are an inadequate consideration of the effects of seepage and evaporation losses and the effect of rainwater as an input to the water balance.

Cost: R105 990
Term: 1997

Determination of the suitability of alternative carbon sources for sulphate reduction in the passive treatment of mine waters

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 802)

Pilot-scale research into low-maintenance passive systems for the treatment of acid mine drainage (AMD), identified the need for a suitable and/or sustainable carbon source to ensure the long-term operation and cost-effectiveness of passive biological sulphate reduction. In a laboratory evaluation, seven defined carbon sources were found to be between 74 and 90% effective for anaerobic sulphate reduction. Some undefined (complex) carbon sources were able to remove sulphate quite effectively from artificial mine water. Sulphate reduction in excess of 90% was achieved for kikuyu grass cuttings, silage, mushroom compost and hay. Fresh cow-manure achieved 81% sulphate removal. In order to document and better understand the complexity of the biocenosis in a passive treatment system, a conceptual model was developed of the main bacterial physiological groups potentially present in the sulphate-reducing reactor of a mine-water treatment system. The model describes the fate of the complex carbon via the various pathways of the respective bacterial groups and provides an indication of preferable pathways, that would maximise the conversion of the complex carbon into suitable products for bacterial sulphate reduction. A review of the potential carbon sources available showed that a number of renewable carbon sources existed, whilst a number of waste products were also identified.

Cost: R263 944
Term: 1997 - 1998

Current

Quantitative evaluation of water utilisation in different rehabilitation methods on gold slimes dams

Envirogreen and Freegold
(WRC Reference No 899)

The rehabilitation/stabilisation of slimes dams at gold mines is important not only from an aesthetic point of view, but also to impede detrimental impacts on the water and general environment. The irrigation requirements of the various rehabilitation methods differ substantially, and are largely governed by a combination of the need to leach excess salts and acidity from the slimes dam "soils" and the water requirement of the vegetation cover. Exotic vegetation often needs more water than indigenous plants. It is thus important to identify the most suitable vegetation for slimes dams. Moreover, a sustainable vegetative cover without the need for further irrigation must be reached as soon as possible in order to save more water in the long term. This project is determining which of the present rehabilitation approaches require the least water during the initial vegetation stage of slimes dam rehabilitation, and identifying the rehabilitation method which requires the smallest amount of water for the most sustainable end-product.

Estimated cost: R123 000
Expected term: 1998 - 2001

Development of a management strategy for the controlled release of saline mine water during flood conditions in the Witbank Dam catchment

Wates, Meiring and Barnard (CE) Inc. and Ninham Shand (Cape) Inc.
(WRC Reference No 900)

A pilot project by DWAF to assess the viability of allowing controlled saline mine-water releases during flood conditions as one of the water quality management tools in the Upper Olifants River catchment, gave some encouraging results, but also raised concerns about the prediction and management of impacts at abstraction points within Witbank Dam, as well as local impacts immediately downstream of mine-water releases. A continuation of the controlled release of saline mine water, will therefore be dependent on the availability of modelling tools to support the decisions which are made. The project aimed to satisfy this need. It achieved two linked objectives; viz. the simulation of water and salinity profiles in the upstream catchment and establishment of a hydrodynamic salinity simulation model of the Witbank Dam. Both these models were tested, using field observations of flow and quality. The models have been integrated and will be used to compile a rule-based approach to the future management of saline mine-water releases in the Witbank Dam catchment.

Estimated cost: R300 000
Expected term: 1998 - 1999

Guideline for the development of rehabilitation management strategies for reclaimed gold- mine dump sites in South Africa

Pulles, Howard and de Lange Inc.
(WRC Reference No 1001)

There are currently more than 300 gold mine dumps in South Africa, covering an area of approximately 180 km^2. They are mostly situated in close proximity to growing residential areas, sensitive agricultural areas and/or perennial streams. It is known that mine dumps can have a significant negative environmental impact on the underlying vadose zone and subsequently the ground-water system. This project has produced a comprehensive set of guidelines to assist the mining industry, government departments, consultants and research institutions in decision-making relating to the treatment, rehabilitation and optimal use of land which was once covered by mine discard material. These guidelines should play a major role in decision-making processes such as the evaluation of proposed Environmental Management Plans, as well as the development of rehabilitation strategies to satisfy mine-closure requirements.

Estimated cost: *R595 000*
Expected term: *1999 - 2001*

Understanding and modelling of water flow through soil covers used for rehabilitating coal discard dumps and open-cast mines

Wates, Meiring and Barnard (CE) Inc.
(WRC Reference No 1002)

Since 1993 the contractors have, with the collaboration of DWAF and with funding from the WRC, been running an experiment to determine the recharge through ten different natural soil covers. Part of this research was aimed at calibrating existing computer models for use as a tool to predict recharge through natural soil covers. The available models, however, did not adequately predict the relationship between rainfall events and recharge, especially for the typical short-duration thunderstorms of high intensity observed in South Africa. This follow-on project, therefore, has aimed to develop a clear understanding of the flow mechanism in the top unsaturated soil layers of a natural soil cover on a micro-scale, in order to accurately model recharge. Existing mathematical models have been used as a basis for the study. Evapotranspiration has been derived with the help of a continuous logging weather station while the soil-water profile has been monitored regularly.

Estimated cost: *R247 000*
Expected term: *1999 - 2001*

Investigation of water usage at gold-and platinum-mine flotation plants

Department of Environmental Engineering, Technikon Pretoria
(WRC Reference No 1003)

The flotation process forms an integral part of the gold-and platinum-mining industry and is mainly used for the recovery of gold, platinum and pyrite. While flotation plants use large amounts of water their effluent carries a high pollution load due to the chemicals used in the flotation process. This project investigated these issues and identified the effects that the released chemicals have on the water environment. Possible areas of water savings and means to address the pollution load of the effluent were also indicated.

Estimated cost: *R224 000*
Expected term: *1999 - 2001*

Field testing of real-time continuous flow and water quality monitoring instrumentation

Wates, Meiring and Barnard (CE) Inc.
(WRC Reference No 1004)

The successful implementation of water quality management schemes such as the managed release of saline mine water during flood conditions, is increasingly dependent on a real-time on-line communication system linked to continuous water quality and flow monitoring equipment. Because there was a general lack of information on the operating requirements, costs and performance of continuous monitoring equipment, this project set out to test such instrumentation. As part of this project, equipment manufacturers and suppliers were identified and a number of weirs selected for the installation of the equipment. A manual sampling programme provided a base data set against which the accuracy and the calibration requirements of the equipment could be established. The performance of the equipment was evaluated in terms of accuracy, reliability, calibration frequency, operating costs and maintenance requirements.

Estimated cost: *R300 000*
Expected term: *1999 - 2001*

On-site and laboratory investigations of spoil in open-cast collieries and the development of acid-base accounting procedures

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1055)

The pyrite present in coal and other deposits oxidises when exposed to water and air to generate sulphuric acid. The base potential of the surrounding rock determines to what degree the acid is neutralised and whether mine drainage water will be acid or alkaline. Mines are required to carry out acid-base accounting (ABA) as part of their Environmental Management Programme Reports. During the past 15 years, various methodologies have been developed for the determination of the acid-base characteristics of mine waste material. The results from these methods do not agree and the regulating authorities as well as the mining industry have to standardise on ABA procedures as a matter of urgency. In this project *in situ* testing of spoil at three collieries was undertaken. This was supplemented by extensive laboratory investigations using static and kinetic tests. The results were compared to historic ABA results and recommendations for standardised test procedures were proposed. The procedures were accepted at a workshop representative of regulators, consultants and the mines.

Estimated cost: *R866 000*
Expected term: *1999 - 2000*

Investigation into the long-term impact of inter-mine flow in the Mpumalanga collieries

Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1056)

The mining industry in 1996 conducted a pilot investigation into inter-mine flow for a 30 x 30 km area. From this investigation it was concluded that mining activities have disrupted natural groundwater flow paths to such an extent that it is the pathways within mines which in future will dictate flow of underground water and where water will decant onto the surface. The potential impact of inter-mine flow and water to be decanted onto the surface is of a magnitude not previously anticipated. The flow of polluted mine water between collieries in Mpumalanga is an issue that needs to be resolved before a holistic mine-water management scheme can be implemented. This investigation established a geographic information system for all the collieries in the Mpumalanga coal-field (200 x 200 km), showing mined out areas, future areas to be mined, mining methods employed, mine floor elevation and other salient features. From these data seepage and decant positions were identified where water from mines will impact on groundwater and surface water. Decant quantities were quantified through field investigation and modelling.

Estimated cost: *R897 000*
Expected term: *1999-2001*

Neutralisation of acid mine-water and sludge disposal

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1057)

Because of low pH and high metal content, AMD has to be neutralised and steps taken to ensure the safe disposal of the metal-rich sludge which is formed during neutralisation. Several alternative and supplementary processes to increase the efficiency and/or reduce the cost associated with the active treatment of acid mine water, have been identified and tested over the years. Researchers on this project were in the past able to significantly reduce the cost of neutralising chemicals by substituting lime with limestone in the neutralisation process. The project made further advances by developing an integrated neutralisation process for water of relatively low sulphate but high iron(II) content, improving the high density sludge process and determining the conditions for rapid iron(II) oxidation under acidic conditions. Plans are to modify DWAF's Brugspruit neutralisation plant to use this technology. Further tests conducted on the iron-rich sludge which is formed during neutralisation, indicated that the present stringent limitations on its disposal may be overdone.

Estimated cost: *R700 000*
Expected term: *1999 - 2001*

Development and piloting of the integrated biodesalination process for sulphate and heavy metal removal from mine drainage water incorporating co-disposal of industrial and domestic effluents

Department of Biochemistry and Microbiology, Rhodes University
(WRC Reference No 1078)

The development of active biological processes for the treatment of high-volume AMD flows is constrained by cost-effective reactor design and the availability of carbon sources. WRC-funded research into low-cost algal ponding technologies has led to the development of a biological sulphate-reducing process using sewage solids as the complex carbon source and electron donor. In this project the integrated process is being tested on pilot-plant scale, over an appropriate time period to support process scale-up. The final configuration will be operated as a demonstration plant for an appropriate period for technology transfer and generation of the input data required for modelling and full-scale engineering.

Estimated cost: *R1 700 000*
Expected term: *1999 - 2002*

Investigation into sulphur chemistry with specific application to biological sulphate removal processes

Department of Civil Engineering, University of Cape Town
(WRC Reference No 1079)

This project complements other current research into biological processes for sulphate removal. This project aimed to:

- Develop process models for the precipitation and selective optimised recovery of metals in various process configurations;
- Characterise the effects of pH and temperature on sulphur speciation (aqueous and gaseous phases) and solubility with active stripping of hydrogen sulphide; and
- Develop a process for the recovery of elemental sulphur through oxidation of soluble sulphides.

Estimated cost: *R280 000*
Expected term: *1999 - 2001*

Mechanism and kinetics of biological treatment of metal-sulphate-containing effluent

Department of Chemical Engineering, University of Cape Town
(WRC Reference No 1080)

Bioprocessing of AMD using relatively expensive electron donors for bacterial sulphate reduction is generally not economically viable in South Africa. The use of other cheap but more complex organics as carbon sources shows promise. This project is providing engineering and modelling input to WRC projects which are being carried out by Rhodes University and which are aimed at using sewage sludge as the complex carbon source. This project is specifically aimed to develop a simulation model to effect process optimisation; to establish the kinetics of critical subprocesses; and to optimise the recovery of elemental sulphur as an end-product.

Estimated cost: *R574 000*
Expected term: *1999 - 2001*

Tier 1 risk assessment of radionuclides in selected sediments of the Mooi River

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 1095)

An investigation into the fate of radioactive metal releases into the Mooi River conducted by DWAF, indicated that the radionuclides in the water column dissipate with distance from the source - presumably because the radionuclides bind to sediments. The implication is that large quantities of radionuclides which have been removed from the water phase in this way, may be remobilised under a different set of conditions. This project established under

which conditions these radionuclides may be remobilised, and if this occurs, how much of a risk to human health they may pose. A large database of water-column radiological data has been collected by the earlier DWAF investigation. This current investigation acquired the data to provide an adequate understanding of the fate of radionuclides in the Mooi River and the risk they pose. The release of radionuclides at levels of potential concern cannot be ruled out and further research needs are being indicated.

Estimated cost: *R107 000*
Expected term: *1999 - 2001*

Assessment of short-, medium- and long-term impacts on groundwater quality associated with the filling of dolomitic cavities

Metago Environmental Engineers (Pty) Ltd.
(WRC Reference No 1122)

De-watering of the dolomitic aquifers overlying ore-bearing reefs has, since the 1960s, resulted in the formation of a large number of cavities in the dolomitic compartments on the West Rand. These cavities need to be filled both for safety reasons as well as to prevent further inflows of surface water which would lead to aggravated ground instability and accelerated recharge of the mine void. The State Technical Committee for Sinkholes had raised the alarm about the potential for groundwater contamination when the cavities are filled with various mine waste materials including slimes and waste rock. This investigation will focus on the impacts arising from the future filling of cavities and assess the effectiveness of alternative fill materials and methods, in reducing those impacts. Impacts will be assessed over the short-, medium- and long-term. The investigation will furthermore assess the relative significance of the filling of sinkholes as a source of groundwater contamination in comparison to other sources of contamination such as tailings dams, waste rock dumps, return water dams and streams, and assess the provisions of both current and pending legislation to ensure that proposals arising from the project conform to the requirements of such legislation.

Estimated cost: *R440 000*
Expected term: *2000 - 2001*

Predicting the environmental impact and sustainability of irrigation with gypsiferous mine water

Coaltech 2020
(WRC Reference No 1149)

The coalfields in the Highveld of Mpumalanga generate significant quantities of surplus neutralised acid mine water which is gypsiferous in nature. Because of their high salinity these waters cannot be freely discharged to river systems. However, irrigation with these waters holds much promise to significantly reduce the salt load emanating from mine drainage, while at the same time extracting value from water which would otherwise be a polluting agent. An initial rough estimate is that up to 10 000 ha of land could potentially be irrigated with coal-mine waters in the Mpumalanga Highveld. This project is building on successful previous and current field-scale research using gypsiferous water for irrigation, by addressing the following aims:

- Determine the impact of several gypsiferous water/soil combinations on soil conditions and groundwater quality;
- Further develop and refine the soil-water-balance model for use in predicting gypsum precipitation, crop response, water quality and water balance;
- Predict the likely long-term impact of gypsiferous irrigation waters on the groundwater system;
- Determine whether these waters can be used to produce crops on a commercial basis; and
- Evaluate the sustainability of irrigation with gypsiferous water.

Estimated cost: *R4 400 000*
(WRC R1 530 000,
Mining R2 870 000)
Expected term: *2000 - 2003*

Water-related impacts of small-scale mining - Nature of the impact and development of management options

Pulles, Howard and de Lange Inc.
(WRC Reference No 1150)

Small-scale mining already takes place widely in South Africa. The White Paper on Mineral Development in South Africa, identifies small-scale mining as an important sector of the mining industry. The interests of the country and the community, however, require that all forms of mining, whether large-, small- or micro-scale, should be subject to the same requirements in respect of licensing, safety, health and the environment. It is also the view of Government that small-scale mining, like the rest of the mining industry, will be required to adopt measures that will promote environmental sustainability by means of the application of consistent standards and acceptance of the concept. This project has identified and characterised the critical water-related impacts of small-scale mining and is developing appropriate tools to assist in their environmental management. The project has focused primarily on the water-related issues of peat extraction, clay-mining for brick making, alluvial diamond-mining and other small-scale mining activities associated with gravels, alluvial sands and sediments.

Estimated cost: *R738 000*
Expected term: *2000 - 2001*

New

Assessment of current and future water pollution risks due to gold-mining in dolomitic areas

Council for Geoscience
(WRC Reference No 1214)

An earlier Tier 1 risk assessment of radionuclides in sediments of the Mooi River, has indicated that the release of radio nuclides at levels of potential concern, cannot be ruled out. In a separate study, the Potchefstroom University found that significant variations in the chemical conditions of the river water can occur over periods of hours or less, suggesting that existing data on samples collected at a much lower frequency, particularly those collected on a regular weekly schedule, may not adequately represent the short-term variations in chemistry. Other researchers have demonstrated that isotopic analyses can quantify the contributions of different water sources to polluted ground-and river-water. In this project this approach is being extended to include the material bound to the sediments. It will furthermore assess the current and future risk to local and

downstream water users due to pollution, including heavy metals and radionuclides and establish a near real-time continuous monitoring capacity to determine the short-term variations in water chemistry as a guide to future monitoring needs.

Estimated cost: *R300 000*
Expected term: *2001 - 2002*

Development of an appropriate procedure for the closure of deep underground gold-mines
Pulles, Howard and de Lange Inc.
(WRC Reference No 1215)

There are a number of regions within South Africa where large-scale cessation of mining activities at deep underground gold mines has occurred and can be expected to continue to occur in future. Although these mines pose long-term threats to the surrounding ground- and surface-water environment, there is currently no clear procedure that can be applied to successfully close these mines. Contributing reasons for this are that adjacent mines are mostly hydraulically interconnected, making it difficult to apportion responsibility for water volumes and contaminant loads. Mines are, furthermore, often partially flooded, making it difficult to collect certain data and to apply certain pollution prevention measures. There is also uncertainty regarding assessment procedures that should or could be applied to assess the long-term problems and to evaluate alternative management strategies. The premise of this project is, therefore, that the closure of gold-mines should be planned and evaluated on a regional and not on a mine-by-mine basis, unless a mine can clearly and unequivocally prove that it is hydrologically and geohydrologically isolated from all other surrounding mines. This necessitates the development of strategies that encompass and enforce the principle of regional co-operation between mines - a concept that has implications for mine environmental planning and management (EMPRs) and closure. This project therefore aims to develop an appropriate and agreed procedure that will enable mines to plan and implement closure in a responsible manner and in a way agreed to by all stakeholders.

Estimated cost: *R503 8000*
Expected term: *2001 - 2002*

Evaluation and validation of geochemical prediction techniques for underground coal-mines in the Witbank/Highveld region
Pulles, Howard and de Lange Inc.
(WRC Reference No 1249)

The Witbank/Highveld coal-field in Mpumalanga is the most important coal-mining area in South Africa. While this coal-field makes a significant contribution to the economic development of the country it is also the source of potentially the most serious water quality problem facing the region over the longer term. There is thus an urgent need to develop and test tools with which to predict the progression of acid mine drainage (AMD) over time, and to develop, test and apply management options that will alleviate the situation. This project, together with projects No 1263 and 1264 will investigate the management of underground water flow in collieries at various stages of closure with an aim to minimize the salt load emanating from them, evaluate alternative geochemical prediction techniques to use in the longer term, comparison of alternative management options, and the mapping of modal proportions of primary and secondary minerals.

The contribution of this project will be to evaluate alternative geochemical prediction techniques for the prediction of water quality at underground coal-mines, based on on-site investigations and predictions, and to develop the ability to provide a long-term prediction of water quality and the effect of alternative management strategies on this water quality.

Estimated cost: *R1 416 100*
Expected term: *2001 - 2003*

Investigation of water decant from underground collieries in Mpumalanga and Free State, with special emphasis on predictive tools and long-term water quality management
Institute for Groundwater Studies, University of the Free State
(WRC Reference No 1263)

The Witbank/Highveld coal-field in Mpumalanga is the most important coal-mining area in South Africa. While this coal-field makes a significant contribution to the economic development of the country it is also the source of potentially the most serious water quality problem facing the region over the longer term. There is thus an urgent need to develop and test tools with which to predict the progression of acid mine drainage (AMD) over time, and to develop, test and apply management options that will alleviate the situation. This project, together with projects No 1249 and 1264 will investigate the management of underground water flow in collieries at various stages of closure with an aim to minimise the salt load emanating from them, evaluate alternative geochemical prediction techniques to use in the longer term, comparison of alternative management options, and the mapping of modal proportions of primary and secondary minerals.

The contribution of this project will be to investigate and describe the *status quo* in terms of mining methods, scheduling, geology, geohydrology, hydrochemistry, water and salt balances at six underground collieries that are in the process of decanting or where decanting is imminent, investigate management options whereby the quality of mine water can be influenced in operating underground collieries and identify those management options that should be applied to achieve the long-term goal of minimising the salt load to the environment.

Estimated cost: *R843 000*
Expected term: *2001 - 2002*

The quantitative evaluation of the modal distribution of minerals in coal deposits in the Highveld area and the associated impact on the generation of acid and neutral mine drainage
Department of Geology, University of the Free State
(WRC Reference No 1264)

The Witbank/Highveld coal-field in Mpumalanga is the most important coal-mining area in South Africa. While this coal-field makes a significant contribution to the economic development of the country it is also the source of potentially the most serious water quality problem facing the region over the longer term. There is thus an urgent need to develop and test tools with which to predict the progression of acid mine drainage (AMD) over time, and to develop, test and

apply management options that will alleviate the situation. This project, together with projects No 1249 and 1263 will investigate the management of underground water flow in collieries at various stages of closure with an aim to minimise the salt load emanating from them, evaluate alternative geochemical prediction techniques to use in the longer term, comparison of alternative management options, and the mapping of modal proportions of primary and secondary minerals.

This project deals with the mapping of modal proportions of primary and secondary minerals and will perform a survey of the coal-mines and coal-residue deposits that would contribute to the evaluation of the environmental impact associated with AMD generation. Through on-site investigations and laboratory-based studies, it will evaluate the modal proportions of primary and secondary minerals *in situ* in coal seams and residue deposits. It will furthermore prepare a guideline on the significance of the modal distribution of primary and secondary mineral phases in terms of their potential impact on the generation of AMD.

Estimated cost: *R503 8000*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

The only effective measure identified thus far to prevent the formation of AMD in coal discard dumps, is to cover the dumps with soil in order to exclude oxygen and stop the bacterial action which produces AMD.

- Multi-layered soil covers exceeding 1m in thickness were found to significantly improve drainage water quality, although drought-induced soil cracking temporarily allowed oxygen to pass through the cover.
- The percentage through-flow of rain was also reduced.

Research continues to refine knowledge about the impact of mining-related activities on the water environment and to provide the means of coping with resulting problems. Current and recently concluded projects indicated that:

- There are more than 300 gold-mine tailings dams covering an area of 180 km^2. The soil underneath reclaimed tailings dams has been found to be contaminated with pollutants associated with AMD, and an evaluation of the future contamination (pollution) impact of a number of test cases varied from moderate to high. Guidelines were compiled to rehabilitate the contaminated reclaimed areas using a phased, risk-based approach.
- Records kept by coal-mines are mostly inadequate to compile a proper water balance. From the available data it was deduced that an average of 130ℓ of water is used per ton of coal mined. More than a third of the used water was consumed by beneficiation plants.
- Radionuclides originating from gold mines are sorbed onto sediments in water courses, thereby protecting the water phase. The danger that has been identified is that nuclides can be released under changed environmental conditions. Uranium can, e.g. be mobilised when exposed to oxic conditions and lower pH values.

Current and recently completed projects have also improved the ability of mining professionals to predict the contribution of mining activities to present any future water quality degradation.

- An Internet Service Centre has been established to assist with the identification of models which are available for a specific purpose or task, together with information on their applicability, usability, data and computer requirements, as well as case studies conducted by using the model.
- Acid-base accounting procedures for static and kinetic tests (which are used to predict the likelihood that a material will produce AMD) have been evaluated and an agreement has been reached on a standardised methodology/approach for South Africa.
- The potential for underground inter-mine flow has been quantified and likely decant points identified for the 40 000 km^2 area of the Mpumalanga coal-field.

The development of a low-cost method for the effective treatment and/or management of AMD, remains an elusive goal. Steady and significant improvements are, however, being made in treatment efficiency and in identifying and improving processes that find application in specific niche areas. Most of these processes are aimed at neutralisation, settling of an iron-gypsiferous sludge and/or the removal of sulphate. Reverse osmosis processes are dealt with under the ***Membrane*** field.

- The BioSure process whereby sewage sludge is used as energy source for the active biological removal of sulphate is continually being refined.
- Chemical costs for the active neutralisation of AMD were significantly reduced by using agricultural lime instead of slaked lime as neutralising agent in a modification of the high-density sludge neutralisation process.
- An innovative approach whereby gypsum is precipitated within the soil profile under irrigation with gypsiferous water, was demonstrated on a commercial scale. By precipitating gypsum in the soil, it is removed from the water environment and an otherwise polluting water is used beneficially.
- Our understanding of the chemical processes and interactions which operate during biological sulphate removal is being improved through research conducted at UCT. This is opening up opportunities for refinement of existing processes and the development of new approaches.
- An evaluation of available AMD treatment processes, indicated that for the most cost-effective processes, the monetary value of benefits (i.e. sale of water and waste products and a reduction in the salinity-related cost experienced by water users) is approximately equal to the treatment costs.
- A real-time simulation model has been developed to predict the effect that releases of AMD in the Witbank Dam's catchment, will have on the dam's water quality during the following season.

Benefits to South Africa

In the past three years research in this field has made large contributions to the growth

in awareness of the gravity of the mine-water threat (both short- and long-term) to the environment, if left unattended. Equally beneficial progress has been made in acquiring knowledge and tools which can be used to begin to address this problem. Some examples of specific benefits are:

- The availability of provisional guidelines for the design of soil covers that inhibit AMD formation and reduce through flow of water to underlying pyritic material, resulted in a major revision of cover design criteria in coal mining.
- An assessment procedure with which to assess the risk mining operations pose to groundwater pollution, and to assess the benefit of alternative management approaches.
- A GIS database of the location and other available details for more than 300 gold-mine tailings dams, a procedure to evaluate the pollution potential of tailings dam footprints and a guideline for their rehabilitation.
- A generic water balance for the coal industry against which individual mines can be benchmarked.
- An Internet Service Centre to assist regulators, industry and consultants with the selection of appropriate models for their specific purposes.
- Standardised static and kinetic acid base accounting procedures, which will ensure the use of uniform future reporting standards to the regulating authorities.
- An overview of the regional intermine flow which can be expected in the Mpumalanga coal- field as a result of mining and the identification of future decant points. This will assist with the identification of sites for future regional AMD treatment facilities.
- The cost of treatment has for some treatment technologies been reduced to a point where it is almost equal to the total benefit derived by society.

Innovation/application of knowledge

Knowledge generated through current programmes and projects is already being, or will be, applied in the following ways:

- In changing the way in which discard dumps are covered and to some degree also the way in which open-cast land is rehabilitated;
- In being able to anticipate the eventual impact and risk associated with choosing alternative mining and rehabilitation methods during the planning and re-evaluation phases of mining projects;
- In rehabilitating tailings dam footprints;
- By benchmarking the water use of specific coal mining types and beneficiation practices with similar practices on comparable mines;
- Through the provision of guidance for the selection of models appropriate for specific management tasks;
- By selecting the appropriate acid base accounting procedure and using standardised methods;
- Through planning regional treatment facilities to coincide with groundwater decant points in Mpumalanga;
- In the selection of an appropriate AMD treatment technology; and
- Through the judicial use of the dilution capacity available during heavy runoff conditions, in order to release accumulated polluted water.

Capacity/competence development

Capacity and competence developed through current WRC programmes resides in the following institutions:

Institute for Groundwater Studies (IGS), UFS
The IGS has for many years been involved in the study of the effect of mining on groundwater, both on behalf of the WRC and industry. This has produced a steady stream of geohydrologists trained in a mining environment, who presently find employment as consultants or in industry. Over years the IGS has developed a unique competence in SA for mining-related geochemical analyses, GIS coverages, data processing and display software, as well as groundwater and geochemical modelling.

In a unique capacity-building exercise sponsored by the Carl Düssberg Gesellschaft with R5 million over six years, IGS trained 76 students from Africa (6 from South Africa) with B.Sc. degrees to B.Sc. Hons level during the 1995 - 2000 period. Experience in mining-related geohydrology gained through WRC contracts enriched this training.

During the past three years, the WRC-sponsored research in this field led to the awarding of 3 Masters degrees, all to White males. Five Black students (3 female, 2 male) are presently registered for their B.Sc. Hons degrees.

Pulles, Howard and de Lange Inc. (PHD)
PHD specialises in mine-water research and investigations. The company was started by former employees when the Chamber of Mines Research Organisation was disbanded. It remains research-orientated and generates more than half of its turnover from research. PHD has developed a wide range of competencies and a wide knowledge base. It has special skills in geochemical modelling and passive treatment systems for mine effluents, as well as the necessary laboratory facilities to back it up. DACST awarded PHD with a multimillion Rand Innovation Fund contract to further develop passive treatment technology while they were completing a WRC project on the subject. During 2000 PHD entered into a strategic alliance with the Department of Mining and Environmental Engineering at the University of Venda (UNIVEN). As part of this initiative PHD has (at their own cost) made services of their own staff available for periods of up to a week for lecturing at UNIVEN. UNIVEN students are also involved in research projects.

One Ph.D. researcher (White male) used outputs from a WRC-sponsored project to obtain a Ph.D. degree.

University of Cape Town, Departments of Chemical Engineering and of Civil Engineering
These departments have been co-operating on a number of research projects and have become authorities on the reactions and kinetics related to sulphate chemistry as applied to biological sulphate removal, metal sulphates and pH.

Two Ph.D. (Black female and male) and four Masters (3 White male and one White female) degrees awarded during the past three years were based on output from WRC-sponsored projects. Three students (Black female) are presently registered for their Masters and two (White male) for their Ph.D. degrees. Two White female and three Black male students are using project information to complete their 4th year B-theses.

Environmentek, CSIR
Partly as a result of WRC projects, Environmentek has developed research and implementation competencies in the active treatment of AMD, notably in the replacement of slaked lime with agricultural lime as neutralising agent, and in integration of treatment processes.

The building of individual capacity during the past three years by using WRC-sponsored research has resulted in one Ph.D. in progress (White male).

Leveraging of resources

Outside contributions to research projects are often of an in-kind nature. For example, instrument and signal transmitter manufacturers made their equipment available free of charge for the project which conducted field tests on real-time continuous-flow water quality monitoring instruments. DWAF analysed AMD drainage samples from the soil cover experiment free of charge. Consultants have generally charged less than their government charge out rate and have provided analyses at cost. Mines have also provided much support during field investigations.

Direct financial contributions have been made to individual current projects within the following programmes:

R225 000	Prevention of mine-water pollution (Coaltech 2020)
R135 000	Water quality assessment studies (Dolomitic Water Association)
R2 870 000	Treatment of AMD (Coaltech 2020)
R330 200	Remediation (ARC)
R491 400	Remediation (National Dept Agriculture)
R2 900 000	Assess and contain AMD impacts (Coaltech 2020)

International linkages

Mine-water research programmes and projects have developed strong linkages to the following international institutions, which have made considerable indirect contributions to the research.

- US Bureau of Mines
- Canadian MEND Programme
- CSIRO, Australia
- School of Mines, University of Colorado
- Golder and Associates, USA
- University of Newcastle
- Edinburgh University
- University of Vermont

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Chapter 18

Water Policy

Dr GR Backeberg

Scope

The democratic transition to a new political dispensation and acceptance of a bill of rights in the constitution was instrumental in bringing about major public policy reforms regarding water resources. The opportunity exists to introduce and seek further improvements through timeous and reasoned contributions based on sound research. The target group or clients of research activities are policy-advisers and policy-makers specifically in the executive branch of government. Top managements and ministries of national and provincial departments, as well as local authorities, require decision-support which will improve their bargaining position. At the same time research results must create an awareness amongst members of the public of the expected benefits and costs of proposed policy changes and institutional arrangements. The issues which must be addressed are determined by the content of public policy on water resources, i.e. the principles and intentions expressed in policy statements and water legislation. Such issues could, typically, arise because of inadequacies, incompleteness or contradictions in public policy.

Through research the best possible information must be provided for policy-making and evaluation in order to achieve the objectives of equitable, efficient and sustainable allocation and conservation of water resources. This information includes the following:

- Quantification of basic human needs and instream flow requirements of water-stressed river systems;
- Measurement of existing water use, runoff for different land uses and possible water quality changes;
- Development of organisational structures for involvement of water users in resource management and specification of standards for water services;
- Valuation of water resources for domestic, irrigation, forestry, industrial and power generation purposes in different catchment areas;
- Determination of the impact of higher tariffs on the level of consumption in various water-use sectors; and
- Maintaining or improving the quality of water through incentive-based pollution and effluent charges.

Although a number of research projects have in the past provided support for policy formulation and contributed to policy evaluation, water policy was for the first time listed as a separate research field in 1996. As shown in Table 1, expenditure increased to 4 to 5% of the total and has

TABLE 1
Investment in **Water Policy**

	1997	1998	1999	2000	2001/02
Expenditure (total or committed)	R1 362 100	R2 268 191	R2 308 624	R2 487 100	R1 970 680
% of research fund	3.37%	5.1%	4.35%	4.01%	3.4%

declined since 2000. The reasons for a gradual decrease are the inclusion of a new but related research field of ***Water Services: Institutional and Management Issues*** and also a decline in the number of research proposals to be considered for funding.

Links to Key Strategic Areas (KSAs)

Water Resource Management

Water Policy as a research field will be incorporated as a whole in the **Water Resource Management** KSA. All the current programmes and projects will be accommodated under the Thrust: Policy Development and Institutional Arrangements.

Objectives

Primary

To improve policy for promoting equitable, efficient and sustainable conservation and allocation of water resources.

Secondary

- To evaluate policy impacts and provide assistance or guidance for the effective implementation of policy;
- To assess institutional arrangements and facilitate the resolution of conflicts for effective use and development of water resources;
- To test the influence of different policy instruments on the behaviour of water users for the effective management of the demand and supply of water; and
- To analyse and improve the functioning of water organisations and effective performance of water services.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

Development of a tool for evaluating the effect of alternative funding options (with different risk profiles) on water tariffs

PAA Ramsden, Private Consultant
(WRC Reference No 887)

This project resulted in the completion and refinement of a model FUNDWAT. It is a spreadsheet- based computer model used for evaluating optional ways of funding water resource development projects. FUNDWAT is particularly appropriate for use at the planning or preliminary stages of projects.

Macro-buttons can be used to operate FUNDWAT in either a deterministic mode for goal seeking the required tariff to attain a specified objective (such as a required rate of return) given the most likely input parameters; or to operate FUNDWAT in a stochastic mode to derive a probabilistic distribution of tariffs given the probability distribution of input parameters.

FUNDWAT provides the ability to make projections of:

- Water sales and revenue from each project phase or component
- Disbursements related to the construction and operation of each project phase
- Loan repayments, interest charges, and outstanding debt and equity balances for up to 10 individually specified loans, each of which can be either of the annuity, fixed payment or bullet type
- Future financial statements, including balance sheet, income statement and funds flow statement associated with the project
- Indicators such as internal rate of return and return on assets and return on equity.

Although FUNDWAT was specifically developed for evaluating funding offers or options at the planning stage of a water resource development project, the ability to develop the model further by fixing inputs as they become known during the project development cycle is very attractive. FUNDWAT can thus be evolved continuously throughout the project by fixing attributes as they become known enabling FUNDWAT to be used as a benchmark against which the project finance model developed by the project finance professionals can be continuously verified.

FUNDWAT can thus be seen as a pro-forma project finance model that can be readily adapted to suit the specific circumstances of the project to be analysed.

Cost: *R192 000*
Term: *1998 - 2000*

Preparation of guidelines and a model for the financing of district councils' water supply functions

Palmer Development Group
(WRC Reference No 994)

It is evident that district councils are faced with a relatively complex set of financial challenges and particularly those responsible for former homeland areas, have serious capacity constraints. The intention of this project was to provide information which can be used to build their capacity to manage water supply services in their areas, through the provision of models to assist with financial analysis and guidelines to assist with decision making.

The result of this study is a user guide and associated financial model, *District Services Model*, for use by District Councils in their planning of services. The model will assist in the business planning process of water services. It will enable financial forecasting, investment scheduling and determining tariffs and expected revenue generation. The model also allows for determining the effects of and extent of cross-subsidisation. Of most importance and use, the model is able to indicate the viability

of the operations of the district council. This will allow for improved decision-making for the success of district councils.

Cost: *R97 000*
Term: *1999 - 2000*

Development of guidelines for the financing of catchment management in South Africa
Palmer Development Group
(WRC Reference No 1044)

The National Water Act and the *Pricing Strategy for Raw Water Charges* provides the financial framework within which CMAs operate. The two main sources of funding for CMAs are user charges (for water resource management) and parliamentary appropriations (through DWAF). The intention is that CMAs are largely financed through user charges on water resource management.

The following process is proposed for estimating user charges for water resource management.

Step 1: Estimate registered water use
Water use charges can only be raised from registered water users, therefore this must be estimated for the different sectors over time (10 years)

Step 2: Estimate the total costs
The capital and operating costs of the CMA establishment and functioning must be estimated (over time), taking into account any subsidies or grants to the CMA.

Step 3: Allocate functional cost components to water use
The benefit received from a water resource management function must be linked to each water user group, which enables the unit cost per user group to be calculated.

Step 4: Set user charges
User charges should be set through a process of negotiation with user groups (based on the unit costs), so that the CMA cash flow is managed, and considering the financial affordability of the charges for the users, willingness to pay these charges, and possible implications for default.

Step 5: Reconcile income and expenditure
The annual and cumulative cash-flow projection provides the basis for reconciling of CMA income vs. expenditure.

Cost: *R235 000*
Term: *1999*

Current

Review of industrial effluent tariff structures in South Africa and guidelines on the formulation of an equitable effluent tariff structure
DA Kerdachi
(WRC Reference No 854)

General experience in South Africa is that effluent charges are so unrealistically low, that there is no incentive for industrialists to allocate funds to improve the quality of their effluent. However, if the true cost of effluent discharges is borne by industry, it will relieve the burden on the domestic consumer. The charging system must allow for an equitable proportion of finance to be provided by industry for their contribution towards the cost of effluent treatment to the required standard. If proper effluent-charging systems and formulae are in place, industrialists will pay more attention to effluent management, resulting in financial benefit to all users. Guidelines will be formulated for implementation by local authorities.

Estimated cost: *R175 000*
Expected term: *1997 - 2001*

Development of a methodology to determine the true value of water in the Berg River basin
Department of Agricultural Economics, University of the Free State
(WRC Reference No 943)

Until recently water management has been mainly supply-driven by determining the cost of providing water. No water system analysis has been done on the demand schedule for water and the value of water for current levels of consumption by different water users. The approach in this project is therefore threefold: Firstly, evaluation of the economic consequences of competition for water, which involves issues of technical and economic feasibility, pricing of water rights and social welfare. Secondly, assessment of rules for improving the outcomes of allocation, that is, the principles and standards that guide policy choices. Thirdly, formulating proposals for an integrated water management system that will improve performance of the existing allocative mechanisms.

Estimated cost: *R665 000*
Expected term: *1998 - 2001*

Development of a framework for the introduction of waste discharge charge systems in South African catchments
Stewart Scott (Pty) Ltd
(WRC Reference No 949)

The National Water Act makes provision for a system of economic incentives to encourage reduction in pollution. Charges will be introduced for the discharge of waste into water bodies. A WRC project laid the foundation for this provision by developing a philosophy and methodology for the implementation of the polluter pays principle. The current project was designed to build on the findings of the previous study by including a wider range of pollutants and by focusing on implementation issues. At an early stage of the project the WRC became aware that DWAF was about to start developing the protocol for implementing waste discharges. In order to prevent duplication, the WRC decided to integrate this project's activities with those of DWAF. Phase I of this joint initiative was completed with the publication of a *Framework Document* which describes the technical and legal frameworks for the waste discharge system, and the principles on which the development of the system is based. The WRC's contribution will end when the draft implementation strategies are completed under Phase II.

Estimated cost: *R400 000*
Expected term: *1998 - 2001*

Incorporation of economic considerations into quantification, allocation and management of the environmental water reserve
Institute for Natural Resources, University of Natal
(WRC Reference No 978)

Instream flow requirement assessment provides a process whereby the environmental reserve from an ecological perspective is quantified and characterised. This project is aimed at introducing economic criteria into this process. Policy measures are

being implemented to promote efficient use of water. To achieve this, there is a movement towards a water allocation system in which the value of water is acknowledged and taken into account. Without this knowledge and understanding, one cannot anticipate responsible stewardship of the resource. This project, therefore, aims at evaluating the utility of a resource economics approach in contributing to the determination of the environmental water reserve.

Estimated cost: *R488 000*
Expected term: *1998 - 2001*

The value of water as an economic resource in the Great Fish and Sundays River catchments

Department of Agricultural Economics, University of Natal
(WRC Reference No 987)

The value of water as an economic resource in the Great Letaba River catchment

Economic Project Evaluation
(WRC Reference No 989)

The value of water as an economic resource in the Vaal River system

Greengrowth Strategies
(WRC Reference No 990)

Apart from separate sectoral analyses in defined subregions, no comprehensive comparison on the value of water for different uses has been undertaken in South Africa. The best option under these circumstances is to estimate water values through economic modelling. In view of the research backlog and the unacceptability of generalisations regarding water values, tenders were invited and approved according to specified guidelines. The outcomes of these projects will enable the determination of the value of water in different catchment areas, for various combinations of water-use sectors, following different modelling approaches by a number of competent research organisations.

No. 987	*Estimated cost:*	*R443 No. 190*
	Expected term:	*1998 - 2001*
No. 989	*Estimated cost:*	*R795 No. 625*
	Expected term:	*1998 - 2001*
No. 990	*Estimated cost:*	*R807 180*
	Expected term:	*1998 - 2001*

The gender dimension of the water policy and its impact on water on water and sanitation provision and management

Department of Development Studies, University of Fort Hare
(WRC Reference No 1021)

Although government policy on water and sanitation services delivery recognises the important role that women have to play, there are currently no enabling policies for promoting the participation of women. This study is undertaking a critical analysis of the gender dimension in the development of the water policy. It is also investigating strategies and institutional arrangements for water services delivery in terms of decisions concerning the location of the water supply scheme, choice of technology; operation and maintenance, community involvement and how these affect women as managers of households.

Estimated cost: *R303 000*
Expected term: *1999 - 2001*

Security, ecology, community: contesting the "water wars" hypothesis in Southern Africa

Centre for SA studies and Department of Earth Sciences, University of the Western Cape
(WRC Reference No 1106)

Decision-making processes concerning allocation and use of scarce water resources within certain SADC river basins are being investigated with a view to clarifying issues of potential conflict and common security relating to water scarcity. In the process, a number of graduate students are receiving appropriate training.

Estimated cost: *R400 000*
Expected term: *2000 - 2001*

Updating of 1989 manual for cost-benefit analysis in South Africa to 2000

Conningarth Consultants
(WRC Reference No 1132)

The method of cost-benefit analysis (CBA) provides a logical framework and a means by which projects can be evaluated as an aid in the decision-making process. Over the past 15 to 20 years, CBA has been applied mainly to the evaluation of the economic viability of the investment of public capital in infrastructure such as storage dams and canals on irrigation schemes. Due to increasing fiscal constraints, investment in water infrastructure will have to be compared with alternative investments in schools, hospitals, roads, etc. Updating of the CBA manual is essential, owing to recent changes in economic opportunities that necessitate the development of a new set of shadow and surrogate prices. Specific attention is being given to water resource development which covers a range of infrastructural projects such as storage, distribution, sanitation, irrigation, transportation, electrification, etc.

Estimated cost: *R419 000*
Expected term: *2000 - 2001*

An evaluation of the role of water user associations in water management in South Africa

Pula Strategic Resource Management
(WRC Reference No 1140)

The institutional arrangements for water resource management adopted in the Water Act delegate many water resource management functions (particularly resource protection and allocation) to organisations within a Water Management Area (WMA), namely catchment management agencies (CMAs) and water user associations (WUAs). WUAs are intended to operate at a restricted localised level, to facilitate co-operative associations of individual water users who wish to undertake water-related activities for their mutual benefit. This study is aimed at clarifying the roles of WUAs, evaluating the functioning of a number of established WUAs against this framework and the particular needs of the local conditions, and formulating guidelines for the institutional and management arrangements.

Estimated cost: *R380 000*
Expected term: *2000 - 2001*

National benchmarking project for the South African Association of Water Boards

The SA Association of Water Boards (SAAWB) and Rand Water
(WRC Reference No 1201)

During November 1999, discussions were held between the members of the SAAWB with regard to the need for comparative management information between the Water Boards. It was agreed that a National Benchmarking Project should be undertaken to define the performance indicators required to effectively and efficiently measure performance and improve competitiveness.

Thus, the aim of this project was to assist SAAWB to set up a benchmarking system. It was further agreed that the information obtained from this system would also be made available to the WRC and DWAF via an Internet environment.

The final output from this initiative was the development and commissioning of an Internet-based benchmarking system fully capable of:

- User controlled login/logout facilities;
- Options to capture month, year-to-date or annual data;
- Options to report on any category of captured data;
- Presenting information in a bar or line format;
- Analysing monthly or annual data based on number of times the indicator was selected for viewing by users;
- Retaining monthly/year-to-date data in detail for the previous and current year periods; and
- Presenting annual data providing three years of historical values, current year budget and target to be achieved (best of class/world standard).

Estimated cost: *R350 000*
Expected term: *2001 - 2001*

Researching, developing and testing of payment strategies for the poor four selected urban communities in order to manage charges for use

Market Survey and Statistical Analysis (MSSA)
(WRC Reference No 1202)

According to available research results, the non-payment of bills for water services is increasing. This has been observed in particular in households amongst lower income groups. The reasons for non-payment in townships and informal settlements have been identified. They include unemployment and poverty, majority default, i.e. non-payment because everybody else does it, and dissatisfaction with the service. However, only a minority of local authorities (e.g. 40% in the Gauteng Province) are implementing a comprehensive strategy with sufficient consistency to place persisting pressure on payment defaulters.

It is expected that domestic water use will increase due to urbanisation. This has created an urgency to establish a "culture of payment" for water services based on willingness to pay, responsibility and accountability of water users. The perceptions of individuals in households of all income levels will change if it is experienced that higher payment levels lead to better services that are financially sustainable.

Most of the studies undertaken thus far are descriptive and lack depth in that they have not attempted to uncover causal relationships. Clearly there is a need for more focused research and a re-analysis of many studies. The proposed research project will evaluate previous findings and test the implementation of different payment strategies such as indigence concessions, pre-payment systems and adapted flat-rate systems. The methodology that will be followed spells out a systematic process of interaction with stakeholders, obtaining baseline data, monitoring, measuring change and statistically analysing the results. It is quite correctly a participative approach with involvement and commitment of both City Council officials and water users.

The aims of this project are to:

- Start changing the attitude of water users towards the right of access to water and payment for water services; and
- Test the implementation of identified payment strategies for the poor at four local authorities.

Estimated cost: *R96 000*
Expected term: *2001 - 2001*

Hydropolitical history of South Africa's major international river basins

Centre for International Political Studies, University of Pretoria
(WRC Reference No 1220)

Much has been written about the history of Middle Eastern river basins, but not much about South African rivers. Studies have been conducted on the hydropolitics of international river basins (Kunene and Orange Rivers). Although a historical element has been attached, the focus has been mainly on international relations between the actors involved. The need is felt that the studies should be broadened to cover the hydropolitical history of the Orange, as well as of the Limpopo and Komati Rivers, to the present day.

Analysing the hydropolitical history of these rivers is needed to contextualise the current patterns of conflict and co-operation between the riparian states and users. Studying the hydropolitical history of the respective river basins can tell us how phenomena, operating in the past, may behave in future, and how they impact on the hydropolitical dynamics of the rivers at present. This is particularly relevant in light of the requirements of the SADC Protocol on Shared River Systems and elements of the National Water Act.

Filling of the knowledge gap in South African hydropolitical history will assist water resource planners, hydropolitical scientists, catchment management agencies and government officials to provide reasoned justification for their actions regarding the management of international rivers.

The proposed study has the following aims:

- To record the hydropolitical history of the major international river systems in South Africa in one coherent document;
- To find out what the past experience of water management in these river systems was;
- To establish a framework/backdrop that project planners, water service utilities, government departments and CMAs can use for the effective management of these international river systems;
- To contribute to a multidisciplinary understanding of the dynamics of South

Africa's major international river basins; and
- To build capacity by incorporating research assistants from previously disadvantaged communities into the research team.

Estimated cost: *R398 100*
Expected term: *2001 - 2002*

Outcomes to Date of Current Programmes and Projects

New knowledge

- For supply pricing of urban domestic water use a methodology is proposed which is helpful to assess the broad feasibility of different subsidy and tariff structure options. This method has also been expanded for application in the case of industrial and commercial water use.
- The effectiveness of influencing water consumption in residential areas through levying of water tariffs has been tested by means of the contingent valuation method. This is the first study done in South Africa since 1973 and has confirmed the international observation that water demand is relatively price- or tariff-inelastic.
- In line with other country's studies, an economic analysis has shown how water-right transfers are facilitated by institutional arrangements and can lead to efficiency gains. For the first time in South Africa, water-market trades in irrigated agriculture in the Lower Orange River and Crocodile River catchments have been documented.
- In order to widen the knowledge base of water values, different modelling approaches to determine water values have been evaluated. These will enable determination of water values for different use sectors in different catchment areas of South Africa.

Benefits to South Africa

- The Water Supply Services Model (WSSM) and Sanitation Services Model (SSM) have been developed in a user-friendly format to assist Water Service Authorities in financial planning of their services. The models provide a systematic and standard format towards developing a Water Services Development Plan as required by the Water Services Act of 1997. The methodology for implementation of the retail (third-tier) water tariff policy builds on the WSSM and the existing set of management guidelines for setting urban water tariffs in South Africa. It provides a set of practical guidelines for tariff design by Water Service Authorities on Water Service Providers in respect of residential, industrial and commercial water use.
- In collaboration with DWAF, a framework is being developed for the introduction of waste discharge charge systems in river catchments of South Africa. As required by the National Water Act of 1998, provision is made for a system of economic incentives to encourage reduction in pollution and raise funds for protection of the water resource and management of resource quality. In addition, guidelines are being formulated for a tariff structure applicable to industrial effluent. The charging system will allow for a proportion of finance to be provided by industry for installation of adequate sewerage systems and for treatment of the effluent, relieving the burden placed on domestic consumers.
- Acknowledging that rivers are a resource DWAF has made provision through the National Water Act of 1998, for a portion of the mean annual runoff to be reserved to sustain river systems. Research is currently under way to incorporate economic considerations in quantification and management of the environment reserve. This will ensure optimising the net benefits of services forthcoming from environmental functions.
- Expenditure on resource management relates to functions performed by DWAF or agencies exercising delegated or assigned powers. These functions include, amongst others, monitoring and assessment of water resource availability, quality and use. Budgeting implications of catchment management are specified in the discussion document on *A Strategic Plan for DWAF to Facilitate the Implementation of Catchment Management in South Africa* (WRC Report No KV107/98). Broad *Guidelines on Financing of Catchment Management* are given in WRC Report No KV108/98. Guidelines have now been published on the stepwise process for setting charges for water resource management which can be implemented within the framework of the CMA Financial Model and on which mechanisms should be followed to collect catchment management charges from water users across different sectors. These guidelines are highly relevant for those water management areas where CMAs are currently being established.

Innovation/application of knowledge

- The philosophy behind, and the implementation of "the polluter-pays principle" (PPP) for pollution control under South African conditions were found to be both ethical and economically sound. Pollution charges are a viable water quality management tool for implementation in South Africa and will in all likelihood be implemented in a phased approach.
- The current project on development of a framework for the introduction of a waste discharge charge system will build on the findings of the above-mentioned study by including a wider range of pollutants and focusing on implementation issues. The investigation of overseas charge systems revealed that only a few countries have developed their charges to the point where they form a significant deterrent to polluters. In designing a possible charge system for pollution reduction from the outset, South Africa is therefore, to some extent, pioneering this type of instrument.
- In terms of the National Water Act of 1998, many water resource management functions (particularly resource protection and allocation) are delegated to organisations within the water management areas, namely the CMAs and the WUAs. Although the intention is to involve local communities in decision-making, the role of WUAs has received little attention in South Africa. This current project will make a contribution by developing a framework for the functioning of WUAs, evaluate a number of established WUAs and formulate guidelines for WUAs in South Africa.

Capacity/competence development

The research organisations involved in the ***Water Policy*** research field are either private consulting firms or universities, with the majority of projects being undertaken by private firms. In most cases the projects that lead to publication of guidelines require a high level of expertise and are completed in relatively short periods with tight deadlines. Under these circumstances it is difficult to achieve capacity building. However, in response to requirements of the WRC to promote capacity building amongst previously disadvantaged individuals, consulting firms are establishing internship programmes for in-service training of Black staff members. Alternatively, collaborative research work is done with Black consulting firms or Black staff are appointed on a contract basis, but unfortunately, disruptions do occur.

In the case of projects undertaken by universities, with a single exception, it has thus far not been possible to draw previously disadvantaged post-graduate students for degree purposes. However, successful efforts are being made to involve students in project-related research as part of the practical course work. The exception relates to the University of the Western Cape, where 6 students (5 Black South Africans, 1 Black Zimbabwean) are using a project on conflict and security issues in water management for Masters Degree purposes.

Research output in the form of guidelines and reports can strengthen the capacity of officials in government departments to give policy advice and expertise built up through research projects is available to be employed or contracted by government departments.

Knowledge dissemination

The majority of research results are published in the form of manuals with computer models, guidelines or standard reports. These are disseminated as widely as possible. Since most of the projects are undertaken by private consulting firms, there are few incentives for publication of articles. In the case of projects undertaken by universities the following knowledge dissemination took place in addition to the standard WRC reports since 1997:

Articles	5
Papers	6
M.Sc.	8 (7 ongoing/not completed)
Ph.D.	4 (3 ongoing/not completed)

Leveraging of resources

The research on developing a framework for a waste discharge charge system is done in collaboration with DWAF thereby mobilising resources from that Department.

International linkages

On a research project level, linkages have been established with the CSIRO and ABARE in Australia, the University of London and the University of Colorado. In all cases these contacts have added value to the research output.

On a research management level contributions have been made and information has been exchanged on inter-country comparisons of "Water Institutions and Performance of the Water Sector" by Dr Maria Saleth and Dr Ariel Dinar of the World Bank in Washington.

The University of the Western Cape is collaborating closely with academics in Zimbabwe and Botswana in researching issues of conflict and security in water management in Southern Africa.

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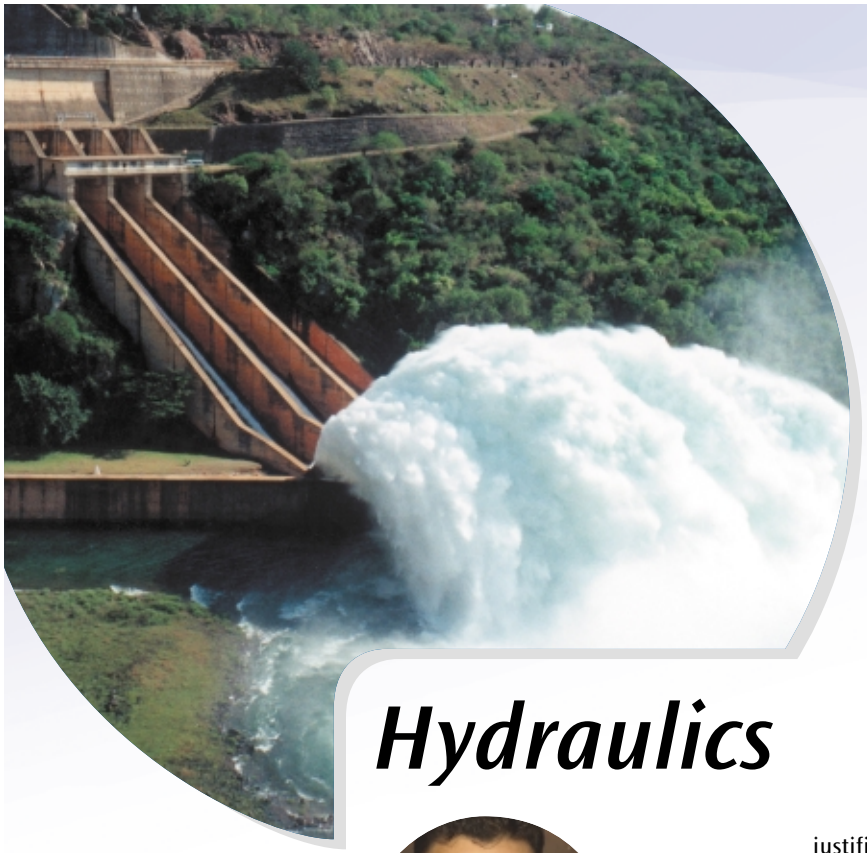

Chapter 19

Hydraulics

Mr JN Bhagwan

Scope

Hydraulics is defined as that branch of science and technology concerned with the mechanics of fluids, especially liquids. In spite of the above statement regarding hydraulics being an integral part of just about all facets of water-related research, it does happen from time-to-time that a specific research topic by way of its very nature or importance, is such that it justifies recognition as a hydraulics research project in its own right, regardless of the field in which the expected research results are to be applied.

The latter view was confirmed by the outcomes of a workshop on research needs in the field of hydraulics which was held during 1998. The needs that were identified during this workshop also guided new research projects which were launched during 1999 and 2000. In view of these new projects and those completed since the 1998 Workshop, it has become necessary to revisit the research needs of this field, especially against the background of the requirements of the stakeholders - mainly DWAF, Environmental Affairs and Tourism; Water Boards; Metropolitan Councils and local authorities and consulting engineers.

Objectives

Primary

The 1998 Workshop formulated the following as the primary goal of hydraulics research in South Africa:

- To acquire adequate understanding of all facets of hydraulics in order to develop appropriate technologies, required for the solution of those problems impacting on the assessment, management and sustainable equitable utilisation of Southern Africa's water resources.
- The formulation of this primary goal was so generic that it is still valid two years and 20 research projects later. As stated earlier, it has the potential to continue guiding hydraulics research in South Africa, but in view of new needs and priorities of stakeholders, the secondary goals may require re-consideration and re-formulation.

Secondary

Those secondary goals that did receive substantial research support during recent years and in which significant progress has been made, are the following:

- Sediment properties, sediment transportation, sedimentation in reservoirs and dams, and desilting
- River hydraulics with special emphasis on river morphology
- Eco-hydraulics, i.e. the hydraulics requirements of rivers and estuaries

- Conveyance and distribution infrastructure: Economic and functional optimisation of tunnels, pipelines and distribution systems
- Flow measurement in pipes, canals, tunnels and rivers: Construction, cost and reliability
- Hydraulics problems associated with water and wastewater treatment infrastructure
- Hydro-informatics and data processing required for, *inter alia*, integrated catchment management, flood management and computational fluid dynamics.

Research Projects

Portfolios of completed, current and new projects which directly address the above-mentioned objectives, are presented below.

Completed

Plunge pool scour reproduction in hydraulic models

Division of Water, Environment and Forestry Technology, CSIR
(WRC Reference No 502)

The project was originally planned for a three-year term, but was eventually executed in three phases, of which the first phase was attended to during 1992 to 1994. Based on the recommendations emanating from **Phase I**, a second phase was funded by the WRC during 1995 to 1998 and subsequently the research was brought to the current stage during 1999 to 2000. The three phases are reported on in separate sections of the final report. The main results of each of the phases are as follows :

Phase I:
The objective during this phase was to develop and test physical model materials or techniques that would more accurately reproduce scour in plunge pools.

- Recent formulae put forward to predict the depth of scour are no more accurate than those originally proposed in the 1930's. In general, scour prediction formulae tend to be unreliable and should be used with caution.
- It would appear that physical model tests are still the most reliable method of determining the expected depth of scour below a dam overflow spillway or flip-bucket.
- The confinement effect of the scour hole has a concentrating effect on the plunging jet that results in a much deeper scour hole. If this confinement is not correctly reproduced in the model, the depth of scour hole produced may be shallower than that occurring in reality, which could lead to an under-designed system.
- As the flow patterns in and around the scour hole play a major role in determining the ultimate scour depth, it is imperative that the downstream topography of the river and dam appurtenant structures are modelled in detail.
- The scour depths obtained from model studies should only be regarded as an indication of the probable scour depths, not absolute values.

Phase II:
The aim of this phase was to further pursue the direction set during **Phase I** by performing additional tests on the mix made up of lime, cement, coke nuts and water.

The results proved to be very different from those obtained during **Phase I** due to the inconsistency of the cement used as the binder. This inconsistency is the main factor responsible for the non-repeatability of the tests using coke nuts. It would, therefore, be tempting to try and use a more reliable binder; however, research in that direction has indicated little success. It should also be concluded that although the coke nuts seemed to give good results during the experiments of **Phase I**, this material remains difficult to obtain and could, therefore, prove unsuitable for further research.

Phase III:
During the execution of **Phase II**, scour-hole investigations were done separately and independently on a model of the Maguga Dam. This concentrated on the prediction of scour-hole dimensions by utilising an aggregate of fairly homogeneous loose material representing the size of eroded elements in prototype, with no binding agent as part of the mix. **Phase III** was, therefore, aimed at applying the Maguga method to the Kariba model to evaluate its suitability as a predictive tool regarding scour-hole formation. The results were as follows:

- Not one of the materials tested modelled the scour depth and scour profile to complete satisfaction with maximum 85% of depth of scour obtained. The natural angle of repose for all model materials tested was the main characteristic influencing the results. If material characteristics like size and relative density could stay the same and the angle of repose would change to a value closer to that found in the Kariba scour, the scour depth and profile might be achieved.
- The loose aggregate method of scour prediction has produced the best results to date in the Kariba model. The loose aggregate method, if applied with the necessary expertise and knowledge of how a physical hydraulic model reacts during the scour process, can produce valuable results and institutes, therefore, a promising approach to modelling of plunge-pool scour.

Cost: *R596 000*
Term: *1992 - 2000*

The hydraulic characteristics of ecological flow requirement components in winter rainfall rivers

Department of Civil Engineering, University of Stellenbosch
(WRC Reference No 979)

This research programme addressed the interaction between moving water and the physical attributes of cobble- and boulder-bed rivers, and as such provides a link between the macro-scale morphological characteristics and the biotope scale, ecologically significant hydraulic characteristics of these rivers. Outputs generated are the development of empirical, semi-empirical and theoretically based models, which define the hydraulic and morphological related characteristics of individual environmental flow components. These models, will serve as tools for determining the hydraulic and morphological characteristics of individual environmental flow components in the cobble- and boulder-bed rivers of the Western Cape. Findings from the study were that:

- The process of scouring of fine sands in a cobble bed and the associated change in absolute bed roughness, is similar to the process of bed deformation in a sand-

bed river, and may be defined by relationships similar to those that exist between absolute bed roughness and particle characteristics under conditions of dynamic equilibrium on a deformed sand-bed river.

- Each type of morphological unit displays significant variability in terms of its habitat diversity, with rapid and riffle morphological units characterised by more biotope classes and flow types than plane-bed and pool morphological units.
- Biotope classes and flow types in cobble- and boulder-bed rivers may be classified in terms of their hydraulic characteristics. However, similar biotope classes and flow types display different hydraulic characteristics depending on the type of morphological unit in which they are situated. This implies that the hydraulic classification of habitat types in cobble- and boulder-bed rivers needs to accommodate the type of morphological unit within which they occur.

Cost: *R450 000*
Term: *1998 - 2000*

Measurement of high flows in rivers

Sigma Beta (CE)
(WRC Reference No 980)

Various facets of and approaches to the problem of high flow measurement have be attended to during the course of this project. These are being reported on in a final report consisting of five volumes. The main results of each facet are as follows:

The rating of compound sharp-crested weirs under modular and non-modular flow conditions

Modular flow conditions

- End contractions can ensure proper aeration for compound sharp-crested weirs. They also have a significant effect on discharge measurements. It was found that this effect could be dealt with by considering an effective notch length.
- The formula developed by DWAF works well for all types of compound sharp-crested weirs. It considers both end contractions (by calculating an effective notch length) and shallow pool depths (by using different coefficients of discharge). However, it is not clearly related to any internationally accepted standards.
- It was possible to develop a method for flow calculation which is based on the IMFT equation, which is included in the ISO standards. End contractions are treated by calculating an effective notch length (as in the DWAF formula). A new coefficient of discharge is also included to deal with shallow pool depths. In this way, H/P ratios of up to 15 are catered for. Based on all the available test data the average error made when using this new method is 0.59% with a standard deviation of 2.4%. This means the error varies between -4.2% and +5.5% at the 95% confidence level.

Non-modular flow conditions

- It was found that the effect of submergence on calculated discharges is not only a function of the ratio t/h. It was proven that submergence could be described in terms of the energy loss occurring at a drowned weir. This energy loss is a function of the velocities at the flow contraction (A_C) and the downstream river section. The greater the difference in these two velocities, the higher the energy loss.
- It was also established that when water is flowing only over the lower notches of a compound weir that is becoming submerged, a dramatic increase in errors occurs as the weir becomes further submerged. This is due to the sudden increase in energy losses as the upstream water level rises, which causes the water to start flowing over the higher notches.

The rating of sluicing flumes in combination with sharp-crested and crump weirs under modular and non-modular flow conditions

This facet of the project concluded the following:

- The errors arising from discharge calculation under non-modular flow conditions for flumes used in combination with both full width and end-contracted sharp-crested weirs as well as crump weirs are considered acceptable. It can be concluded that the method developed here by which allowance can be made for the submergence of a sluicing flume provides satisfactory results.
- It is expected that non-modular discharge estimation in the prototype weirs will be more accurate than is suggested in the report. The largest portion of errors arises from the correction for submergence of the sluicing flume. In prototype weirs, the side weirs are much longer relative to the total width of the compound weir than is the case for the configurations tested in the laboratory (this is due to the restrictions of width in the laboratory canal in which the tests were conducted). This means that the discharge through the flume will constitute a much lower portion of flow past the compound weir in the prototype, and hence discharge estimation should be possible with a greater degree of accuracy.

Discharge measurements in terms of pressure differences at bridge piers

- It has been found possible to develop formulae that can be used to calculate river discharges from pressures measured alongside bridge piers. These formulae cater for both super-and sub-critical downstream conditions.
- The reliability of these formulae under laboratory conditions is underscored by the limited and systematic variations in the calibration coefficients.
- By changing the system of pressure measurement it was possible to increase the prediction accuracy (decreased C_d-value variation) of discharge formulae.
- Calibration curves were constructed in terms of measurable dimensionless flow parameters in the vicinity of bridge piers making it possible to extrapolate these calibration results to prototype structures.

Flow gauging in rivers by means of natural controls: An exploratory study

The objective was to study the possibility of measuring discharge in rivers by means of natural controls, mainly high flows. The hypothesis was that at any control section, a unique relationship exists between the water level upstream of the control, and the flow rate. By recording the upstream water level, a record of the flow rates should then be obtained.

The general conclusion of this facet was that the use of natural controls for flow gauging in rivers holds promise as an economical and environmentally friendly way of recording flows in rivers. In fast-flowing mountain streams controls exist under relatively low-flow conditions. Under high flows many of these controls will become submerged, rendering them useless as flow-gauging devices.

The accuracy of the natural control largely depends on how well the control section is defined, and whether a suitable pool exists upstream of the control in which the water level can be recorded.

The application of Doppler velocity meters in the measurement of open channel discharges

Doppler meter studies mere initiated to establish whether these meters could be used to measure discharges at submerged gauging weirs.
The project indicated that for the flow rates tested in the laboratory, a Doppler meter can be used to obtain a relationship (proved to be linear for both modular and non-modular flow) between the approach velocity and the measured Doppler velocity at a crump weir.

The above-mentioned linear relationship proved that the Doppler meter was not very sensitive to curved flow lines over the crump's crest at different flow depths. Results in the non-modular flow range were encouraging and different linear relationships were obtained for different degrees of submergence.

Under laboratory conditions the Doppler flow meter and an electromagnetic flow meter gave velocity readings within 2.3% of each other. The Doppler meter also performed well under limiting conditions, giving reliable readings close to the channel floor, as well as close to the water surface.

Cost: *R459 908*
Term: *1998 - 2001*

Current

Sediment-induced density current formation in reservoirs

Department of Civil Engineering, University of Pretoria
(WRC Reference No 911)

Density currents in reservoirs form one of the means of sediment transport through a reservoir and can be utilised to pass high sediment loads through a reservoir, thereby limiting reservoir sedimentation. It is important to know under which conditions a sediment-induced density current will form, since this will determine the mode of sediment transport through the reservoir which will affect the sediment deposition process. Tunnel intakes (e.g. Mohale Reservoir, Lesotho), intakes at the dam, pump stations in the reservoir (e.g. Tienfontein at Welbedacht Dam) and purification plants can be severely affected by sedimentation.

The main purpose of this work will be to prove the theory developed in WRC project No 580 **Control of dam siltation in South Africa**, completed in 1997, for predicting the formation of density currents induced by sediment transport in reservoirs. This will be achieved by:

- Use of data provided by various Chinese research organisations;
- Use of Chinese reservoir data;
- Use of laboratory data acquired at the University of Pretoria with a view to confirming the wide range of applicability of the prediction method; and
- Possible modification of the theoretical assumptions according to the results.

Finally, tests will be conducted to establish whether it would be possible to "force" density current formation in a reservoir, based on the new calibrated theory. Such an option would mean a tremendous breakthrough in the control of reservoir sedimentation

This proposal addresses one of the recommendations for further research made in the final report of the previous WRC project. Past research in RSA has elevated theoretical know-how on the subject of density current formation to a level which is the state of the art in the world today. Confirmation and calibration of this theory will not only solve the RSA=s problems when modelling reservoir sedimentation processes, but will also make a substantial contribution to international research and development.

Cost: *R91 000*
Term: *1998 - 1998*

Reduction of urban litter in drainage systems through integrated catchment management

Department of Civil Engineering, University of Cape Town
(WRC Reference No 1051)

In **Volume 1** of the final report (Report No 691/1/98) on the project entitled **The removal of urban litter from stormwater conduits and streams**, reference is made to the dearth of information on litter wash-off rates in urban areas, and the need to reduce the quantity of litter that finds its way into stormwater drainage systems. In addition to amounts, more detailed information is required, not only on the source and types of litter encountered in urban catchments, but also on the efficiency of various catchment management techniques to ensure a reduction in urban litter reaching drainage systems.

Further research in the above regard was strongly supported at a workshop in March 1998. In 1991 it was estimated that 780 000 t of litter annually enter drainage systems in South Africa, and at a current removal cost of approximately R1 000/m^3, it amounts to a total annual cost of R780 m. Ways to reduce litter loadings through better management are, therefore, urgently required - not only from a cost point of view, but also as far as its negative impact on the environment is concerned.

This project will be focusing on the above-mentioned needs, and has the potential to drastically reduce urban litter pollution in streams, resulting in considerable cost savings to local authorities.

Against this background the project addresses the following aims:

- To improve the knowledge of the source type and amount of urban litter coming from different types of urban catchments; and
- To provide scientific data on the efficacy of various management techniques in reducing the amount of urban litter reaching drainage systems. This information, together with that of the first aim, would enable the development of

Litter Management Plans (LMPs) resulting in reduced litter loadings and realising considerable cost savings.

The project will be executed in partnership with the Cape Metropolitan Council which will be contributing to installation costs of the various litter-removal structures.

Cost: R690 000
Term: 1999 - 2002

Hydraulic analysis of tunnel ageing and possible remedial measures

Ninham Shand (CE) Inc.
(WRC Reference No 1088)

During 1997 the WRC accepted the final report on Project No 579, entitled **Hydraulic roughness of tunnels bored by machine through various rock-types**, a project which contributed significantly to the technology available for friction factor determination in machine-bored tunnels. In March 1998, during a workshop on the Research Needs in the Field of Hydraulics, inter alia the effects of tunnel ageing on friction factors and the delivery capacity of tunnels under conditions of ageing, were identified as issues requiring further research attention.

Concrete-lined tunnels could lose as much as 20% of their hydraulic capacity over a period of 30 years due to ageing. Recent commissioning tests of the LHWP transfer and delivery tunnels confirmed the adequacy of the currently available knowledge of the hydraulic roughness of new tunnels. There is, however, a need for a better understanding of the tunnel ageing process in order to plan for future tunnelling requirements as water demands increase.

This project addresses the above issues, and should provide more accurate information in this regard, thereby allowing more acceptable provision for these effects during the design of these tunnels, thus ensuring acceptable performance for longer periods of time. In addition to the above, the project also aims to establish whether remedial measures, e.g. flushing and mechanical cleaning, could be implemented to reverse the tunnel ageing process.

It needs to be mentioned that DWAF (for maintenance purposes) worked on the Orange-Fish Tunnel during 1999, thereby providing an ideal opportunity for facets of this project. In addition the Department is also making a contribution to cover part of the expenses of the project.

Cost: R280 000
Term: 1999 - 2000

Sediment transport through hydraulic structures in rapidly varied channel flow

Department of Civil Engineering, University of Cape Town
(WRC Reference No 1098)

In almost all water-source developments, the impact of human intervention is unavoidable. These structures may give rise to additional sediment in the water through induced scouring, or may require prevention of sedimentation by keeping the sediment in suspension, or may result in deposition of sediment, thereby causing new or additional problems in e.g. reservoirs and estuaries. These problems, together with others related to sediment properties and sediment transportation, have been identified as high research priorities at a workshop on **Research Needs in the Field of Hydraulics.**

This project aims to address the prediction of sediment movement in and around man-made structures, particularly where the flow has significant components in all three dimensions. For various reasons most theoretical analyses of sediment transport approach the problem from a one-dimensional point of view. In those cases requiring analyses from two- or three-dimensional perspectives, semi-empirical or probabilistic equations are being used, often for situations where the conditions of these equations are not altogether being met. Furthermore, those numerical models available for three-dimensional flow patterns are very data-intensive and require substantial expertise and funds to run.

Against this background the project will be addressing the following objectives:

- Investigate the use of the stream-power approach as a method to conceptualise, and subsequently model, the movement of sediment through abrupt changes in channel sections; and
- Develop a simplified design methodology for use by practitioners concerned with the movement of sediment through hydraulic structures located on open channels.

Cost: R440 000
Term: 1999 - 2002

Hydraulics of the impacts of dam development on the river morphology

Department of Civil Engineering, University of Pretoria
(WRC Reference No 1102)

Utilisation of a man-made structure, such as a dam, is very often unavoidable in water-source developments. The impact of the dam is that it alters the river flow regime and with it the sediment transport characteristics, thereby resulting in changes in the river morphology and the river's conveyance capacity.

Both of these factors affect the aquatic habitat of the river. Under regulated flow conditions as a result of a dam, removal of fine sediment through flushing flows does not occur - flows that are very important for the maintenance of several characteristics of the river channel. Flushing flows, one of the facets of in-stream flow requirements (IFRs), has up to now not received adequate attention from a fundamental hydraulics point of view.

Flushing flows are important for a number of reasons. In addition to maintaining a suitable fishery habitat, maintenance of channel geometry and riparian vegetation, formation of pool areas and retention of adequate habitat heterogeneity, are all dependent on the occurrence of flushing flows of the required intensity and frequency. Current methodologies for the determination of the IFR of a river do not fully utilise acceptable hydrodynamic approaches based on sound theory of sediment transport.

The main objective of this project is thus to obtain a better understanding of the river sediment transport processes and the impacts

of dam construction thereon. From this will emanate a methodology for determining flushing flow magnitudes, duration and frequency, thus ensuring maintenance or restoration of river morphology as close as possible to natural or desired conditions. In this regard fundamental hydraulic principles of sediment transport will play a very important role.

This project also emanates from the Workshop on Research Needs in the Field of Hydraulics which took place in March 1998. This workshop identified, *inter alia*, flushing flow IFR, river morphology, river restoration, sediment "management" and computational hydraulics as high priorities in hydraulics research.

Cost: *R660 000*
Term: *1999 - 2002*

Quantifying the influence of air on the capacity of large-diameter water pipelines and developing guidelines for effective de-aeration
Ninham Shand (Pty) Ltd.
(WRC Reference No 1177)

In any major water supply development, the utilisation of large-diameter pipelines is unavoidable. Even though de-aeration has always been a problem, it would still appear that current practices in this regard do not always meet the objectives. These problems result in decreased capacities, which, in turn, result in increased operational costs and even augmentation schemes. In addition, areas of accumulated air are subject to increased corrosion with the accompanying negative effects.

The need for research on acceptable and reliable practices with regard to de-aeration in large-diameter pipelines was also identified during a workshop on research needs in the field of hydraulics in March 1998. The project addressed a need, the importance of which can only increase in future water transfer schemes in South Africa.

In order to achieve the objective of guidelines for effective de-aeration of pipelines, the project will attend to, *inter alia*, the following:

- Field determination of the current hydraulic capacity of large-diameter pipelines and comparing it to design capacities;
- Laboratory investigations into the effect of localised air bubbles on the magnitude of the transient waves and stresses in the pipeline, hydraulic transportability of free air in pipelines and the dynamics of air bubbles at apex points; and
- Establishing the requirements for effective air release from pipelines, the dimensions of accumulators in terms of the pipeline characteristics and the air valve operational features.

It is worth mentioning that significant contributions were made by three parties: Rand Water, Umgeni Water and Vent-O-Mat (Pty) Ltd. These contributions, together with the availability of Rand Water's B8 pipeline, are providing a unique opportunity to address this problem without disrupting normal activities.

Cost: *R750 000*
Term: *2000 - 2002*

Removal and disposal of sediments from pump intakes in rivers by means of permanently installed jet pump type dredge systems
Prestedge Retief Dresner Wijnberg (CE)
(WRC Reference No 1187)

In a previous WRC project (**Removal of floating and suspended materials from streams**) (Project No 691) a relatively small subsection addressed the problem of sediment removal from pump intakes. A major reason for the problem lies in the fact that local conditions often differ from those in regions where many of the classical extraction layouts have been developed. In Southern Africa discharges are highly variable, often carrying heavy loads of suspended sediments. Two distinctive situations are common, namely:

- Streams which carry loads of predominantly fine sediments (major portion of the particles typically smaller than 0.3 mm diameter); and
- Steep rivers that carry heavy sediment loads which may include gravel, cobbles etc.

In both cases, intake structures are necessary for pump inlets. These usually result in complex three-dimensional flow patterns, the investigation of which often requires physical model studies in order to design layouts for optimal efficiency.

This project proposes a novel approach which should provide an economically sustainable solution to the problem of sedimentation (fine and coarse) at pump inlets. The intention is to develop a scaled-down version of the jet pump principle utilised for off-shore diamond mining. Although it is a well-established principle, it requires adaptation to the pump station situation and right-sizing it to the specific conditions. The end-result (i.e. a generic guideline on the utilisation of the system) would address a problem encountered in many parts of the country.

Cost: *R469 000*
Term: *2000 - 2001*

Determination of the accuracy whereby the flow rate of electrically-driven pumps can be calculated when use is made of the measurement of electric power supplied to the electric motor
MBB (CE) Inc.
(WRC Reference No 1190)

Improved management of South Africa's water resources forms the foundation of the new Water Act. In this regard, water metering is one of the most important aids to assist the water user in making optimal management decisions.

Water metering is, however, poorly implemented in the agricultural sector. An investigation in a specific area in the Western Cape Province indicated that only 32% of the pump stations are equipped with water meters (and of these, approximately 40% are inoperable). Even if all these meters were fully operational, they would be measuring only about 11% of the combined capacity of these pump stations.

This project is based on the hypothesis that the equation used to calculate electrical power requirements, together with the characteristics of the pump, could be utilised for flow determination. Theoretically, this hypothesis is sound, on the condition that electrical current and voltage measurements,

as well as hydraulic head measurements, are easily made and are of acceptable accuracy.

Based on this hypothesis, the research team (comprising MBB (CE) Inc. and Cape Technikon) conducted a preliminary investigation into the proposed approach during 1999. This investigation concluded that the relationship between flow rate of a pump and the electrical power supplied to the pump does have the potential for flow rate determination, and that an in-depth research project was justified. Indications are that the cost of suitable instrumentation would compare favourably with that of conventional flow meters. In addition, it will have major advantages with regard to the ease of installation.

The main aim of the project, therefore, is to develop a procedure and supporting instrumentation, whereby water which is pumped with an electrically-driven pump, could be measured indirectly. This requires the measuring unit to be of acceptable accuracy, to be tamper-proof, simple to install and at a cost comparable to that of conventional meters.

Cost: *R600 000*
Term: *2000 - 2001*

New

Factors influencing the friction loss in pipelines and the relationship between water quality, operating conditions and the performance of different liner systems and pipe material

Department of Civil Engineering, University of Pretoria
(WRC Reference No 1269)

This research will quantify the contributing factors altering the hydraulic capacity of pipelines and will reflect the most appropriate pipe material selection and lining systems for different operating characteristics and water quality. An increasing water demand and the objective to provide water to unserved communities requires the optimal utilisation of the existing water infrastructure. The lack of sufficient development capital necessitates the need to prioritise the upgrading and extension to the infrastructure. The effect of ageing, deterioration and failing of the liner systems in conjunction with the operating characteristics and water quality contribute to the change in hydraulic capacity.

Cost: *R746 000*
Term: *2001 - 2003*

Flow measurement at natural river controls and the provision of fish-ways

Department of Civil Engineering, University of Stellenbosch
(WRC Reference No 1270)

South Africa measures its flow in rivers by means of constructed weirs and these impose an obstruction for the movement of fish in the rivers. This project will find hydraulically acceptable ways of continuous flow measurement with fish ladders.

Cost: *R840 000*
Term: *2001 - 2003*

Note to stakeholders

Of the WRC's portfolio of 18 research fields, the field addressing ***Hydraulics*** was closed at the end of March 2002 and the current projects have been re-allocated to linking fields.

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Annexure

Publications emanating from research financed wholly or partially by the WRC. This Annexure contains a list of publications released during January 2001 - 31 March 2002, as well as a complementary list of 2000.

Requests for articles and papers should be directed to the authors.

Rural Water Supply

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