Inland water ecosystems in South Africa — a review of research needs

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A report of the Committee for Inland Water Ecosystems
National Programme for Environmental Sciences

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PREFACE

Inland water ecosystems in South Africa already exhibit striking evidence of the impact both of development and of increasingly intensive utilization. In the face of these threats, research will be needed to put the management and utilization of inland waters on a scientific footing. The Inland Water Ecosystems (IWE) programme has been developed as a section within the National Programme for Environmental Sciences (NPES) to help meet this need.

This document describes the kinds of ecosystems involved and some of the current and possible future research questions in the IWE programme. Attempts are made to allocate priorities for future action. The need for such a document was first expressed by Dr A F Bartsch (US Environmental Protection Agency) who visited South Africa in March 1977 as a consultant to the Water Research Commission. It has been drawn up with both limnologists and decision makers in mind, in order to facilitate their involvement in the planning of the IWE programme.

The IWE programme aims at the promotion, coordination and, where necessary, initiation of research relating to environmental problems and the utilization and conservation of inland water ecosystems. The programme also aims at the synthesis of findings in a form suitable for decision makers. In this regard, the NPES undertakes research on behalf of the Department of Planning and the Environment and the IWE Committee functions as a Coordinating Research and Development Committee for the Water Research Commission.

The IWE programme is a section of the National Programme for Environmental Sciences (NPES), which is one of several cooperative national scientific programmes administered by the CSIR. Participation in NPES is open to all scientists and scientific institutions in South Africa concerned with research relating to environmental problems. The programme includes both research designed to meet local needs as well as projects being undertaken in South Africa as contributions to the international programme of SCOPE (Scientific Committee on Problems of the Environment), the body set up in 1970 by ICSU (International Council of Scientific Unions) to act as a focus for non-governmental international scientific effort in the environmental field.

ACKNOWLEDGEMENTS

Grateful thanks are due to the members of the study group appointed to consider Dr A F Bartsch's report and the IWE scientific planning panel for their detailed discussion of the drafts, to Dr R J Wells and Mr O F Graupner for help with the summary, introduction, priorities and final editing and to Mr W J R Alexander, Professor B R Allanson (particularly coastal lakes and estuaries), Mr P J Ashton (particularly problem plants), Dr J J Barnard (health aspects), Mr G W Begg (estuaries), Dr G M Branch (estuaries), Dr C M Breen, Mr C A Bruwer (impoundments), Dr F M Chutter (particularly rivers), Dr C E Cloete (toxic chemicals), Mrs M de Winter (threatened plants), Dr D Edwards (particularly vleis and problem plants), Dr I G Gaigher (particularly fish), Mr N D Geldenhuys (particularly impact), Dr J R Grindley (estuaries), Dr W H J Hattingh, Professor J Heeg, Dr C Howard-Williams, Mr P B N Jackson (fish), Dr A Jacot Guillarmod, Professor B C Jansen, Dr C J Loedolff, Professor D C Midgley, Dr P F S Mulder (fish), Dr A J H Pieterse (pans), Dr R J Pitchford (snails), Mr R T Rudd, Professor J E Saayman, Professor E A Schelpe (problem plants), Professor H J Schoonbee, Professor D F Toerien (particularly eutrophication), Dr B C W van der Waal, Professor J A van Eeden (snails), Mr G A Visser (particularly impact), Mr F S Vivier (health aspects), Dr J H Wallace (estuaries) and many others who contributed material and ideas and provided invaluable comment at different stages in the preparation of this document.

SUMMARY

The Inland Water Ecosystems (IWE) programme is aimed in particular at the following :

- Developing the understanding necessary to predict the effects of natural events and planned development and management actions on inland water ecosystems.
- Forming a scientific basis for utilizing these ecosystems, for instance for biological production and recreation.
- Seeking solutions to particular environmental and management problems related to inland water ecosystems.

In the introductory chapter, the structure and approach of the IWE programme are described. In the second chapter, descriptions are given of the major ecosystem types involved. In the third chapter, information needs are described in terms of benefits sought from inland water ecosystems and environmental problems affecting them. The relation between the ecosystem types (columns), research themes (rows) and principal information needs (squares) may be illustrated as follows :

Ecosystem types / Research themes	Rivers	Vleis	Pans	Impoundments	Coastal lakes	Estuaries
Sediments and erosion	habitat obliteration	sedimentation		loads, sedimentation, resuspension		loads, sedimentation, resuspension
Eutrophication	nutrient transport	nutrient removal and release	trophic status	nutrient cycling, rôle of sediments and suspensoids, rehabilitation	trophic status	trophic status
Problem plants	weeds	hydraulic effects		algal growth, toxic algae, weeds	weeds	
Utilization of biological production	fish migrations	potential of floodplain pans		angling, fish production	angling, fish production	angling, fish production
Threatened species and habitats	plants, insects, fish, amphibians, reptiles, mammals	plants, fish, amphibians, reptiles, mammals	fish		plants, fish, amphibians, reptiles, mammals	plants, fish
Pests	Simuliidae	snails, mosquitoes	snails, mosquitoes	snails, mosquitoes		
Chemical pollutants	transport, remobilization, ecotoxicology	removal, remobilization	accumulation	accumulation, remobilization, ecotoxicology	accumulation, remobilization	accumulation, remobilization, ecotoxicology
Impact of development	dams, urban, industrial, agricultural, mining development	dams, urban, industrial, agricultural, mining development	urban, industrial, agricultural, mining development	catchment development, effluent treatment	bridges, urban, agricultural development, effluent treatment	bridges, marinas, harbours, recreation, urban, industrial, agricultural development

A summary is given in Table 11 on page 109 of the environmental problems and information needs of the country's principal drainage systems and the priority planning regions of the National Physical Development Plan (NPDP) of the Department of Planning and the Environment.

The fourth chapter briefly describes a few fields of fundamental research considered to form an essential background to the IWE programme. The fifth chapter similarly summarizes a few fields closely related to but which fall outside of the IWE programme.

Far more research needs have been identified than can be met with available manpower and funds. Thus an attempt has been made to allocate priorities on the basis of importance and urgency. The following is a list of items which it is considered should enjoy top priority (essential and very urgent) at present :

Synthesis of existing information on priority planning regions :

- Environmental assessments for the Olifants River (eastern Transvaal) and George-Wilderness-Knysna lakes region.

Synthesis of existing information on selected topics :

- Social and economic costs of eutrophication, criteria to assess trophic status of impoundments and the present state of pollution.

Short term surveys and investigations :

- The rôle of vlei ecosystems, creel analyses in selected waters, the impact of development on selected coastal lakes and bathymetric surveys of estuaries.

Monitoring programmes :

- Nutrient loads, aquatic weeds, chemical pollutants, pollution in estuaries and the rehabilitation of eutrophic impoundments.

Research programmes :

- Nutrient cycling in impoundments, responses to changes in nutrient loading, the rôle of sediments, the rôle of suspensoids, toxic algae, fish production potential of impoundments, and Simuliidae and their control.

OPSOMMING

Die program vir Binnelandse Waterekosisteme (BWE) het veral die volgende ten doel :

- Ontwikkeling van kennis nodig om die invloed van natuurlike gebeure en beplande ontwikkeling en bestuursaksies op binnelandse waterekosisteme te kan voorspel.

- Die daarstelling van 'n wetenskaplike grondslag vir die benutting van sulke ekosisteme vir byvoorbeeld biologiese produksie en ontspanning.

- Die soek na oplossings vir spesifieke omgewings- en bestuursprobleme met betrekking tot binnelandse waterekosisteme.

Die struktuur en benadering van die BWE-program word in die inleidingshoofstuk beskryf. Beskrywings van die betrokke ekosisteemtipes word in die tweede hoofstuk verstrek. Die navorsingsbehoeftes ten opsigte van die voordele wat van binnelandse waterekosisteme verlang word en omgewingsprobleme wat dit beïnvloed, word in die derde hoofstuk beskryf. Die verband tussen die ekosisteemtipes (kolomme), navorsingstemas (rye) en die vernaamste inligtingsbehoeftes (vierkante) kan soos volg geïllustreer word :

Ekosisteemtipes / Navorsingstemas	Riviere	Vleie	Panne	Damme	Kusmere	Getyriviere
Sedimente en erosie	sedimentering van habitatte	sedimentering		beladings, sedimentering, hersuspensie		beladings, sedimentering, hersuspensie
Eutrofikasie	vervoer van voedingstowwe	verwydering en vrystelling van voedingstowwe	trofiese toestand	voedingstofsiklusse, rol van sedimente en suspensoïede, rehabilitasie	trofiese toestand	trofiese toestand
Probleemplante	onkruide	hidrouliese effek		alggroei, toksiese alge, onkruide	onkruide	
Benutting van biologiese produksie	vismigrasies	potensiaal van vloedvlaktepanne		hengel, visproduksie	hengel, visproduksie	hengel, visproduksie
Bedreigde soorte en habitatte	plante, insekte, visse, amfibieë, reptiele, soogdiere	plante, visse, amfibieë, reptiele, soogdiere	visse		plante, visse, amfibieë, reptiele, soogdiere	plante, visse
Plaagdiere	Simuliidae	slakke, muskiete	slakke, muskiete	slakke, muskiete		
Chemiese besoedelstowwe	vervoer, hermobilisering, ekotoksikologie	verwydering, hermobilisering	akkumulasie	akkumulasie, hermobilisering, ekotoksikologie	akkumulasie, hermobilisering, ekotoksikologie	akkumulasie, hermobilisering, ekotoksikologie
Impak van ontwikkeling	damme, stedelike, industriële, landbou, mynbou-ontwikkeling	damme, stedelike, industriële, landbou, mynbou-ontwikkeling	stedelike, industriële, landbou, mynbou-ontwikkeling	ontwikkeling van opvanggebiede, behandeling van uitvloeisels	brûe, stedelike, landbou-ontwikkeling, behandeling van uitvloeisels	brûe, marinas, hawens, ontspanning, stedelike, industriële, landbou-ontwikkeling

'n Opsomming van die omgewingsprobleme en inligtingsbehoeftes van die land se hoofdreineringstreke en die prioriteitbeplanningstreke van die Departement van Beplanning en die Omgewing se Nasionale Fisiese Ontwikkelingsplan (NFO) word in Tabel 11 op bl 109 verstrek.

Enkele gebiede van fundamentele navorsing wat as noodsaaklike agtergrond vir die BWE-program beskou word, word in die vierde hoofstuk beskryf. Enkele gebiede wat as nouverwant aan maar buite die bestek van die BWE-program beskou word, word in die vyfde hoofstuk beskryf.

Veel meer navorsingsbehoeftes word geïdentifiseer as waarin die beskikbare mannekrag en fondse sal kan voorsien. Die volgende is 'n lys van items wat tans die hoogste prioriteit (noodsaaklik en baie dringend) behoort te geniet :

Sintese van bestaande inligting oor prioriteitbeplanningstreke :

- Omgewingswaardering van die Olifantsrivier (Oos-Transvaal) en die George-Knysna-Wildernis-meregebied.

Sintese van bestaande inligting oor bepaalde onderwerpe :

- Sosiale en ekonomiese koste van eutrofikasie, kriteria om die trofiese toestand van damme en die huidige stand van besoedeling te bepaal.

Korttermynopnames en -ondersoeke :

- Die rol van vlei-ekosisteme, vismandjie-analises in bepaalde waters, die invloed van ontwikkeling op bepaalde kusmere en batimetriese opnames van riviermondings.

Moniteringsprogramme :

- Voedingstofbelading, wateronkruide, chemiese besoedelstowwe, besoedeling in riviermondings en die rehabilitasie van eutrofiese damme.

Navorsingsprogramme :

- Plantvoedingstofomset in damme, die gevolge van veranderde voedingstofbelading, die rol van sedimente, die rol van suspensoïede, toksiese alge, visproduksiepotensiaal van damme, en Simuliidae en die beheer daarvan.

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INTRODUCTION

BACKGROUND

South Africa has an impending water crisis and water resources in this country need to be managed in the best possible way to satisfy sometimes conflicting demands for urban, industrial, agricultural, fisheries and recreational uses. Intensive exploitation and sequential use of water resources, the construction of impoundments and other works, pollution and the general pressures of development and growing human population have already had a very marked impact on river systems and other water bodies. These aquatic ecosystems represent a natural resource essential for the optimal use of available water. An understanding of their workings and of the ways in which they can be affected by development and exploitation is needed both for planning and water resource management purposes.

Most of South Africa has a semi-arid climate with a highly seasonal rainfall pattern (Figures 1 and 2). The average annual rainfall is only 475 mm compared with the world average of 860 mm. In addition, especially

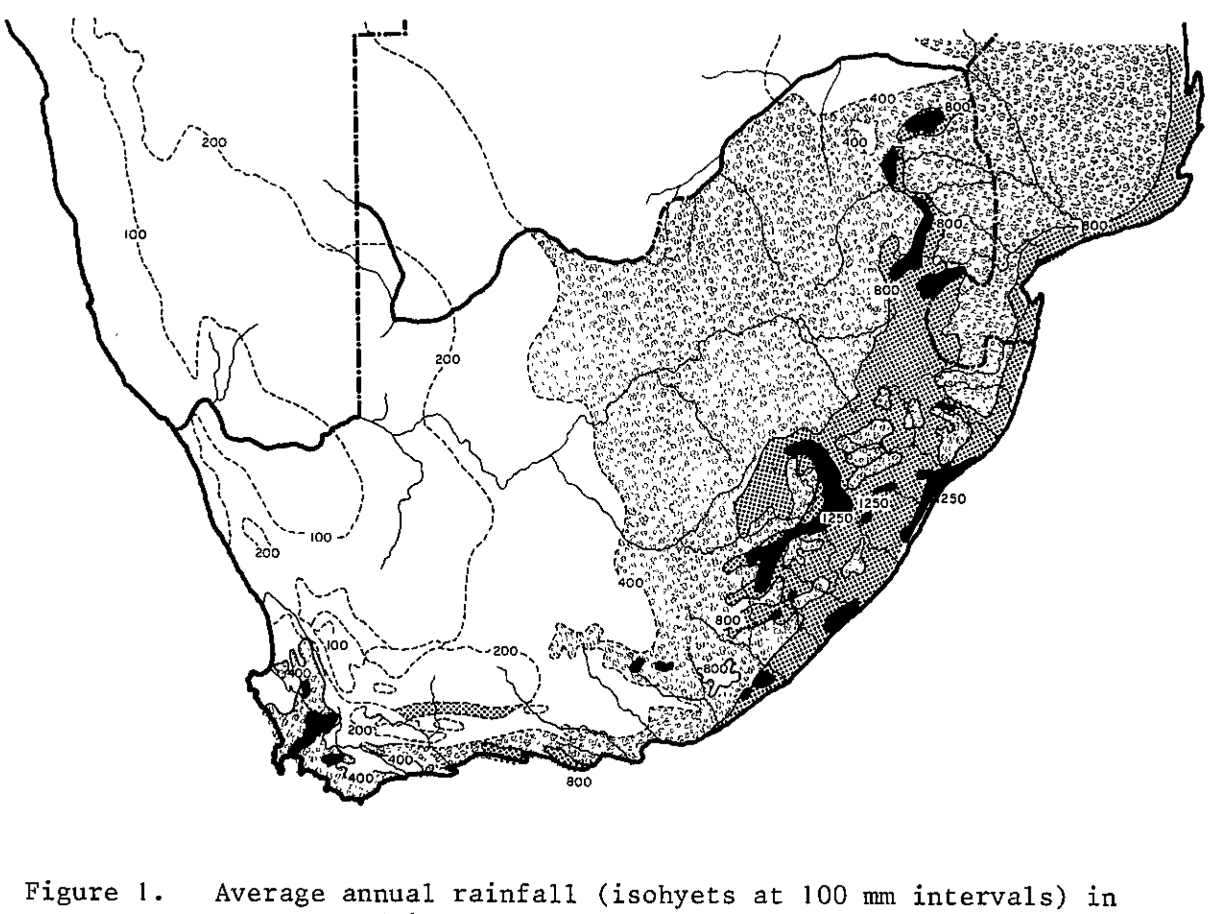

Figure 1. Average annual rainfall (isohyets at 100 mm intervals) in southern Africa.

in the interior of the country, the rainfall fluctuates greatly from year to year. As a general rule, the lower the rainfall the smaller the proportion of the rainfall reaching river systems (less than nine percent in South Africa) and the greater the variability of river flow.

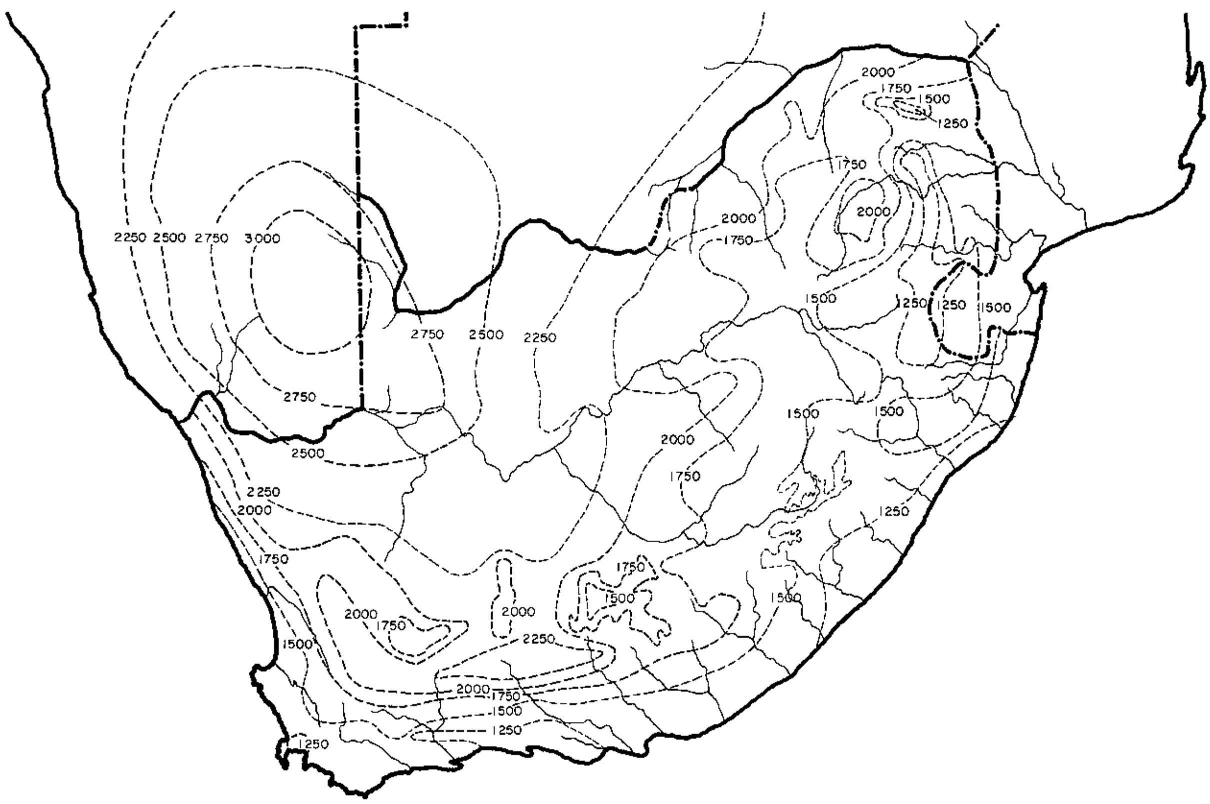

Figure 2. Average annual evaporation (isoevaps at 250 mm intervals) in southern Africa.

This climatic picture, together with South Africa's geomorphological history, has created a landscape characterized limnologically by such features as :

- small rivers of erratic flow, very few with strong perennial flow,
- very few well developed floodplains, but most river catchments with vleis (flattish stretches of river with marshy vegetation and seasonal standing water),
- the interior of the country with pans of various kinds (depressions normally or sometimes filled with water, with no outflow and hence termed endorheic), but no other kinds of lakes (except for one small rockfall lake),
- many man-made impoundments, large and small,
- coastal and estuarine lakes at places along the coasts of the south-western and southern Cape Province and in northern Zululand, and

- estuaries (many with salt marshes, those along the east coast previously with well developed mangrove forest) and estuarine lagoons.

The descriptive regional limnology of South Africa began in the late 1920's with the work of G E Hutchinson. After World War II, J H Day and others (University of Cape Town) undertook a number of important descriptive studies of the more important South African estuaries. In the 1950's the National Institute for Water Research (NIWR) began a series of hydrobiological studies of representative river systems aimed at detecting changes in river fauna and flora resulting from organic pollution. Over a number of years, collections from these surveys were studied by specialists and considerable advances made in taxonomic knowledge of South African estuarine and freshwater organisms.

In the late 1960's, largely due to the impetus provided by the IBP (International Biological Programme), limnological research groups came into being at several universities and became involved in increasingly sophisticated studies of, for instance, the coastal lake Sibaya, the Pongolo floodplain and impoundments such as the Hendrik Verwoerd and Midmar Dams. A programme of research developed in which these as well as limnological groups within the NIWR, provinces, government departments and others participated on a cooperative basis. Through this programme, now known as the Inland Water Ecosystems (IWE) programme, limnologists were able not only to develop basic research into the structure and functioning of a few selected ecosystems, but were also able to identify practical management problems, to direct limnological research at understanding and seeking solutions to these problems and to offer advice to decision makers on the basis of the limnological understanding gained.

THE IWE PROGRAMME

Aims

This document is a general description of the issues considered to be important within the IWE Section of the National Programme for Environmental Sciences (NPES), indicating future directions the programme is expected to take and priorities for these future directions.

The IWE programme includes research in a wide spectrum of disciplines and is aimed broadly at :

- Developing the understanding necessary to predict the effects of natural events and planned development and management actions on inland water ecosystems.

- Forming a scientific basis for utilizing these ecosystems, for instance for biological production and recreation.

- Seeking solutions to particular environmental and management problems relating to inland waters.

Structure of the programme

The IWE programme is administered by the NPES Committee for Inland Water Ecosystems, which falls under the National Committee for Environmental

Sciences (NCES). The Departments of Water Affairs, Agricultural Technical Services, Health, and Planning and the Environment, the provincial administrations (jointly), the Water Research Commission, the CSIR, Rhodes University, University of the Orange Free State and University of Natal are represented in the IWE Committee, which is supported by an executive, a scientific planning panel and working groups for its major integrated research programmes.

Approach of the programme

The overall programme includes long term research, shorter term surveys and projects aimed at particular problems, monitoring, and the periodic synthesis and assessment of information on particular topics or in particular catchments.

The programme aims at identifying limnological and practical management problems which might be expected in the future. These are seen in terms of the needs of government departments, provincial administrations, local governments and other bodies with executive responsibilities relating to inland waters. There are three ways in which the needs identified can be met :

- Through the synthesis of existing information derived both from the literature and from work already completed.

- Through research which government, provincial, statutory and other laboratories are able to undertake with existing resources.

- Through the initiation of new research on a priority basis to fill the gaps that remain, in some instances by making funds available through the IWE programme.

Because of its cooperative nature, the IWE programme is able to bring together different scientific disciplines and institutions and in this way to approach the study of entire systems. This makes it possible to undertake studies of complex ecosystems and problems, and also to study these ecosystems within the whole drainage systems within which they occur.

Liaison with related activities

The IWE programme has close contact with the other NPES sections and further cooperative national programmes administered by the CSIR :

- The NPES Terrestrial Ecosystems Section administers the work on threatened species and pesticide residues described in this report.

- The NPES Marine Pollution Section administers both the programme on chemical elements in the environment and the estuarine surveys carried out within the national marine pollution survey.

- The NPES Solid and Toxic Wastes Section is concerned with various topics with water pollution implications, including toxic wastes disposal and the management of mine dumps, and with the mass culture of algae.

- The Cooperative National Oceanographic Programme (SANCOR) supports estuarine research through its Marine Biology Section.

A large proportion of the funding of the NPES is provided by the Department of Planning and the Environment and its Council for the Environment. Through the Department, the NPES works closely with bodies it administers :

- The Committee for the Coastal Zone of the Prime Minister's Planning Advisory Council provides a forum to consider planning activities and action relating to environmental problems affecting coastal lakes, estuaries and the sea coast.

- The National Committee for Nature Conservation (NAKOR) provides a forum to consider nature conservation questions on a national scale and administers the National Plan for Nature Conservation. At the request of NAKOR, selected fields of research relating to nature conservation are coordinated within NPES.

In terms of a recent agreement between the Water Research Commission (WRC) and the CSIR, the IWE Committee functions as a Coordinating Research and Development Committee for the WRC. The IWE Committee therefore has a national coordinating function and is available to advise the WRC on matters relating to inland water ecosystems research. The WRC also makes funds available for the IWE programme. Through the WRC the IWE Committee has contact with other Coordinating Research and Development Committees :

- The Coordinating Research and Development Committee for Water Quality is administered by the WRC and includes the programme on mineralization which was previously part of the IWE programme.

- Effluents research committees exist for several industries.

- The Research Coordinating Committee for the Hydrological Cycle is administered by the Department of Water Affairs and coordinates hydrological research in South Africa.

Major research groups

Reference is made in this document to research undertaken by many research groups, especially the following :

Government laboratories :

- Department of Water Affairs Hydrological Research Institute (HRI), at Roodeplaat Dam near Pretoria (research and monitoring related to the management of dam systems).

- Department of Agricultural Technical Services Botanical Research Institute (BRI) in Pretoria (includes the National Herbarium, surveys and ecological research).

- Department of Agricultural Technical Services Veterinary Research Institute at Onderstepoort near Pretoria (fish parasites, *Microcystis* toxicity) and Plant Protection Research Institute in Pretoria (biological control).

Provincial nature conservation authorities :

- Cape Provincial Administration (CPA) Department of Nature and Environmental Conservation in Cape Town and Jonkershoek, with research laboratories at Rondevlei (Wilderness) and under construction at the P K le Roux Dam (fisheries, ornithological and other research).

- Transvaal Provincial Administration (TPA) Division of Nature Conservation in Pretoria, Marble Hall and Lydenburg (fisheries and ornithological research).

- Provincial Administration of the Orange Free State (PAO) Division of Nature Conservation in Bloemfontein (fisheries research).

- Natal Parks, Game and Fish Preservation Board in Pietermaritzburg (fisheries research, the St Lucia Scientific Advisory Council research programme).

Council for Scientific and Industrial Research (CSIR) :

- National Institute for Water Research (NIWR) in Pretoria and Durban, the CSIR's national limnological laboratory (eutrophication research and the use of biota in determining environmental quality).

- National Research Institute for Oceanology (NRIO) in Stellenbosch (estuarine pollution and hydraulics), National Physical Research Laboratory (NPRL) in Pretoria (heavy metals) and National Chemical Research Laboratory (NCRL) in Pretoria (*Microcystis* toxin).

Medical Research Council (MRC) :

- MRC Snail Research Unit in the Department of Zoology, Potchefstroom University for CHE (snail systematics and distribution) and Bilharzia Field Research Unit in Nelspruit (*Schistosoma* systematics and parasitology).

Universities :

- Rhodes University (RU) Institute for Freshwater Studies (IFWS) in Grahamstown recently closed its field station at Sibaya, has field stations at Swartvlei and the P K le Roux Dam (coastal lake and large impoundment limnology and offers postgraduate training in limnology). Also JLB Smith Institute of Ichthyology (fish populations).

- University of the Orange Free State (UOFS) Institute for Environmental Sciences (IES) in Bloemfontein (turbid impoundment and Orange River limnology and offers postgraduate training in limnology). Also Departments of Botany (*Microcystis* biochemistry), Zoology (mosquito biology) and Geography (sediment generation).

- University of Natal Departments of Botany and Zoology in Pietermaritzburg, with a field station at the Pongolapoort Dam (eutrophication research, fish populations and floodplain ecology).

- Rand Afrikaans University (RAU) Departments of Zoology and Botany in Johannesburg (fish biology and parasites, vleis).

- University of Cape Town (UCT), Departments of Zoology (estuaries) and Geochemistry (heavy metals), Percy FitzPatrick Institute of African Ornithology (ornithology), School of Environmental Studies (estuaries) and Bolus Herbarium (aquatic plants).

- University of Pretoria (UP) Departments of Chemistry (pesticides, heavy metals), Botany (algae) and Parasitology (fish parasites).

- University of the Witwatersrand Hydrological Research Unit (HRU) (floodplain hydraulics) and Department of Zoology (Simuliidae taxonomy) in Johannesburg.

- University of the North Department of Zoology at Turfloop (fish biology, parasitology, regional limnology).

- Potchefstroom University for CHE Department of Zoology and Microbiology (impoundments).

- University of Port Elizabeth (UPE) Department of Zoology (estuaries).

Museums :

- Port Elizabeth Museum (estuarine fish).

- Albany Museum in Grahamstown (national collection of freshwater organisms).

- South African Museum in Cape Town (systematics of estuarine organisms).

- Natal Museum in Pietermaritzburg (dipteran systematics).

Private research institutes :

- South African Institute for Medical Research (SAIMR) in Johannesburg (bilharzia, medical entomology).

- Oceanographic Research Institute (ORI) in Durban (estuaries).

Place names

Wherever possible, the place names recommended by the Trigonometrical Survey Office (which appear on Government Printer maps such as the 1 : 50 000 series) have been used in this document. The following exceptions should be noted :

- Sibaya (page 39) appears on current maps as Sibayi, but it is understood that a proposal to change the name is being investigated by the Trigonometrical Survey Office.

- The Kosi lakes (page 37) Mpungwini, Nhlange and Amanzimnyana currently appear as ku-Sifungwe, ku-Hlange and Manzimnyama, the Touw River at Wilderness (page 44) appears as the Touws, Zeekoevlei on the Cape Flats (page 45) appears as Seekoevlei and the estuaries of the Nonoti, Mhlanga and Mvuze (Table 9) appear as the eNonoti, Ohlanga and Mkuze, but it is understood that representations are to be made to change these.

INLAND WATER ECOSYSTEM TYPES IN SOUTH AFRICA

Ecosystems are relatively self-contained ecological units comprising mutually interdependent plant, animal and micro-organism populations and the total physical environment in which they live. Each ecosystem is dependent upon solar and perhaps other energy sources and inputs, and may provide outputs and interact to a greater or lesser extent with other nearby ecosystems. Ecosystems are dynamic and their structure may exhibit considerable fluctuations as energy and materials are transferred from component to component through ecosystem processes which may be controlled by such factors as the physical driving forces, the energy and other inputs and the sizes of the biotic components, their enemies or the resources upon which they depend. Thus apparently minor disturbances to one part of an ecosystem can result in perhaps important or even dramatic changes elsewhere which would be difficult to predict without an understanding of the processes involved.

Strictly speaking, the most natural units into which the Biosphere could be divided and considered as ecosystems are entire drainage areas (landscapes comprising whole catchments with their atmosphere, soils and terrestrial and aquatic biota). In practice, however, it is more convenient to define ecosystems on a smaller scale, even though these may be less independent of one another.

The regional limnology of South Africa suggests six broad categories into which inland water ecosystem types may conveniently be divided. This classification omits such minor ecosystem types as underground and interstitial waters, temporary rain pools and so forth, but includes all of the major types, which represent interdependent elements within each drainage system (the interlinked water bodies within one drainage area) in which they occur. The principal drainage systems and their contributions to total mean annual runoff in South Africa are shown in Figure 3. The six ecosystem types they contain are described in the sections that follow.

RIVERS

Hydrology

Almost all limnological work depends to some extent upon an understanding of the rivers which form the catchment of the ecosystem being studied. The nature of these rivers greatly influence the other ecosystems in the drainage system and the water and other material carried into them.

The average annual runoff into rivers in South Africa is estimated at 52 000 million m^3. As shown in Figure 3, this runoff is very unevenly distributed. These differences reflect principally the differences in mean annual rainfall which varies from approximately 50 mm around the mouth of the Orange River to maxima around 1 250 mm in small areas in the south-western, southern and eastern Cape, the Drakensberg, Natal and the eastern Transvaal. In the south-west coastal region, up to 80 percent of the year's rainfall occurs in the winter (April to September). In a narrow strip along the southern Cape coast, rainfall is distributed more or less evenly through the year. Over more than three-quarters of the country an average of 80 percent or more of the rainfall occurs during summer (October to March).

It is a characteristic of the Republic's rainfall that the lower the annual precipitation, the greater the variability. As an illustration, one may compare the Breë River in the south-western Cape with the Hartbees River (with one quarter the rainfall of the Breë but a catchment area eight times as large) near Kakamas in the Orange catchment. The mean annual runoff from the Hartbees River in one year was 1 700 percent of the annual average, the minimum in one year was only nine percent of the average and in 1961 alone, the runoff was more than the previous 27 years of record. No river in the wetter parts of the country shows such variations in runoff. As shown in Table 1, both the runoff and the utilizable proportion of the runoff are far lower in the erratic Hartbees than in the more equable Breë.

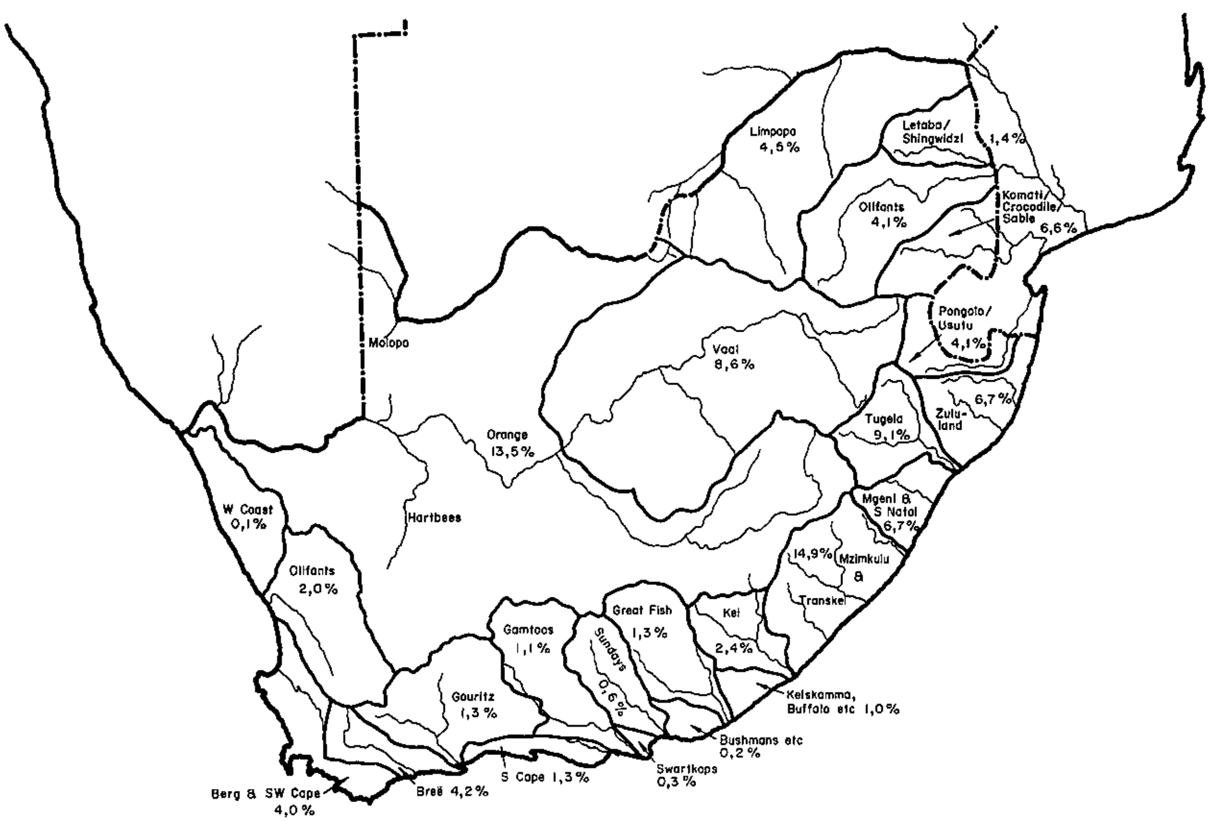

Figure 3. Principal drainage systems in South Africa and their contribution to total mean annual runoff.

Because of the erratic flow of most of South Africa's rivers, dams have had to be built to stabilize the flows and create an assured supply of water. Impoundments are therefore an important ecosystem type in most drainage systems, as will be seen in a later section, and have a marked effect on riverine ecosystems.

Table 1. Comparison of runoff and average annual rainfall for the Breë and Hartbees Rivers.

River	Average annual rainfall	Runoff (percent of rainfall)	Percent of rainfall utilizable from dam of capacity equal to mean annual runoff
Breë	602 mm	25 percent	16 percent
Hartbees	144 mm	0,5 percent	0,1 percent

The outstanding example of deficient rainfall is the Molopo River. As far as can be ascertained, despite its tremendous catchment (equivalent to nearly 21 percent of South Africa), the flow in the Molopo has not reached the Orange River during the past 100 years.

One of the important factors characterizing and influencing a great number of South African inland water ecosystems is fluvial sediment. Most South African rivers carry considerable loads of sediment consisting mainly of particles smaller than 0,2 mm in size. When exposed to weathering, the shales and mudstones of the Beaufort and Molteno series of the Karoo system are particularly susceptible to erosion. Spectacular examples of advanced sheet and donga erosion in these formations are to be found, notably in the north-eastern Cape Province. It has been estimated that during the period 1930 to 1970 the total average sediment loads in the catchment of the Orange River decreased by more than 50 percent, due perhaps to a decrease in the amount of easily erodable material in the catchment and the effects of soil conservation.

It has been estimated that somewhere between 100 and 150 million tons of sediment are transported annually by South African rivers, some 40 million tons of which are transported by the Orange River. Estimated annual sediment production rates (see Figure 4) vary from less than 10 to more than 1 000 t km^{-2} for different catchments.

By far the greatest proportion of the sediment loads of rivers are transported during floods, but the relation between sediment load and flow is by no means simple and depends to a large extent on the immediate past history. A small flood following a long period of drought can for instance transport a far larger sediment load than a larger flood following a period of rains. Concentrations of suspended material can vary at one site from as low as 0,001 in some cases to as high as perhaps 5 percent by mass. Average sediment concentration figures are often difficult to obtain and must be interpreted with care as it must be borne in mind that 98 percent of the annual sediment load of a river can be transported in a single day. If this is missed, the average becomes meaningless.

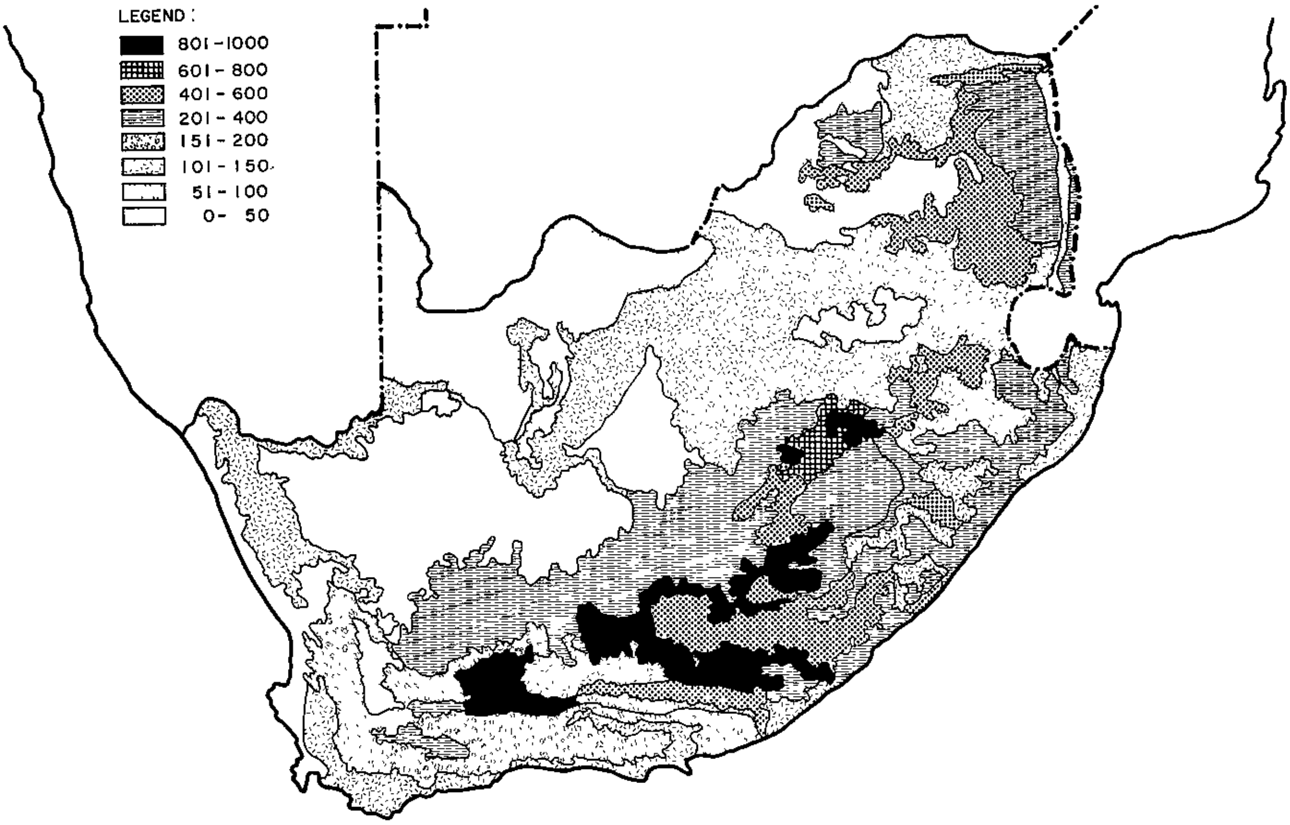

Figure 4. Distribution of average annual sediment production (t km^{-2}) in South Africa.

Classification of rivers

The environmental (or hydroclimatic) factors which primarily determine the structure and productivity of riverine ecosystems include the amount of fine sand and sediment in the river bed, the water flow velocity, the physical nature of the substratum, temperature fluctuations, turbidity, the dissolved salts and nutrients.

In rivers like the Berg and Tugela, several dramatic changes in these factors take place along the length of the river from source to mouth. Many rivers arise at high altitude in waterlogged areas termed sponges. Mountain catchment streams are typically steep and fast-flowing with clear water, low in dissolved salts and nutrients. Further downstream, the slope generally decreases and there are usually more and more areas of deposition and fewer and fewer stony runs. In other rivers, such as the Vaal and several rivers in southern Natal, this zonation is less well marked. Depending mainly on topography, rivers to a greater or lesser extent exhibit a zonation of the type shown in simplified form in Table 2.

Most minor tributaries of these rivers arise in the fourth zone at middle and low altitudes. A great many of these are non-perennial and are

Table 2. Zonation in South African rivers.

Zone	Description	Temperature	Water flow	Turbidity	Biota	Environmental disturbance
1. Mountain source and cliff waterfall	Source often with sponge (high altitude mire) vegetation on humic turf, sometimes with rocky waterfalls over which the stream descends a steep escarpment.	Summer mean well below 20°C	Fast to torrential, turbulent and always oxygenated	Negligible even during storms	Many species only able to survive cool, flowing, oxygenated water, some specially adapted to torrential flow	Rare
2. Mountain stream	Starting with mountain torrents, small waterfalls and rapids and little true emergent vegetation. Descending to foothills where the stream bed has a steep gradient, with occasional pools, the bottom consists of rock, pebbles and coarse sand and there are patches of marginal Cyperaceae and grasses. Deposition negligible and stone and vegetation surfaces clean.	Summer mean around 20°C	Fast to torrential, turbulent and always oxygenated	Negligible even during storms	As above, also species living between stones and others intolerant of sediment	Where mining and other disturbance cause sediment deposition, the characteristic fauna is quickly eliminated
3. Foothill sandbed	In which the flow velocity is further reduced as the gradient decreases and in which stony runs alternate with sand or sediment and marginal riverine vegetation.	Summer mean well above 20°C	Generally slow, but fast in rapids and during floods	Extremely variable, turbid at least during floods	Most species with with fairly wide temperature tolerances. Many dependent on but tolerant of sediment and low dissolved oxygen	Organic and toxic pollution, sedimentation, water extraction, canalization, aquatic weeds and so forth
4. Low and midland stream and river	Characterized by reduced gradient of the river bed with zones of deposition alternating with stony runs in the low foothills and where the river passes over rock outcrops. Erosion often occurs during flooding. In exceptional cases, like the Pongolo, with a well developed floodplain.	Summer mean well above 20°C	Generally slow	As above, the water often turbid, especially during floods	As above but fewer flow-dependent species. Many standing water species	As above
5. Estuary	See the chapter on estuaries.	Summer mean well above 20°C	Generally very slow		Species tolerant of salinity fluctuations	Sedimentation, pollution and interference with tidal exhange

reduced in the dry season as a general rule to a series of disconnected pools. Where a stream is able to spread, marshy areas are formed which are waterlogged in the wet season and dry in the dry season. These are termed vleis.

A simple classification of South African rivers is shown in Table 3, based on topography, the zonation exhibited, geological effects on water chemistry, as well as the biota found.

Utilization and management problems

Hydrobiological surveys of the Berg, Tugela, Crocodile (Limpopo system), Vaal, Mgeni and other Natal and southern Cape rivers have been carried out by the NIWR. These have produced a reasonable understanding of the factors influencing the distribution and abundance of riverine flora and fauna, the levels of organic pollution found in different rivers and the effects of pollution on the biota. An index of water quality based on invertebrates inhabiting rapids has been developed and successfully applied by various user agencies.

As will be shown elsewhere in this document, some work has also been done on the biology of both indigenous fish and exotics such as trout and on some of the rare endemics considered to be threatened. Efforts have been made to identify present and possible future threats to rivers and their species and habitats. Recommendations have been made for the conservation of representative riverine habitats in different parts of the country.

Very detailed snail distribution surveys have been carried out largely by the Department of Health and Potchefstroom University for CHE. Some work has also been done on the ecology and ecophysiology of problem snails in order to explain their distribution and predict situations in which habitats for them may be created.

Work has been done and has been restarted on the biology of the larvae of Simuliidae causing problems along fast-flowing stretches of the Vaal and Orange Rivers through the cattle-biting habits of the adult females of certain species. The unnatural flow regime in the river created by impoundment is an important factor contributing to outbreaks of Simuliidae.

Future needs

Details will be given in a later chapter of new research being proposed on the transport and loadings of nutrients and persistent pollutants carried by South African rivers, the dynamics of their uptake and re-release by biotic and abiotic components and the self-purification capacity of rivers.

It is notable that South African limnologists were once among the world leaders in river hydrobiology, but that this work came to a virtual standstill once the pollution survey and research programmes were completed. The earlier work has mostly been synthesized and it might be extremely valuable at this stage to review it in the light of modern trends, new insights on mechanisms of self-purification of rivers and subsequent developments affecting the levels of pollution of the river systems studied earlier.

Table 3. A classification of South African rivers.

Type	Region	Zonation	Geological features	Water quality	Biotic features	Examples
Cape clear acid rivers	SW Cape	(1), (2), (3), (4), and (5) all generally well developed	Table Mountain sandstones (TMS) above, Malmesbury shales etc downstream	Clear, acid with low dissolved solids on TMS, dissolved solids > 400 mg/ℓ^{-1} downstream	Low productivity but diverse fauna with many endemic groups	Olifants (Cape) Berg Breë
South Cape acid rivers	S Cape	(1), (2), and short (5)	Table Mountain sandstones (TMS) mostly	Brown, humic stained, very acid with low dissolved and suspended solids	Low productivity, specialized fauna with endemic species, moss *Wardia hygrometrica* in torrents	Kaaimans Groot Storms
Southern Karoo rivers	S and E Cape	(3), (4) and (5)	Karoo series	Usually very turbid, medium to very high dissolved solids	Unknown	Gouritz Gamtoos Sundays Great Fish
Transkei and Natal degrading rivers	Transkei Natal	(1) in some, (2), (3) and (5)	Largest rivers arise on Drakensberg Basalt rim, otherwise Karoo series	Clear mountain streams and generally very turbid rivers, dissolved solids variable	Mountain, intermediate altitude and coastal belt faunas distinguishable	Buffalo Great Kei Mzimvubu Mzimkulu Mkomazi Mgeni Tugela
Escarpment-floodplain rivers	E and N Transvaal N Zululand	(3), (4) and (5)	Karoo series (Natal) and a variety of systems in Transvaal	Clear to turbid, generally low dissolved solids	Poorly known, except Crocodile River and Pongolo floodplain	Crocodile-Limpopo Letaba-Shingwidzi Olifants (Tvl) Komati-Crocodile-Sabie Mfolosi Mkuze Pongolo-Usutu Komati
Vaal (catchment of the central plateau)	S and W Transvaal N and W Orange Free State	(1) and (2) in Elands tributary, (3), (4)	Witwatersrand, Transvaal, Ventersdorp and Karoo series	Mostly turbid	Many tributaries blanketed by deposited fine sediments, the most important factor affecting the biota	Vaal
Orange	Lesotho, E and S Orange Free State N Cape	(1), (2), (3), (4) and (5)	Main river arises on Basalt, the catchment otherwise Karoo series	Clear with low dissolved solids on Basalt, very turbid elsewhere (especially NE Cape tributaries)	Poorly known, deposited sediments an important factor	Orange

VLEIS AND FLOODPLAINS

The term vlei is applied in South Africa to a wide range of situations. These include seasonally or perennially wet areas within river drainage systems which are dominated by emergent hydrophytes, as well as coastal and estuarine lakes, many of which have extensive areas of reeds and sedges.

River source sponges

Many streams in the wetter parts of South Africa arise in seepage areas, for instance on mountain slopes. These are seasonally or perennially waterlogged, with a vegetation dominated by sedges and other hygrophilous angiosperms and perhaps mosses and are here termed sponges. Many sponges are mires (waterlogged areas on soil with an organic content greater than 50 percent) and some contain peat (organic soil composed of material recognizable as plant remains). However, this peat is composed generally of higher plants rather than of mosses and peat of any age (a thousand years or more) is quite rare.

The best developed and most studied sponges in southern Africa are those found in the Lesotho, Transkei and Natal Drakensberg at altitudes between 1 800 m and 3 500 m, where freezing can occur even in summer. These include perennially wet sponges on the slopes and mires with accumulated peat (described in the literature as bogs) in the mountain valleys. They have a low (10 cm to 1 m high) vegetation dominated by sedges and other angiosperms, and some mosses. The low vegetation in the valleys forms walls which dam up the perennial seepage water in a series of open pools in which hydrophytes and algae may be found. Small mounds of angiosperms and a few mosses are also found in the valleys. Peat up to possibly 10 000 years in age and perhaps 7 m in depth has been found in the valley mires although the water is not particularly acid (pH 6 or above).

Aspect is extremely important in these mountains in determining the incidence of frost and ice. This in turn limits the distribution of many plant species. At altitudes below about 2 000 m, reeds and taller sedges start appearing and sponges on seepage areas intergrade with marshes developed around streams.

Similar but generally smaller sponges with approximately neutral water are found at almost any altitude on slopes in the summer rainfall areas, for instance the eastern Transvaal Drakensberg, Natal, Transkei and eastern Cape. The vegetation is composed of sedges, grasses and other angiosperms. A good example is the source of the Broederstroom (Great Letaba system) in the Woodbush Forest Reserve in the eastern Transvaal.

Sponges with acid (pH 3,5 - 6) and often very brown humic stained water are also found on slopes in the perennial rainfall area of the southern Cape and winter rainfall area of the south-western Cape, also at almost any altitude. The vegetation is mostly Restionaceae and Bruniaceae (both macchia/fynbos vegetation groups) and a variety of other angiosperms. Both the winter rainfall sponges and summer rainfall sponges at moderate altitudes have some immature peat, but deep peat deposits are rare.

Extensive damage to sponges has taken place in the important river source areas of the Drakensberg. As a result of overgrazing and erosion, many headwater streams that were once clear now turn into muddy torrents in summer.

Marshes and swamps

Throughout South Africa, even in many of the drier parts, there are in most river systems flat stretches overgrown with reeds and other marshy vegetation which are inundated and become waterlogged in the wet season and which are locally termed vleis (Figure 5). There is reason to believe that vleis were once far more widespread than they are now, but that many have been invaded, drained and eroded away, often forming large dongas in the process, as a result of farming and other practices during the past 150 years. There are also reasons to suspect that a natural resource of some considerable value may have been damaged and may still be being lost in the process.

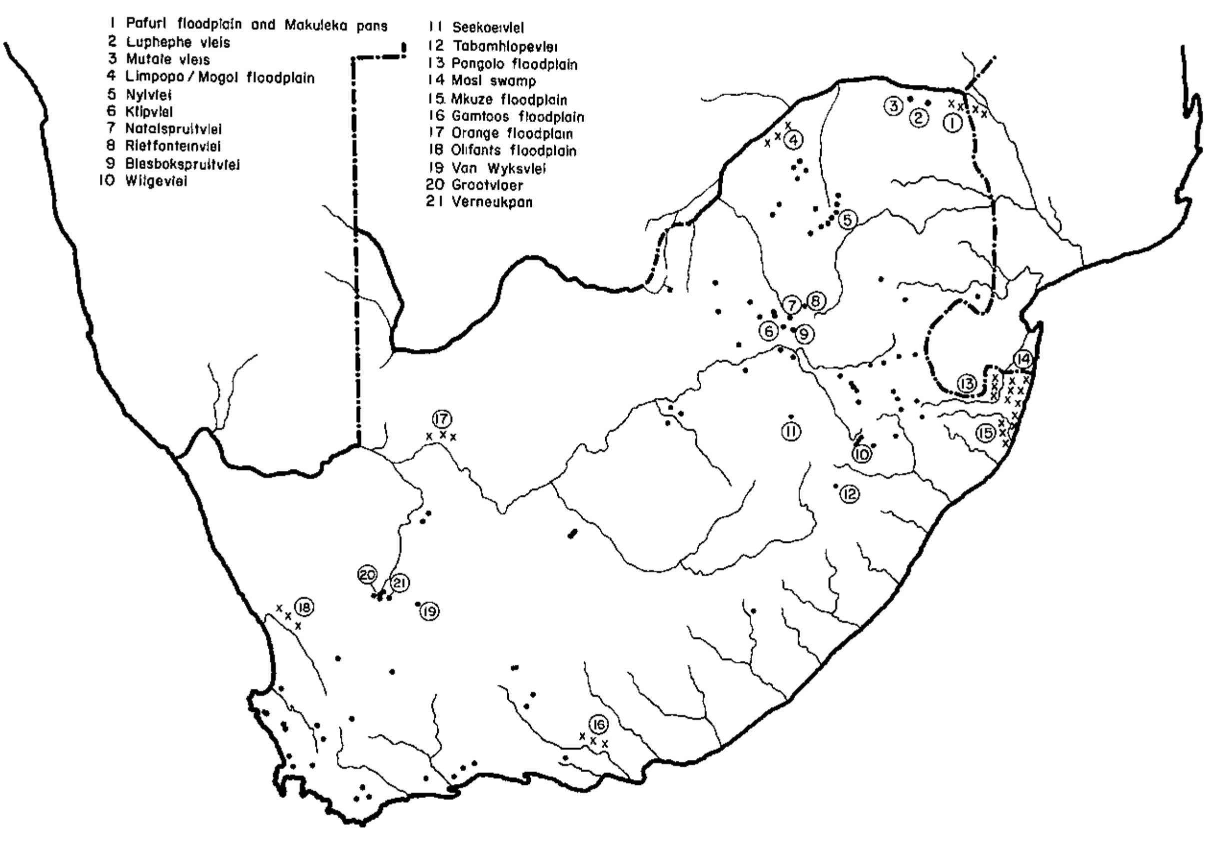

Figure 5. Major vleis (dots) and floodplains (crosses) in South Africa.

Vleis can accumulate some immature peat, but most are found on soil with a high clay, sand or gravel content. Some vlei ecosystems can be described as marshes (the water level not much above soil level in the wet season, with emergent plants mostly less than 2 m in height) and others can be described as swamps (the water level well above soil level in the wet season, generally more perennial than are marshes and with a generally less diverse vegetation with sedges, reeds or trees, many plants being 3 m or more in height). No classification of vlei types has been undertaken, but the following may very tentatively be distinguished :

- Sedge marshes dominated by sedges, hygrophilous grasses and similar plants perhaps 1 m in height, which are perennially waterlogged and may have some accumulated peat. These intergrade with river source sponges on mountain slopes and with reedbed marshes at lower altitudes.

- Restio marshes which are the equivalents of the first type in the southern and south-western Cape and which are acid and dominated by Restionaceae (characteristic of macchia/fynbos vegetation) and sedges.

- Many vleis in the interior of the country can be described as reedbed marshes, which can be dominated by *Phragmites* in situations where the water level is somewhat below the soil surface in the dry season (for instance on the fringes of non-perennial streams) and can have a more diverse vegetation with stands of *Typha, Scirpus, Cyperus* and other taller sedges (1-2 m in height) in situations where the water level remains close to the soil surface in the dry season. Reedbed marshes intergrade with sedge marshes at higher altitudes and with reedswamps in wetter situations.

- Reedswamps are found in perennial standing water on floodplains and fringe many coastal and estuarine lakes. *Phragmites australis* is the reed most characteristic of these swamps and can tolerate exposure to salinities close to seawater, particularly if the seepage water is less saline. *Typha, Scirpus, Cyperus* and other taller sedges (2-3 m in height) also occur but are less tolerant of saline water. Reedswamps intergrade with reedbed marshes where there is no perennial standing water and with salt marsh plant communities at the upper ends of estuaries.

- Papyrus swamps dominated by *Cyperus papyrus* (2-3 m high) are found in perennial and somewhat deeper freshwater situations in northern Natal (Mfolosi, Mkuze, Richards Bay).

- Cape seasonal wetlands are areas on the Cape Flats and elsewhere along the south-western Cape coast which become waterlogged in winter, forming seasonal pools.

- Swamp forests are found on freshwater streams along the Natal coast and are dominated by *Ficus trichopoda* and other trees. A climbing fern *Stenochlaena tenuifolia* is another characteristic feature. Most of these forests have been destroyed. The best remaining example is south of the Kosi lakes and includes patches of *Raphia* palms. The most southerly example is at Langler Park near Port Edward.

- Salt marshes are found on tidal sand and mud flats in most South African estuaries. The vegetation consists chiefly of low salt-tolerant grasses, sedges and creeping succulent angiosperms.

- Mangrove swamps are dominated by mangrove trees 3-4 m high. Mangroves were previously found in almost all estuaries with tidal exchange along the east coast. The most southerly example is in the Qolora estuary in the Transkei. Most have been destroyed.

Reedswamps fringing coastal lakes can accumulate peaty material and encroach into the open water, as may be seen around Groenvlei and at Ruigtevlei (connected to Swartvlei). These situations resemble fens (perennially wet areas in which peat accumulates under neutral or alkaline conditions).

Vlei ecosystems have been little researched in South Africa. Water balance studies have been carried out by the University of the Witwatersrand Hydrological Research Unit (HRU) in the Mkuze River above Lake St Lucia and in vleis in the Witwatersrand area. There is, however, great uncertainty about the effects of vleis on total evaporative and evapotranspirative losses and examples are available in the literature showing both increases (for instance from floating or low vegetation and from burnt vleis) and decreases (for instance under tall reeds) in total losses. Infiltration losses and gains are also difficult to estimate. The vleis south of the Witwatersrand, for instance, pass over dolomite pockets which at different times can account for very significant losses and gains.

Vleis can have both deleterious and advantageous effects on flooding. Generally the flood peak is decreased downstream but can be increased upstream. On the other hand the flood will be attenuated downstream, leading to longer periods of inundation. Where urban and other development has been permitted to encroach on to floodplains, damage to vleis can take place and serious flooding and sediment movement problems can result.

Vleis are also created artificially by the Department of Agricultural Technical Services to control erosion and provide sources of perennial clean water and a measure of flood control. They can also provide vegetation which could be used for grazing or as a source of fibre and act as a wildlife refuge. On the other hand, vleis and the areas around them can provide breeding places for insects, including locusts and mosquitoes, and snail intermediate hosts of animal parasites and can obstruct the movement of stock.

Catchments vary greatly in their sediment production rates and experience has shown that it is important for the success of artificial vleis to achieve the appropriate sediment gradient. In most areas, the greatest threat to artificially established vleis is the excessive sediment loads being produced from the catchment and a very great need exists for catchment soil erosion control. It is not desirable in artificial vleis to allow too much sediment to deposit or even to allow trees or an uneven surface to develop.

In South Africa preliminary findings on Olifantsvlei south of Johannesburg have shown clearly that particulate organic and inorganic material was retained in reedbeds while allowing clear water to pass through. In addition, there was virtually complete removal of pathogenic bacteria of faecal or possible faecal origin. Nothing is known about the removal of viruses, however, or about the possible decrease or increase of mineral compounds.

Indications, for instance in the catchment of Rietvlei Dam, are that N and P compounds are removed from river systems by vleis. If this is so, vleis may offer one of the few possible means of controlling diffuse sources of nutrients which enter river systems and which can cause eutrophication problems in impoundments downstream.

Floodplains

A few South African rivers have short floodplains developed in their middle or lower reaches, where the river has attained grade and overflows its banks during floods and inundates areas on either side. The following types may be distinguished :

- Karoo salt flats (the largest examples are Van Wyksvlei, Grootvloer and Verneukpan) are connected to drainage systems, into which they occasionally discharge water. At other times, however, these flats are indistinguishable from the closed drainage salt pans described in the next section.

- Floodplain vleis comprise a riverine area (either a reedbed marsh or a reedswamp) and a grassy floodplain of varying width on either side. The riverine area is normally seasonally inundated and the grassy floodplain is only inundated by occasional floods. Good examples of floodplain vleis include the Nylvlei in the northern Transvaal, the Blesbokspruitvlei and other Witwatersrand vleis, Seekoeivlei near Memel in the Orange Free State and the Tabamhlope vlei near Estcourt in Natal.

- Storage floodplains also comprise a riverine area and an adjacent floodplain inundated by flooding, but retain standing water on the floodplain for long periods between floods in small lakes and smaller water bodies termed pans. The Pongolo, Mfolosi and lower Limpopo are good examples of storage floodplains.

In some storage floodplains, the river meanders on the alluvial floodplain and there may be small oxbow floodplain lakes (a loop of the river which has been cut off as a result of a change in the river course) which are filled only during floods. The floodplain at the junction of the Limpopo and Mogol Rivers includes an oxbow floodplain pan Tonnelgat. Floodplains with a river meandering on a grassy floodplain with small oxbow lakes are found in Lesotho on the Tsoelikane River in the Sehlabathebe National Park and in the Malibamatso River system near Oxbow. Both of these floodplains are at about 2 450 m altitude.

In other storage floodplains, the river is confined by a levee on either side and is flanked by floodplain pans. These can have been formed by the levee damming tributaries, as is the case along the lower Mfolosi, in which the lake Mfutululu and several pans have been formed in this way. They can also have been formed by changes in water course, as in the case of the Pongolo floodplain, the Limpopo River floodplain and pans in the northern Transvaal.

The best known storage floodplain in South Africa is the Pongolo floodplain, which is 70 km long, at an altitude between 25 and 45 m above sea level. After inundation, an area of 5 000 ha is left under water in the 35 or so pans flanking the river. In a normal dry season, the area of water falls to about 3 000 ha. Its largest pan is Nyamiti in the Ndumu

Game Reserve, which is about 4 km long, covers 140 ha and has maximum and mean depths of about 5 m and 2 m respectively. The smallest pans are only a few metres across. The Pongolo River is broad and shallow as it enters the floodplain and becomes narrow and deeply entrenched further downstream, where it is unstable and cuts a new bed from time to time through the rich sandy alluvium forming the banks. Vegetation consists of *Potamogeton crispus* and other aquatics, marginal *Phragmites*, *Cynodon* lawns which are exposed when the water recedes, and riverine forest.

The Pongolo floodplain system has been studied in some detail, principally by the University of Natal, in relation to the impact of the upstream Pongolapoort Dam and the planned development of an irrigation scheme on the adjacent Makatini Flats. Research carried out on the Pongolo floodplain has demonstrated a strong interdependence between periodic flooding and drying out and a number of key ecosystem processes. Primary production, decomposition by micro-organisms, as well as fish migrations, reproduction and growth are all very markedly affected by flooding. The pans serve as breeding and nursery grounds for many of the principal fish species, whose life histories are also greatly influenced by flooding. As the water recedes, the productive *Cynodon* lawns become available for ungulate grazers on the floodplain. When the pans fill again, the fertilized shallows are important sites for both plant production and fish spawning and feeding.

The construction of the Pongolapoort Dam has already had a clear effect on the floodplain system, for instance by attenuating floods and drowning *Acacia xanthophloea* trees by prolonged inundation. The research is aimed at predicting the impact of a changed flow regime and saline and other pollution from the irrigation scheme on the floodplain ecosystems and at finding ways of combining irrigation and other development on the floodplain with the conservation and continued and improved utilization of its natural resources, for instance for fishing. The biological research on the Pongolo floodplain is at an advanced stage and the future need is to complete the hydrological, socio-economic and fisheries aspects.

Little is known of other floodplain systems. There are floodplains on the Mozambique plain and on the Mkuze and Mfolosi Rivers which have been studied hydrologically, for instance by the University of the Witwatersrand HRU, in relation to the freshwater inputs to St Lucia. Other rivers in South Africa with well developed floodplains include the Olifants (western Cape), Orange, Sundays and Gamtoos Rivers, all valuable irrigation areas. Highveld floodplains include those in the catchments of the Vaal and Buffalo (Natal).

Future needs

Vleis appear from several points of view to be potentially highly beneficial components of South African drainage systems and yet at the same time a source of considerable practical problems. Surprisingly, however, totally insufficient information is available on them to take even simple decisions on their conservation, utilization, management or removal. Efforts to gain this information should enjoy high priority in the IWE programme, both with their possible rôle in eutrophication control and value as habitats for waterfowl and threatened species in mind.

ENDORHEIC PANS AND OTHER LAKES OF THE INTERIOR

Characteristics and classification of pans

Some of the drier parts of South Africa, as well as a small area in the wetter south-eastern Transvaal where the mean annual rainfall is around 800 mm, have numbers of oval depressions and water bodies termed pans scattered about the landscapes. These have no outlet (and are hence termed endorheic, having a closed drainage) and are either semi-permanently or periodically filled with water. Some of the larger of these pans (Lakes Chrissie and Banagher, Barberspan) are large enough and permanent enough to be called lakes.

The origin of these depressions is something of a mystery and several processes might have been involved. However, it is thought that a combination of animal and wind erosion during periods when the pans were dry was at least an important contributory factor in their maintenance, especially in former times when large herds of antelopes were to be found in these areas.

Pans are characteristic of the Kalahari, the western and north-central Orange Free State and western and south-eastern Transvaal, forming the so-called pan belt of southern Africa. Several characteristic types can be distinguished :

- Salt pans are dry for most of the time but may contain perennial pools filled by springs. Their soils are highly saline and devoid of any higher vegetation. The fauna includes typical temporary water forms like phyllopod crustaceans, the eggs of which need to dry out. Salt pans are found especially in the karoo, kalahari and western Orange Free State and Transvaal and intergrade into the next type.

- Temporary pans are shallow and are also dry for long periods (again perhaps with perennial pools). Their soils are alkaline and moderately saline. The higher vegetation is restricted to a few salt-tolerant grasses. The fauna includes phyllopods. Temporary pans intergrade with salt pans, grass pans (next type) and perhaps semi-permanent pans (last in this list). Temporary pans are the most common pan type and are found throughout the northern Cape, the western Orange Free State and the Transvaal. They have been variously described as brackish pans, alkaline pans, mud pans and vegetationless pans and could probably be subdivided into several subtypes.

- Grass pans are seasonal and dry up in winter (except for perennial pools). They are covered by a thick growth of hygrophilous grasses and other low terrestrial vegetation (some salt-tolerant). This is usually inundated in summer and a diverse flora of submerged hydrophytes and filamentous and macrophytic algae may develop. Phyllopods may be present. The water is rich in nutrients, usually fresh in summer and slightly brackish in winter. Grass pans are found in the southern and eastern Transvaal (mean annual rainfall 650-800 mm) and intergrade with both temporary pans and with sedge pans (the next type).

- Sedge pans are also seasonal, but do not dry out sufficiently in the centre for terrestrial vegetation to establish. They have a thick growth of marsh vegetation about 1 m high, mainly Cyperaceae, around their edges and have no emergent vegetation in the middle. Phyllopods may be present in some. The water appears to be rich in nutrients, fresh in summer and slightly brackish in winter. Sedge pans are apparently only found in the Lake Chrissie area.

- Reed pans are temporary or semi-permanent pans with a dense stand of *Phragmites* reedswamp in the middle and open water never more than a narrow peripheral ring. The water is clear and can apparently be fresh to quite brackish and the sediments are rich in organic matter. A rich hydrophyte and filamentous and macrophytic algal population can develop in summer in the peripheral ring of water.

- Semi-permanent pans and lakes are generally deeper than the other types. Some may be fresh, at times at least, but most are somewhat brackish. Some may develop fairly permanent *Potamogeton* and other hydrophyte and algal growths while others apparently do not. Most have a few sparse grasses around the margins. Examples include Barberspan in the western Transvaal, Lake Chrissie and several neighbouring pans. Semi-permanent pans intergrade with shallow mud pans. Eilandsmeer near Lake Chrissie may have some of the features of a sedge pan.

It is not known what factors are responsible for establishing and maintaining the characteristic features of emergent hydrophyte distribution in different pan types. Possible reasons for the absence of emergent plants around the edges of mud pans, reed pans and semi-permanent pans could conceivably include salinity in the peripheral muds when they dry out and trampling by large animals. It is perhaps significant to note that where marginal vegetation is destroyed, as has happened with at least two sedge pans in the Lake Chrissie area, it does not readily re-establish.

A great many pans are fed from springs and their water level fluctuates with the water table. Others, on the other hand, may be fairly independent of the water level. The processes involved are presumably important in influencing changing salt concentrations in the water and sediments and must greatly affect the composition of the vegetation.

Little is known of the sediments found in pans. Some, like the grass and sedge pans are rich in organic matter from the decomposition of plant material and the depth of the sediments varies greatly from pan to pan. It is thought that the muds in pans lacking rooted vegetation are generally much less deep (a few centimetres) than the sediments in grass, sedge and reed pans.

Wind plays an extremely important rôle in mixing the water in shallow pans and resuspending the sediments. The same pan can have clear water after a windless period and then rapidly become very turbid and only reed pans are apparently always clear. Most of the algae found in the water column are benthic species in suspension and true planktonic species are rare.

The characteristics of a few representative pans (see Figure 6) are summarized in Table 4. A great many of these have been damaged by agricultural development. Salt mining has taken place in salt pans in the western Transvaal and Orange Free State. Several pans near Kimberley, near Allanridge and Welkom in the Orange Free State and in the East Rand areas have been severely polluted or partially filled by refuse dumping, while others are used for boating and fishing. It seems a great pity that more have not been offered some form of protection and conserved in their natural state, especially in view of their potential value as wildlife refuges.

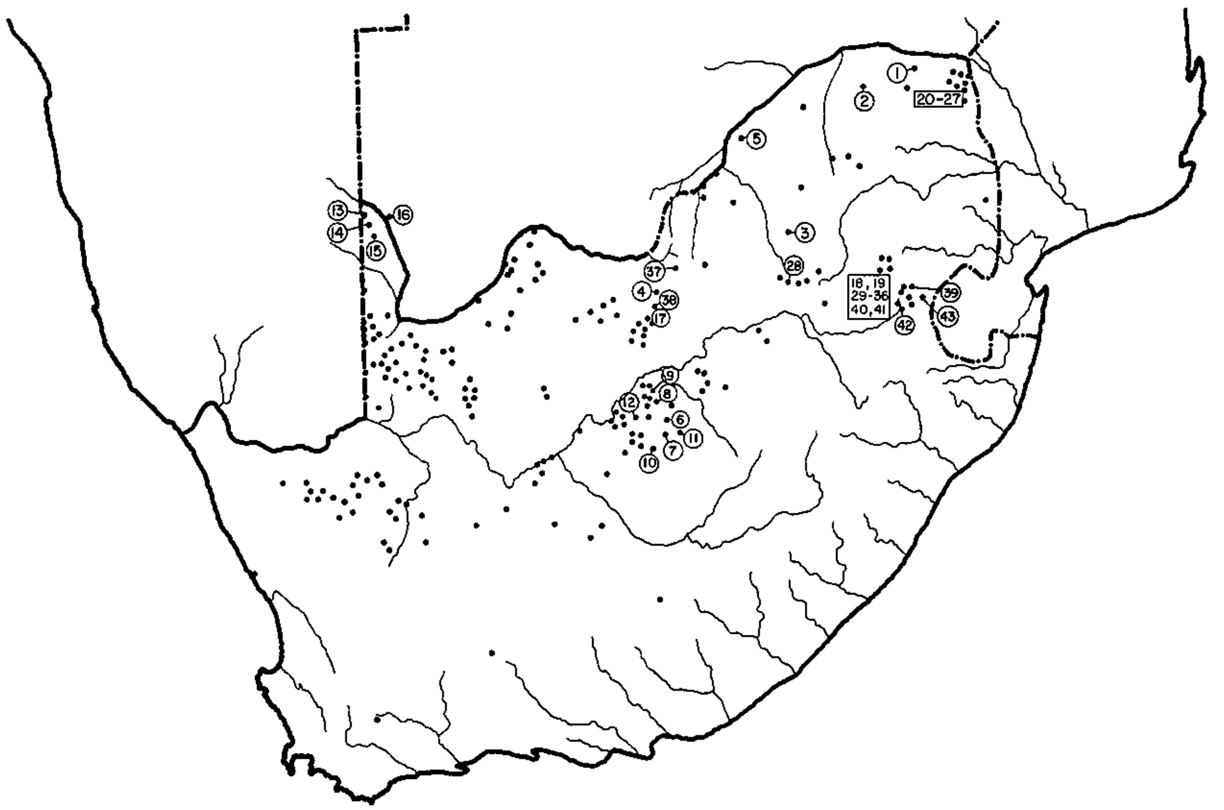

Figure 6. Endorheic pans and lakes in the interior of South Africa (refer to Table 4 for names).

Barberspan

Barberspan is possibly the best known of the lakes of the interior and is a semi-permanent body of water some 5 km by 4 km in size, with a maximum depth of about 7,5 m. Barberspan dries out once every twenty years or so, only a few pools remaining. Possibly formed by subsistence or animal and wind erosion, it previously dried out more regularly. Earlier in this century, the channel connecting the lake to the Harts River was widened and the lake is now filled mostly from this source.

Table 4. Characteristics of lakes and representative endorheic pan types in the interior of South Africa.

Pan/lake	District	Surface area ha	Type	Altitude m	Significance for waterbirds	Limnological characteristics	Exploitation
1. Fundudzi $22^{o}51'S$, $30^{o}19'E$	Sibasa (Venda)	∿ 500	rockfall lake	∿ 1 000			
2. Soutpan $22^{o}58'S$, $29^{o}20'E$	Louis Trichardt (Tvl)	∿ 176	salt pan	783			extensive salt works
3. Pretoria Salt Pan $25^{o}24'S$, $28^{o}05'E$	Pretoria	∿ 20	salt pan	1 050		water very salty	salt extracted until 1939
4. Salt pan on the farm Klein Zoutpan $26^{o}22'S$, $25^{o}36'E$	Delareyville (Tvl)	∿ 15	salt pan	1 310	flamingoes	transient water only	salt extracted until 1939
5. Salt pan on the farm Zoutpan $23^{o}54'S$, $27^{o}22'E$	Waterberg (Tvl)	∿ 28	salt pan	1 006	flamingoes and other waterfowl stop over	transient water only	salt extraction in the past
6. Klippan $28^{o}37'S$, $25^{o}51'E$	Boshof (OFS)	∿ 40	salt pan	∿ 1 000		temporary water with semi-permanent pool	
7. Salt pan on the farm Goede Hoop $28^{o}43'S$, $25^{o}50'E$	Boshof (OFS)	∿ 30	salt pan	∿ 1 000		temporary water only	
8. Salt pan on the farm Colenso $28^{o}25'S$, $25^{o}44'E$	Boshof (OFS)	∿ 50	salt pan	∿ 1 000		temporary water only	
9. Witpan $28^{o}22'S$, $25^{o}42'E$	Boshof (OFS)	∿ 40	salt pan	∿ 1 000		temporary water only	
10. Salt pan on the farm Goedgedacht $29^{o}01'S$, $25^{o}48'E$	Bloemfontein	∿ 40	salt pan	∿ 1 100		temporary water with semi-permanent pool	
11. Salt pan on the farm Sunnyside $28^{o}39'S$, $26^{o}09'E$	Brandfort (OFS)	∿ 70	salt pan	∿ 1 200	flamingoes	temporary water with semi-permanent pool	

Table 4 (continued).

Pan/lake	District	Surface area ha	Type	Altitude m	Significance for waterbirds	Limnological characteristics	Exploitation
12. Soutpan (on the farms Prinspan and Brakfontein) 28°30'S, 25°17'E	Boshof (OFS)	~ 80	salt pan	~ 1 200		temporary water with spring	
Pans in the Kalahari Gemsbok National Park 13. Nelsiespan 25°10'S, 20°10'E 14. Haaspan 25°17'S, 20°16'E 15. Seven Pans 25°29'S, 20°20'E 16. Kwang Pan 25°17'S, 20°32'E	Kalahari	various	salt and temporary pans	various			
17. Temporary pan on the farm Eleazar 26°39'S, 26°50'E	Potchefstroom	~ 66	temporary pan	1 412		shallow, temporary pan, phyllopods	earth works
18. Neethlingpan (temporary pan on the farm Grasdal) 26°18'S, 30°23'E	Ermelo (Tvl)	~ 25	temporary pan	1 676		shallow, temporary pan	
19. Van Aardt kaalpan (temporary pan on the farm Goedehoop) 26°19'S, 30°17'E	Ermelo (Tvl)	~ 12	temporary pan	1 676		shallow, temporary pan	
Pans in the Kruger National Park 20. Ximuweni 22°37'S, 31°22'E 21. Klawer 22°38'S, 31°17'E 22. Mathlaguza 22°38'S, 31°22'E 23. Mintomeni 22°37'S, 31°18'E 24. Masokosa 22°37'S, 31°16'E	Kruger National Park	various	temporary pans	various		refuges for *Nothobranchius* spp	none

Table 4 (continued).

Pan/lake	District	Surface area ha	Type	Altitude m	Significance for waterbirds	Limnological characteristics	Exploitation
25. Nwambiya 22°41'S, 31°21'E 26. Magwitsi 22°42'S, 31°22'E 27. Xirhamberhombe Pans 22°43'E, 31°20'E							
28. Grass pan on the farm Rietfontein 26°05'S, 28°16'E	Kempton Park (Tvl)	∿ 15	grass pan	1 700		irregularly seasonal water, phyllopods	water pumped out for irrigation
29. Grass pan on the farm Grasdal 26°18'S, 30°22'E	Ermelo (Tvl)	∿ 17	grass pan	1 668		temporary water with semi-permanent pool	
30. Van Aardt graspan (grass pan on the farm Goedehoop) 26°20'S, 30°17'E	Ermelo (Tvl)	∿ 5	grass pan	1 676			
31. West Tweelingpan (sedge pan on the farm Weltevreden) 26°22'S, 30°15'E	Ermelo (Tvl)	∿ 36	sedge pan	1 700		water apparently fresh	greatly damaged, only patches of sedges left
32. Sedge pan on the farm Knockdhu 29°19'S, 30°17'E	Ermelo (Tvl)	∿ 10	sedge pan	1 690		apparently slightly brackish	greatly damaged, only patches of sedges left
33. Sedge pan on the farm Coalbank 26°26'S, 30°16'E	Ermelo (Tvl)	∿ 40	sedge pan	1 701		rich sediments, zoo-plankton	
34. Small reed pan on the farm Tevreden 26°13'S, 30°13'E	Carolina (Tvl)	∿ 3	reed pan	2 432	rich avifauna	with semi-permanent ring of water and reed island	
35. Reed pan on the farm Florence 26°16'S, 30°15'E	Ermelo (Tvl)	∿ 25	reed pan	1 707	rich avifauna	with semi-permanent ring of water and reed island	

Table 4 (continued).

Pan/lake	District	Surface area ha	Type	Altitude m	Significance for waterbirds	Limnological characteristics	Exploitation
36. Reed pan on the farms Goederverwachting, Mooiplaats and Gemsbokheuvel 26°17'S, 30°07'E	Ermelo (Tvl)	∿ 73	reed pan	1 770	rich avifauna	with semi-permanent ring of water and reed island	
37. Polfonteinpan 26°03'S, 25°51'E	Lichtenburg (Tvl)	∿ 11	reed pan	1 402		shallow but apparently permanent with spring	reeds removed at times
38. Barberspan 26°35'S, 25°34'E	Delareyville (Tvl)	∿ 2 000	semi-permanent pan	1 348	flamingoes and waterfowl refuge	TDS∿2 $g\ell^{-1}$ turbid, maximum depth 7,6 m, *Potamogeton*, *Barbus holubi* and other fish	
39. Lake Chrissie 26°20'S, 30°13'E	Ermelo (Tvl)	1 046	semi-permanent pan	1 660	flamingoes	maximum depth ∿ 6 m, turbid, springs, inflowing stream, brackish, *Potamogeton*	
40. Semi-permanent pan on the farm Liefgekozen 26°23'S, 30°21'E	Ermelo (Tvl)	∿ 200	semi-permanent pan	1 687		turbid, brackish	
41. Perennial pans on the farm Blaauwater 26°15-16'S, 30°17-18'E	Ermelo (Tvl)	various	semi-permanent pans	1 689 to 1 713		perhaps 6 m deep, turbid, brackish, apparently almost vegetationless	
42. Eilandsmeer 26°20-21'S, 30°18-19'E	Ermelo (Tvl)	∿ 530	semi-permanent pans	1 679		turbid, brackish, apparently almost vegetationless, divided into two	
43. Lake Banagher 26°20'S, 30°18'E	Ermelo (Tvl)	∿ 132	semi-permanent pan	1 660	fairly rich avifauna	shallow, relatively clear, almost no higher plants, algal blooms	

A study of the fish populations and general limnology was carried out about ten years ago by Potchefstroom University for CHE and the Transvaal Provincial Administration. The TPA has a resident ornithologist at the site and this is the most active waterfowl ringing and research station in the country. The water can be clear or turbid, depending on wind conditions, and the vegetation is sparse but includes *Potamogeton* and macrophytic algae.

Lake Chrissie

Lake Chrissie is the largest of the endorheic pans, being about 6 km long, more than 2 km across at its widest point and has a maximum depth of perhaps 6 m. It is a semi-permanent lake and may dry out every ten years or so. The vegetation includes dense *Potamogeton* zones and a diverse desmid algal flora. The fish fauna includes *Barbus anoplus*. Some observations of the zooplankton have been made and a study of the algal and water chemistry has been carried out at the University of Pretoria.

Fundudzi

Fundudzi is a natural lake, about 5 km by 1,2 km in size when full, situated on the northern slopes of the Soutpansberg near Sibasa in Venda, northern Transvaal. It was formed by a landslide across the Mutale River (Limpopo River system), which now re-emerges some 25 km further downstream. The exact age is disputable, perhaps around 500 years.

The subtropical surrounding area was settled by the BaVenda about 200 years ago and few of the original Lemba remain, acting as priests in the sacred rites of their Venda overlords. Folklore holds the lake to be bottomless, since it is fed by two streams but never overflows. Ancestral spirits are said to inhabit the lake, believed to be guarded by a large white crocodile to whom first fruits are, and according to legend young maidens were, sacrificed. Interference, even scientific investigation, is resented to some extent, although some attempts have been made to exploit the fish for food.

Future needs

There is considerable limnological interest in further research into these natural inland standing waters. Needs might also arise to investigate problems of their eutrophication and perhaps toxic pollution, there being no outlet through which persistent pollutants can leave the pans. Particular problems, such as the transmission of parasites and pathogens to wildlife and domestic stock, also require investigation. Efforts should be made to collect information on the physical characteristics and conservation of pans and to assess their importance, for instance as habitats for waterfowl.

IMPOUNDMENTS

Characteristics

Due to the climatological and topographical factors described in the introduction, there are no natural lakes of any size in the interior of South Africa. This lack has been more than made up for, however, by the large number of impoundments which have been constructed, ranging in size from small farm dams to large man-made lakes. There are now about 150 with a full supply capacity of 5×10^6 m^3 or greater and a large number of smaller dams. Their total capacity amounts to some 40 percent of South Africa's total average annual river runoff.

South African impoundments (see Figure 7) can be characterized as shallow water bodies, with high incident solar energy input which are stratified in summer wherever impoundment morphometry and meteorological conditions permit, are usually monomictic (the water column being destratified and mixing taking place in the autumn of each year) and are often subject to sediment-laden inflows. High evaporation rates occur and river inputs are subject to wide variations dependent on geographical location and meteorological conditions. Water retention times consequently also fluctuate considerably. Some characteristics of a number of South African impoundments are summarized in Table 5.

The catchments of impoundments differ greatly in geological structure and hence in the ionic content of their runoff water. Many catchments also contain sources of urban, industrial and agricultural pollution. Impounded water quality consequently varies with location but from the ecosystem standpoint the importance and interest lies in the relation between the characteristics of the catchment and the characteristics of the impoundment which together govern the nature of the ecosystem that develops and the availability and utilization of solar energy and nutrients. For this reason research on impoundments is primarily concerned with biological productivity and the advantages or disadvantages that it confers.

The anticipated doubling of the human population in the next 25 years and the expected increase in urbanization and industrial development will undoubtedly increase the demands made upon these water bodies, both as sources of supply and for recreation and other purposes. At the same time increased water usage and effluent discharge can be expected to increase the amounts of contaminants reaching these impoundments and thus influence the quality of the water and the nature of the aquatic communities that they support.

Present state of knowledge

The first limnological observations of South African impoundments were made by G E Hutchinson, who for instance in 1929 found Hartbeespoort Dam to be oligotrophic. Starting in the late 1950's, studies of the physical limnology, water quality and descriptive biology of several impoundments were undertaken. In 1968 a pre-impoundment survey and subsequent study of the developing Hendrik Verwoerd Dam by the University of the Orange Free State was begun and in 1971 a eutrophication research programme to be described in a later chapter was begun. This has involved both extensive surveys of large numbers of impoundments and studies of nutrients and algal growth in eutrophic impoundments such as Hartbeespoort, Rietvlei, Roodeplaat, Lindleyspoort, Laing and Ntshongweni Dams and similar studies of impoundments not yet as badly affected by eutrophication, such as Midmar and Buffelspoort Dams.

Many South African impoundments are stratified at least at times in summer. The thermocline is frequently not as sharply defined as is usually the case in Northern Hemisphere lakes and minor temperature discontinuities are commonly found. These may be above the thermocline (in the epilimnion)

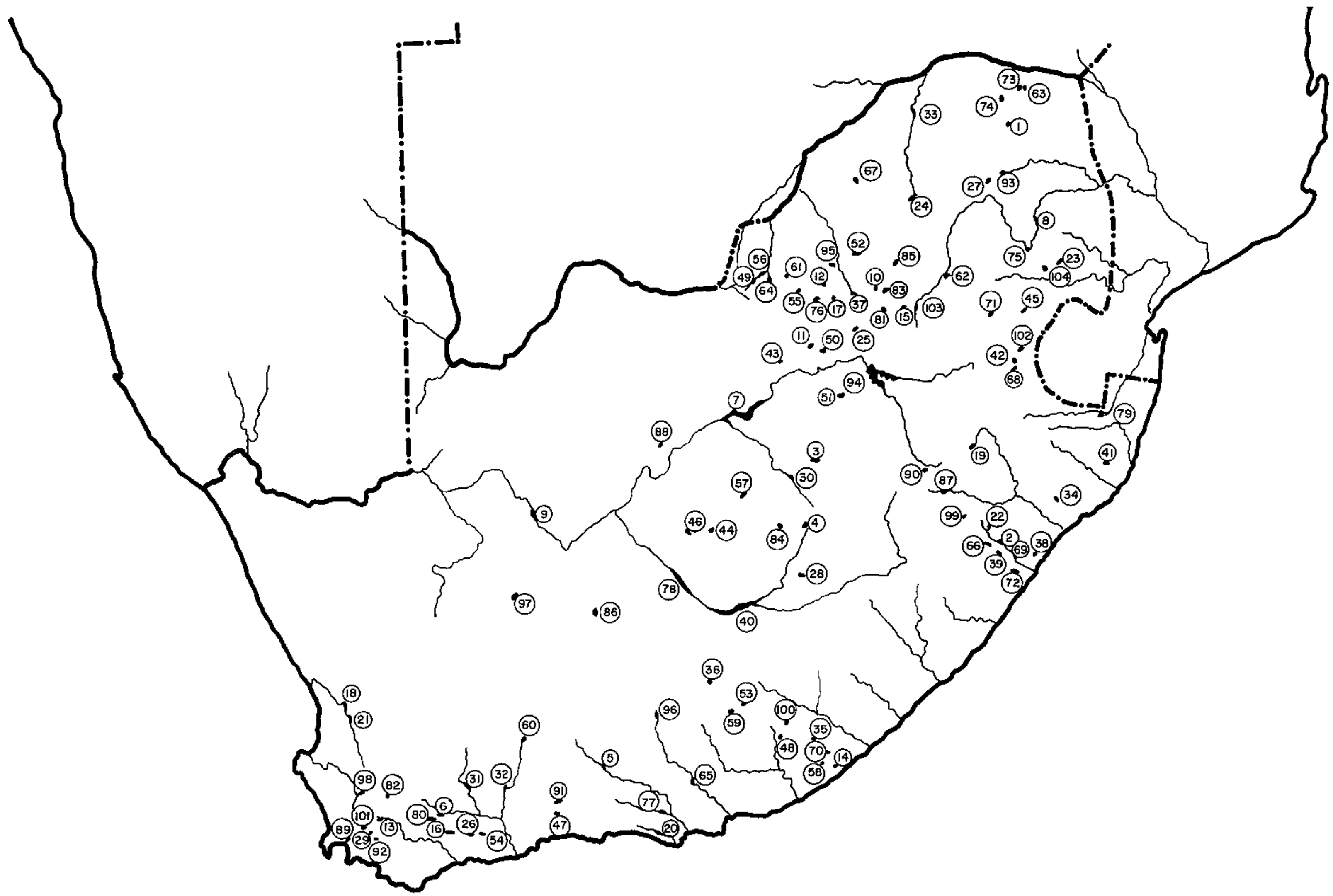

Figure 7. Distribution of major impoundments in the Republic of South Africa (refer to Table 5 for names).

Table 5. Some characteristics of South African impoundments.

Impoundment	Altitude (m)	Catchment area (km^2)	Mean annual runoff ($10^6 m^3$)	Volume at full supply level ($10^6 m^3$)	Surface area at full supply level (ha)	Maximum depth (m)	Mean depth (m)	Sediment erosion from catchment ($t\ km^{-2} a^{-1}$)	Shoreline type A = shallow slope B = steep slope c = clay s = sand r = rock	Suspended solids concentration H = High M = Moderate L = Low	Total dissolved solids H often > 1000 $mg\ell^{-1}$ M normally 200-1000 $mg\ell^{-1}$ L normally < 200 $mg\ell^{-1}$	Utilization P = Potable supply I = Irrigation A = Angling B = Boating
1. Albasini	751	509	26	25,2	313	23,5	8,0			M	M	
2. Albert Falls	656	1 644		292,8	2 387	24,6	12,2		A c	L	L	P A B
3. Allemanskraal	1 369	3 665	104	174,3	2 697	16,5	6,5		A c	H	M	
4. Armenia	1 515	858	28	14,5	407	12,2	3,6		A c	H	H	
5. Beervlei	706	20 336	75	93,5	2 294	12,1	4,1		A B c r	L	M	
6. Bellair	555	558	2	11,1	198	11,1	5,6	63		L	H	
7. Bloemhof	1 229	107 911	2 115	1 273,0	22 821	20,4	5,6		A c	L	M	
8. Blyderivierspoort	665	2 176		55,1	263	53,0	20,9		B r	L	L	
9. Boegoeberg	886	342 952		21,1	787	6,7	2,7			L	M	
10. Bon Accord	1 251	315		6,5	182	7,4	3,6	130	A c	L	M	A
11. Boskop	1 387	3 287	69	20,5	373	13,3	5,5		A c	L	M	P A
12. Bospoort	1 076	1 080	25	19,4	363	13,0	5,3	108	A B c	M	M	P I A B
13. Brandvlei	202	62		83,0	1 916	7,7	4,3		A s	M	L	
14. Bridle Drift	147	1 176	129	75,5	616	40,9	12,3		A c	H	M	
15. Bronkhorstspruit	1 430	1 263	52	57,6	848	19,4	6,8		A c	H	M	
16. Buffeljags	85	601	91	5,2	130	18,3	4,0		B r	L	L	
17. Buffelspoort	1 223	119	15	10,7	135	24,0	7,9		A s	L	M	I A B
18. Bulshoek	62	2 769		5,3	173	10,4	3,0			L	L	
19. Chelmsford	1 241	830	121	83,1	2 020	15,2	4,1	433	A c	H	L	
20. Churchill	155	357	64	33,3	253	25,0	13,2			L	L	
21. Clanwilliam	104	2 033	434	121,4	1 104	28,7	11,0	148	B r	L	L	
22. Craigieburn	1 305	152	27	25,1	221	22,0	11,4		B c	L	L	
23. Da Gama	873	62	22	14,3	134	32,2	10,7		A c s	L	L	I A B
24. Doorndraai	1 179	579	30	46,9	583	22,0	8,0					
25. Doornpoort	1 535	3 626		5,2	220	12,0	2,4	3	A c	H	M	
26. Duiwenhoksrivier	194	148	27	5,7	51	33,3	11,2		B r	L	L	

Table 5 (continued).

Impoundment	Altitude (m)	Catchment area (km^2)	Mean annual runoff ($10^6 m^3$)	Volume at full supply level ($10^6 m^3$)	Surface area at full supply level (ha)	Maximum depth (m)	Mean depth (m)	Sediment erosion from catchment (t $km^{-2} a^{-1}$)	Shoreline type A = shallow slope B = steep slope c = clay s = sand r = rock	Suspended solids concentration H = High M = Moderate L = Low	Total dissolved solids H often > 1000 $mg\ell^{-1}$ M normally 200-1000 $mg\ell^{-1}$ L normally < 200 $mg\ell^{-1}$	Utilization P = Potable supply I = Irrigation A = Angling B = Boating
27. Ebenezer	1 353	170	44	67,3	383	45,7	17,5		B c	L	L	
28. Egmont	1 456	314	17	9,8	249	10,7	4,0	120	A c	H	M	
29. Elandskloof	510	43		11,3	61	50,5	18,5					
30. Erfenis	1 332	4 750	21	224,1	3 308	30,5	6,7		A c	H	M	
31. Floriskraal	598	4 001	23	62,9	787	16,6	8,0		A c s	M	M	
32. Gamkapoort	380	17 076	39	54,3	682	30,8	8,0		A c r	L	H	
33. Glen Alpine	818	11 292	129	23,6	468	16,7	5,0		A c	L	L	
34. Goedertrou		1 273		313,3								
35. Gubu	1 014	23	6	8,8	107	24,7	8,2			L	H	
36. Grassridge	1 058	4 325	34	58,4	1 456	14,9	4,0					
37. Hartbeespoort	1 162	4 112	157	193,7	2 000	31,7	9,6	61	A B c	L	L	P I A B
38. Hazelmere	86	381	117	22,0	211	25,1	10,4		B c	M	L	P A B
39. Henley	933	238		6,0	69	20,0	8,7			H	L	P A
40. Hendrik Verwoerd	1 259	70 749	9 840	5 952,4	36 433	64,0	16,3		A B c r	M	L	I A B
41. Hluhluwe	81	734	40	31,3	368	29,3	8,5		A c s	M	M	I
42. Jericho	1 466	218	42	59,7	979	19,5	6,1			L	L	
43. Johan Neser		5 452		5,8	232	7,0	2,5			L		
44. Kafferrivier	1 396	922		33,0	805	10,0	4,1					
45. Kafferskraal	1 057	3 112	318	78,8	662	38,4	11,9		A B s	L	M	
46. Kalkfontein	1 229	10 268	181	343,2	5 139	19,0	6,7	82	A c s	M	M	
47. Kammanassie	384	1 505	38	32,9	349	29,0	9,4	119	A c r	M		
48. Katrivier	750	258	35	26,1	214	48,0	12,2			L	H	
49. Klein Maricopoort	1 161	1 180	9	8,0	140	12,8	5,7	25	A c r	M	M	I A B
50. Klipdrif	1 368	1 088		14,4	485	5,0	3,0					
51. Klipkopje	942	78		12,1	235	15,2	5,1					
52. Klipvoor	989	6 138	146	43,8	758	16,2	5,8			L	M	

Table 5 (continued).

Impoundment	Altitude (m)	Catchment area (km^2)	Mean annual runoff ($10^6 m^3$)	Volume at full supply level ($10^6 m^3$)	Surface area at full supply level (ha)	Maximum depth (m)	Mean depth (m)	Sediment erosion from catchment ($t\ km^{-2} a^{-1}$)	Shoreline type A = shallow slope B = steep slope c = clay s = sand r = rock	Suspended solids concentration H = High M = Moderate L = Low	Total dissolved solids H often > 1000 $mg\ell^{-1}$ M normally 200-1000 $mg\ell^{-1}$ L normally < 200 $mg\ell^{-1}$	Utilization P = Potable supply I = Irrigation A = Angling B = Boating
53. Kommandodrif	1 018	3 623	42	66,7	893	43,0	7,5	86	A c r	H	H	
54. Korinte Vet	321	37	9	8,5	104	27,4	8,1		B r	L	L	
55. Kosterrivier	1 267	281	13	11,2	243	11,0	4,6		A c	M	L	
56. Kromellenbogen	1 051	1 786	15	9,9	236	9,5	4,2		A c	M	M	
57. Krugersdrif	1 248	6 349	196	78,0	1 807	20,3	4,3		A c	H	M	
58. Laing	310	913	52	22,0	211	30,0	10,4	136	B c r	M	H	P I
59. Lake Arthur	898	4 497	68	30,5	881	18,7	3,5	521	A c s	H		
60. Leeuwgamka	614	2 088	30	15,6	517	10,9	3,0	31		H	H	I
61. Lindleyspoort	1 177	704	22	14,2	176	22,5	8,1		B c r	H	L	I A
62. Loskop	997	12 285	466	180,0	1 688	25,0	10,7	39	A c r	M	M	I A B
63. Luphephe	568	157	26	14,2	137	25,0	10,4				M	
64. Marico Bosveld	1 063	1 219	33	30,0	435	17,7	6,9		A c r		L	I A B
65. Mentz	247	16 826	159	205,6	3 594	34,0	5,7	206	A c r	L	H	I
66. Midmar	1 044	928	206	177,7	1 560	19,8	11,4		A c	L	L	P A B
67. Mokolo	912	4 319		157,0	859		18,3					
68. Morgenstand		528		113,7	1 045	30,8	10,9					
69. Nagle	404	2 535		23,2	154	24,4	15,2		B c	L	L	P A
70. Nahoon	154	473	40	5,9	82	24,1	7,2		B c	H	H	P
71. Nooitgedacht	1 529	1 569	63	81,3	772	33,5	10,5		A c	H	L	
72. Ntshongweni	301	803		7,2	81		8,9	193	B c s	M	L	P A
73. Nwanedzi	569	109		5,2	57	21,0	9,1			L	M	
74. Nzhelele	607	842	35	57,4	607	28,6	9,5	184		L	M	
75. Ohrigstad	1 402	83	17	12,3	94	30,5	13,1				L	
76. Olifantsnek	1 200	492	15	14,2	257	14,4	5,6	149	A c	M		I
77. Paul Sauer	149	3 887	178	131,8	562	55,0	23,6		B r	L	L	
78. P K le Roux	1 170	89 842		3 236,6	13 867		23,3		A B c r		L	I A B

Table 5 (continued).

Impoundment	Altitude (m)	Catchment area (km^2)	Mean annual runoff ($10^6 m^3$)	Volume at full supply level ($10^6 m^3$)	Surface area at full supply level (ha)	Maximum depth (m)	Mean depth (m)	Sediment erosion from catchment ($t\ km^{-2} a^{-1}$)	Shoreline type A = shallow slope B = steep slope c = clay s = sand r = rock	Suspended solids concentration H = High M = Moderate L = Low	Total dissolved solids H often > 1000 $mg\ell^{-1}$ M normally 200-1000 $mg\ell^{-1}$ L normally < 200 $mg\ell^{-1}$	Utilization P = Potable supply I = Irrigation A = Angling B = Boating
79. Pongolapoort	137	7 831	1 588	2 500,6	13 274	69,8	18,8		A B c r	H	L	I A
80. Poortjeskloof	370	94	8	10,4	106	22,0	10,0					
81. Rietvlei	1 475	479	13	11,2	188	17,2	6,0		A c s	L	L	P A B
82. Roode Elsberg	573	139	14	8,2	37	54,9	22,2		B r	L	L	
83. Roodeplaat	1 214	684	35	42,1	398	29,0	10,6		A c s	L	M	P A B
84. Rustfontein	1 373	940	37	75,4	1 162	22,1	6,5		A c r	M	M	
85. Rust de Winter	1 035	1 147	54	28,1	493	24,1	5,7		A c s	M	M	I A B
86. Smartt Syndicate	1 094	13 394	55	98,0	3 089	13,5	3,2					
87. Spioenkop	1 071	2 452		281,8	1 544	46,8	18,2		B	M	L	
88. Spitskop	1 043	26 914		61,3	2 495	9,4	2,5		A c	M	H	
89. Steenbras	347	67	48	33,7	397	23,4	8,5		B s	L	L	P
90. Sterkfontein	1 678	193	102	1 203,3	5 073	61,0	23,7		B c r	H	L	
91. Stompdrif	444	5 235	27	61,2	642	32,9	9,5		B c r	H	M	
92. Theewaterskloof	309	497		432,9	4 787	33,3	10,4		A s	L	L	P
93. Tzaneen	724	652		158,7	1 169	42,7	13,6					
94. Vaal	1 484	38 505	2 270	2 330,2	29 269	30,0	8,0	125	A c	H	M	P A B
95. Vaalkop	981	6 110	167	57,6	1 103	19,9	5,2		A c s	L	M	
96. Van Ryneveldspas	788	3 681	36	51,8	1 094	10,5	4,7					
97. Van Wyksvlei		1 339		75,3	3 726	7,0	2,0					
98. Voëlvlei	79	40	45	164,1	1 573	17,6	10,4		A c	M	H	P A B
99. Wagendrift	1 180	744	233	59,9	505	30,5	11,8	380	A B c	M	L	P A B
100. Waterdown	1 171	603	63	38,2	262	36,2	14,6		B r	L	L	
101. Wemmershoek	297	86	70	58,5	296	53,3	19,8		B c s	L	L	P
102. Westoe	1 551	531	79	59,6	727	21,3	8,2		A s	L	L	
103. Witbank	1 535	3 618	135	16,1	220	18,0	7,3		A B c r	H		P A B
104. Witklip	1 007	64	25	13,7	194	41,1	7,0		A B c s	L	L	I A B

and represent perhaps temporary incomplete mixing and warming of the upper layers during periods of low wind velocity, or may be below the thermocline (in the hypolimnion) and represent perhaps density currents of cool, sediment-laden water from the inflowing rivers.

The water brought into impoundments by rivers is often rich in suspended matter, especially during floods. Even where the river water is clear during low flow, the water in the impoundment may be turbid. The inflowing water is frequently cooler, or at least more dense as a result of its sediment load, than the impounded water and can flow as a more or less discrete layer below the less dense water. If some of the suspended material is organic, this can decompose and decrease the dissolved oxygen concentration or even completely deoxygenate the hypolimnion, even in an oligotrophic impoundment.

Impoundments used for irrigation or hydro-electric power generation characteristically have greatly fluctuating water levels, which inhibit the growth of marginal emergent or submerged vegetation. When the water level falls, a sterile beach is exposed. In impoundments in the south-western Cape, like Brandvlei and the Theewaterskloof Dam under construction, wind-driven sand from the beaches exposed in late summer can itself be a serious problem in the surrounding area. Limnologically, the slope, aspect and physical nature of the littoral and intermittently exposed area and the presence or absence of remains of drowned terrestrial woody plants, as well as the water level fluctuations themselves, will be of enormous importance in determining, first, whether or not plants and animals will be able to establish themselves there and, second, what physical cover and feeding and spawning areas might be provided for fish. The plants can include terrestrial plants like *Cynodon* grasses which can establish on the exposed beach, reeds and other emergent aquatics which readily establish themselves around standing waters with relatively stable water levels, *Potamogeton* and other submerged plants which can serve as nutrient traps and provide habitat and cover for invertebrates and fish, and *Eichhornia* and other floating plants which anchor in woody remains. Key animals of the littoral include chironomid larvae and other benthic (bottom living) invertebrates on which carnivorous *Barbus* feed and snails which can be important herbivores on aquatic plants and some of which can transmit *Schistosoma* and other parasites.

A proportion of the sediment load carried by South African rivers is trapped and deposited in impoundments. This can result in serious loss in storage capacity, the capacity of Lake Arthur in the eastern Cape, for instance, having been reduced by some 74 percent by sedimentation. Limnologically, sedimentation has the effect of blanketing the bottom with sediment and obliterating habitats of benthic invertebrates, thus decreasing the food supply of carnivorous fish.

As will be described in the chapter on eutrophication, much of the current work on South African impoundments aims at relating nutrient inputs and algal growth in an attempt to determine nutrient input limits that would not cause undesirable algal standing crops, associated problems in water treatment and water quality deterioration. Empirical mathematical eutrophication models developed to relate external nutrient loading and primary production in European and North American lakes are being tested for their applicability to South African impoundments and used to determine permissible nutrient loadings. Important findings to date include differences in the algal growth responses to enrichment of turbid and clear impoundments. Another important finding is that limitation of nitrogen input to impoundments can not be relied upon to restrict algal growth since nitrogen deficiency can be counteracted by the development of blooms of nitrogen-fixing algae such as *Anabaena circinalis*.

One of the factors influencing primary production in South African impoundments is the turbidity of the water. As will be described in the chapter on eutrophication, a project has been initiated to determine the rôle of suspensoids in a turbid impoundment. Here an attempt will be made to gain an understanding of the effects of wind and physical limnology on the resuspension of sediments and the effects of suspensoids on light penetration, nutrient availability, primary productivity and secondary production by microbes which serve in turn as food for zooplankton.

Although the primary purpose of impoundments is to supply water of suitable quality for urban, industrial, mining and agricultural purposes the recreational value of these water bodies is increasing, particularly in areas near centres of high population density, and this trend can be expected to continue. Problems reducing the recreational value of impoundments include aquatic weeds and the excessive growth of algae, the latter invariably and the former frequently being a symptom of eutrophication, as will be described in the later chapter on problem hydrophytes and algae. Spectacular examples include the recent infestation of water hyacinth *Eichhornia crassipes* on Hartbeespoort Dam and the unpleasant blooms of the blue-green alga *Microcystis aeruginosa* common on eutrophic Transvaal dams, especially in late summer.

As will be described in later chapters, impoundments can be important sites for the accumulation of toxic pollutants and for the transmission of bilharziasis and veterinary parasites. Moreover, the construction of a dam can have a dramatic impact on the river, especially downstream.

Another later chapter is devoted to possibilities that exist for the increased utilization of the fish production potential of impoundments for both sport angling and food fishing. Although very few studies of fish populations and production have been carried out in South Africa, enough information is available to demonstrate that a considerable potential for fish production exists. Population studies are being initiated which are aimed at providing some of the knowledge which will be required to achieve this potential.

Future needs

A growing need is expected for knowledge of limnological processes in impoundments to make possible the management of these impoundments for multiple use and to find solutions to the practical problems which will inevitably arise. In order to meet this need, it can be expected that both short and long term research projects on impoundments will feature prominently in the IWE programme.

There is a need as an aid to research planning and for the determination of priorities to maintain a register of information on impoundments. This should include assessments of their relative potential for utilization and water supply for different purposes, as well as of possible problems which could arise with their management for multiple use. Attempts should be made to derive relative estimates of economic and other values to the community of different existing and potential uses and relative costs of possible problems.

There is a need to consider the applicability of existing limnological knowledge to assist in the formulation of multiple use strategies for impoundments. Doing this might at the same time serve to identify information needs which could receive attention within the IWE programme.

There is a need to identify existing and possible future practical problems which are likely to arise with the management of impoundments and to which limnological knowledge could be applied. At the same time, gaps in knowledge necessary to solve these problems should be identified and attempts made to gain this knowledge through short and long term investigations within the IWE programme.

Several existing and projected research programmes are described in later chapters. The most important of these are short and long term programmes aimed at the protection of oligotrophic impoundments, the restoration of eutrophic impoundments and the utilization of impoundments for recreation, angling and food fishing.

COASTAL AND ESTUARINE LAKES

With the exception of Fundudzi and the closed drainage systems described earlier, all natural lakes in South Africa lie adjacent to the coastline. The major part of the total lake surface in the country is contributed by the lake systems of northern Natal. The remaining lakes are limited to the southern and south-western Cape coast and to the West coast north of the Berg River mouth (Figure 8).

These lakes can be broadly divided into coastal lakes, which may contain fresh or brackish water and organisms of estuarine origin (algae, crustaceans and fish, which are relicts in the case of lakes cut off from the sea since the last Ice Age) but which are normally uninfluenced by the sea, and estuarine lakes which are temporarily or permanently connected to the sea, which exhibit varying degrees of marine salinity and into which marine fish regularly migrate. Each group can be subdivided into three types, depending on the degree of marine influence as shown in Table 6.

The lakes will be described in order from northern Zululand around the coast to the Cape West Coast.

Kosi lake system

The Kosi lake system consists of three interconnected estuarine lakes opening to an estuary at the northern end of the system 5 km from the Mozambique border. Immediately south of the estuary is Mpungwini with a surface area of 3 km^2, a maximum depth of 18 m and a mean depth of 8 m. Next is Nhlange with a surface area of 31 km^2, maximum depth of 31 m and mean depth of 7 m, and then Amanzimnyama with a surface area of 1,5 km^2 and mean depth less than 2 m. The total surface including the estuary is approximately 40 km^2. Freshwater input is via two small rivers draining the local coastal plain and salinity increases from the freshwater Amanzimnyama in the south to the estuary in the north. Tidal fluctuations and exchange of water are restricted by the narrow connecting channels between the lakes, but there is occasional seawater incursion into Nhlange. The geological history is similar to that of Sibaya.

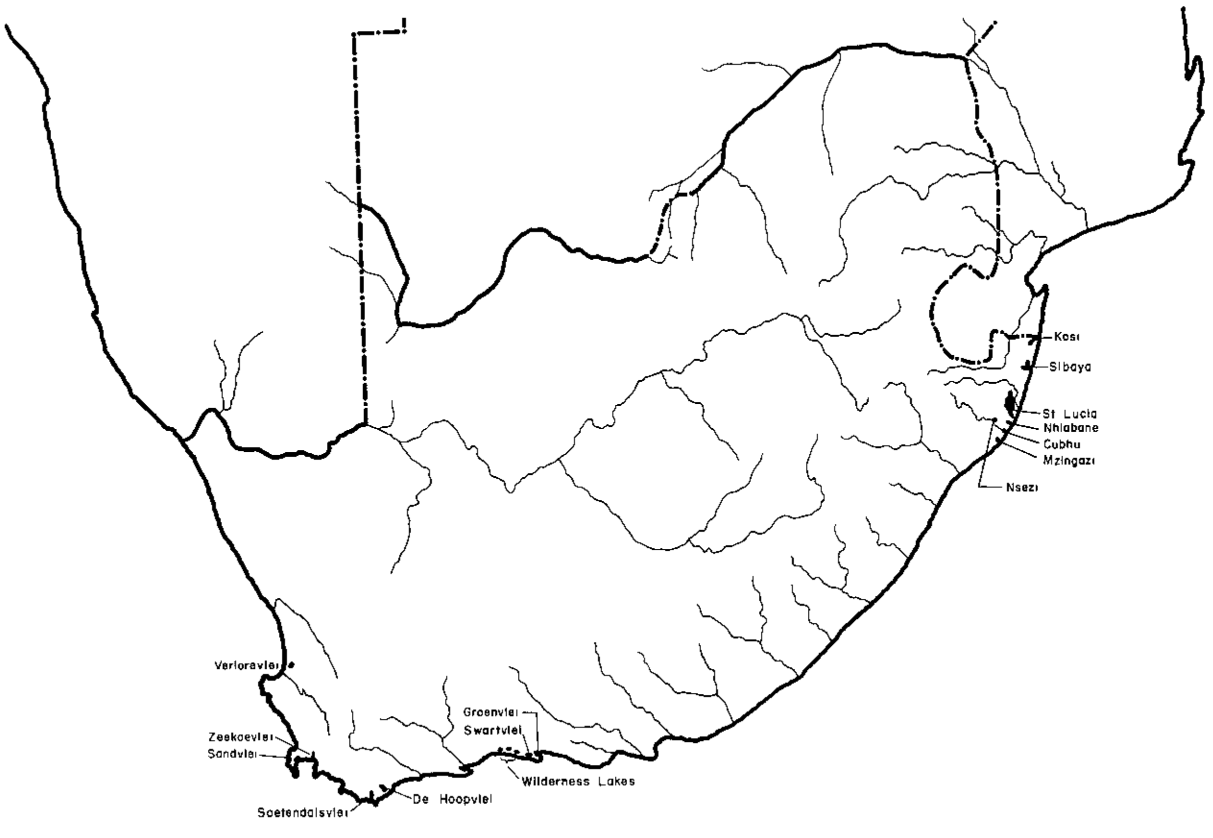

Figure 8. Coastal and estuarine lakes in South Africa.

Utilization of the surrounding catchment involves pastoral grazing for the local Thonga population and fishing provides an important contribution to local animal protein food supplies. Recreational use is limited by the inaccessibility of the area. No development is planned in the foreseeable future.

Because of its natural state and general interest the Kosi system has been studied by the University of Cape Town Department of Zoology, the Natal Parks Board and the Rhodes University IFWS at different times during the past 30 years. Quite extensive limnological and ecological studies have been made and the information is available in published form. The University of Natal Department of Zoology has been working on the fish.

Mgobezeleni-Shazibe lake system

The two coastal lakes Mgobezeleni and Shazibe are connected to the Mgobezeleni estuary by an extensive reedswamp. The lakes are apparently fresh but contain euryhaline fish species.

Table 6. Types of coastal and estuarine lakes in South Africa.

Types	Sub-types	Examples
Coastal lakes		
Freshwater or brackish, marine influence minimal, may contain relict estuarine biota	Brackish with seepage outflow only	Sibaya (Natal), Groenvlei (south Cape), De Hoopvlei (south-west Cape)
	Freshwater or brackish with outflow to sea but no tidal exchange	Mzingazi, Nsezi, Cubhu (Natal), Soetendalsvlei (south-western Cape), Zeekoevlei (western Cape)
	Freshwater or brackish with outflow to sea. Occasional seawater input	Verlorevlei, Wadrifsoutpan and other west coast vleis
Estuarine lakes		
Freshwater to highly saline, estuarine biota, permanent or semi-permanent tidal connection to sea	Freshwater to saline. The lake shallow, normally with no vertical salinity stratification	Wilderness lakes (southern Cape), Sandvlei (Cape Flats)
	Freshwater to saline. The lake less shallow, often with vertical salinity stratification	Swartvlei (southern Cape), Kosi lake system (northern Natal)
	Freshwater to hypersaline	St Lucia system (Natal)

Sibaya

Sibaya in northern Zululand is a coastal lake formed by an estuary cut off from the sea in the late Pleistocene. The lake surface covers approximately 65 km^2 with a maximum depth of 40 m and an average depth of 13 m. There are no large rivers draining into it and there is no outflow. The water is slightly brackish and subject to variation in level and the catchment consists of coastal savanna and dune forest on sandy soils. The lake is mesotrophic and has low turbidity.

Utilization is limited to fishing by the local Thonga population, mainly of the large population of stunted Mozambique tilapia *Sarotherodon mossambicus* present. No further use is made of this water body due to absence of any development in the area. There is an urgent need to conserve the lake within a permanent nature reserve in order to protect its fish production, recreational and scientific value. Any form of pollution or development could potentially damage the lake permanently.

Considerable information is available on the lake as a result of the Rhodes University IFWS research programme here during the last decade. The field programme was discontinued in 1977 when the research station was flooded.

St Lucia estuarine lake system

The St Lucia estuarine lake system in northern Natal forms the largest natural body of open water in the Republic of South Africa and constitutes more than 75 percent of the total estuarine area of the whole coastline. Its geological history is similar to that of the other lakes of the Zululand coastal plain. The system is operated at present primarily as a wildlife sanctuary and aquatic recreational use is limited to angling and boat tours. The major components of the lake ecosystem are fairly well documented, particularly the fish and penaeid prawn populations.

The freshwater supply to St Lucia is variable, dependent on annual rainfall and flow in the rivers discharging to the northern and western shorelines. Tidal exchange of seawater is restricted by the narrow channel between the estuary and the lake. The Mfolosi River no longer discharges into the St Lucia estuary, but a channel is currently being planned to allow freshwater inflow into St Lucia from this source.

Historically the lake has undergone wide fluctuations in salinity. During periods of drought, salinities up to three times that of seawater have been experienced, driving out or eliminating crocodile, hippo, fish and macro-invertebrates and greatly damaging the swamps along the verges of the lake. Floods from the Hluhluwe and Mkuze Rivers flush the system with fresh water, but also devastate the fauna. The suggestion is also that past attempts to canalize the freshwater inflow into St Lucia through the Mkuze swamps, in an attempt to avoid evapotranspiration water losses in the swamps, have been even more damaging than the opening of the mouth. Besides damaging the swamps, it has allowed a good deal of sediment to enter the lake which would otherwise have been trapped in the swamps. Sedimentation is in fact probably the greatest threat to the lake and greatly aggravates the impact of periodic drought and flooding.

Mathematical models of the St Lucia lake and estuary, Mkuze swamps and Mfolosi floodplains have been developed by the University of the Witwatersrand HRU. These are able to predict likely lake levels and salinities in the lake system. The lake, estuary and Mfolosi floodplain models are currently being integrated to check the design of the planned link channel and to formulate operational procedures to prevent sediment from entering the estuary. The modelling approach has made it possible to develop strategies which it is hoped will reduce the damaging fluctuations that periodically occur and to maintain a relatively fresh area within the lake during times of extreme drought. Substantial development of the St Lucia mouth area as a tourist and holiday area is intended in the near future and the demand for water-orientated recreation can be expected to increase considerably with possible conflict between recreational needs and conservation objectives.

Nhlabane

Nhlabane is a small circular freshwater coastal lake with a surface area of approximately 4 km^2 lying behind the coastal dunes approximately midway between St Lucia mouth and Richards Bay. It receives surface drainage from the area behind the dunes which is mostly pastoral grazing land with some forestry plantations. The lake is connected to the sea via a narrow winding estuary. Previously almost totally undisturbed, the lake was cut off from the estuary in 1977 by the construction of a barrage.

Utilization of this water body began with the raising of the water level for process water for large scale ilmenite, rutile and zircon extraction from the coastal dune sands. There is virtually no information available on the ecology of this lake but it is thought to be similar to that of Lakes Mzingazi and Cubhu further to the south.

Mzingazi

Mzingazi is a coastal lake, the southern shore of which lies 3 km to the north of the Richards Bay harbour, and is also the remains of an estuarine lagoon cut off from the sea in recent geological times. The lake is supplied by streams draining the area behind the coastal dunes and some subsurface input from the surrounding sandy catchment area.

The lake has its long axis parallel with the coastline and is 5 km in length and 3 km in width at its widest point with a total surface area of approximately 11 km^2. The maximum depth is 14 m and the average depth about 6 m. The water is fresh with some humic colouration and discharges to the harbour via the short Mzingazi River. The natural vegetation of the lake shoreline is largely undisturbed and most of the shallow areas less than 5 m in depth are covered with dense growth of two species of the submerged hydrophyte *Potamogeton*.

Utilization of Mzingazi began in 1970 with construction of the new town of Richards Bay. At present, residential suburbs have been constructed along the southern shoreline and along the southern half of the eastern shoreline. According to existing plans almost the entire lake will eventually be surrounded by suburbs. At present the lake supplies the total water requirements of the urban and industrial development and, for a water level fall of 1 m, provides an assured supply of 54 $M\ell d^{-1}$. To date a reduction in level of 1 m has not been required and the effects of such a withdrawal on the peripheral vegetation are uncertain.

A considerable effort has been made to preserve the lake in its original state and no industrial development has been permitted within the catchment. The long term effects of surface runoff from the surrounding suburbs on the lake water quality are uncertain.

Increasing water requirements are expected to exceed the supply capacity of the lake in the 1980's but alternative sources are available. However, the lake will always provide part of the total requirements of the Richards Bay area.

Prior to about 1970 very little was known of the hydrology or ecology of Mzingazi. In 1972 to 1973 a nitrogen and phosphorus budget estimate for a one year period was made by the NIWR in an attempt to assess the impact of increased nutrient input that could result from urban development. This study included some general physical limnology but no ecological studies were undertaken. Subsequent work by the National Physical Research Laboratory (NPRL) provided information on the subsurface movement of water into and out of the lake as part of an investigation into the potential of the ground water in the area as a significant source for local supply.

Nsezi

Nsezi is also a coastal lake, about 10 km inland from Mzingazi and supplied by the Nseleni River which cuts through the escarpment. At the southern end the lake discharge flows across the floodplain of the Mhlatuze River to join the Mhlatuze about 3 km before its discharge into the Richards Bay estuarine reserve.

The lake is 5 km long and 2 km at its widest point and is probably less than 5 m in depth over most of its area of approximately 10 km^2. There are extensive stands of emergent and floating hydrophytes and open water areas are limited.

Utilization is limited to a small part of the water supply to the town of Empangeni and the lake is a wildlife reserve. At the request of the Richards Bay Town Board, the Natal Parks Board is at present assessing the possibility of development of the lake area for recreation. There is also the possibility of its future use as an industrial water supply as development in the area proceeds.

Very little information is available on Nsezi apart from routine water supply analyses. The salt concentration tends to increase at times, especially during droughts, and the lake is alleged to be highly eutrophic as a result of runoff from adjacent fertilized cane lands.

Cubhu

Cubhu is a coastal lake located about 2 km south of the southern shore of Richards Bay and was formed in the same way as Mzingazi which it is thought to resemble quite closely as regards water quality and ecology. The surface area is approximately 5 km^2 and the input consists of small streams draining the sandy soils behind the coastal dunes. The lake drains to the Richard Bay estuarine reserve via the short Mthantatweni River.

At present the lake is used as a freshwater supply for a paper mill in the area. Development of the suburb of Esikaweni as part of the total Richards Bay complex is now in progress and eventually the lake shore and most of its catchment will be occupied by residential suburbs and light industries.

Use of the lake as a water supply for this area is under consideration but its supply capacity is estimated to be less than half of that of Mzingazi.

Some information on water quality is available from the NIWR but no ecological investigations have been carried out until recently. At present a limited study on water quality and primary productivity is being undertaken by the University of Zululand.

Groenvlei

Groenvlei is a coastal lake situated between Wilderness and Knysna and is separated from the sea by high coastal dunes. The lake is 3,7 km long and 0,9 km wide with a surface area of 2,48 km^2. The small catchment consists entirely of vegetated dunes. Maximum depth is less than 6 m and most of the lake is less than 3,7 m deep. There are no distinct input streams and there is no outlet. The water level fluctuates to a limited extent from year to year. The lake margins support a fringe of *Phragmites*, *Typha* and various Cyperaceae. The lake and its seaward catchment form part of the Goukamma Provincial Nature Reserve.

Only limited information is available on Groenvlei, which differs from the other Wilderness lakes in that it lacks any connection with the sea. The water is known to be brackish (TDS $\sim$ 2g ℓ^{-1}) and is normally turbid. Water analyses and zooplankton sampling have been undertaken by the Cape Provincial Administration. Apart from introduced fish species there is a land-locked population of the estuarine whitebait *Gilchristella aestuarius*, as well as several relict estuarine crustacean species.

Swartvlei

Swartvlei is the largest of four estuarine lakes located on the southern Cape coast, between Groenvlei in the east and the Touw River mouth in the west. The surface area is 11 km^2 with a maximum depth of 14 m and a mean depth of 10 m. The freshwater input to the lake is via small rivers flowing from the coastal Outeniqua mountain range and seawater input via the Swartvlei estuary only occurs at spring tides. Seasonally the estuary is closed by a sand bar. The lake is termed meromictic in that the occasional seawater intrusion sinks to the bottom establishing a semi-permanent vertical salinity stratification. The deeper layers are consequently semi-permanently deoxygenated.

There are extensive growths of submerged and emergent hydrophytes in the shallow areas (less than three metres in depth) with open water in the deeper central area. There is *Salvinia* in the tributaries, which is presumably prevented by the salinity from invading the lake. The estuary has well developed salt marsh flats. Development of the area is restricted and the lake is largely unaltered from its natural state.

Swartvlei forms part of the natural lakeland area of the southern Cape and is a popular holiday area for aquatic recreation of all types. Recreational use by the public increases with time and provision of a scientifically based management and development programme to preserve the amenities and attraction of the area is considered a priority need.

Since 1975 Rhodes University IFWS research on the ecology of the lake and estuary and a survey by the National Research Institute for Oceanology (NRIO) of the hydrography of the estuary have provided detailed information on certain aspects of the lake ecosystem, in particular the importance of the hydrophyte *Potamogeton pectinatus* belt and its periphyton for nutrient cycling and as a basis for primary production in the lake. The rich macro-invertebrate fauna is largely dependent on this belt and decomposition in the belt releases a significant proportion of the mineral nutrients available for primary producers. These studies have also allowed prediction of the likely impact of bridge construction and other development. Although incomplete, research on Swartvlei has so far provided a valuable contribution to the understanding of lake ecosystem function in the Wilderness-Knysna lake area.

Wilderness lakes

The Wilderness system of three interconnected estuarine lakes lies parallel to the coastline to the west of Swartvlei and is linked by a narrow winding channel and *Phragmites* covered floodplain to the estuarine lagoon of the Touw River at the western end. The lake levels are determined by flooding of the Touw River and the state of the estuary mouth. Seawater intrusion rarely reaches the first lake, Eilandvlei, but flooding pushes back into Eilandvlei, Langvlei and Rondevlei. The lakes are normally not stratified and salinities increase from Eilandvlei through Langvlei to Rondevlei.

All of the lakes support dense growths of submerged and emergent hydrophytes which form the basis of the foodweb in the system. Langvlei has extensive beds of macrophytic algae (Characeae) which occasionally die off. The die-off can be followed by H_2S production from the rotting material and then blooms of phytoplankton.

The Wilderness lake system is a more important tourist and recreational centre than is Swartvlei and utilization for these purposes will steadily increase. Plant growth imposes restrictions on the use of the lakes and there is clearly a need for ecological data that will assist in improving recreational use without undesirable impacts on the lake ecosystems. The lake system has recently come under the control of the newly established Lake Areas Control Board.

Little factual information is available on the bathymetry and hydrology of the system. Limited studies have recently been undertaken by the Cape Provincial Administration on the zooplankton and fish of the lakes.

De Hoopvlei

De Hoopvlei is a long narrow coastal lake which lies between Bredasdorp and the sea on the southern Cape coast and has been formed by blocking of a river valley through limestone formations at the seaward end by 3,6 km of sand dunes. The lake is supplied by the Sout and Potberg Rivers and by subsurface springs. There is no surface outlet to the sea. When full the lake is 18 km in length and approaches 1 km in width with a maximum depth of 15 m. In very dry years the lake has been reduced to a number of deep pools fed by perennial springs. The water is clear with extensive areas of *Potamogeton* in the shallows and no emergent hydrophytes.

Utilization of De Hoopvlei water is apparently limited to angling for introduced gamefish. Very limited information is available on this lake apart from extensive observations on the avifauna. Little is known of the aquatic ecology, but the fauna includes relict estuarine species like the isopod *Pseudosphaeroma barnardi*. The water is usually brackish (TDS $\sim$ 5,5g ℓ^{-1}) and alkaline. The trophic status of the water is uncertain and the only indigenous fish species present is *Sandelia capensis*.

Soetendalsvlei

Soetendalsvlei is a large shallow coastal lake which lies to the west of De Hoopvlei in the Bredasdorp area of the south-western Cape. The lake is approximately 7,5 km in length and 2,5 km in width. The surface area when full is about 20 km^2 and it is probably nowhere more than 3 m in depth. The lake is fed by a catchment which includes extensive flat areas of reedswamp, a smaller coastal lake Voëlvlei and several much smaller water bodies. Soetendalsvlei is intermittently connected to the sea via a narrow side branch of the Heuningnes River which enters the sea through a well developed estuary in the centre of the Struisbaai coastline.

The river water input is alkaline and brackish as a result of passage through the limestone-bearing Strandvlei sands of the catchment. The shallower parts of the lake have extensive beds of emergent hydrophytes. Utilization is apparently restricted to angling for marine fish. The lake lies in a comparatively infrequented area and is largely unaltered from its natural state. However, apart from observations on the fish and avifauna no information appears to be available on the aquatic ecology.

Acid Cape lakelets

There are a number of small, acid, brown and peat stained bodies of water along the south-western Cape coast. The best examples of these are possibly the Grootvleie and Malkopsvlei near Betty's Bay. Their fauna includes species characteristic of acid waters, such as the isopods *Protojanira* and *Preatoicus*.

Zeekoevlei

The coastal lake Zeekoevlei is the largest freshwater body on the Cape Flats in the vicinity of Cape Town. With a surface area of 250 ha and a mean depth of 3,6 m, it is heavily utilized as a boating and recreation area by the urban population of the area. As a result of development in the area the lake ecology has been considerably modified from its original state and recreational utilization rather than conservation has become the management objective. The water level is artificially controlled and Zeekoevlei has been separated from the adjacent Rondevlei.

Utilization is mostly sail and power boating, angling and general recreation but excessive nutrient enrichment and algal growth detract considerably from the value of the lake for public use. The adjacent Rondevlei is a bird sanctuary.

Information available is limited to intermittent observations on obvious ecological changes recorded since the early 1920's, and a substantial amount of data on the chemistry of the water and sediments of Zeekoevlei accumulated by the Cape Town City Engineer's Department. Since the early 1950's the original *Potamogeton* growth has been replaced by dense populations of planktonic algae which have persisted up to the present. This has resulted in accumulation of decomposing algal material on the lake bottom in certain areas and masses of floating decomposing algal material, both of which are considered objectionable by the public.

Fish population studies have shown that large populations of introduced carp *Cyprinus carpio* and Mozambique tilapia *Sarotherodon mossambicus* are present, but the indigenous fish population is negligible.

Most of the problems encountered result from excessive nutrient input to the lake derived from surface runoff and subsurface seepage from adjacent sewage treatment pond systems.

Sandvlei

Sandvlei is an estuarine lake on the Cape Flats and differs from Zeekoevlei in that a narrow channel provides access to False Bay and allows intermittent passage of marine organisms into the lake and a limited input of saline water. The lake is approximately 2,5 km in length and 0,5 km at its widest point. It is shallow and supports extensive growths of submerged hydrophytes (*Potamogeton*).

Utilization as a recreational and residential area is heavy due to its proximity to the Cape Town urban area. Boating, angling and birdwatching are popular. The east shore has been extensively modified by construction of a marina. The lake also acts as a stormwater drainage channel to the sea from the surrounding urban area, which includes a small coastal lake, Princess Vlei. As with Zeekoevlei, recreational utilization rather than conservation is the main management objective.

Little information is available on water movement to and from the lake but research has been done on the water chemistry, nutrients, algae, macrophytes and invertebrates. Excessive algal growths, restriction of recreational use by submerged hydrophytes, H_2S from plant decomposition in stagnant side arms and fish kills caused by toxic algae are the main problems encountered.

Verlorevlei

Verlorevlei is a long and narrow coastal lake located on the western Cape coast north of St Helena Bay. The lake is approximately 15 km long and 1,5 km in width and is probably not more than 5 m deep. It is supplied by the Hol and Krom Antonies Rivers and discharges to the sea via a short narrow estuary into Elands Bay.

The surrounding area is used for pastoral grazing and the lake probably provides some angling and boating although details are lacking. Completion of the main road from Cape Town to Lamberts Bay is likely to cause increased recreational use of this area.

The lake water is brackish, at least in summer, and the salt is thought to be derived from geological formations in the catchment. Considerable information is available on the avifauna and a study of the general ecology is in progress at the University of Cape Town. The lake has a large population of emergent hydrophytes and may be threatened by *Eichhornia* invasion.

Future needs

There is a need for information to make it possible to foresee environmental threats (including eutrophication) to coastal and estuarine lakes, in particular those that are increasingly utilized for recreational purposes or as sources of water supply, such as the Wilderness lakes, St Lucia and the Richards Bay lakes, as well as those that could be exposed in the future to such threats.

There is a need for information on the fish populations of coastal and estuarine lakes, to facilitate the protection of their angling potential in most cases and in order to make possible the utilization of the fish production potential for food production in one or two cases. Such information is available only for Sibaya.

There is a need for an understanding of the marine interactions between those coastal and estuarine lakes connected to estuaries.

There is a need for an understanding of energy flow and nutrient cycling in coastal and estuarine lakes.

There is a need for an understanding (possibly expressed in mathematical models) of the hydraulics and hydrology of lakes subject to flooding, such as those at Wilderness. It is necessary to be able to predict water levels in such lake systems in a dynamic way for any given set of circumstances and for any management action, such as the opening or closing of the estuary mouth or the dredging of channels. To make such management possible, there is also a need for information on the hydraulic properties as well as the implications of aquatic plants in and around these lakes.

In the case of St Lucia, there is a need for information on the rôle of the floodplain swamps of the inflowing rivers in trapping sediment, on the evapotranspirative loss in water through these swamps and on the costs and benefits of possible means of supplying St Lucia with freshwater.

ESTUARIES AND ESTUARINE LAGOONS

Present state of knowledge

There are a large number of estuaries around the South African coast (see Figure 9), only a small number of which discharge into the sea via estuarine lake systems and most of which are small in size. In the post World War II period biological surveys of a number of major estuaries from the Kosi system near the Mozambique border, including in particular the Knysna estuary on the Cape south coast and Langebaan on the Cape west coast, to the Orange were carried out by the University of Cape Town. These surveys were primarily descriptive but were followed by others and provided an invaluable first understanding of South African estuaries, as well as a great deal of baseline information.

Important later study sites have included St Lucia, studied in relation to the drastic effects of decreased freshwater inflow in the lake. Richards Bay, the Mgeni, Manzimtoti, uMgababa, Fafa, Swartkops and other estuaries have been studied in relation to the effects of development. A good deal of work has been carried out by the Oceanographic Research Institute (ORI) and others of fish populations in Natal estuaries and at Rhodes University and the University of Cape Town on the ecophysiology of estuarine macro-invertebrates. More recently, the NPES marine pollution survey has collected a good deal of information on concentrations of heavy metals, pesticide residues and other pollutants in estuarine sediments and biota around the coast and work has been carried out on aspects of the hydraulics of a number of estuaries.

Estuaries may be defined as partially enclosed bodies of water receiving freshwater inflow, in which mixing between fresh and seawater occurs, which are connected to the sea and at least at some time under tidal influence. They are by their very nature, and as a result of the highly erratic inputs of freshwater they receive, highly dynamic ecosystems. If the mouth is open, a wedge of saltwater will enter and leave the estuary and the water level will rise and fall twice daily. Depending on the size of the rivers

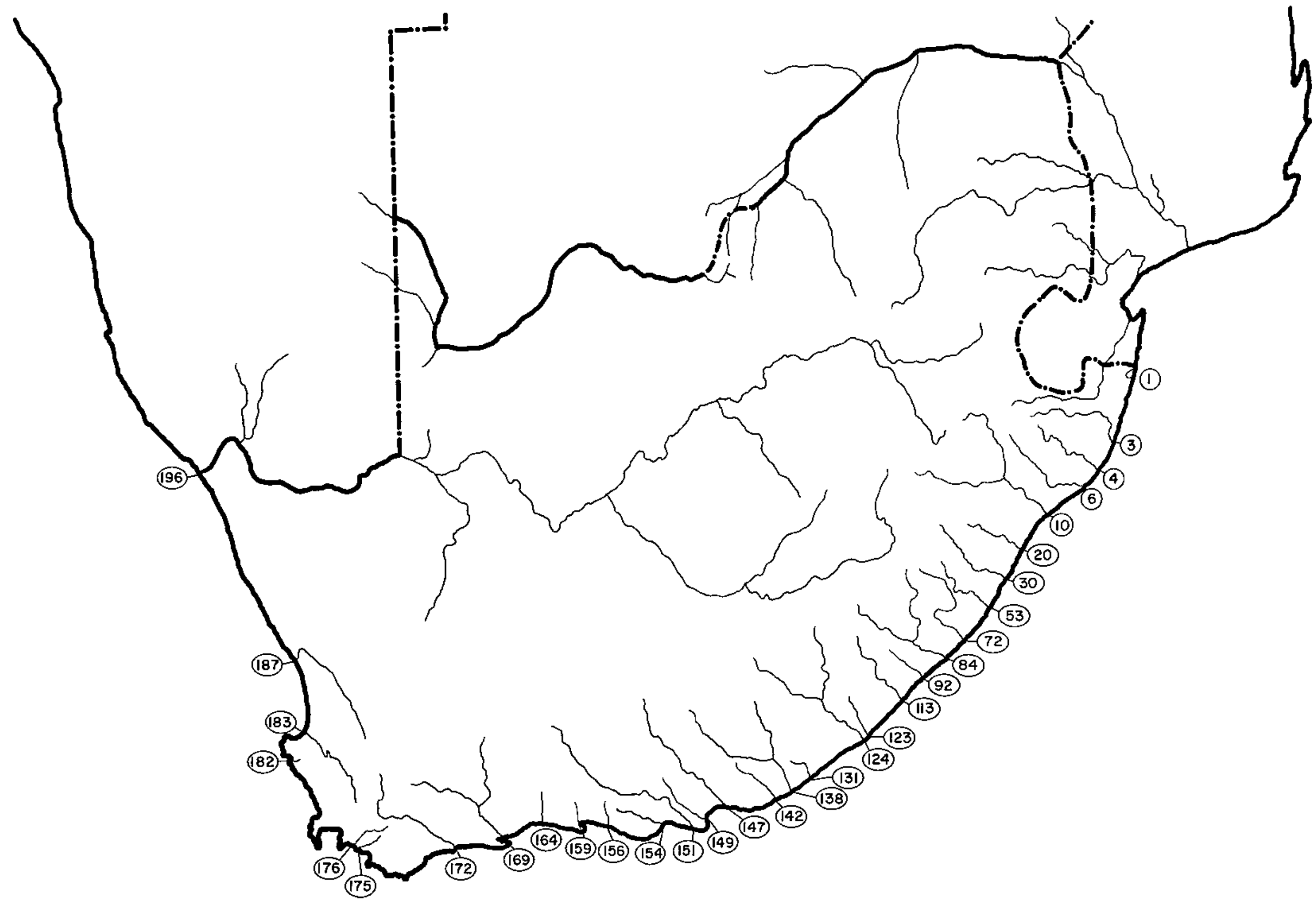

Figure 9. Major estuaries in South Africa (refer to Table 8 for names).

they receive, estuaries can at times of flood be entirely flushed by freshwater and the zone of salinity mixing can be pushed right out to sea. At times of abnormally low flow, if the estuarine area or estuarine lake is large (St Lucia is the extreme example), evaporation can increase salinities to well above that of seawater. Geomorphologically estuaries are also very changeable. River courses meander and dramatic changes (for instance the creation of sand and mud banks and the cutting of new channels and mouths) can take place in a single flood.

A few freshwater organisms are able to penetrate into estuaries. There are many marine animals that can either live permanently in estuaries or migrate into estuaries and spend large parts of their life there. There are also many purely estuarine species never found anywhere else. The distribution of these organisms in the estuarine area will depend on various factors, for instance their ability to tolerate salinity fluctuations, temperature extremes or solid material either in suspension or being deposited, their dissolved oxygen requirements and any specific food, substrate or water level requirements they may have.

The numbers of species found depend primarily on the diversity of physical habitats, the oxygenation of the deeper water and sediments, and the absence of excessive sedimentation. In addition, the marine component of the biota (for instance crabs and fishes) tends to be most diverse on the east coast and least diverse on the west coast.

If freshwater discharge into the estuary is relatively small and the mouth is open, salinities near the mouth will not fluctuate a great deal and will approach that of seawater. This part of the estuary will then be colonized by marine organisms favoured by shelter from wave action. If the area near the mouth offers a variety of physical habitats, as is the case in the Knysna estuary, the biota of this part of the estuary, and especially the sand and mud banks, will be very diverse (comprise many species). While most of these species are able to tolerate lower salinities, many may not survive long exposure or may only be able to achieve a reproductive state at salinities near that of seawater.

Salinity fluctuations are normally highest at the head of the estuary, near the erratic freshwater inflow, and can vary from freshwater to brackish and even to well above seawater in some instances. The biota of this part of the estuary is normally very poor in numbers of species, but may be high in biomass in some cases.

The tidal sand and mud flats in the middle and upper reaches of estuaries normally support a characteristic salt marsh vegetation of low grasses, sedges, succulent angiosperms and sea grasses. In many east coast estuaries, these tidal flats previously had well developed mangrove forests, most of which have been destroyed. Each vegetation zone has an associated fauna, as does the belt of eel grass *Zostera* found at low tide level in most clear estuaries with good tidal exchange.

Primary production within the estuary itself normally accounts for only a small proportion of the energy base for macro-invertebrate and fish production and is supplemented by material carried into the estuary. This material includes plant detritus (derived mainly from the decomposition of shallow-water rooted vegetation) and organic sediment (negatively charged particles of which are precipitated by positively charged cations in the estuary). Detritus input results in the development of rich sediments which are a characteristic feature of estuaries. It seems likely that microbes growing on detritus particles synthesize proteins and serve as an important food for micro-invertebrates and larger animals. The addition of detritus makes estuaries highly productive ecosystems, able to support large populations of macro-invertebrates and fish.

South Africa has a coastline characterized by relatively high wave energy and moderately low tidal ranges. Wave action and longshore drift tend to build sand bars across estuary mouths. In a few, such as Knysna, the mouth is never closed by the sand bar but the tidal mixing is reduced and is insufficient to break down the vertical salinity stratification. In others, such as St Lucia, the mouth may occasionally be closed, for instance during extreme droughts. The mouths of a great many estuaries are closed for varying periods seasonally, being opened whenever the river level rises. The mouths of a great many smaller rivers are closed for extended periods, forming seasonal lagoons.

Lagoons may be defined as shallow brackish standing water bodies connected intermittently to the sea. Several changes take place after they are cut off from tidal mixing. Mangroves and other plants that depend on tidal rise and fall in water level die and some die-off of salt marsh plants can take place. Anaerobic areas (black and smelling of hydrogen sulphide) develop under the sand and mud surface. Many of the fish and macro-invertebrates tend to decline in numbers and become stunted. The salinities decrease with time, except in the lagoons of the dry west Cape coast, which can dry out completely in summer. If the water is shallow, the salinity stratification is broken down by wind mixing.

Classification of estuaries

Descriptions are given in Table 7 of five estuarine types found around the South African coast. The dynamic nature of estuaries makes them difficult to place in categories and the types are not distinct from one another and represent a continuous series.

These types could be said to represent phases through which estuaries can pass. An estuary of one type can behave at times like quite a different type, depending on fluctuations in river flow and the changing condition of the mouth. A typical example is an estuary which forms a lagoon cut off from the sea at times of low river flow. The same estuary may behave like a typical estuary when the mouth is open. It will show tidal exchange and have a vertical salinity stratification during this phase. For brief periods when the river comes down in high flood, the same estuary may behave like a river mouth. During this phase it will be entirely fresh, with the zone of salinity mixing having been pushed out to sea.

Of all inland water ecosystems, estuaries are probably under most pressure from urban and other development, sought after as recreation sites and threatened by the consequences of such development. Some have been developed as harbours, some have been greatly damaged by industrial development and a few have been used for salt production and other purposes. A great many have been exposed to uncontrolled building development, alteration in water levels or destruction or modification of the aquatic or littoral environment by, for instance, bridges, dykes, embankments and other structures. Because of their dynamic nature, estuaries are also more sensitive to interference than are most other ecosystem types.

Table 7. Types of estuaries on the coast of South Africa.

Type	Examples
<u>Estuaries forming temporary lagoons</u> Sometimes termed blind estuaries. A closed standing water body formed at times (usually seasonally) by closure of the mouth by a low sand bar. Freshwater dominated and non-tidal while closed, usually with only occasional vertical salinity stratification. Plant communities requiring tidal movement absent (mangroves, salt marsh). The system will behave like a typical estuary (tidal exchange, salinity stratification) when open and like a river mouth (no tidal exchange, freshwater into sea) briefly during floods.	Mhlanga (Natal) and Kleinriviersvlei (south-western Cape) are good examples. Lagoons are formed at the mouths of most smaller rivers along the Natal, Transkei and southern Cape coasts.
<u>Embayment estuaries</u> Tidal waterbody and wetlands on landward side of a coastal barrier. Always or almost always tidal, with typical estuarine characteristics (salinity stratification, rich sediments, estuarine biota), salinity dominated by seawater. Almost never behave like river mouths.	Knysna (southern Cape) is the best example and has all the features of a Cape estuary well developed. Mhlatuze/Richards Bay, Durban Bay (Natal) were typical Natal examples with mangroves, but are now disturbed. Langebaan (western Cape) is shallow with little freshwater inflow and a wide mouth.
<u>Estuaries connected to coastal/estuarine lakes</u> Otherwise like typical estuaries (next type) or (in one case) lagoons.	Kosi, St Lucia (Natal) and Swartvlei southern Cape) are typical estuaries. Touw (southern Cape) is a lagoon.
<u>Typical estuaries</u> Estuaries with a mouth which is usually open, often with a relatively large tidal and wetland area (with salt marsh or mangroves showing that mouth closes for short periods only) showing typical estuarine characteristics (salinity stratification, rich sediments, estuarine biota). This category could be divided into several subtypes (for instance mangrove estuaries, estuaries with salt marsh, estuaries with extensive mudflats, estuaries lacking extensive wetlands). Those fed by larger rivers will behave like river mouths during floods.	Mlalazi (Natal mangrove estuary), Kowie and Heuningnes (eastern and southern Cape estuaries, but the first physically disturbed and the second intermittently linked to Soetendalsvlei), Matigulu (Natal, without extensive wetland), Swartkops and Breë (eastern and southern Cape, with salt marsh), Sundays (eastern Cape, with mudflats).
<u>River mouths</u> River valley extends to coastline and volume of discharge large, area of tidal exchange limited (fresh and seawater mixing largely in sea), wetland area negligible and typical estuarine characteristics (salinity stratification, rich sediments, estuarine biota) absent or poorly developed.	Tugela (Natal), Orange (western Cape).

Table 8. Some characteristics of South African estuaries. Catchment areas are in some instances averages of literature figures.

Estuary	Catchment area (km^2)	Mean annual runoff ($\times 10^6$ m^3)	Sediment erosion	State of development	Classification	State of knowledge
1. Kosi	∿ 500	unknown	-	growing population	mouth mostly open, linked to lakes	good
2. Mgobezeleni	33	unknown	-	bridges	mouth mostly open, linked to lake	fair
3. St Lucia (Mkuze)	8 982	295	sediment	dredging, wetland destruction	mouth mostly open, linked to lake	very good
4. Mfolosi	10 645	729	heavy sediment	sugar cane, wetland destruction	river mouth	poor
5. Nhlabane	104	29	-	industry, impoundment	mouth mostly open, linked to lake	very poor
6. Richards Bay (Mhlatuze)	4 373	616	heavy sediment	harbour, pollution, sanctuary	embayment, mouth mostly open	good
7. Mlalazi	454	135	sediment	-	estuary, generally open	fair
8. Siyai	18	unknown	sediment	-	lagoon	very poor
9. Matigulu/Nyoni	980	181	sediment	prawn culture	estuary, often closed	fair
10. Tugela	28 702	5 017	sediment	industry, pollution	river mouth	poor
11. Zinkwazi	73	14	sediment	agriculture	lagoon	poor
12. Nonoti (eNonoti)	251	48	sediment	pollution	lagoon	very poor
13. Mdlotane	43	10	-	agriculture	lagoon	very poor
14. Mvoti	2 651	297	sediment	industry	estuary, generally open	poor
15. Seteni	16	unknown	sediment	-	lagoon	very poor
16. Mhlali	294	55	sediment	-	lagoon	poor
17. Tongati	412	89	sediment	pollution, embankments	lagoon	poor
18. Mdloti	558	112	sediment	pollution, embankments, wetland destruction	lagoon	poor
19. Mhlanga (Ohlanga)	135	25	heavy sediment	pollution, embankment	lagoon	fairly poor
20. Mgeni	4 871	707	sediment	industry, urban development, bridges	estuary, generally open	good
21. Durban Bay	210	unknown	-	industry, urban development, harbour	embayment	fairly poor
22. Sipingo	39	3	heavy sediment	industry, bridges	lagoon	fair
23. Mbokodweni	243	10	sediment	industry	lagoon	fairly poor
24. Manzimtoti	30	1,5	sediment	urban development, bridges	lagoon	good
25. Little Manzimtoti	12,5	unknown	sediment	urban development, bridges	lagoon	very poor
26. Lovu	938	115	sediment	industry, urban development bridges	estuary, often closed	poor

Table 8 (continued).

Estuary	Catchment area (km^2)	Mean annual runoff (x 10^6 m^3)	Sediment erosion	State of development	Classification	State of knowledge
27. Msimbazi	36	unknown	-	embankments	lagoon	fair
28. uMgababa	37	14	heavy sediment	bridges	lagoon	good
29. Ngane	16,5	unknown	sediment	-	lagoon	poor
30. Mkomazi	4 315	1 072	sediment	industry, bridge	estuary, generally open	poor
31. Mahlongwana	17	unknown	-	-	lagoon	very poor
32. aMahlongwa	100	15	-	-	lagoon	poor
33. Mpambanyoni	548	39	heavy sediment	embankments	lagoon	poor
34. Mzimayi	31	unknown	-	-	lagoon	very poor
35. Mzinto	164	25	sediment	embankments	lagoon	poor
36. Mkumbane	28	unknown	sediment	-	lagoon	very poor
37. Sezela	20	unknown	-	industry	lagoon	poor
38. Mdesingane	6	unknown	-	-	lagoon	very poor
39. Fafa	252	30	sediment	pollution	lagoon	good
40. Mvuze (Mkuze)	8	unknown	-	embankments	lagoon	very poor
41. Mtwalume	551	68	heavy sediment	embankments	lagoon	poor
42. Mnamfu	15	unknown	-	embankments	lagoon	very poor
43. kwaMakosi	10	1,5	-	embankments	lagoon	very poor
44. Mfazazana	15	unknown	-	-	lagoon	very poor
45. Mhlungwa	31	unknown	sediment	embankments	lagoon	poor
46. Mhlabashane	42	unknown	sediment	-	lagoon	poor
47. Mzumbe	617	75	sediment	embankments	lagoon	poor
48. iNtshambili	34	unknown	-	-	lagoon	poor
49. Koshwana	12	unknown	-	-	lagoon	very poor
50. Domba	26	unknown	-	-	lagoon	poor
51. Mhlangamkulu	12	unknown	-	-	lagoon	very poor
52. Mtentweni	53	4	sediment	-	lagoon	fairly poor
53. Mzimkulu	6 694	1 455	sediment	embankments	estuary, generally open	fair
54. Mbango	12	unknown	-	-	lagoon	very poor
55. Boboyi	31	unknown	-	-	lagoon	poor
56. Zotsha	71	12	-	embankments	lagoon	fairly poor
57. Mhlangeni	44	unknown	sediment	urban development	lagoon	fairly poor
58. Vungu	102	18	-	-	lagoon	fairly poor
59. Kongweni	18	unknown	-	urban development	lagoon	very poor
60. Uruzana	7	unknown	sediment	-	lagoon	very poor
61. Bilanhlolo	19	unknown	-	urban development	lagoon	poor

Table 8 (continued).

Estuary	Catchment area (km²)	Mean annual runoff (x 10^6 m^3)	Sediment erosion	State of development	Classification	State of knowledge
62. Mvutshini	6	unknown	-	-	lagoon	poor
63. Mbizane	150	20	sediment	-	lagoon	poor
64. Kaba	12	unknown	sediment	-	lagoon	very poor
65. Mhlangamkulu	10	unknown	sediment	urban development	lagoon	good
66. Mpenjati	87	16	sediment	-	lagoon	poor
67. Kandandlovu	11	unknown	-	-	lagoon	very poor
68. Tongazi	20	unknown	-	-	lagoon	very poor
69. kuBoboyi	4	unknown	sediment	-	lagoon	very poor
70. Sandlundlu	19	unknown	sediment	embankments	lagoon	very poor
71. Zolwane	7	unknown	-	-	lagoon	very poor
72. Mtamvuna	1 589	281	-	-	estuary, generally open	good
73. Mzamba	658	107	-	-	estuary	very poor
74. Mnyameni	306	68	-	-	estuary/lagoon	very poor
75. Mtentu	1 595	221	-	reserve	estuary, often closed	fair
76. Msikaba	1 629	251	-	reserve	mangrove estuary	fair
77. Mkweni	212	69	-	-	estuary	very poor
78. Mlambomkulu	236	82	-	-	estuary, always open	very poor
79. Mbotyi			-	-	lagoon	very poor
80. Mzimpunzi			-	-	estuary	very poor
81. Mzintlava	591	194	-	-	estuary	very poor
82. Mutafufu	238	75	-	-	mangrove estuary	very poor
83. Nkodusweni			-	-	estuary	very poor
84. Mzimvubu	19 904	3 417	heavy sediment	old harbour	estuary	very poor
85. Mngazi	922	127	-	-	estuary	very poor
86. Mngazana	632	110	-	planned harbour	estuary, mostly open	very poor
87. Mtonga			-	-	mangrove estuary	very poor
88. Mnenu	458	120	-	-	estuary	very poor
89. Mtakatye	878	126	-	-	estuary	very poor
90. Lwandile			-	-	estuary	very poor
91. Mdumbi	324	55	-	-	estuary	very poor
92. Mtata	2 800	406	sediment	-	estuary	very poor
93. Mapuzi			-	-	estuary	very poor
94. Nenga	161	40	-	-	estuary	very poor
95. Mpako	140	32	-	-	estuary	very poor
96. Mncwasa	300	64	-	-	estuary	very poor
97. Bulungula			-	-	estuary	very poor
98. Xora	622	88	-	-	lagoon	very poor
99. Ntlonyane	205	45	-	-	estuary	very poor

Table 8 (continued).

Estuary	Catchment area (km^2)	Mean annual runoff ($x\ 10^6\ m^3$)	Sediment erosion	State of development	Classification	State of knowledge
100. Mbashe	6 358	942	-	-	estuary	very poor
101. Mendu			-	-	estuary	very poor
102. Nqabara	1 210	191	-	reserve	estuary	very poor
103. Shixini	567	93	-	-	estuary	very poor
104. Jujura			-	-	estuary	very poor
105. Qora	1 041	164	-	-	estuary	very poor
106. Ngqwara			-	-	estuary, often closed	very poor
107. Gqunqe	205	40	-	-	estuary	very poor
108. Cebe			-	-	estuary	very poor
109. iNxaxo	140	27	-	-	estuary/lagoon	very poor
110. Kobonqaba	433	60	-	-	estuary	very poor
111. Qolora			-	-	lagoon, southernmost mangrove	very poor
112. Gxara	47	9	-	-	estuary	very poor
113. Kei	20 559	1 001	sediment	-	estuary	very poor
114. Incarha			-	-	lagoon	very poor
115. Quko	254	41	-	-	estuary	very poor
116. Kwenxura	272	25	-	-	estuary	very poor
117. Cefane			-	-	estuary	very poor
118. Cintsa			-	-	estuary	very poor
119. Bulura			-	-	estuary	very poor
120. Kwelera	464	32	-	-	lagoon	very poor
121. Gqunube	660	35	-	-	lagoon	very poor
122. Qinira			-	-	lagoon	very poor
123. Nahoon			-	urban development, bridges	lagoon	very poor
124. Buffalo	1 295	82	-	harbour, bridges, dredging, urban development, pollution		very poor
125. Goba	80	6	-	-	estuary	very poor
126. Gxulu	106	6	-	-	estuary	very poor
127. Ncera	114	6	-	-	lagoon	very poor
128. Tyolomnqa	469	25	-	-	lagoon	very poor
129. Kiwane	67	2	-	-	estuary	very poor
130. Ngqinisa			-	-	estuary	very poor
131. Keiskamma	2 751	133	-	settlement, suggested harbour/marina	estuary	very poor
132. Cqutywa	83	2,5	-	-	lagoon	very poor
133. Bira	254	6	-	-	lagoon	very poor
134. Mgwalana	197	5	-	-	lagoon	very poor
135. Mtati	130	3,5	-	-	lagoon	very poor

Table 8 (continued).

Estuary	Catchment area (km^2)	Mean annual runoff ($x 10^6 m^3$)	Sediment erosion	State of development	Classification	State of knowledge
136. Mpekweni	65	2	-	-	lagoon	very poor
137. Old Woman's			-	-	lagoon	very poor
138. Fish	30 427	479	sediment	-	estuary	very poor
139. Oos-Kleinemond	140	6	-	-	lagoon	very poor
140. Wes-Kleinemond			-	-	lagoon	fair
141. Riet	117	4	-	-	lagoon	very poor
142. Kowie	769	23	-	urban development, dredging, embankments	estuary	fair
143. Kasuka	130	5	-	-	lagoon	poor
144. Kariega	686	15	-	-	lagoon	poor
145. Bushmans	2 678	38	-	settlement	estuary	poor
146. Boknes	202	13	-	-	lagoon	very poor
147. Sundays	3 877	29	sediment	settlement, bridges	estuary	poor
148. Coega	624	13	-	salt works, extensive earth works	lagoon	very poor
149. Swartkops	1 370	84	-	urban development, industry, pollution, bridges	estuary	good
150. Yellowwoods	544	45	-	-	lagoon	poor
151. Gamtoos	34 491	485	sediment	bridges	estuary, often closed	poor
152. Kabeljou	502	27	-	-	lagoon	poor
153. Seekoei	502	27	-	-	lagoon	poor
154. Krom	1 085	105	-	marina, bridge	estuary	poor
155. Klipdrif	197	35	-	settlement, bridge	estuary, always open	very poor
156. Storms	179	69	-	reserve	estuary, always open	poor
157. Groot			-	settlement	lagoon	very poor
158. Elandsbos	189	67	-	-	estuary	very poor
159. Keurbooms	1 085	160	-	settlement, embankments, reserve	estuary, mostly open	poor
160. Noetsie			-	-	lagoon	very poor
161. Knysna	526	110	-	town, marinas, industry	embayment	very good
162. Goukamma	233	44	-	reserve	estuary, often closed	poor
163. Swartvlei	456	73	longshore only	settlement	estuary connected to lake, seasonally closed	good
164. Touw	155	30	longshore only	town, bridges	estuary connected to lakes, seasonally closed	fair
165. Kaaimans	342	59	-	bridges	estuary, seasonally closed	very poor
166. Groot Brak	192	29	-	settlement, bridges, oil slick recently	estuary, open	fair

Table 8 (continued).

Estuary	Catchment area (km^2)	Mean annual runoff ($x 10^6 m^3$)	Sediment erosion	State of development	Classification	State of knowledge
167. Klein Brak	552	45	-	-	estuary/lagoon	poor
168. Hartenbos	207	5	-	-	lagoon	very poor
169. Gouritz	45 742	744	sediment	settlement	estuary	very poor
170. Kafferkuils	1 549	141	-	-	estuary	very poor
171. Duiwenhoks	1 336	131	-	-	estuary	very poor
172. Breë	12 587	1 893	-	settlement	estuary, open	poor
173. Heuningnes	1 401	78	longshore only	reserve	estuary, intermittently connected to lakes, seasonally closed	poor
174. Uilskraal	391	65	longshore only	-	estuary	very poor
175. Kleinriviersvlei	741	96	-	settlement	lagoon	good
176. Botriviersvlei	927	116	-	settlement, marina	lagoon	very poor
177. Palmiet	539	310	-	-	estuary, open	very poor
178. Sandvlei			-	urban development, marina, artificially controlled mouth	estuarine lake	good
179. Wildevoëlvlei	114	38	-	-	estuarine lake and tidal lagoons	very poor
180. Sout	113	38	-	urban development, industry, bridges, pollution		very poor
181. Diep	246	43	sediment	urban development	estuary, seasonally closed	good
182. Langebaan	unknown	unknown	sediment from dredging	reserve, but nearby Saldanha harbour	embayment	very good
183. Berg	4 807	234	-	artificial mouth, villages, fishing	estuary, open	poor
184. Verlorevlei	1 891	102	-	bridges	estuary connected to coastal lake	fair
185. Wadrifsoutpan	658	19	-	-	lagoon/estuarine lake	very poor
186. Jakkals	896	10			lagoon	very poor
187. Olifants	46 084	1 217	some sediment	villages	estuary, almost an embayment	poor
188. Sout	unknown	unknown	-	-	lagoon	very poor
189. Groen	unknown	unknown	-	-	estuary	very poor
190. Bitter	unknown	unknown	-	-	lagoon, often dry	very poor
191. Spoeg	unknown	unknown	-	-	lagoon, often dry	very poor
192. Swartlintjies	unknown	unknown	-	-	lagoon, often dry	very poor
193. Buffels	unknown	unknown	-	-	estuary, often dry	very poor
194. Kamma	unknown	unknown	-	-	estuary, often dry	very poor
195. Holgat	unknown	unknown	-	-	estuary, often dry	very poor
196. Orange	852 000	9 344	-	-	river mouth	fair

Future needs

The Oceanographic Research Institute (ORI) is currently synthesizing available data on Natal estuaries on behalf of the Natal Town and Regional Planning Commission. There is a need for data on Cape estuaries to be similarly synthesized and for this information to be used for planning, for the assessment of environmental effects, to identify research needs and to recommend representative estuaries for conservation. There is also a need for these syntheses to be supported by preliminary bathymetric surveys.

There is a need for information on the transport of sediment and pollutants into estuaries, their transport through estuaries to the sea and possible ecological implications, in order to guide management policies for estuaries.

These pollutants include potentially toxic chemicals. There is a need for information on the quantities of these chemicals, the forms in which they occur, any transformations they may undergo, their pathways through estuarine ecosystems and potential or actual ecotoxicity.

There is a need for information on the biology of juvenile stages of marine fish which enter Cape estuaries. There is also a need for information on the marine stages of these fish species. There is further a need for an understanding of the effects of angling and other exploitation and of management of the estuary (including closing and opening of the mouth) on the fish populations.

There is a need for information on the rôle of microbes, sediments, suspensoides and plant detritus in estuaries, in particular in regard to energy flow in estuarine ecosystems. There is also a need for autecological information on estuarine macro-invertebrates, in particular those with potential for utilization.

There is a need for an understanding of the rôle of tidal exchange and water movement in maintaining estuarine ecosystems, in order to make it possible to predict possible consequences of management actions or construction works which could alter the tidal movement.

There is a need for information on the environmental requirements of *Zostera* beds and other vegetation in estuaries in order to make it possible to predict possible consequences for the vegetation of any changes which may occur or be planned.

A general decrease in the volume of river flow to South African estuaries may be expected in the future. There is a need for an assessment of the possible consequences of such a reduction for estuaries, for energy flow in estuaries and for salt marshes and other wetlands.

ENVIRONMENTAL PROBLEMS AND RESEARCH NEEDS

Many of the environmental problems of inland waters in South Africa are shared by more than one of the ecosystem types described in the previous chapter. In fact, there are a number of overall questions or themes which run through the IWE programme and may be seen as its "horizontal" components (with the ecosystem types being its "vertical" components).

NUTRIENT DYNAMICS AND EUTROPHICATION

Nature of the problem

Aquatic plants (hydrophytes) and algae in the aquatic environment depend for their growth on plant nutrients leached out of soils and rock and cycled in aquatic ecosystems. When the activities of man, such as the disposal of nutrient rich effluents or the application of fertilizers to land, result in greater quantities of plant nutrients entering the aquatic environment, more hydrophytes and algae will grow. When this fertilization is excessive the result is the overabundant growth of primary producers (photosynthesizing hydrophytes and algae).

Eutrophication is the process of enrichment of the aquatic environment with plant nutrients and is a worldwide problem because of the adverse effects caused by the overabundant growth of hydrophytes and algae. These can result in a variety of water quality problems, increasing the costs of the production of potable water, reducing aesthetic and recreational value of water bodies, posing health hazards through blooms of toxic algae and producing adverse changes in water quality such as the depletion of oxygen in the deeper water layers and the release of manganese, iron and phosphates from the bottom sediments.

Most of these eutrophication problems have already occurred in South Africa. The costs of producing water from the Ntshongweni, Rietvlei and Hartbeespoort Dams have been increased by blue-green algal blooms. Taste and odour problems due to the algal growth have been experienced in the potable water from Rietvlei and Hartbeespoort Dams and aesthetic problems due to algal scums and layers are common in a number of impoundments. The recreational use of Hartbeespoort Dam was almost terminated by a massive infestation of water hyacinth *Eichhornia crassipes* which was brought under temporary control in 1977 through a chemical spraying programme costing about R150 000. Health problems such as gastro-enteritis have been ascribed to toxic algae in Hartbeespoort and Roodeplaat Dams. Extensive anaerobic conditions occur in the deeper water layers (the hypolimnion) of eutrophic (highly enriched) impoundments such as Hartbeespoort, Roodeplaat and Rietvlei Dams and may be accompanied by the release of manganese and iron from the sediments.

The rapidly increasing population and urbanization in South Africa will result in increased discharge of effluents to the aquatic environment. If these effluents are rich in plant nutrients, eutrophication will increase. The potential dangers of eutrophication were recognized by the Department of Water Affairs and the South African Bureau of Standards who requested the Water Research Commission (WRC) in 1971 to sponsor suitable research on the control of the problem. As a consequence a contract study of eutrophication in impoundments was undertaken by the NIWR and the WRC sponsored a study of the rôle of hydrophytes in the nutrient dynamics of Swartvlei carried out by the Rhodes University IFWS. In addition, some of the research projects sponsored by IWE have dealt with certain aspects of eutrophication, one example being the University of Natal study of the rôle of sediments in Midmar Dam.

Present state of knowledge

Initial studies involved the use of algal bioassays to determine algal growth potential and growth limiting nutrients in 98 South African impoundments, including Hartbeespoort, Roodeplaat, Rietvlei and Vaal Dams. About 50 percent of these impoundments were found to be low in plant nutrients (oligotrophic), 11 percent were heavily enriched (eutrophic) and the remaining 39 percent were intermediate (mesotrophic). Phosphorus (P) compounds were the most frequent algal growth limiting nutrient in non-eutrophic impoundments and nitrogen (N) compounds the most frequent algal growth limiting nutrient in highly eutrophied ones. Algae capable of fixing atmospheric nitrogen were found in Rietvlei Dam and elsewhere and it was suggested that limiting the access of phosphates to impoundments might be the long term solution to eutrophication problems in South Africa.

The discharge of sewage effluents after secondary treatment has been found to be the main source of nutrients for most eutrophic South African impoundments. The nutrient contributions of urban and agricultural runoff are generally much lower, but could be of sufficient magnitude to result in elevated algal or plant growth in certain instances, for instance Hartbeespoort Dam. Rainwater could also be a significant source of nutrients in some instances.

A coordinated programme is in progress to compare algal growth and N and P compound loadings of 22 impoundments in different parts of the country. It is hoped that an analysis of the findings may assist in suggesting nutrient loading limits for impoundments, reveal possible differences between the algal growth responses of impoundments to external nutrient loading, suggest factors responsible for the differences and indicate the possible extent and importance of nutrient recycling (internal loading).

Studies of algal growth, the availability of P compounds and the sediment-water exchange of phosphates in isolation columns in Midmar Dam by the University of Natal Department of Botany have shown that the accumulation of P compounds in sediments can be an important aspect of the nutrient budgets in impoundments and that considerable sediment-water exchange and recycling can take place, depending on circumstances. When nitrates (but not phosphates) were added to individual columns in one experiment, considerable release of phosphates from the sediments took place and eutrophic conditions were established in the column. In a situation where considerable phosphate accumulation has taken place in the sediments, therefore, nutrient cycling phenomena may be taking place which could drastically affect the effect of phosphate loading alone on primary production and which could negate the control of eutrophication by phosphate limitation alone. However, the second year of this study did not clearly indicate the same trends and the above interpretation of the findings is still subject to confirmation.

Another factor influencing the relation between nutrient loading and algal growth is the turbidity of the water. Artificial fertilization of a relatively clear impoundment (Buffelspoort Dam) and a turbid impoundment (Lindleyspoort Dam) resulted in similarly increased algal growth in both, but average standing crops were lower in the turbid impoundment, suggesting that the response of turbid impoundments to fertilization may not be identical to that of clear water impoundments and that different control strategies may have to be followed in different cases.

Most impoundments in the mid-interior are highly turbid and it is clear from preliminary work that suspensoids have a marked effect on primary production rates in these water bodies, not only by restricting sunlight penetration, but also by absorbing and re-releasing N and P compounds necessary for plant growth. In addition, suspensoids appear to provide a substratum for heterotrophic micro-organisms (decomposers) which in turn serve as food for zooplankton. This might explain some of the observations of high zooplankton numbers in some very turbid impoundments. These aspects are at present being investigated in a study being carried out by the University of the Orange Free State IES, for instance at Wuras Dam, a small turbid impoundment in the Orange Free State.

The research at Swartvlei has dealt with the nutrient dynamics within a submerged hydrophyte band around the lake, mostly *Potamogeton pectinatus*. Very little phosphorus-containing material is present in the water column either in solution or suspension and a large amount of phosphorus is locked into the deepwater sediments. Most of the mobile phosphorus is circulating between the shallow sediments and *Potamogeton* growth and its associated organisms.

Preliminary results suggest that vlei systems retain significant quantities of nutrients from streams passing through them, at least during periods of moderate and low stream flow. Nutrient concentrations in the catchment streams of Rietvlei Dam show sharp decreases immediately below two vleis and nutrient concentrations and algal growth in the dam are significantly lower than might be expected from the nutrient pollution in the catchment. This suggests that the beneficial effects of the vleis might not be completely negated by periodic flooding. The technology exists to remove nutrients from point source effluents, and possibilities should be explored of utilizing the capacity of vleis to retain nutrients as a means of controlling diffuse sources of nutrients which would otherwise contribute to the eutrophication of impoundments. It might even be possible to control eutrophication in some instances through the artificial establishment of reedbeds, if some of the other disadvantages of reedbeds described in the chapter on vleis can be overcome.

Information required

1.1 Assessment and prediction of eutrophication problems

A proposed programme to monitor the incidence of hydrophytes and excessive algal growth in State and other dams will be described in the next section (see 2.1.2). This will provide part of the information required to make the following possible :

- The development of a scientific and economic basis for assessing eutrophication and determining priorities for research.

1.1.1 Social and economic costs of eutrophication and its side effects

Information is required to make possible an assessment of community costs (for instance increased costs of water treatment, loss in amenity value) and of possible benefits to be derived from research and from different control strategies.

1.1.2 Criteria to assess trophic status

Criteria to assess the trophic status of South African impoundments need to be developed from the existing preliminary criteria and used to recommend what trophic status could be regarded as acceptable or unacceptable, to re-evaluate procedures for the classification of impoundments using monitoring data (see 1.2.1 and 2.1.2) and to re-examine the goals and guidelines for eutrophication prevention and control in the Republic of South Africa.

1.1.3 Procedures for the prediction and assessment of eutrophication

Procedures need to be developed for the identification of streams and impoundments actually or potentially threatened by eutrophication, for the routine and ongoing assessment of eutrophication and for prediction of eutrophication problems (using planning and other information).

1.2 Nutrient transport in rivers and streams

Information is needed on the nitrogen and phosphorus balances of a small number of representative river catchments in which good hydrological measurements are being made in order to make the following possible :

- The estimation of the N and P compound loadings of these rivers from such sources as rainfall, agricultural fertilizers, synthetic detergents, wastes treatment plants and urban runoff and their fluctuations with time.

- An understanding of the rôle of land use practices and other factors in determining the N and P compound loadings of these rivers.

- An understanding of rates of transport of N and P compounds in these rivers, transformations undergone by these compounds and the sites and times of their accumulation and release.

- The prediction based on this knowledge of the possible effects of different possible eutrophication prevention and control strategies on nutrient loads transported by rivers into impoundments.

1.2.1 Monitoring of nutrient loads in South African rivers

There is a need for methods for the estimation of nutrient loads in rivers to be reviewed. At the same time, the Department of Water Affairs and the WRC Coordinating Research and Development Committee for Water Quality should be requested to provide for the monitoring of nutrient loads transported by rivers into major impoundments in South Africa.

1.3 Rôle of vlei ecosystems in accumulating and re-releasing nutrients, sediment and other pollutants

Information on the rôle of vlei ecosystems is required in order to make the following possible :

- The estimation of the uptake, accumulation and re-release of nutrients, sediment and toxic pollutants by vlei ecosystems and of possible fluctuations in these rates with time, flooding and so forth.

- The estimation of the influence of vlei ecosystems on water losses in river systems through evaporation, evapotranspiration and infiltration.

- An understanding of the hydrological, health and other implications of vlei development, such that predictions can be made of practical consequences of vlei growth and destruction under different conditions.

- An understanding of the factors influencing nutrient, sediment and toxic pollutant retention and release from vleis, such that predictions can be made of water quality consequences of vlei growth and destruction under different conditions.

- An assessment of the distribution and conservation status of existing vlei ecosystems in South Africa.

- An assessment of the prospects, costs and benefits of artificially establishing new vlei ecosystems at selected points in certain river systems.

1.3.1 Distribution and status of vlei ecosystems

Information is required on the distribution, characteristics, types and conservation status of vlei ecosystems in the Republic of South Africa.

1.3.2 Retention of nutrients and evapotranspirative water loss in existing vlei ecosystems

Information is required for at least one suitable vlei of its inputs and outputs of nutrients, sediment and toxic pollutants measured for a period during different hydrological and other conditions in order to assess the extent to which nutrients and so forth may be accumulated and re-released and in order to assess the possible significance of these processes for the nutrient loading of downstream impoundments. The vlei should have a relatively high external nutrient loading rate (as do those south and north-east of Johannesburg), should have accurate flow gauging facilities upstream and downstream of the vlei and should have insignificant underground water losses and gains (unlike many Witwatersrand vleis).

1.3.3 Water relations, nutrient turnover and growth kinetics of emergent marsh plants

Information is required on these parameters for different emergent marsh plants (see 2.2.2) in order to improve understanding of the effects of vleis on total water loss from river systems through evaporation and evapotranspiration.

1.3.4 Retention of nutrients and other pollutants in artificially established vlei ecosystems

If the information from 1.3.2 confirms that nutrients and other pollutants are retained by vlei ecosystems, possibilities should be considered of measuring their retention in a new and artificially established vlei.

1.4 Nutrients and algal growth in impoundments

Research is in progress on several impoundments and a good deal of further work will be required in order to provide the information to make the following possible :

- The estimation of quantities of N and P compounds from different sources (see 1.2) entering selected catchments, their rates of transport, quantities accumulated and released at different places, the fluctuations that occur with time and under different flow conditions and the transformations undergone.
- An understanding of the nutrient budgets of selected impoundments, the fluctuations in concentrations of different N and P compounds in the water, biota and sediments and rates of transfer between different components.
- An understanding of the rates and factors influencing the uptake and release of different N and P compounds by sediments (see 1.5) and suspensoids (see 1.6).
- An understanding of the availability to primary producers of different N and P compounds and of factors influencing their uptake and re-release.
- An understanding of factors influencing the biological cycling of nutrients within the water column.
- An understanding of the significance of physical mixing processes for nutrient cycling.
- An understanding of the factors influencing algal growth and primary production rates and the transfer of energy from primary producers to other trophic levels.
- The development of models to predict the responses of impoundments to altered nutrient loading and other changes.

1.4.1 Nutrient loading of selected impoundments

Some estimates of nutrient loading of impoundments are available from the current eutrophication programme. A mathematical model of the transport of conservative ions in the Mgeni catchment is being developed using existing data. There is a need to develop this approach to include non-conservative constituents, in particular, N and P compounds and monitoring programmes instituted (see 1.2.1) in order that transport rates, accumulation and re-release of nutrients may be estimated and predicted under differing conditions.

1.4.2 Nutrient cycling in selected impoundments

Current research is aimed at relating algal growth and the external nutrient loading of impoundments and research is in progress at the Universities of Natal and the Orange Free State on other aspects of nutrient cycling in impoundments. There is a need to review available literature and other information on N and P compounds in inland waters and their identification, quantification, availability, uptake and release by biota, sediments and suspensoids, cycling and budgets, in order to assess research needs. It seems clear that there is an urgent need to undertake the research needed to draw up nutrient budgets of at least one oligotrophic and at least one eutrophic impoundment. There is a need to obtain estimates of the nutrient concentration fluctuations and rates of internal loading of nutrients in these impoundments and estimate how the internal loading might fluctuate during the year. Thereafter, it might be necessary to study the uptake and release of nutrients from different components of the ecosystem (biota, sediments, suspensoids), their short and long term cycling and the physical and other factors affecting uptake and release.

1.4.3 Nutrient availability, algal growth and energy flow in selected impoundments

There is a need to review the available literature and other information on the rôle of nutrient concentration and availability in determining algal growth and on the factors influencing energy flow in impoundments, in order that an assessment can be made of future research needs.

1.4.4 Development of models to predict the response of impoundments to changes in external nutrient loading

Models are being tested to relate algal growth in oligotrophic impoundments to external nutrient loading, nutrient recycling and other factors and to predict the response of these impoundments to either increased or decreased nutrient loading. It is hoped to base the models both on literature information and on the findings of the current NIWR 22 dam study. It is also hoped to use the models to predict, for instance, possible effects on individual impoundments of projected development or planned eutrophication prevention or rehabilitation programmes.

1.5 The rôle of sediments in nutrient cycling in impoundments

A cooperative research programme between the University of Natal Department of Botany and the NIWR is in progress to determine factors influencing water-sediment nutrient exchange and nutrient availability for primary producers in isolation columns in Midmar Dam. This is aimed at obtaining information to make the following possible :

- An understanding of the rôle of sediments as a sink for nutrients and in re-releasing sediments.
- An understanding of the factors influencing the uptake and release of nutrients from sediments.
- An understanding of the chemical transformations undergone by nutrients in sediments.

1.5.1 Nutrient uptake and release from sediments in impoundments

The present research on the release of P compounds from sediments needs to be continued. Available literature and other information needs to be reviewed in order to assess future research needs.

1.6 The rôle of suspensoids in impoundments

A study has been begun, centred on the University of the Orange Free State IES, of the effects of suspensoids on nutrient availability, primary production, secondary production by heterotrophic bacteria and fish in turbid impoundments, aimed at obtaining information to make the following possible :

- An understanding of the contribution of suspensoids to the external chemical loading of turbid impoundments and the association of different chemical constituents of the water with suspensoids.
- An understanding of the influence of suspensoids on physical properties (light penetration and so forth) and of the effects of physical limnology (for instance wind-induced movements) on sedimentation and resuspension.
- An understanding of the adsorbtion of N and P compounds onto suspensoids, the availability of adsorbed N and P compounds for algal and macrophyte growth and the re-release of nutrients from suspensoids.
- An understanding of the influence of suspensoids on primary production and growth rates of macrophytes, periphyton and phytoplankton, on microbial species and their availability as food for zooplankton, and on zooplankton, zoobenthos and fish.
- An understanding of possible importance of the origin of suspensoids in determining their influence on nutrient availability and algal and hydrophyte growth.

- The development of models to simulate interactions between suspensoids and the physical, chemical and biological properties of turbid impoundments and to predict the responses of turbid impoundments to increased and decreased external nutrient loading.

1.6.1 Sediment transport from the catchment to turbid impoundments

Estimates are required of sediment production from different soil types and areas of differing land use, as well as the total sediment load transported to a turbid impoundment as a function of rainfall, time of year and other factors.

1.6.2 Influence of suspensoids on biological production and nutrient cycling processes

A cooperative study is in progress of the rôle of suspensoids in nutrient cycling and production process in turbid impoundments. There is a need in this study to investigate the influence of wind and other factors on the physical limnology and settlement and resuspension of suspensoids, the water-sediment phosphate exchange, nutrient availability to algae and macrophytes, primary production rates of algae and hydrophytes, the extent to which sediment particles provide a substratum for heterotrophic microbial production, fluctuations in zooplankton and available food, fish population fluctuations, feeding, growth and recruitment rates.

1.7 Nitrogen-fixing algae

The available information concerning the fixation of atmospheric nitrogen by algal species in South Africa needs to be reviewed in order to make the following possible :

- An assessment of the species of algae that fix nitrogen, their occurrence and importance in nutrient cycling.

- An understanding of the factors responsible for controlling their growth rates and reproduction processes.

- An assessment of their nutritional and environmental requirements.

- An assessment of possible implications of nitrogen fixation for different eutrophication prevention and control strategies.

- The development of mathematical models to predict contributions of nitrogen-fixing algae to aquatic ecosystems.

1.7.1 The rôle of nitrogen-fixing algae in the nutrient budgets of impoundments

Observations of nitrogen-fixing algae and estimates of fixation rates have been made by the NIWR. The available literature and other information needs to be reviewed in order to assess the importance of nitrogen fixing in the budgets of impoundments and in order to assess future research needs.

1.8 Short term investigations of impoundments

Either in response to information derived from monitoring programmes (see 2.1), in the light of projected development plans likely to affect certain catchments, or where particular rehabilitation or eutrophication control measures are being considered for a given impoundment, the need is bound to arise from time to time for information required to make one or more of the following possible :

- The prediction of likely changes (increases or decreases) in future nutrient loads entering particular impoundments.
- Assessment of the trophic status of particular impoundments and prediction of likely problems which may arise as a result of expected increases in nutrient loading.
- Assessment of possible consequences of eutrophication of particular impoundments, including costs and efficiency of water purification.
- The planning of eutrophication prevention and rehabilitation strategies for individual impoundments.
- The assessment of the effectiveness and possible side-effects of eutrophication prevention or rehabilitation strategies applied.

1.8.1 Limnological investigation of oligotrophic impoundments threatened by excessive external nutrient loading

Investigations by the HRI are in progress into the nutrient loading and algal growth in Bloemhof Dam and other impoundments.

1.8.2 Assessment of the trophic status and requirements for rehabilitation of eutrophic impoundments

Studies are in progress of eutrophication in several eutrophic impoundments including Rietvlei (NIWR) and Roodeplaat Dams (HRI).

1.8.3 Monitoring of rehabilitation and eutrophication control programmes

The Department of Water Affairs recently completed a programme of herbicide spraying to control *Eichhornia* on Hartbeespoort Dam and the efficacy and effects were monitored by the NIWR, HRI and BRI.

1.9 Management of impoundments

An assessment is required of the likely effectiveness of possible eutrophication control strategies and applicability under South African conditions of such treatment of eutrophication symptoms as destratification and such lake rehabilitation techniques as hypolimnetic aeration or drawoff and chemical nutrient inactivation for the restoration of eutrophic impoundments. Techniques of this sort will be required for impoundments which have accumulated large quantities of phosphates and other nutrients in their sediments and elsewhere. Reducing the external nutrient loading of these impoundments could be ineffective as this would be insignificant in comparison with the internal loading caused by recycling. Information is required to make the following possible :

- The estimation of the requirements involved in protecting oligotrophic waters in South Africa (based on the criteria described in 1.1).

- An assessment of the requirements involved in the rehabilitation of eutrophic impoundments in South Africa.

- The assessment of possibilities offered by the available strategies for eutrophication prevention and impoundment rehabilitation.

- An understanding of ecosystem functioning necessary to be able to predict the efficacy and possible consequences of different eutrophication protection strategies available.

- The testing of promising eutrophication protection strategies in the field.

- An assessment of the costs and benefits which could be involved in different restoration strategies.

1.9.1 Assessment of eutrophication prevention techniques

Literature and other information on means for preventing eutrophication (for instance on the efficacy of techniques for removing P compounds from sewage works effluents) should be assessed.

1.9.2 Requirements for the rehabilitation of eutrophic impoundments

Literature and other information should be used to assess the conditions to be met in rehabilitation and eutrophication control strategies.

1.9.3 Assessment of lake rehabilitation techniques

Available literature and other information on available lake rehabilitation techniques and their effectiveness, costs and benefits should be reviewed and the possibilities assessed for their use in South Africa in terms of the criteria developed in terms of 1.1.

1.9.4 Field trials of lake rehabilitation techniques

The effectiveness of any field trials or experiments undertaken to rehabilitate eutrophic impoundments in South Africa should be monitored and the necessary limnological observations made to ensure that the techniques can be adequately evaluated.

1.10 Coastal lake eutrophication protection studies

A study by the Rhodes University IFWS of rôle of the *Potamogeton* belt in protecting Swartvlei from eutrophication is in progress and a preliminary investigation was carried out of the likely threat of urban development to Mzingazi. Information is required on coastal lakes threatened with eutrophication to make the following possible :

- The estimation of the present and possible future external nutrient loading, in view of likely development, and the detection of any trends towards increased productivity.

- An assessment of the rôle and ecological importance of submerged hydrophytes.

- An assessment of possible eutrophication prevention measures (such as reedbed development).

- An assessment of the requirements for and consequences of controlled public amenity use of the lakes.

- Prediction of possible ecological effects of changes in water level.

1.10.1 Nutrient budgets and internal nutrient cycling in coastal lakes threatened with eutrophication

Information is required on the rôle of hydrophytes, water level fluctuations and other factors on nutrient cycling in lakes threatened by development in order to be able to predict the possible consequences of such changes.

1.11 Estuary eutrophication protection studies

Information on estuaries threatened with eutrophication is required in order to make the following possible :

- The estimation of present and possible future nutrient loading, in view of likely development, and the detection of any trends towards increased productivity.

- An understanding of the rôle of suspensoids and sediments in nutrient cycling processes and their influence on primary production.

- The identification and prediction of likely eutrophication problems and the detailed assessment of trophic status of estuaries.

- An assessment of possible eutrophication prevention measures.

- The planning of eutrophication prevention strategies for individual estuaries.

- An assessment of the requirements for and consequences of controlled public amenity use of estuaries.

1.11.1 Nutrient loading and the transport of sediment to individual estuaries

Estimates are required from models and from monitoring data of the N and P compound and sediment loads reaching selected estuaries.

1.11.2 Short term studies of selected estuaries

Surveys are required to assess the trophic status and plan eutrophication prevention strategies for selected estuaries.

PROBLEM HYDROPHYTES AND ALGAE

Nature of the problem

Growing human population and the increasingly intensive utilization of water resources in South Africa must result in the increasing control of river flows, the creation of a great variety of small and large standing water bodies, increasing concentrations of N and P compounds and more and more habitats for a large variety of algae and vascular plants. Some of the species involved are extremely troublesome weeds, such as the floating aquatic plants *Salvinia* and *Eichhornia*. Some are generally beneficial but can become weeds if their physical presence in certain situations is undesirable, such as the rooted but floating *Myriophyllum aquaticum*, emergent forms such as *Phragmites* and *Typha* and submerged hydrophytes such as *Potamogeton* and *Lagarosiphon*.

The excessive growth of algae is a common characteristic of eutrophic lakes and impoundments and can impair the value of the water for recreation and use. Many blue-green algae are not eaten to any great extent by animals and can accumulate in rotting heaps. *Microcystis aeruginosa* does this and some of its blooms are also highly toxic and kill cattle and other animals drinking water containing the algae. The toxin causes gastro-enteritis in humans and liver damage in primates and is not removed from the water by conventional purification processes. Certain blue-green algal species fix atmospheric N and thus have the potential to create conditions of excessive algal and macrophyte growth.

Knowledge of the responses to environmental conditions (in other words the autecology) of individual undesirable species normally makes it much easier to control the weed or to eliminate its habitat. A good deal of attention is therefore being given world-wide to the autecology of the most dangerous weeds. As understanding of aquatic ecosystems improves, problems relating to more and more key algal and hydrophyte species will become revealed and knowledge of their autecology will be called for.

Floating hydrophytes are apparently the most troublesome aquatic weeds in South Africa and at the same time the best known. A heavy *Eichhornia* infestation was once cleared from the Vaal Barrage, another has now been greatly reduced by chemical spraying on Hartbeespoort Dam while other infestations remain on Bon Accord Dam and at places in certain rivers. A serious *Salvinia* infestation is moving up the riverine reedbeds in the Caprivi Strip towards the Okavango Swamps in spite of chemical spraying and no means is presently available to stop it from invading the extensive swamp system.

The autecology of *Salvinia* has been studied and a study by the BRI of *Eichhornia* is well advanced, both studies being concentrated upon the growth kinetics necessary to predict growth rates under different conditions. An autecological study of *Azolla filiculoides* has also been completed, this study concentrating on the capacity of this plant to fix atmospheric N and its ability to flourish on nutrient-poor water.

Prospects for biological control of *Eichhornia* and *Salvinia* do not appear to be very promising from the work done overseas as well as in Rhodesia and Botswana. The most promising for the control of *Eichhornia* appears to be a stem boring weevil, *Neochetina*, but like most of the other candidate insects, this species is unable to overwinter successfully. Work being undertaken in the United States on fungal pathogens of *Eichhornia* may lead to new developments in the control of this weed.

Eichhornia can be mechanically harvested, but this is expensive. If the standing crop is large, the growth rate can far exceed the maximum possible harvesting rate on a body of water such as Hartbeespoort Dam, so that harvesting is not a feasible control measure on large bodies of water. Possibilities for utilizing hyacinths exist, for instance for composting and animal feed. However, these have been explored overseas and, though promising, cannot compete on a cost basis with alternative materials.

Rooted hydrophytes are usually no more than a nuisance in South Africa. *Myriophyllum aquaticum* is a nuisance in the upper Berg River and could have the potential to invade Voëlvlei Dam. A study of the autecology of this species has just been completed. Vlei systems can sometimes aggravate the effects of flooding. *Phragmites* and other marsh vegetation can cause the encroachment of the margins into water bodies and block water channels. Surprisingly little work has been done in South Africa on emergent hydrophytes and problems they might cause, however.

Submerged hydrophytes such as *Lagarosiphon* can be considered a nuisance in some small water bodies. Plants such as *Potamogeton*, however, although they may make boating inconvenient in places and hinder fishing, are really very beneficial in trapping sediment and nutrients, acting as a substratum for epiphytic algae which can contribute greatly to the productivity of waters and provide a refuge for young fish. Studies of *Potamogeton pectinatus* at Swartvlei and *P crispus* on the Pongolo floodplain have contributed greatly to the understanding of the rôle of these plants in aquatic ecosystems.

Even in rivers, submerged hydrophytes like *Potamogeton* are probably beneficial. However, little is known of the introduced submerged aquatic moss *Fontinalis antipyretica* which occurs in the Eerste River and accumulates sand, thus obliterating invertebrate habitats.

Toxic *Microcystis* blooms are known to have caused cattle deaths in a wide variety of situations in the Transvaal and are a potential threat to human health. It is not yet known whether particular strains of *M aeruginosa* are toxic and others not, or whether particular environmental conditions cause blooms to produce the endotoxin. Research on the toxin (a polypeptide) is in progress at the National Chemical Research Laboratory (NCRL) and research on the biochemistry of its production is in progress at the University of the Orange Free State Department of Botany. Techniques for the laboratory culture of *Microcystis* have been improved and models of growth rates for different temperatures, light intensities and so forth have been developed by the NIWR.

Nitrogen-fixing blue-green algae such as *Anabeana circinalis* can themselves cause nuisance blooms but their importance lies in the fact that major blooms of other algae utilizing nitrogen released by the declining *Anabaena* population can occur in nitrogen deficient waters. An *Anabaena-Microcystis* succession of this type in Rietvlei Dam near Pretoria has been described in recent years.

Information required

2.1 Assessment of the extent of aquatic weed problems in South Africa

Information is required on the distribution of aquatic hydrophytes and the occurrence of nuisance algal blooms in the Republic of South Africa. The information is required to make the following possible :

- The development of criteria based on scientific as well as cost-benefit considerations for assessing algal growth and aquatic weed problems.
- Predictions of future algal growth and hydrophyte problems.
- An assessment of possibilities for the possible future exploitation of the plants as a natural resource.
- An assessment of the economic viability of any scheme concerned with the removal, control or utilization of aquatic plants.
- An improved understanding of the environmental factors responsible for the growth and development of aquatic plants.

2.1.1 Identification manual for aquatic weeds

The Cape Provincial Administration has published a book on weeds in South Africa and a start has been made by the Departments of Water Affairs and Agricultural Technical Services in the production of an identification manual, containing descriptions and drawings/photographs of the most economically important aquatic hydrophytes. The completion of this manual will facilitate the training of personnel involved in a questionnaire survey and/or field survey(s).

2.1.2 Questionnaire and field surveys

Information is required to obtain as complete a picture as possible of the distribution of aquatic hydrophytes. Further routine monitoring by means of quarterly or half-yearly questionnaires by the Department of Water Affairs will enable a check to be made of any changes in the status or distribution of economically important species.

2.1.3 Criteria for the assessment of aquatic plant problems

Criteria are required, to be based on all the available published and other information, for the evaluation of aquatic plant problems, to be able to compare control, eradication and utilization strategies in areas needing immediate attention.

2.2 Growth potential and other ecophysiological parameters for individual hydrophyte and algal species

Growth potentials and kinetics of several economically important hydrophyte and algal species are being determined and are needed in order to make it possible to predict growth rates under different conditions in the field and to plan and develop control and utilization strategies. Information on nutrient uptake and release rates is needed for nutrient balance studies and information on water relations of emergent hydrophytes is needed for water balance studies. Much overseas information is available, but is frequently not directly applicable under South African conditions.

2.2.1 Autecological and growth kinetics studies of selected aquatic weeds

Autecological studies of *Eichhornia, Myriophyllum aquaticum, Salvinia* and *Azolla filiculoides* have been completed.

2.2.2 Growth kinetics, nutrient uptake and water relations of emergent marsh plants

Information is required on the growth kinetics of *Typha, Phragmites, Scirpus* and other marsh plants in the field, the capacity for these and other marsh plants to take up N and P compounds from the surrounding water and soil and their rates of evapotranspirative water loss under different conditions. This information is required for an assessment of the effects of vlei ecosystems on river drainage systems (see 1.3).

2.2.3 Growth kinetics of selected algae

Estimates are available of the growth rates of *Microcystis* and other selected algae in the field and on comparative growth kinetics in the laboratory as functions of physical and chemical conditions. Information is also required on the ability of certain algae to overwinter in lake sediments, as well as on the factors responsible for their release from the sediments.

2.3 Factors influencing algal succession

All the available information on algal succession, as it may apply to South African impoundments and other inland waters, should be reviewed. This information is required in order to make the following possible :

- An assessment of research needs relating to algal succession and the factors responsible for succession.
- An understanding of the conditions under which *Microcystis* or N-fixing cyanophytes either replace or are replaced by green or other algae.
- A preliminary assessment of the possibilities of manipulation of algal succession in the future in South African impoundments.

2.3.1 Factors responsible for algal succession in eutrophic impoundments

Some observations have been made of patterns of algal succession in eutrophic impoundments (in particular those involving *Microcystis* or nitrogen-fixing cyanophytes) and the conditions under which succession takes place.

2.4 Hydraulic and hydrological implications of hydrophytes

Hydrophytes, particularly emergent species, can markedly affect the flow of rivers. Estimations of the relationships between plant density and flow are required in order to make the following possible :

- An understanding of the influence of emergent riverine or vlei vegetation on flooding regimes.
- An understanding of problems which might be caused by plant growth in irrigation canals.
- Estimates of the flow resistance in riverine vleis and reedbeds of differing densities around and between coastal lakes.
- An understanding of the flow conditions through vleis and reedbeds essential for calculations of nutrient uptake rates and efficiencies.
- An understanding of the water relations of floating and emergent hydrophytes and of the factors influencing rates of water loss from water bodies where they occur.

2.4.1 Flow resistance measurements of emergent hydrophytes

Information is required on the effects of different plant densities on the resistance to water flow offered by riverine vleis and the reedbeds around and between coastal lakes. This information is intended for use in developing hydraulic models.

2.4.2 Water relations and evapotransporative water loss by floating and emergent hydrophytes

Rates of water loss from *Eichhornia* are being determined by the HRI.

2.5 The rôle of hydrophytes in production processes

Information is required on primary production rates of different hydrophytes, as well as the interactions between species under South African conditions. This information is required in order to make the following possible :

- An understanding of the effects of climatic variables on production rates in the field.
- An understanding of the contribution by hydrophytes to energy fluxes in different inland water ecosystems.

2.5.1 Methods for determining hydrophyte production rates

Methods used to measure primary production in hydrophytes need to be reviewed and standardized, to permit direct comparison of results. Where possible, different methods may be used simultaneously to allow evaluation of accuracy and precision of each method. An important aspect will be the production of a manual containing a comprehensive series of descriptions and comparisons of the various methods available, with suggestions for their implementation.

2.5.2 Measurement of primary production rates by hydrophytes

Information is required on hydrophyte production rates under different environmental conditions, using standardized methods. The data from different existing projects should be synthesized and may provide a useful basis for future research programmes.

2.5.3 Measurement of hydrophyte reproduction rates

The available information on sexual and vegetative reproduction in hydrophytes and the effects of environmental variables should be synthesized.

2.6 The control of aquatic plants

Information on the chemical, mechanical and biological control of aquatic plants is required in order to make the following possible :

- An assessment of the possibilities, costs and benefits of different strategies for the control of aquatic weeds.
- An assessment of the practical difficulties involved in different control strategies.
- An assessment of the side effects of different control strategies.
- The possible development of improved control strategies.

2.6.1 Possibilities for the biological control of aquatic weeds

Available information on possibilities for the biocontrol of exotic aquatic weeds should be reviewed and the needs for research in South Africa assessed. Such research should be centred in a laboratory with the experience and facilities to work in this difficult field. The first question to be answered is whether or not any of the insects and fungi tested elsewhere in the world for the biocontrol of *Eichhornia* could be used in South Africa. Thereafter, a search could be initiated for biocontrol agents for *Salvinia* and *Myriophyllum*.

2.6.2 Mechanical control of aquatic weeds

The available information on mechanical control and harvesting of algae and aquatic hydrophytes should be reviewed. Particular emphasis should be paid to cost-benefit estimations.

2.6.3 Chemical control of aquatic weeds

The registration of chemicals for use as herbicides in South Africa is handled by the Department of Agricultural Technical Services. Due to the relatively low cost of chemical control strategies, high priority must be given to the production of some form of manual to provide guidelines for the use of chemical control agents. Particular attention should be paid to the effects of :

- different environmental conditions on the activity of the agent,
- biodegradability,
- possible side-effects on other members of the aquatic biota,
- the possibility of using chemical control agents in integrated control strategies, and
- methods of application.

The manual produced should, if possible, be frequently updated, perhaps by means of quarterly or half-yearly supplements, to take cognisance of improved control agents, methods of application and so forth.

2.7 Utilization of aquatic plants

Available information on the utilization of aquatic plants should be reviewed to make the following possible :

- An assessment of aquatic plants as sources of fuel, food, soil additives, and so forth.
- Estimates of costs and benefits of any promising form of utilization.
- An assessment of the possibilities of using aquatic weeds as nutrient sinks in sewage purification.
- The assessment of any research needs.

2.8 Toxic algae

Information is required to make the following possible :

- An understanding of the growth requirements of *Microcystis*.
- An understanding of the biochemical pathways involved in toxin production.
- An understanding of the hydroclimatic conditions necessary for toxin production in *Microcystis aeruginosa*.
- An assessment of the significance of *Microcystis* toxin in inland water ecosystems and its possible hazards for humans and animals.

- Means for the identification and assay of the toxin and a rapid method to measure the toxicity of water, possibly using either radio-isotope techniques or some form of biological indicator organism.

2.8.1 Factors responsible for the development of toxic *Microcystis* blooms in eutrophic impoundments

A cooperative research programme has been initiated on the biochemical pathways and physical and chemical conditions necessary for toxin production in *Microcystis aeruginosa*. Techniques for the culture of the algae have also been improved.

2.9 Algal control

Consideration must be given to the possible objectives of algal control in South Africa and to the particular species at which control strategies should be aimed. The information available on algal control methods should be reviewed and the possibilities assessed.

UTILIZATION OF BIOLOGICAL PRODUCTION IN INLAND WATERS

Fish production potential of inland waters

Rapid human population growth and the threat to marine fish stocks through over-utilization and pollution are likely to create animal protein shortages in South Africa. The possibility exists that these shortages could at least in part be met by better utilization of the fish production potential of impoundments and other inland water ecosystems. At the same time, these impoundments and estuaries are becoming increasingly important recreational centres and the angling pressure, particularly on those bodies in close proximity to metropolitan areas, is intensifying.

Recreational fishing is at present the most important form of utilization of the production potential of inland waters. There are some 250 000 licenced freshwater fish anglers in the Republic (no licence is required to fish in estuaries) and it has been conservatively estimated that their annual catch amounts to about 15 000 tons of fish. It has also been estimated that these anglers spend on average about R400 each annually on fishing tackle, petrol, vehicle repairs, clothes, boats, outboard motors and so forth. The contribution of angling related activity to the general economy of peri-urban and rural areas can not be insignificant.

In certain areas there is an apparent conflict between recreational and food fishing which needs to be settled to the mutual advantage of both. The evidence strongly suggests that the netting of considerable quantities of non-angling fish species (for instance *Labeo* spp and canary kurper *Tilapia sparrmanii*) is feasible, that this netting will benefit and not detract in any way from the production potential and availability of the angling species and that there is a considerable market for the coarse fish so netted. However, the experimental data to test the compatability of sport and food fishing are still incomplete.

Considerable potential also exists both for the intensive culture of fish and for subsistence farming in South Africa. These will be dealt with in a later chapter on aquaculture.

Present state of knowledge

A large number of exotic fish species have been introduced into South Africa during the past 100 years, either for culture or for angling. Some, such as the rainbow trout *Salmo gairdneri* and largemouth bass *Micropterus salmoides*, have been very successful introductions in certain water bodies and filled real needs. Others, such as the wild carp *Cyprinus carpio* and bluegill sunfish *Lepomis macrochirus*, have become widespread pests and yet others, such as tench *Tinca tinca* and perch *Perca fluviatilis*, were only able to establish themselves in certain river systems. A good deal of information is available on the general biology, environmental requirements and so forth of these species in their countries of origin, but some of this information is unfortunately not always directly applicable to local conditions.

Several further exotic fish species have been imported into South Africa recently. These include the herbivorous grass carp *Ctenopharyngodon idella*, the plankton eating silver carp *Hypophthalmichthys molitrix* and the bighead carp *Aristichthys nobilis*, all of which require rather special conditions of large, slow-flowing rivers to breed successfully in the wild. The first is seen as a possible agent to control aquatic weeds, as well as a promising culture fish. The second is seen as occupying an unoccupied niche (food resource) in this country and therefore a useful addition to both large impoundments and fish culture. These fish have been released in Natal, but in the other provinces are being kept and bred in isolation while possible implications of their release are being considered.

Introductions of freshwater fish in the past were made without any knowledge at all of the indigenous species which could have been used very successfully in many instances. Although more information on the biology of individual species is available now, the position is by no means satisfactory. A certain amount of published information is available on such species as the Mozambique tilapia *Sarotherodon mossambicus*, redbreast kurper *Tilapia rendalli*, largemouth yellowfish *Barbus kimberleyensis* and smallmouth yellowfish *B holubi* (both of the Orange-Vaal system), large *B marequensis* and small scaled yellowfish *B polylepis* (both of the Limpopo system and other east-flowing rivers), scaly *B natalensis*, moggel *Labeo umbratus*, moddervis *L capensis* and barbel *Clarias gariepinus*, including their general biology, breeding, growth and food. However, for most of these important angling and commercial species, basic information is mostly lacking on such aspects as breeding physiology, age at maturity, fecundity, migrations, hatching times, development and growth rates under different conditions, environmental tolerances, diet, daily ration and food conversion ratios. Some of these species can not even be bred successfully in captivity. This information is essential for any planned development of the freshwater fish resources of the country, whether for angling, food fishing or fish culture.

In the same way, surprisingly little is known of the biology of individual species of estuarine fish and the marine fish that enter estuaries, their migrations between estuaries and the sea, breeding biology and so forth. These include a large number of important angling fish and several species of mullet and others of obvious potential either for commercial netting or for culture.

Some important work has been done on some of the more important macro-invertebrates of estuaries that are either used as bait organisms, such as the bloodworm *Arenicola loveni* and the mudprawns *Callianassa kraussi* and *Upogebia africana*, or could be a natural resource in their own right, such as the prawns *Penaeus indicus* and *P monodon* and the giant crab *Scylla serrata*. This work has provided an indication of the environmental requirements and reproductive and production potential of these species but more research would be required to plan their rational utilization, determine quotas and so forth.

Population studies involving the mark and recapture of fish and the estimation of population numbers, growth rates and so forth, as well as the life histories of the species concerned, have been carried out in only a few inland waters. Barberspan and Loskop, Boskop, Sterkrivier and Roodeplaat Dams have been worked on by the Transvaal Provincial Administration, Zeekoevlei by the Cape Provincial Administration, and Sibaya by the Rhodes University IFWS and the Pongolo floodplain by the University of Natal Department of Zoology. Similar studies are planned in Wuras and the P K le Roux Dams, respectively by the Provincial Administrations of the Orange Free State and Cape. Gill netting, which is less informative, has been carried out in the Hendrik Verwoerd Dam and several other water bodies.

Population studies of fish in estuaries have been carried out in the Kleinemond and Berg estuaries and Botriviersvlei by the Cape Provincial Administration, and on several Natal estuaries and St Lucia by the ORI and University of Natal Department of Zoology. Similar studies are planned in Swartvlei and the Knysna estuary by the Port Elizabeth Museum. Most of the important fish species in estuaries are marine. They breed at sea and invade estuaries as juveniles. It is hoped that the new studies will fill the gap in knowledge which exists on the juvenile stages of the Cape species. A more serious gap, in information on the marine phase of their life history exists in both Natal and the Cape.

At present, insufficient information is really available to be able to answer even fairly simple questions related to the management of freshwater and estuarine fish populations. It is not known, for example, what anglers remove, how this fluctuates from year to year, how this compares with the production potential or what effect angling might be having on the populations and their production rates. Little useful information is available on the diets of any but the carnivorous fish. Very little is known of the diseases and parasites which attack fish, of the environmental tolerances of these fish, or of the conditions that make them susceptible to disease and parasite attack. Few facts are available on which to base plans for fish ladders or other devices to overcome barriers to breeding migrations.

Fish standing crop estimates (of fish over 12 cm length) in impoundments vary from 46 kg ha^{-1} (Loskop Dam, where spawning sites are limited) to 225 kg ha^{-1} (Sterkrivier Dam, overpopulated with moggel *Labeo umbratus*) and 774 kg ha^{-1} (Zeekoevlei, which is highly eutrophic). It is thought that anglers possibly remove on average about 30 percent of the standing crop annually and fears have been expressed that angling waters near metropolitan areas (Hartbeespoort Dam has 77 000 licensed anglers) might not contain enough fish to support both sport and food fishing. However, it has to be remembered that different fish species are involved.

Information on the effects of fishing pressure and an understanding of possible interactions between species would be of immense importance for the management of fish resources. Information from the Orange Free State suggests that significant quantities (up to 100 kg ha^{-1} annually) of coarse fish less favoured by anglers (mainly *Labeo*, *Cyprinus* and *Clarias*) can be taken from dams by netting without adversely affecting the angling fish. In fact, there is the distinct possibility that exploitation of the coarse fish might improve the angling. The story is told, for instance, of the Transvaal Provincial Administration being called in to investigate a decline in the bass fishing in the 3,4 ha Koringfontein Dam and netting from the dam an incredible 15 tons of *Labeo*, which had obviously been crowding the bass out of the dam.

Both in order to manage large impoundments for their angling potential and in order to manage or consider possibilities for commercial netting in particular instances, a good deal of short term information is required. Reliable estimates are required of the quantities of fish removed by anglers and programmes have been initiated in Natal and the Transvaal to get this information. Population estimates are then required from time to time to monitor the impact of angling and identify problems which might arise due to inadequate recruitment of certain species or overpopulation of juveniles or non-angling species. These problems can then be overcome by appropriate stocking or netting programmes.

In order to consider possibilities for commercial netting, the short term need is for experimental netting programmes, as is being planned by the Provincial Administration of the Orange Free State on Bloemhof Dam, to estimate possible yields and the impact of netting on the angling and non-angling species. It is interesting to note that commercial fishing operations have been set up in this way on all of the larger impoundments in Rhodesia. Most of these operations are fairly small, capital outlay being limited to not much more than the refrigeration equipment, but all seem to be profitable.

In the longer term, more detailed population biology information might be even more urgently needed, in order to gain the understanding which will be required to place the management of inland water fish resources on a sounder footing and in order to plan the commercial exploitation of the very large impoundments remote from the major centres. The three obvious examples are the P K le Roux, Hendrik Verwoerd and Pongolapoort Dams. The needs of anglers are presumably in no danger of ever approaching the enormous fish production potential that could be realized if the fish populations of these three impoundments were developed scientifically. The exciting prospect thus exists of developing the excess for commercial exploitation.

A number of possible fishing strategies could be considered for the large impoundments, including seine netting to remove only certain species, gill netting using fleets of nets of selected sizes and placements to catch particular species and size distributions, netting only at particular times or in prescribed areas, and the use of electrical trawling and other more sophisticated gear. Attempts could be made through selective fishing and perhaps through stocking to regulate the relations between different species and size classes. Indigenous fish from other river systems (P B N Jackson has suggested the eastern Cape sardine *Gilchristella aestuarius*) and perhaps even exotics could be introduced to fill niches which will be unfilled in the man-made ecosystems. However, these possibilities can only be considered against a background of reliable information on the hydroclimates created within these lakes, the primary production and biomass of zooplankton and other food sources which can be expected and the biology, reproductive potential and interactions of the fish populations present. Moreover, the kind of basic understanding required to manage fish populations will take several years to develop. In addition, the fisheries potential and fishing strategies to be applied will be greatly influenced by the length and nature of the shoreline and the presence or absence of suitable areas of lake bottom, for instance cleared areas for seine netting.

Information required

3.1 Autecology of fish of angling and commercial importance

The provincial nature conservation authorities have already collected a good deal of the information required to make the following possible :

- An understanding of the general biology of fish species of present or potential value to man.
- An understanding of the habitat requirements of different species, taking into account different stages in their life history.
- An assessment of possible needs that may exist for fish ladders and other management measures in impoundments and river systems.
- An assessment of the potential of these fish for angling and food utilization.
- An assessment of advantages, disadvantages and possible implications of any new introductions or releases of exotic or indigenous fish into waters outside their natural range.
- An assessment of any management problems that might arise with the exploitation of particular species.

3.1.1 Autecology of freshwater angling and food fish

There are several fish species of present or potential value for man for which autecological information is still incomplete. Assessment of their potential and planning of management strategies will require more research of the sort being carried out by the provincial nature conservation bodies on life histories, breeding biology, food, growth, migrations and so forth. There is also a need from time to time to synthesize available information on particular species and re-assess future research needs.

3.1.2 Autecology of estuarine fish and marine fish entering estuaries

Most of the existing information on these fish have come from population studies. The greatest need at this stage is for information on the biology of the larval stages of marine fishes entering Cape estuaries. Needs also exist for information on the biology of *Mugil* spp and on the habitat requirements, food, breeding biology and so forth of a number of fish.

3.1.3 Biology of fish being considered for introduction

Information is required to make it possible to assess the potential and implications of introducing exotic fish for particular purposes, as is being currently collected for three species by the provincial nature conservation bodies. Indigenous species which could similarly be considered for introduction into particular water bodies include the whitebait *Gilchristella aestuarius*, being studied in the southern Cape lakes.

3.1.4 Autecology of commercially important invertebrates

Information is required on macro-invertebrates with potential for commercial exploitation, as well as organisms used as bait or important as forage for fish. Several important studies have been carried out in the past and knowledge of particular species should be synthesized from time to time.

3.2 Environmental tolerances of fish and invertebrates

Important work has been done for instance in the Rhodes University Department of Zoology and Entomology on the temperature and salinity tolerances of some estuarine invertebrates. Further information is required to make the following possible :

- An understanding of the lethal limits for key fish and invertebrates of temperature, salinity, dissolved oxygen and other factors and of the acute and sublethal effects of exposure to extremes of these factors.

- An understanding of the differences in sensitivity of different stages in the life histories of key fish and invertebrate species.

- An understanding of the lethal and sublethal effects of pollutants on these species under different conditions.

- An understanding of physiological effects of exposure to lethal and sublethal conditions.

- The development of physiological parameters and criteria to assess exposure of animals in the field to toxic substances and sublethal conditions.

- An understanding of the effects on growth rates, fecundity and other life functions of different regimes of temperature, dissolved oxygen and other factors and of exposure to toxic substances.

3.2.1 Lethal limits for freshwater fish

Information is required on the lethal limits for important angling and food fish of temperature, dissolved oxygen and other factors in the light of extreme conditions likely to arise and cause fish kills in rivers and impoundments.

3.2.2 Physiological effects on freshwater fish of exposure to lethal and sublethal conditions and concentrations of toxic substances

Information is required on the blood chemistry and other physiological effects on important fish species of exposure to various conditions. An assessment is also needed of the possible value of techniques to detect and assess exposure to toxic substances and sublethal conditions in fish.

3.2.3 Effects of environmental conditions on fish growth rates and other functions

Information is needed to be able to predict growth rates, breeding and fecundities of fish under different temperature, dissolved oxygen and other conditions.

3.3 Nutrition of important fish species

Information is required to make the following possible :

- An understanding of the diet, feeding preferences and daily ration of different fish species in the field.

- Estimates of food conversion rates of fish in the laboratory and field.

- An understanding of the energy expenditure and balances of fish under different conditions.

- An understanding of the rôle of nutrition in determining growth rates of fish in the field.

- Estimates of the food available to fish in the field.

- An understanding of the factors responsible for the stunting of fish in certain waters.

3.3.1 Food availability, daily ration and growth rates of important fish species

Information is needed on the food and its importance in determining growth rates in commercially important fish species.

3.4 Potential fish yields in different water bodies and the effectiveness of different fishing methods

Short term information is required to make the following possible :

- Estimates of the yields which may be obtained by netting in different impoundments and natural waters.

- Estimates of quantities of fish taken by anglers from impoundments and natural waters.

- Prediction of results obtained using different fishing techniques, gear and strategies.

- Prediction of the effects of netting on the populations of different species.

- Prediction of the effects of angling on the populations of different species.

- Decisions by the provincial nature conservation bodies concerned on commercial netting policies, quotas and so forth.

3.4.1 Creel analysis in selected impoundments and natural waters

Analysis is required to estimate the quantities, sizes, species and so forth of fish taken by anglers and others from impoundments and natural waters. There are plans to undertake creel analyses of certain Transvaal impoundments and to estimate the quantities of fish taken by the indigenous Thonga population from the Pongolo pans.

3.4.2 Experimental netting in selected impoundments and natural waters

Experimental netting is required in a number of impoundments (there are plans to net for instance Bloemhof and Hartbeespoort Dams) and natural waters (for instance the Pongolo pans), where possible involving both the nature conservation bodies and private interests, to assess the yields possible from these impoundments.

3.4.3 Effectiveness of different fishing gear, techniques and strategies in impoundments

Information is required on the results possible from different fishing gear (from gill nets to electric trawling gear) and strategies (netting of particular species or sizes, or in certain parts of the lake only).

3.5 Fish populations and production potential, hydroclimate and energy flow in impoundments

In the longer term, information is required to make the following possible :

- An understanding of the hydroclimate of key impoundments and its significance for biological production processes and the fish populations.

- An understanding of factors influencing primary production rates, zooplankton fluctuations and other potential sources of food for fish in these impoundments.

- An understanding of the factors influencing the population dynamics and migrations of fish in these impoundments.

- Estimates of fish growth, reproduction, recruitment, mortality and other losses in the impoundments.

- An assessment of the angling and food fishing potential of the impoundments and of the likely impact of different forms and patterns of utilization.

- Regular re-assessment (monitoring) of changes (in fish populations and their age and size distributions) in these impoundments.

- The extrapolation of findings to other impoundments.

A fish population study by the Provincial Administration of the Orange Free State is in progress at Wuras Dam as part of the study of the rôle of suspensoids in a turbid impoundment (see 1.6).

3.5.1 Limnology of a major impoundment in relation to its potential fish production

A start has been made by the Rhodes University IFWS on a study of the physical limnology and zooplankton of a large impoundment with limited angling pressure, the P K le Roux Dam, to form an integral part of a programme to examine the basis of the fish production potential of the lake.

3.5.2 Fish population dynamics, migrations, production and possible exploitation in a major impoundment

A start has been made by the Cape Provincial Administration and Rhodes University JLB Smith Institute of Ichthyology on a study of the fish populations of the P K le Roux Dam, in which it is hoped to obtain estimates of population sizes and yields using different fishing techniques and to study different aspects of their population biology, assess the production potential and examine various fishing strategies.

3.5.3 Fish population estimates in important impoundments

Estimates are required from time to time (using mark-and-recapture or some equivalent technique) of fish populations and age and size distribution in impoundments where either are or may be netted. This information is required in order to place experimental netting, creel analysis and other information (see 3.4) in perspective and in order to place management strategies upon a more scientific footing.

3.5.4 Marketability and economics of commercial fishing

Reliable information should be obtained on the marketability of fish netted from impoundments and perhaps prepared in different ways, as well as on the economics of commercial fishing.

3.6 Fish populations in estuaries

Fish population studies have been undertaken in a small Cape estuary and in several Natal estuaries. Information from such studies is required in order to make the following possible :

- Fairly regular estimates in different estuaries of the fish populations and their size and age distributions.

- The regular re-assessment of the angling and netting potential of these estuaries.

- An understanding of the fish population dynamics and migrations in and out of estuaries and of the biology of the juvenile stages of the most important species.

- An understanding (from marine programmes) of the marine stages of the fish that migrate into estuaries.

3.6.1 Fish population studies in selected estuaries

Studies are in progress of certain estuaries in Natal and there are plans to study at least three Cape estuaries, giving attention especially to the juvenile fish.

3.7 Fish diseases and parasites

There is a need for a permanent centre for research into fish diseases and parasites to be established in South Africa. The centre should also be in a position to maintain an identification service, conduct postmortem investigations and offer advice to official and private bodies in regard to fish diseases, parasites and causes of mortality. From the centre and elsewhere, information is required to make the following possible :

- The updated taxonomy and routine identifications of parasites.

- The diagnosis of causes of death from postmorten investigations and pathology.

- An understanding of the life histories of major parasites.

- An understanding of the incidence, spread and pathology of major diseases.

3.7.1 Taxonomy and life histories of fish parasites

Some research is in progress at the Rand Afrikaans University and University of the North Departments of Zoology, the University of Pretoria Faculty of Veterinary Science.

3.7.2 Fish pathogens and pathology

There is a need for information on fish pathogenic fungi, bacteria and viruses and pathology to make possible diagnosis of causes of death, including death due to cold and other causes.

CONSERVATION OF THREATENED AQUATIC SPECIES AND ECOSYSTEMS

Aquatic ecosystems may be seen as a natural resource to be conserved, in other words to be utilized in a rational and non-destructive way. Conservation involves the management of inland waters to create conditions required for different purposes. This is really only possible if the necessary knowledge is available on the different ecosystems and their functioning, as well as on the factors which may threaten the survival of particularly sensitive species and ecosystem types.

Some of the effects of development on aquatic ecosystems are beneficial (such as the creation of water bodies of great potential value for recreation and food production) while others are clearly deleterious (such as the destruction of habitats and breeding sites, for instance by canalization or sediment deposition). However, development represents a very real threat to threatened species and their restricted habitats, as well as to rare and threatened ecosystem types.

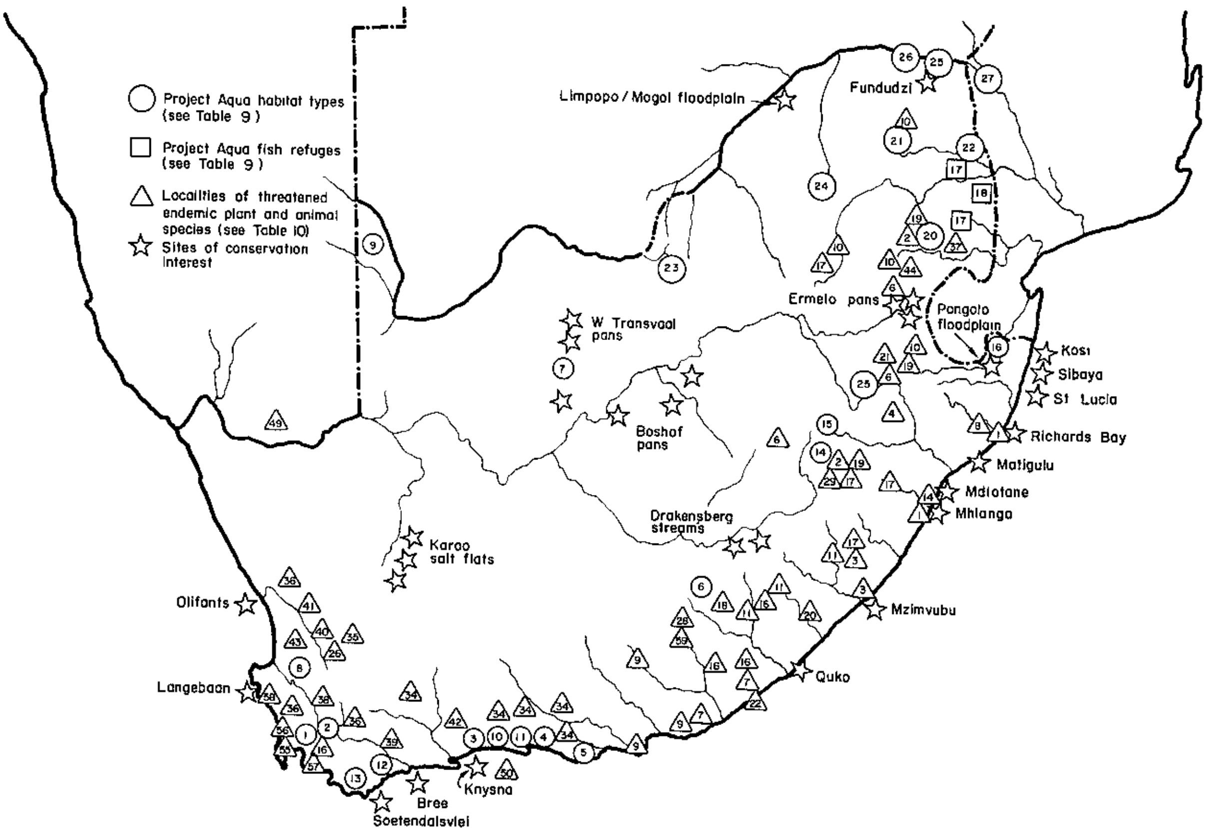

Figure 10. Project Aqua conserved aquatic habitats (circles), threatened aquatic species refuges (squares) and localities (triangles) and sites of particular conservation interest (stars) in South Africa (refer to Tables 9 and 10 for names).

Threatened ecosystems

An attempt was made during the IBP Project Aqua to assess the conservation status of inland water ecosystem types and to recommend representative sites for conservation where no representatives were to be found in existing National Parks, forest or nature reserves. A list of the representative ecosystem types being conserved and existing refuges for threatened fish species is given in Table 9 and their distribution illustrated in Figure 10.

Insufficient representatives of the following types are as yet being conserved :

- Headwater streams in the north-eastern Cape Province and upper Orange River catchment.
- Open and closed sinkholes in the dolomitic area of the Transvaal.
- Salt, brackish, vegetationless, grass, sedge and reed pans in the Orange Free State, western and eastern Transvaal.
- Summer and winter rainfall area sponges, sedge and restio marshes, peat bogs, papyrus swamps, swamp forest and mangrove swamps.
- Salt and brackish flats in the north-western Cape.
- Coastal, estuarine and other lakes.
- Estuaries and estuarine lagoons.

Threatened species

Attempts are being made within the NPES Terrestrial Ecosystems Section to assess the conservation status of threatened plants and animals in South Africa, including aquatic as well as terrestrial species. Lists are maintained of threatened plant, fish, amphibian, reptile and mammal species (Table 10). Information on the vertebrate animal species was recently published in IUCN (International Union for the Conservation of Nature and Natural Resources) Red Data Book form and showed that the status of many of these species is still poorly known. A provisional list of threatened plants is being prepared for publication for the IUCN Threatened Plants Committee.

Several invertebrates (Megaloptera, Trichoptera, Odonata and Crustacea, for instance) could possibly qualify for inclusion in Table 10, but too little is known of their distribution to make this possible. A single dragonfly has therefore been included to illustrate the gap that exists.

Autecological studies have been carried out on only one of the fish species and on the Nile crocodile. The fish studied is one of the several Cape endemic redfin gieliemientjies on the list, *Barbus trevelyani*, in the Tyume River in the eastern Cape. Like most of the other species listed, this species is threatened by the almost total destruction of its physical habitat and, to a lesser extent, also by excessive predation by exotic trout.

The Olifants River in the western Cape is from this point of view the most important catchment in South Africa because it contains six endemic fish species, five of which are threatened. These include the Clanwilliam yellowfish *Barbus capensis*, a fish with considerable angling potential. The gravel runs in which this species spawns have been extensively covered with sand. Exotic predators such as smallmouth bass have eliminated the endemic species from large parts of the system.

Table 9. Project Aqua representative ecosystem types conserved in existing National Parks and nature reserves in South Africa.

Site	Ecosystems
Cape Province	
1. Upper Jonkershoek - Eerste River catchment	headwater streams
2. Holsloot River catchment (Breë system)	headwater streams
3. Touw River entire catchment (Wilderness)	headwater streams, river
4. Groot River entire catchment (Nature's Valley)	headwater streams, river, estuarine lagoon
5. Storms River entire catchment	headwater streams, river, estuary
6. Upper Buffalo River catchment (eastern Cape)	headwater streams
7. Kuruman eye	dolomitic spring
8. Rocherspan (western Cape)	seasonal coastal wetland
9. Salt and brackish/mud pans, Kalahari Gemsbok National Park	endorheic salt and brackish pans
10. Wilderness lakes system	estuarine lagoon and lakes
11. Groenvlei (Wilderness)	coastal lake
12. De Hoopvlei	coastal lake
13. Heuningnes River and estuary	estuary
Natal	
14. Upper Mooi River catchment (Tugela system)	headwater streams, river
15. Upper Mlambonja River catchment (Tugela system)	headwater streams
16. Nyamiti Pan and other Pongolo floodplain pans	storage floodplain
Transvaal	
17. *Serranochromis meridianus* refuge, Sabie River, Kruger National Park	river, temporary pans
18. *Nothobranchius orthonotus* refuge, pans, Kruger National Park	temporary pans
19. *Nothobranchius rachovii* refuge, pans, Kruger National Park	temporary pans

Table 9 (continued).

Site	Ecosystems
20. Upper Houtbosloop catchment (Crocodile - Komati system)	headwater streams
21. Upper Debengeni River catchment (Letaba system)	headwater streams
22. Tsende River catchment (Letaba system)	non-perennial streams
23. Barberspan	semi-permanent lake
24. Part of the Nylvlei (northern Transvaal)	floodplain vlei
25. Luphephe vleis (Venda)	floodplain vleis
26. Mutale vleis (Venda)	floodplain vleis
27. Makuleka pans and Limpopo floodplain (Venda and Kruger National Park)	storage floodplain

The conservation of threatened fish species appears in many instances to require the setting aside of small catchments as refuges. The refuges need to be protected from erosion and other physical damage, as well as from the introduction of exotics. Before a refuge can be created, the biology of the species in question needs to be investigated, in order to ensure that its habitat requirements will be satisfied.

Key habitats for conservation

The conservation of indigenous species and natural ecosystems should involve their management for some purpose (scientific, educational, aesthetic, recreational or commercial, or for food or water production). This may involve in part the setting up of National Parks, nature reserves, protected catchment areas and so forth, which are essential for the conservation of water source areas, representative ecosystems and threatened species. Their siting and management should be planned to provide as many ecosystem types and species as possible with the best possible prospects of survival, viewed in the time perspective not simply of decades but of hundreds and even thousands of years.

For aquatic sites, it is important to consider geomorphological and successional processes and catchment effects which may influence the sites being conserved. It is necessary to plan reserves not only for the conspicuous species already known to be rare, but also for the many rare but inconspicuous invertebrates and other organisms about which we as yet know nothing. This would suggest that it might be important to seek diversity in both physical habitat and in biota in selecting sites for reserves. Furthermore, the sites selected should be those in which rare species have survived and will continue to survive extreme conditions such

Table 10. Threatened freshwater and estuarine plant and animal species in South Africa. Symbols refer to the IUCN threatened status categories Extinct (X), Endangered (E), Vulnerable and declining (V), Rare (R), Indeterminate (I = E, V or R), Uncertain whether threatened or not (U) and Not threatened outside of South Africa (nt). Species not endemic to South Africa are indicated by the symbol (ne).

Ferns and flowering plants		Endemism	Status in South Africa	Status in World	Habitat
1. Fern	Christella altissima	Natal	X	X	swamp
2. No common name	Aponogeton ranculiflorus	Lesotho and Natal	V	V	Drakensberg pools
3. Red hot poker	Kniphofia drepanophylla	Transkei	V	V	coastal swamp
4. Red hot poker	Kniphofia flammula	Natal	V	V	vleis
5. Mangrove swamp tree	Lumnitzera racemosa	ne	V	nt	estuary, estuarine lake
6. No common name	Crassula tuberella	Tvl, Ntl, Les	R	R	vleis
7. Vlei lily	Crinum campanulatum	E Cape	R	R	vleis
8. Waterklawer	Marsilea fenestrata	Natal	R	R	seasonal ponds
9. Waterklawer	Marsilea schelpeana	E Cape	R	R	seasonal ponds
10. Aquatic orchid	Neobolusia tysonii	sthn Afr	R	R	streambanks
11. Nerine	Nerine gibsonii	E Cape, Transkei	R	R	vleis, streambanks
12. Mangrove	Ceriops tagal	ne	R	nt	estuary
13. Lotus lily	Nymphaea lotus	ne	R	nt	pans, rivers
14. Granny's bonnet	Disperis stenoglossa	Natal	I	I	vleis
15. Western Cape isoetes	Isoetes stephansenii	S W Cape	I	I	vleis
16. Mountain lily	Cyrtanthus rectiflorus	E Cape, Transkei	U	U	streambanks
17. Marsh disa	Disa rhodantha	Tvl, Ntl, E Cape	U	U	vleis
18. Marsh disa	Disa scullyi	E Cape	U	U	streambanks
19. Granny's bonnet	Disperis concinna	South Africa	U	U	vleis, streambanks
20. Nerine	Nerine masonorum	Transkei	U	U	seepage in rocks
21. Nerine	Nerine platypetala	Transvaal	U	U	vleis
22. Eastern Cape isoetes	Isoetes wormaldii	E Cape	U	U	vlei pools
23. Brasenia	Brasenia schreberi	ne	U	nt	vleis
24. Burmannia	Burmannia madagascariensis	ne	U	nt	streams, vleis
	Insects				
25. Dragonfly	Metacnemis valida	E Cape	U	U	streams
	Freshwater fish				
26. Fiery redfin	Barbus phlegethon	W Cape	E	E	rivers
27. Treur River barb	Barbus treurensis	N E Tvl	E	E	rivers
28. Border barb	Barbus trevelyani	E Cape	E	E	rivers
29. Drakensberg minnow	Oreodaimon quathlambae	Lesotho	E	E	rivers
30. Southern kneria	Kneria auriculata	ne	E	nt	rivers

Table 10 (continued).

Freshwater fish		Endemism	Status in South Africa	Status in World	Habitat
31. Blueband killifish	Nothobranchius rachovii	ne	E	nt	pans
32. Black tilapia	Sarotherodon placidus	ne	E	nt	rivers, pans, inland lakes, estuaries
33. Broadhead sleeper	Eleotris melanosoma	ne	E	nt	coastal lakes
34. Smallscale redfin	Barbus asper	S Cape	V	V	rivers, estuaries
35. Twee River redfin	Barbus erubescens	W Cape	V	V	rivers
36. Witvis	Barbus andrewi	S W Cape	R	R	rivers
37. Sibayi gobi	Silhouettea sibayi	N Zululand	R	R	coastal lakes
38. Berg River redfin	Barbus burgi	S W Cape	R	R	rivers
39. Burchell's redfin	Barbus burchelli	S W Cape	R	R	rivers
40. Clanwilliam redfin	Barbus calidus	W Cape	R	R	rivers
41. Clanwilliam yellowfish	Barbus capensis	W Cape	R	R	rivers
42. Slender redfin	Barbus tenuis	S Cape	R	R	rivers
43. Clanwilliam rock catfish	Gephyroglanis gilli	W Cape	R	R	rivers
44. Incomati rock catlet	Chiloglanis bifurcus	E Tvl	R	R	rivers
45. Burrowing gobi	Croilia mossambica	ne	R	nt	coastal lakes
46. Striped robber	Alestes lateralis	ne	R	nt	rivers, pans and coastal lakes
47. Pongola rock cat-let	Chiloglanis emarginatus	ne	R	U	rivers
48. Spotted killifish	Nothobranchius ortho-notus	ne	R	nt	vleis, pans and coastal lakes
49. Namaqua barb	Barbus hospes	ne	U	U	rivers
Estuarine fish					
50. Knysna seahorse	Hippocampus capensis	S Cape	V	V	estuaries
Amphibians					
51. Cape platanna	Xenopus gilli	S W Cape	R	R	various
52. Ghost frog/Rose's frog	Heleophryne rosei	S W Cape	R	R	rivers
53. Micro frog	Microbactrachella capen-sis	S W Cape	R	R	vleis
54. Cape dainty frog	Cacosternum capense	S W Cape	R	R	vleis
55. Amatola toad	Bufo amatolica	E Cape	R	R	vleis
56. Green leptopelis	Leptopelis xenodactylus	ne	R	R	vleis
Reptiles					
57. Nile crocodile	Crocodylus niloticus	ne	V	nt	rivers
58. Water monitor	Varanus niloticus	ne	V	nt	various

Table 10 (continued).

Birds		Endemism	Status in South Africa	Status in World	Habitat
59. African fish eagle	Haliaëtus vocifer	ne	V	U	various
60. Mangrove kingfisher	Halcyon senegaloides	ne	V	U	rivers, coastal lakes and estuaries
61. Pink-throated longclaw	Macronyx ameliae	ne	V	U	vleis
62. Pink-backed pelican	Pelecanus rufescens	ne	V	nt	various
63. White pelican	Pelecanus onocrotalus	ne	V	nt	various
64. Goliath heron	Ardea goliath	ne	V	nt	various
65. Openbill stork	Anastomus lamelligerus	ne	V	nt	vleis
66. Saddlebill	Ephippiorhynchus senegalensis	ne	V	nt	rivers and vleis
67. Wood stork	Ibis ibis	ne	V	nt	various
68. Woolly-necked stork	Dissoura episcopus	ne	V	nt	rivers, vleis and pans
69. Lesser jacana	Microparra capensis	ne	V	nt	vleis and pans
70. Caspian tern	Hydroprogne caspia	ne	V	nt	vleis and pans
71. Roseate tern	Sterna dougallii	ne	V	nt	estuaries
72. Fishing owl	Scotopelia peli	ne	V	nt	rivers, vleis and pans
73. Rufous-bellied heron	Erythrocnus rufiventris	ne	V	nt	vleis
74. White-crowned plover	Xiphidiopterus albiceps	ne	V	nt	rivers and vleis
75. White-winged plover	Hemiparra crassirostris	ne	V	nt	rivers and vleis
76. Greater flamingo	Phoenicopterus ruber	ne	V	nt	various
77. Lesser flamingo	Phoeniconaias minor	ne	V	nt	various
78. White-backed night heron	Gorsachius leuconotos	ne	R	U	various
79. Striped crake	Porzana marginalis	ne	R	U	vleis
80. White-winged flufftail	Sarothrura ayresi	ne	R	U	vleis
81. Wattled crane	Bugeranus carunculatus	ne	R	U	vleis and pans
82. Skimmer	Rhynchops flavirostris	ne	R	nt	rivers, coastal lakes
Mammals					
83. African water rat	Dasymys incomtus	ne	R	U	vleis
84. Hippopotamus	Hippopotamus amphibius	ne	R	nt	rivers and coastal lakes

as floods, droughts and even climatic fluctuations over a much longer time frame.

Many angling and commercially important fish migrate at certain times to spawn in specific places. Interception of these migrations could have drastic effects on the populations. Waterfowl also migrate and depend on key wetland areas during these migrations. The increasingly sophisticated management of these populations will make it necessary to identify and conserve the key habitats utilized at times by migrating species.

Formal conservation areas will never cover any more than a very small proportion of the country. The vast areas outside the reserves provide essential habitat for countless species of plants and animals. Natural and semi-natural aquatic ecosystems on private land need conservation so that their perhaps as yet unknown present or potential value for erosion control, for the improvement of water supplies, as wildlife refuges or for recreation and fish production can be realized. River catchments need conservation because they can be the sources of diseases, sediments and pollutants in nature reserves and important aquatic ecosystems downstream. They can also supply the water upon which downstream ecosystems depend. The conservation of drainage systems is in turn just one aspect of the planning and management of land use in the landscapes concerned.

Information required

4.1 Conservation status of aquatic species

Information on threatened species in inland waters is required in order to make the following possible :

- Updating of lists of threatened species.
- Monitoring of the distribution and abundance of threatened species.
- Assessment of the principal factors responsible for the decline of these species.
- Regular re-assessment of the conservation status of threatened species.

4.1.1 Field surveys of the conservation status of threatened species

Information is required on the distribution and abundance of threatened species to enable the regular re-assessment of their conservation status and the factors responsible for their decline and to make it possible to recommend steps for conservation. A preliminary assessment of groups other than fishes which might require conservation action is also required.

4.1.2 Red Data Books

Red Data Books on threatened species need to be compiled, published and regularly revised.

4.2 Autecology of threatened species

Information on the biology of threatened species is required in order to make the following possible :

- An understanding of the biology and environmental requirements of threatened species, as well as of the factors responsible for any decline in numbers.

- The planning of conservation measures (perhaps the setting aside of a refuge).

4.2.1 Autecology of threatened fish species

Information is required on the autecology of the endemic fish of the Olifants River, the rare endemic redfin *Barbus* spp and other threatened species.

4.3 Identification of representative ecosystems and key habitats for conservation

Information is required to make the following possible :

- The identification of representative ecosystem types and of key habitats of as large as possible numbers of species of plants, invertebrates and vertebrates, for possible conservation.

- An assessment of the areas required to be conserved and the conditions required to be conserved.

- An assessment of needs to conserve aquatic wildlife in South Africa outside of nature reserves.

- An assessment of conditions which are required for the conservation of aquatic wildlife outside of nature reserves.

4.3.1 Procedures for the identification of representative ecosystem types and key habitats for conservation

Such procedures need to be developed. This should involve in the first instance the formulation of criteria and guidelines for the recognition of ecosystem types (based on a classification system, plant communities and so forth) and of key habitats (based on the occurrence and numbers of rare and endemic species and so forth). Subsequent steps should include field surveys of candidate localities and the compilation of a register of the conservation potential of selected areas in the Republic.

4.3.2 Assessment of conservation requirements in estuaries

Information is required in order to assess steps which might be necessary to conserve representative estuary types. As a first step, available literature and other information should be synthesized and assessed and short term field surveys undertaken to identify gaps in knowledge (for instance of the morphology of estuaries). A classification system of the current status of estuaries and relative suitability for different uses should be developed and the findings used to assess future research needs.

PEST ANIMALS, PATHOGENS AND PARASITES

In developing the water resources of South Africa, habitats can easily be created (as a result of the creation of artificial water bodies, the inundation of new areas, changes in vegetation or in the flow regime) which will allow the distribution or increase in number of particular pest animals. These can include mosquitoes (Culicidae) and other insect vectors of human and animal parasites (for instance malaria) and of arboviruses (for example Rift Valley fever). They can include insects like blackflies (Simuliidae) which can be a very serious nuisance in sufficient numbers through their cattle-biting or other habits. They also include species of freshwater snails which act as intermediate hosts for human bilharziasis (*Schistosoma*) and several veterinary parasites.

Simuliidae

The Simuliidae are a group of biting flies whose larvae live in flowing water where they feed by filtering particulate matter from the water by means of higly modified mouthparts. In the species which are pests of man and his livestock, the female requires a blood meal from a vertebrate animal (cattle in the case of the problem *Simulium chutteri* and *S bovis*) before her ovaries will develop mature eggs.

Adult Simuliidae, which are little bigger than a match head, have surprising powers of dispersal, often wind aided. In the northern Cape, females have been found 50 km from the nearest flowing water.

In Central Africa and Central America, Simuliidae transmit an unpleasant human parasite, *Onchocerca volvulus*, which causes permanent blindness. In North America they transmit a commercially important bird blood parasite, *Leucocytozoon*. In most parts of the world, however, it is the very numbers of the flies that cause the death of cattle and other livestock.

In South Africa cattle-biting Simuliidae have caused severe problems in areas adjacent to stretches of the lower Vaal and, more recently, the Orange River where conditions favourable for the larvae have been created. A cooperative programme of research has been initiated within IWE in order to investigate :

- the biology of the larvae, with a view to their control by such means as manipulation of the river flow pattern,
- aspects of the behaviour of the adult males and females, with a view to improved chemical control,
- the possible (probably passive) transmission of veterinary diseases (for instance *Chlamydia*, causing blindness in sheep and Rift Valley fever and others) by Simuliidae,
- the taxonomic separation of sibling species (for instance *Simulium damnosum*, now known to consist of eleven or more siblings, only some of which bite man and transmit onchocerciasis), and
- pesticide control in emergency situations.

Mosquitoes

A great number of Culicidae and other bloodsucking Diptera which are able to act as vectors of malaria and several arboviruses of medical and veterinary importance are found in South Africa. The sibling species of *Anopheles gambiae* have been sorted out in this country, but very little is known of the cytotaxonomy of other groups, of differences in biology between species or of their potential as arbovirus vectors. This information is needed in order to be able to predict possible outbreaks, for instance in rainy years or when new State water schemes are brought into being. Several potentially dangerous situations could arise in this way.

The South African Institute for Medical Research (SAIMR) has been concerned for many years with research of this sort into mosquito systematics and arbovirus transmissions and at the University of the Orange Free State Department of Zoology a study of mosquito biology has been started and is funded by the Department of Agricultural Technical Services.

Snails

Snails serve as intermediate hosts of human bilharziasis and a large number of parasites of veterinary importance. Current work on snail systematics and biology is centred at the MRC Snail Research Unit at the Potchefstroom University for CHE. This includes an identification service which serves such official bodies as the Department of Health as well as the general public. Very thorough surveys have been carried out over many years and the results are currently being summarized in a detailed atlas being prepared for publication.

Suitable habitats for problem snail species can be created in a wide variety of situations. The distribution surveys and the autecological research carried out in Rhodesia and South Africa during the past fifteen years now make it possible to explain the broad features of snail distribution and predict when situations may be created for particular snail species. The pace of this research has considerably slackened in recent years and it seems clear that a great deal would be gained from an examination of current and future research needs.

Present understanding of the factors determining the geographic distribution of different snail species is also based on laboratory studies carried out a few years ago of the age-specific fecundity and mortality of snails under different conditions (producing life table estimates of positive or negative population increase rates). Many of the conclusions reached as a result of this research will be tested in a new study being begun of the population dynamics of different snail species in a stream near Potchefstroom. This area is close to the geographical limits of the distribution of some of the species present and the populations are exposed for periods to temperatures which the life table studies showed were too low for the populations to maintain themselves permanently.

It has been shown that there is a disparity between the limits of *Schistosoma* infestation in humans and the distribution of the snail hosts. There is a great reduction in transmission as one approaches the limits of distribution to the snail hosts. Two possibilities appear to exist. It has been shown that snails carrying heavy parasite loads are far less resistant to stressful conditions (as for instance during drought, when the snails lie dormant in dry mud) than are snails free of parasites. It has therefore been suggested that infested snails have a diminished likelihood of survival near the limits of the snail distribution than do those free of parasites. Alternatively, it has been suggested that the development of the parasites in the snail intermediate host is very temperature dependent (cercaria are not shed from the snails at temperatures below 20°C, for instance) and that temperatures are not high enough near the limits of the snail distribution to permit the development to proceed to completion each summer. The suggestion is therefore that cercaria are only shed in warmer summers in these areas, thus accounting for the drop observed in the human infestation rate.

Far less is known of the details of transmission of parasites of veterinary importance. There might be considerable value in re-assessing research needs in this field.

Work of the MRC Bilharzia Field Research Unit in Nelspruit has shown that it is possible even on a limited geographical scale to reduce the bilharziasis infestation rates from 80-100 percent to 20-40 percent at very reasonable cost through fairly simple measures involving water supply, sanitation and restricted access to snail habitats. This is a more dramatic reduction in incidence than may appear at first sight as it means the virtual elimination of morbidity, which is increasing in the eastern Transvaal as parasite burdens increase. It has been estimated that it might cost as little as R500 000 to R1 000 000 to undertake such a control campaign over all of the area in South Africa in which the incidence is higher than 40 percent and that the cost of the campaign should be shared. The number of direct deaths due to bilharziasis would then be very few.

Information required

5.1 Taxonomy, biology and control of problem Simuliidae

A cooperative programme is in progress intended to provide the information to make the following possible :

- The routine identification of Simuliidae larvae, pupae and adults.

- The differentiation of sibling species within complexes of problem Simuliidae (such as *Simulium damnosum*).

- An understanding of the biology of the larvae of problem Simuliidae (for instance *Simulium chutteri*) and an assessment of possibilities for their control, for instance through river flow manipulation and other non-pesticide means where possible, but using pesticides when necessary.

- An understanding of the biology, behaviour and dispersal of the adults of problem Simuliidae and an assessment of the possibilities for their control.

- The testing of different possible measures for the control of Simuliidae outbreaks.

- An assessment of the likelihood of transmission of arboviruses and other diseases by Simuliidae.

- The prediction of possible Simuliidae outbreaks and advice on the best means of dealing with these outbreaks.

5.1.1 Simuliidae taxonomy

A national reference collection is maintained by the SAIMR and the University of the Witwatersrand Department of Zoology. A cytotaxonomic study of *Simulium damnosum* and other complexes is in progress.

5.1.2 Biology of *Simulium chutteri* and the effects of flow manipulation and other control measures

Studies by the NIWR are in progress of the larval biology and some success has been obtained in controlling numbers in the Vaal River at Warrenton by shutting down the flow from Bloemhof Dam each weekend, when water is not required for irrigation.

5.2 Autecology of mosquito species

Information is required to make the following possible :

- An understanding of the distribution of mosquito species in South Africa, especially those thought to be vectors of arboviruses.

- An understanding of the life histories and environmental requirements of different stages of mosquito species of medical and veterinary importance.

- An assessment of the rôle of different mosquito species as vectors of arboviruses.

- The prediction of the occurrence of mosquito vectors and of possible arbovirus epidemics.

5.2.1 Life histories and environmental requirements of mosquito species

A study of aspects of the life histories and behaviour of selected mosquitoes has been begun at the University of the Orange Free State.

5.3 Taxonomy, distribution, autecology and parasite transmission by freshwater snails

Information is required to make the following possible :

- The routine identification of snails.

- An understanding of the factors influencing the occurrence, distribution and abundance of particular snail vectors.

- The prediction of possible appearances of snail vectors of human and animal parasites, particulary in habitats inadvertently created.

- An understanding of the factors influencing the transmission of medical and veterinary parasites.

- An assessment of methods for the control of snails and reduction of parasite transmission.

5.3.1 Systematics and distribution of freshwater snails

Well covered by the MRC Snail Research Unit, Potchefstroom University for CHE.

5.3.2 The ecophysiology and experimental ecology of freshwater snails

Studies have been initiated of the effects of environmental variables on snail populations.

5.3.3 Effects of temperature and other factors on the life cycles and transmission of parasites

Information is particularly needed on the effects of temperature on the life cycle of *Schistosoma* in its snail intermediate hosts in order to determine the importance of temperature in the transmission of bilharziasis.

5.3.4 Effects of parasite infestation upon resistance of snail intermediate hosts to environmental extremes

Information is required on the effects of *Schistosoma* infestation and other environmental factors on the resistance of the snail intermediate hosts to cold, dessication and other extremes.

CHEMICAL POLLUTANTS

Nature of the problem

The increasing sophistication of South African industrial and agricultural development has resulted in an increase in the variety and complexity of toxic or potentially toxic materials reaching the environment. This trend will continue as development proceeds and the possibility of unexpected and undesirable effects of these materials, either direct or indirect, on man and on aquatic ecosystems will increase with time.

Common pollutants toxic to aquatic organisms include ammonia (from sewage and various industrial wastes), acids like sulphuric acid, alkalis, lead, zinc, copper, chrome and other metals in industrial wastes, cyanides used in industry and mining, fluorides from mining and fertilizers, phenolic substances derived from coal tar and petroleum, pesticides, synthetic detergents and high total dissolved solids concentrations.

Due to the requirements of the Water Act (1956) regarding standards for effluent discharge the concentrations of toxic materials in effluents are normally low and further reduced by dilution. However, there are certain toxic compounds and their decomposition products, as well as some toxic elements and complexes they may form which, although present in small amounts, represent potentially serious hazards. Both heavy metals and chlorinated hydrocarbons may be toxic to man and to aquatic organisms in low concentrations. They may also be accumulated by organisms to levels which can be detrimental or lethal to animals at the next trophic level in the foodweb. This concentration process is multiplied at each step in the foodweb and the animals most vulnerable to accumulated persistent pollutants are usually the top predators, of which man and birds of prey are good examples.

Little is yet known of the effects of these chemicals on aquatic ecosystems and, because the concentrations present are usually low, instances of direct mortality are comparatively infrequent. Effects, if any, are therefore likely to be of a more subtle nature, acting on organisms in ways that affect growth, reproduction or other normal life patterns. Such effects can change the structure of a community by altering predator-prey relationships, or in other ways, such that important components of a system become reduced and the effects are felt at higher trophic levels. Often it is only at this stage that it is realized that important changes in ecosystem structure have occurred.

Until recently, serious research on trace elements and compounds in the environment was greatly hampered by major problems regarding methods for the identification and determination of these chemicals. For this reason, an investigation into techniques for the determination of chemical elements in fresh and salt water, sediments and biological materials is being carried out by the NPRL for the NPES Marine Pollution Section and a study of identification and determination of techniques for pesticide residues in the environment is being undertaken by the University of Pretoria Department of Chemistry for the NPES Terrestrial Ecosystems Section.

As a result of these projects, the position in regard to methodology has greatly improved. Expert advice is now available in many cases to analysts and inter-laboratory calibration tests are carried out to ensure reliability of analytical procedures.

As research proceeds, new methodologies will need to be developed. For example, it is now evident that the toxicity of heavy metals is governed by the compounds and complexes in which they occur, sometimes exhibiting orders of magnitude differences in toxicity, and that these forms can change depending on conditions in the environment.

Some work has started at the University of Pretoria Department of Chemistry on the factors influencing the uptake of heavy metals in sediments and their remobilization under different conditions. This is a first step towards an understanding of the fate of these pollutants in aquatic systems but far more detailed studies will be required before a predictive capability can be developed.

In estuaries, the national marine pollution survey has produced systematic determinations of heavy metals and pesticides, where the levels permitted, in water, sediments and representative organisms. In rivers and impoundments much less information is available, but initial observations have been made which indicate that, with a few exceptions (such as particular chemicals like the pesticide BHC widely used in locust control, and particular places, for instance near effluent outfalls), levels of the heavy metals and pesticides determined may be lower (perhaps by an order of magnitude in most instances) than might have been expected in similar situations in the Northern Hemisphere. Nevertheless, certain instances have been recorded of concentrations considered to be dangerous.

Realistic control over the introduction of pollutants to inland waters is dependent on the development of basic exposure criteria for man and aquatic organisms. In most cases the acceptable degree of exposure is either unknown or is only approximately quantified.

Available evidence suggests that the results of acute toxicity studies on fish and other organisms carried out in the Northern Hemisphere are applicable to similar genera in this country, although there may be some differences from indigenous species. However, acute toxicity data are of limited value in situations where the effects of sub-acute concentrations are likely to be of more importance and it is in this field that information is almost entirely lacking except for some studies of estuarine organisms initiated in 1976 at the NIWR and limited studies at the University of Cape Town Department of Zoology.

Information required

6.1 Identification and assessment of potential chemical pollutants

The scope of present programmes for the determination of hazardous chemicals in the environment has been determined mainly by overseas trends (as evidenced in the available literature) and by the availability of suitable analytical procedures. As it is evident that South African conditions may differ from those elsewhere, that they may also vary from area to area and furthermore that normally only those pollutants in the environment which are being looked for will be found, there is a need for information to make possible the systematic screening, evaluation and assessment of hazardous or potentially hazardous chemicals in the environment.

6.1.1 Screening of chemical pollutants

Four parameters are critical for the evaluation of a pollutant's importance :

- Rates of release into the environment.

- Lifetimes in the environment (or residence times where accessible to biological systems).

- Concentration factors in parts of the system (e g sediments or estuaries) or into organisms (bioaccumulation).

- Levels of toxicity.

The second and third of these are considered in 6.2 and the fourth in 6.4. The first parameter, rates of release into the environment, requires information on the production, import, uses, possible wastage or losses and disposal, with the necessary attention also being given to inputs to the South African environment from other areas (for instance via atmospheric circulation and ocean currents).

6.2 Environmental forms and pathways of chemical pollutants

Information is required to make the following possible :

- An understanding of the distribution of priority pollutants in the environment.

- An understanding of their residence times and concentration factors (bioaccumulation) in various compartments.
- An understanding of the forms in which priority pollutants occur under different conditions.
- An understanding of the factors influencing the transport and uptake of priority pollutants and their ultimate fate.

Literature on the environmental pathways of pollutants considered to require priority attention should be critically reviewed and used to assess any possible needs for future research.

6.2.1 Speciation of metals in the environment

The determination of absolute concentrations of metals is of limited value, as both the uptake and the toxicity of metallic species are critically dependent upon the form in which the metals occur. It is now known that the toxicity of certain metals may vary over three or four orders of magnitude, depending on the type of complex or compound formed. Information on the speciation of metallic species is therefore essential for an understanding of the significance of metals in the environment.

6.2.2 Factors influencing the remobilization of metallic species in sediments

Up to now sediments have been regarded as permanent sinks of metals. Under certain circumstances, however, fluctuations in environmental conditions may cause metallic species adsorbed on sediment particles to be released to the water with resultant possible uptake by biota. Information on the factors influencing this remobilization, coupled with information on speciation (see 6.2.1) and adequate methods (see 6.3) are required in order to be able to predict the release of toxic species.

6.3 Analytical procedures for the identification and quantification of chemical pollutants

Programmes involving research, the testing of methods, advice to analysts and the execution of interlaboratory calibration exercises are in progress, aimed at :

- The availability to analysts in South Africa of modern adequate techniques for the identification and quantification of trace metals and pesticide residues in the environment.
- The intercomparability and reliability of analytical results of different laboratories.

6.3.1 Methods for the identification and quantification of trace metals and their complexes

A programme at the NPRL is concerned with the development of methods for the determination of trace metals and other elements in fresh and saline water, sediments and biological material. The need exists for methods for the determination of the various forms in which the elements occur, i e the metal speciation problem.

6.3.2 Methods for the identification and quantification of pesticide residues

A programme in the University of Pretoria Department of Chemistry makes provision for the development of and advice on analytical procedures for pesticide residues in water, biological material and other media.

6.3.3 Methods for the identification and quantification of other chemical pollutants

Apart from metals and pesticides, virtually no research is in progress on other chemical pollutants, mainly because it is extremely difficult to say which chemicals might be important and because of the lack of suitable methods. There is an urgent need for suitable analytical procedures for those chemical pollutants which are shown by screening (see 6.1) to be of priority importance.

6.4 Ecotoxicology of chemical pollutants

There is a need for a facility for determining the acute toxic and sublethal effects of priority pollutants on both individual plant and animal species of importance and whole ecosystems and for information on the following :

- Acute toxic limits of selected pollutants and their species, complexes, compounds and degradation products for the sensitive stages in the life histories of selected fish species and riverine and benthic freshwater and estuarine invertebrate species based on an understanding of the pathways of transfer and accumulation of these pollutants through the foodweb in inland water ecosystems and the identification of critical pathways and of species and tissues in which marked bioaccumulation takes place.

- Effects of chronic exposure to sublethal concentrations of key persistent pollutants on individual species and whole ecosystems.

- Criteria for acceptable and non-acceptable levels of different persistent pollutants in different inland water ecosystems.

6.4.1 Short term toxicity tests of chemical pollutants

There is a need for a service offering rapid screening of potentially toxic effluents and new or untested chemicals for use in the environment (insecticides, herbicides, oil spill dispersants, etc). Also for rapid comparison of toxicity of metal species and complexes and pesticide degradation products. Where marked toxicity is detected sublethal studies may be necessary.

6.4.2 Sublethal toxic effects of chemical pollutants

There is a need for information on the transfer and accumulation of priority pollutants in key biological components of ecosystems. Screening of candidate species for susceptibility and availability would be required, as would be short term methods of detecting sublethal responses.

6.4.3 Toxicity criteria for chemical pollutants

Criteria for permissible levels of priority pollutants in aquatic ecosystems of different kinds should be developed from 6.4.1 and 6.4.2.

6.5 Monitoring of chemical pollutants

After selection of priority pollutants (see 6.1), monitoring would provide an early warning system and would also measure the success of existing control measures in preventing contaminants in the environment from reaching harmful or otherwise undesirable levels. In selecting an economic and meaningful strategy for monitoring, due consideration should be given to environmental forms and pathways (see 6.2), the availability of adequate analytical procedures (see 6.3) and the bioaccumulation and ecotoxicology of the priority pollutants (see 6.4).

6.5.1 Monitoring of chemical pollutants in rivers and impoundments

The WRC Coordinating Research and Development Committee for Water Quality should be requested to investigate the monitoring of priority pollutants in freshwater, freshwater sediments and biota.

6.5.2 Monitoring of chemical pollutants in estuaries

The NPES Committee for Marine Pollution should be asked to implement the monitoring of priority pollutants in estuarine water, sediments and biota on a permanent basis. Both these monitoring programmes should be periodically assessed and revised as necessary.

IMPACT OF DEVELOPMENT ON AQUATIC ECOSYSTEMS

Nature of the problem

A large part of the IWE programme is concerned with the prediction of environmental consequences of development and with developing the understanding of ecosystem processes to make such predictions possible. As shown in Table 11, environmental problems tend to be concentrated in the catchments where development is taking place. In assessing the environmental effects of a development project it is usually necessary to consider the entire catchment as a single ecological entity. Thus a dam may be affected by other development in its catchment and may also itself have considerable environmental effects downstream.

The Department of Planning and the Environment, through its Council for the Environment, is seeking the cooperation of governmental, statutory and private bodies in South Africa to develop procedures for assessing the environmental effects of development projects. Such assessments will benefit both planning authorities and developers undertaking major projects by identifying possible problems at an early stage of planning, by suggesting solutions to these problems, by revealing information gaps and by providing an objective comparison of options. In each assessment indicators of environmental change are identified which need to be monitored during the different stages of the project (for instance during construction and thereafter) in order that corrective measures can be taken where necessary.

Some environmental assessments, such as that being carried out on the Pongolo floodplain, require many years of intensive research. For others it may be possible for the necessary understanding of processes involved to draw upon past experience on comparable ecosystems, either in this country or elsewhere. As it will not in the foreseeable future be possible to study all of the water bodies threatened by development, and as environmental assessments are unfortunately often required at too short notice for the necessary research to be carried out, there is a need to collect information on the impact of different kinds of past development, so that this knowledge can be applied to other water bodies where similar problems may arise in the future. This could involve in certain instances the study of water bodies which may not themselves be under any threat of development, but which could serve as models for the study of key phenomena.

In Table 11 a brief summary is given of information needs for planning and environmental assessment purposes in the major drainage systems and priority planning regions of the Department of Planning and the Environment's National Physical Development Plan (NPDP). The drainage systems and planning regions are themselves illustrated in Figure 11.

Agricultural and forestry development

The pattern of agricultural and forestry development in South Africa has very largely been determined by water availability and the nature of the topography and soils. This development has in turn had a dramatic impact upon virtually all river systems in this country, in many of them most notably through the construction of large irrigation impoundments and small farm dams.

The most serious consequence of agriculture for river systems in South Africa during the past 100 to 150 years has probably been through erosion, involving extensive donga formation and the drainage and erosion of vleis in certain areas, and the deposition of sediments. Historical records suggest that considerable sediment loads might always have been transported by many rivers (for instance the Orange) but confirm that many estuaries, in Natal at least, have almost completely filled up during the past 50 years or so. Some have as a result been considerably reduced both in surface area and depth.

Sediment deposition in rivers fills the deeper pools favoured by large fish and smothers the gravel runs used as spawning sites by angling fish such as yellowfish *Barbus* spp. Sediment deposits in rivers, impoundments and estuaries are often unstable, can support only a very sparse benthic fauna and hence offer a greatly reduced food supply to bottom feeding fish. In impoundments and estuaries, suspensoids limit light penetration and hence primary productivity. This could have the beneficial effect of reducing possible undesirable symptoms of eutrophication, although little is yet known of the effects of suspended material on production processes. It is probably true to say that sediments and suspensoids of agricultural origin, viewed on a country-wide basis, represent the greatest of all of the impacts of human activities upon aquatic ecosystems in South Africa.

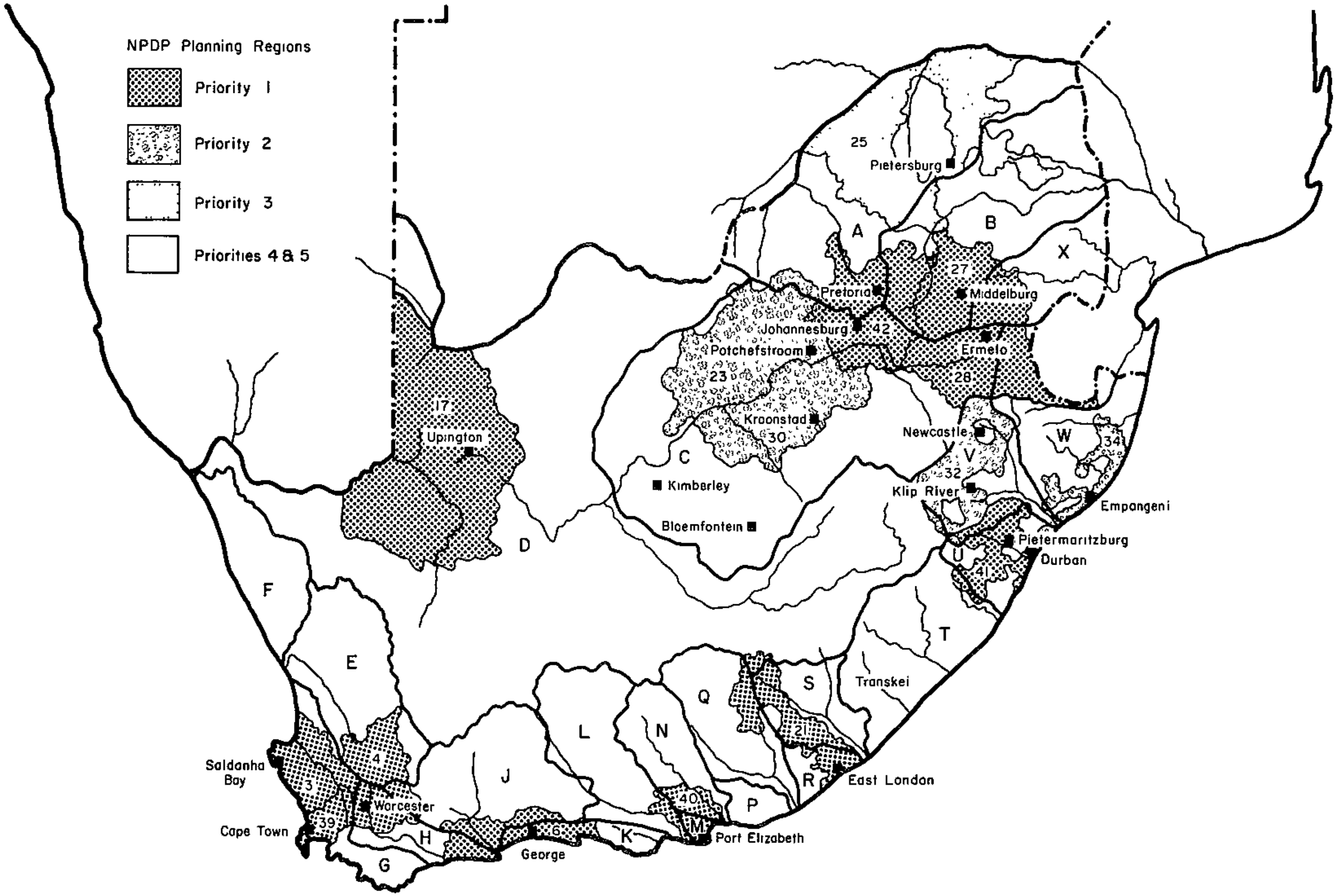

Figure 11. Principal drainage regions (indicated by Department of Water Affairs code letters) and priority planning regions (indicated by National Physical Development Plan code numbers and shaded to indicate priorities).

Table 11. Summary of principal research needs related to practical problems in ecosystem types within major river drainage systems and planning regions in South Africa.

Drainage system	Priority planning regions	Principal research needs	Ecosystem types
Crocodile and Marico (Limpopo system) (drainage region A 110-130)	Pretoria-Witwatersrand-Vereeniging (planning region 42, priority 1)	impact of urban and industrial development, mining, recreation, dams	Impoundments, vleis and rivers
		eutrophication (severe problems experienced)	rivers (Crocodile, Pienaars), vleis (Crocodile) and impoundments (Rietvlei, Hartbeespoort, Roodeplaat)
		problem plants (*Eichhornia*) and algae (*Microcystis*, N-fixing algae)	impoundments (Hartbeespoort, Roodeplaat) and rivers (Crocodile)
		utilization of fish (angling)	impoundments (Hartbeespoort, Roodeplaat)
		threatened species (1 plant)	river, vlei
		chemical pollutants (heavy metals, fluorides)	rivers (Crocodile, Pienaars), vleis (Crocodile) and impoundments (Rietvlei, Hartbeespoort, Roodeplaat)
Limpopo (excluding Crocodile and Marico) (drainage region A 140-190)	Pietersburg (planning region 25, priority 3)	impact of mining, agriculture, forestry, recreation and industrial development	rivers, impoundments
		utilization of fish	impoundments
Olifants-Letaba (drainage region B)	Witbank-Middelburg (planning region 27, priority 1)	impact of agriculture, mining, industrial development, recreation, forestry, fish farming, dams	rivers, impoundments and vleis
		eutrophication	impoundments
		utilization of fish	impoundments
		threatened species (3 plants, 3 fish)	rivers, vleis, pans
		pest animals (bilharzia, malaria)	rivers, impoundments
Vaal (drainage region C)	Pretoria-Witwatersrand-Vereeniging (planning region 42, priority 1)	impact of urban and industrial development, mining, recreation, agriculture	rivers, vleis and impoundments
	plus	eutrophication (vleis and suspensoids offer protection)	rivers (Witwatersrand), vleis (Witwatersrand) and impoundments
	Bethal-Ermelo (planning region 28, priority 1)		
	plus	problem plants (*Myriophyllum*)	rivers (Vaal)
	Welkom-Kroonstad (planning region 30, priority 2)	sediments (mining, agriculture)	rivers (Vaal) and impoundments (Vaal)
	plus	chemical pollutants	rivers (Witwatersrand) and vleis (Witwatersrand)
	Potchefstroom (planning region 23, priority 2)	pest animals (Simuliidae, mosquitoes, freshwater snails)	rivers (Vaal and Mooi) and vleis
		utilization of fish (angling as well as food potential)	impoundments (Bloemhof)
		threatened species (1 plant)	vlei

Table 11 (continued).

Drainage system	Priority planning regions	Principal research needs	Ecosystem types
Orange (drainage region D)	Upington (planning region 17, priority 1)	sediments and suspensoids	impoundments (Hendrik Verwoerd) and rivers
		mineralization	rivers (lower Orange, Karoo)
		utilization of fish (food production potential)	impoundments (Hendrik Verwoerd, P K le Roux)
		pest animals (Simuliidae)	rivers (Orange)
		threatened species (2)	river (Orange)
		impact of dams, agriculture, mining	river (Orange)
		threatened species (2 plants)	rivers, pools
Olifants (western Cape) (drainage region E)	no priority planning regions	impact of roads, agriculture	river, estuary and coastal lake (Verlorevlei)
		problem plants (*Eichhornia*)	coastal lakes (Verlorevlei)
		threatened species (5 fish)	rivers (various tributaries)
West Coast coastal rivers (drainage region F)	no priority planning regions	impact of mining	estuaries
Berg and south-western Cape rivers (drainage region G)	Cape Town (planning region 39, priority 1) plus Saldanha-Vredenburg (planning region 3, priority 1)	impact of urban and industrial development, agriculture, mining, forestry, dams	rivers (Berg, Diep, Swart, Eerste) and estuaries (Berg, Diep)
		eutrophication	coastal lakes (Zeekoevlei, Sandvlei)
		mineralization	rivers (Berg)
		problem plants (*Eichhornia*, *Myriophyllum*) and algae (*Microcystis*)	rivers (Berg, Kuils), coastal lakes (Princess Vlei, Zeekoevlei),
		threatened species (1 plant, 2 fish)	rivers, vlei
		chemical pollutants	rivers (Berg) and estuaries (Berg)
		artificial groundwater recharge	Cape Flats
Breë - Riviersonderend to Kafferkuils (drainage region H)	Worcester (planning region 4, priority 1)	problem plants (*Salvinia*, *Myriophyllum*)	river (Breë)
		drift sand	impoundments (Brandvlei, (Theewaterskloof)
		threatened species (2)	rivers (tributaries)
		mineralization	rivers (Breë)
		impact of roads, agriculture, industrial development, forestry, dams	rivers (Breë) and estuary (Breë)
Gouritz (drainage region J)	no priority planning regions	threatened species (2)	rivers (tributaries)
		impact of dams	rivers
Southern Cape coastal rivers (drainage region K)	George-Knysna-Wilderness (planning region 6, priority 1)	impact of urban development, roads, recreation, holiday townships, industry	coastal lakes (Swartvlei, Wilderness), associated vleis, estuaries (Knysna, Krom)

Table 11 (continued).

Drainage system	Priority planning regions	Principal research needs	Ecosystem types
Gamtoos (drainage region L)	no priority planning regions	threatened species (2)	rivers (tributaries)
Swartkops and Port Elizabeth area (drainage region M)	Port Elizabeth-Uitenhage (planning region 40, priority 1)	impact of urban and industrial development, mining, forestry, recreation	rivers and estuaries (Swartkops, Coega)
		eutrophication	coastal lake (North End Lake)
		problem plants (*Eichhornia*)	rivers (Swartkops)
		chemical pollutants	impoundments and estuaries (Swartkops)
Sundays (drainage region N)	Port Elizabeth-Uitenhage (planning region 40, priority 1)	impact of urban and industrial development, agriculture	rivers and estuaries (Sundays)
		eutrophication	rivers (Sundays)
		problem plants	rivers (Sundays)
		sediments	rivers and impoundments (Lake Mentz)
		mineralization	rivers (Sundays) and impoundments (Lake Mentz)
		utilization of fish (angling as well as food potential)	impoundments (Lake Mentz)
Bushmans, Kowie, etc (drainage region P)	no priority planning regions	impact of agriculture, mining, recreation, urban development	rivers and estuaries (Kowie)
		mineralization	rivers (Bushmans)
		threatened species (2 plants)	vleis, seasonal ponds
Great Fish (drainage region Q)	no priority planning regions	mineralization	rivers (Fish)
		sediments	rivers and estuary (Fish)
		utilization of fish (angling as well as food potential)	impoundments (Lake Arthur, Grassridge)
		threatened species (1 plant)	seasonal ponds
		impact of agriculture, urban development	rivers
Keiskamma, Buffalo, Nahoon and East London area (drainage region R)	East London (planning region 21, priority 1)	impact of urban and industrial development agriculture, forestry, mining	rivers and estuary (Buffalo)
		eutrophication	impoundments (Bridle Drift, Nahoon)
		threatened species (3 plants, 1 fish)	rivers (Buffalo), vleis
		chemical pollution	rivers (Buffalo)
Kei (drainage region S)	no priority planning regions	impact of agriculture, dams	rivers (Kei)
		sediments	rivers and estuary (Kei)
		threatened species (1 plant)	rivers, vleis

Drainage system	Priority planning regions	Principal research needs	Ecosystem types
Mgeni, Mkomazi and southern Natal (drainage region U)	Durban-Pietermaritzburg (planning region 41, priority 1)	impact of urban and industrial development, agriculture, mining, forestry, recreation, dams	impoundments (Ntshongweni, Midmar), rivers and estuaries (Mzumbe, Fafa, Mkomazi, uMgababa, Lovu, Manzimtoti, Mbokodweni, Sipingo, Durban, Mgeni, Mhlanga, Mdloti, Tongati, eNonoti)
		eutrophication	rivers (Mgeni) and impoundments (Midmar, Albert Falls, Nagle, future low level dam (Inanda))
		sediments	rivers and estuaries (Mzumbe, Mtwalume, Fafa, Mzinto, Mpambanyoni, Mkomazi, uMgababa, Lovu, Mbokodweni, Mgeni, Mhlanga, Mdloti, Tongati, Mhlali, Mvoti, eNonoti), impoundments
		chemical pollution	rivers and estuaries (Mkomazi, Lovu, Mbokodweni, Sipingo, Durban, Mgeni, Mvoti)
Tugela (drainage region V)	Newcastle-Klip River (planning region 32, priority 2)	impact of industrial and possible hydro-electric development, recreation, forestry, mining, dams	rivers and estuary (Tugela)
		chemical pollution	rivers and estuary (Tugela)
Mhlatuzi, Mfolosi, Mkuze and Zululand (drainage region W 2110-2130, 2170)	Richards Bay-Empangeni (planning region 34, priority 2)	impact of urban and industrial development, agriculture, recreation, forestry, mining	floodplains (Mfolosi, Mkuze), coastal lakes (Sibaya, Mzingazi), estuarine lakes (St Lucia), rivers and estuaries (Richards Bay, Nhlabane, Mfolosi)
		sediments	rivers and estuaries (Matigulu, Mlalazi, Richards Bay, Mhlatuze, Mfolosi), impoundments
		chemical pollutants	coastal lakes (Mzingazi etc) and estuaries (Richards Bay, Nhlabane)
		pest animals (bilharzia, malaria)	rivers
		aquaculture	estuary (Matigulu)
		threatened species (5)	pans, rivers, coastal lakes
Pongolo-Usutu (drainage region W 2140, 2150)	Richards Bay-Empangeni (planning region 34, priority 2) Bethal-Ermelo (planning region 28, priority 1)	impact of dam, agriculture, forestry, mining	floodplain (Pongolo)
		pest animals (bilharzia, malaria)	rivers
Crocodile-Komati-Sabie (drainage region X)	no priority planning regions	impact of urban development, agriculture, mining	rivers (Komati, Crocodile, Sabie)
		problem plants (*Eichhornia*)	rivers (Komati)
		threatened species (4)	rivers (Sabie)
		pest animals (bilharzia, malaria)	rivers
		chemical pollutants	rivers (Komati, Crocodile, Sabie)

A further dramatic impact on streams in some places has been the large scale extraction of water from rivers. In spite of the rapidly growing needs of other water users, irrigation and stock watering still account for about 80 percent of water use in South Africa. Instances of excessive water extraction are unfortunately not uncommon and result in loss of habitat and reduced angling potential.

Changing land use patterns can also alter the quantities of water reaching streams. Increasing afforestation accounts for a measurable drop in stream flow in mountain catchments. A good deal of research into the effects of vegetation and practices such as burning, clearing and grazing on stream runoff has been carried out by the Departments of Forestry and Water Affairs. The suggestions from this work are that runoff has decreased somewhat in the past 30 years or so, possibly as a result of improved farming and conservation measures.

Irrigation schemes are possibly the major sources of agricultural pollutants reaching South African rivers. Work has been done on the contribution of irrigation seepage water to the mineralization of the Fish, Sundays and other rivers. Work has also been done on the leaching of pesticide residues from irrigation schemes, for instance from cotton fields along the lower Orange River. A variety of pesticide residues have been detected in estuarine and marine animals around the South African coast.

Little information is available on the effects of agricultural development (improved pastures, dry land crops, irrigation, animal feedlots) on nutrient loading of streams. In the catchments where nutrient sources have been investigated, agricultural development has been limited and fertilizer application was negligible.

Also poorly documentated are the effects of wetland reclamation for agriculture (for instance for sugar cane on the Natal coastal plain), the encroachment of plantations and croplands on streams, the destruction and draining of vleis and the reclamation of floodplains such as the Gamtoos, Orange and western Cape Olifants for irrigation schemes.

Mining development

In terms of the volumes of earth moved in prospecting, open cast and underground mining and the volumes of such solid wastes produced, South Africa has perhaps the most severe mining waste problem of any country in the world.

A good deal of information is available on the effects of acid mine drainage on streams and standing waters in the gold and coal mining areas of the southern and south-eastern Transvaal, northern Orange Free State and northern Natal. Acid water results from the exposure of the water to pyrites in mine dumps, slimes dams and old worked out mines and the subsequent precipitation of iron hydroxides when the water reaches the surface and is exposed to the air. The water is clear, acid (pH 1,8 - 4) and can have a high sulphate concentration. These low pH values are lethal for many species and the biota of acid waters is extremely depleted. The outbreak of a chironomid midge, the larvae of which were tolerant of very acid water, was recently controlled in Germiston Lake by neutralization with sodium hydroxide. This allowed predatory and other invertebrates to return and fish eventually to be re-introduced.

Acid drainage can erode underground dolomite, causing sinkholes. When neutralized, the water retains its high sulphate concentration. This may reduce its value for certain purposes but in certain situations where relatively high chloride concentrations are found this may be slightly beneficial for irrigation.

The crushing and exposure of fluospar, apatite and other phosphatic rocks, as well as certain gold and coal ore, can release toxic fluoride concentrations into the water. Chrome, cobalt, nickel, cadmium and other mining can result in toxic heavy metal pollution. The tailings from gold mines in parts of the eastern Transvaal can contain toxic arsenic concentrations.

Certain mining processes use toxic chemicals. For instance, certain uranium extraction processes result in high nitrate concentrations in the effluent. Gold extraction involves the use of cyanides, but these do not normally reach water courses. Other processes expend considerable quantities of water. A more serious general problem associated with mining, however, is the erosion of sediment from mining wastes into streams.

Building material

An activity closely related to mining is the excavation from river beds of sand and (more rarely in South Africa) gravel for building material. This can be either beneficial or detrimental, depending on the circumstances and the way it is done.

Salt production

Many salt pans have been exploited in the past for salt production. Most salt is produced nowadays by evaporation of seawater, however. This involves the construction of a system of evaporation dams with its associated extensive earth works. These dams are sealed to stop seepage, but the surrounding and underlying soils inevitably become saturated with salt. There is consequently no way of reclaiming salt works. The best example of a salt works is probably the Coega estuary near Port Elizabeth.

Urban development

Urban development very often has drastic consequences for any aquatic ecosystems included in the area involved. Streams often serve as refuse dumps and vleis become encroached upon in spite of well intentioned controls. Even if sewage and industrial wastes are treated and re-routed, street runoff will introduce organic waste, debris, nutrients and toxic material into streams and any standing body of water. This obviously reduces the value of these water bodies for recreation and other purposes and can make them a health hazard. Zeekoevlei on the Cape Flats is a good example of a valuable water body severely polluted and eutrophied as a result of urban development.

Vleis probably play a valuable rôle in retaining nutrients from urban runoff. However, encroachment onto floodplains can of course increase the damage caused by unusually severe floods. Changes in the configuration and vegetation of the floodplain and its reedbeds can alter its flood characteristics and greatly increase the risk of flooding. However, these changes usually go unnoticed. It is only when the flood occurs that the changes become apparent.

Drainage of urban areas can have the other effect of drying out interesting aquatic habitats. An example of this is Isoetes Vlei and other similar water bodies on the Cape Flats.

A more serious consequence of urban development is pollution by sewage works effluents. These have been shown to account for 90 to 95 percent of the phosphorus loading of a few of South Africa's most eutrophic impoundments. The technology to remove nutrients, though expensive, is now available and eutrophication research and environmental assessments will be required in order to determine where this technology will be required and what standards should apply in different situations.

Urban development around estuaries has similar effects of pollution, eutrophication and physical destruction. Ignorance of the physical dynamics is, however, a perhaps even greater threat to estuaries. The dynamic nature of estuaries makes them especially sensitive to physical interference by dredging, dykes and so forth.

Industrial development

Urban and industrial water needs are growing at a rate of about 7,5 percent annually. Industrial water use and pollution control in South Africa are regulated through the Water Act (1956). Each large water user is required to obtain a permit from the Department of Water Affairs which stipulates the amounts of water he may use either consumptively (the water is lost, for instance to evaporation) or non-consumptively (the water is returned to a stream after suitable treatment). The permit also lays down the standards to which the effluent must comply.

Power generation

Power generation in South Africa is mostly from coal. Most use water cooling towers and produce heated effluents. However, since the volumes produced are generally small, they are not considered to be a problem. The most serious limnological consequence of conventional power generation in South Africa is probably the doubling of the total salt concentration in the effluent.

The only major hydro-electric schemes are those of the Orange River Project and Tugela Scheme. The Koeberg nuclear power station is remote from any inland water.

Dams and weirs

A wide range of environmental effects, both beneficial and detrimental, occur when a construction is placed across a river altering the flow regime. A good deal of information on some of these effects has been collected for South African rivers and impoundments. This information could be used for prediction in the planning of future schemes.

The first effect of a dam is to create a standing water mass inundating what was previously either dry land or floodplain. The riverine vegetation and other features will be inundated and animals displaced. A new habitat is created in the impoundment for a wide range of aquatic species.

Depending on the size of the dam in relation to the flow of the river, the flow regime downstream of the dam will be altered. Even if there is no manipulation of the releases, an impoundment will absorb and attenuate particularly the small floods. These might previously have maintained the physical structure of the riverine vegetation, provided the water required for the maintenance of floodplain pans, wetlands, estuaries and plant communities such as mangrove forests, and periodically inundated fish spawning grounds.

Information on some of the effects of altered flow regime is available, for instance from the Pongolo research programme. This work has shown that several components of a floodplain ecosystem are dependent upon periodic flooding and the fluctuation of water levels in the floodplain pans. Reduced flooding will destroy habitats and the communities dependent upon them as well as interfere with fish breeding.

The management of a dam can also have as great an effect on downstream flow patterns and riverine habitats. For instance, if the compensation water is released periodically as small floods instead of as a regular stream, many of the riverine habitats will be destroyed by the alternating scouring and drying out. This was the case some years back below the Wemmershoek Dam.

Again, as has been shown on the Pongolo floodplain, altered flow regimes can have sometimes unexpected implications for the human population which utilize the river and floodplain downstream from the dam. For instance, grazing on the floodplain may be destroyed and fishing possibilities greatly altered.

Considerable quantities of suspended material can be deposited in an impoundment. The rate of deposition will depend on the quantities involved and the particle size distribution of the incoming sediment as well as the relationship between the capacity of the dam, the average flow of the river and the average water level within the dam.

The sediment carrying capacity of the incoming water is very sensitive to velocity changes, with the result that most of the sediment, particularly the coarser material, will be deposited in the form of a delta at the point where the river enters the dam. Finer fractions which have settling times of more than a day will be deposited at a rate which depends on the depth of the dam (the deeper the water the greater the volume of sediment in suspension above that point). Over a long period of time the original valleys or depressions in the dam basin will tend to fill with fine sediment. The sediment deposits within a dam that has been in operation for a long time will therefore be characterized by a delta of coarse material at the upper end, a near horizontal layer of fine sediment in the deeper sections, and relatively sediment-free shores where wave action will tend to cause the resuspension and redistribution of the finer material.

Although incoming flood water may be cooler and have a higher suspended sediment concentration than the water in the dam, the difference in density is seldom enough to sustain density currents within the relatively shallow water depths and flat gradients common to most South African dam basins. Some of our dams have been equipped with sediment evacuation valves (for instance Hendrik Verwoerd and P K le Roux), or large flood control gates at river bed level (Floriskraal), or have been specifically designed for evacuating density currents (Nooitgedacht). None of these measures has as yet been shown to have a significant effect on the reduction of the rate of sediment deposition.

Due to the deposition of most of the sediment load within the dam, the sediment content of water discharged from the dam, even during major floods, will be appreciably less than that of the incoming water. With the passage of time, the sediment deposits in the river bed downstream of the dam will tend to be transported further downstream and in some circumstances the river may change from an aggrading to a degrading river in the reach immediately downstream of the dam. Changes in river morphology (typically bank erosion together with a widening of the river channel) are further consequences of changing flow regimes following dam construction.

An unusual situation exists on the Orange River where two of South Africa's largest dams (Hendrik Verwoerd and P K le Roux) have been built in tandem on the river. These two dams can be expected to have very different suspended sediment concentrations with consequent significant differences in biological activity.

Differing environmental effects are of course experienced during the different phases of a dam project. During construction, impacts include the building of access roads and construction and excavation work with its attendant additions to the sediment load of the river. During filling of the impoundment, besides the inundation of habitats, sites and structures, humans and animals can be displaced and riverine vegetation drowned. Rotting plant material on the bottom may cause deoxygenation of the hypolimnion and the production of hydrogen sulphide, the release of nutrients into the water and a growth of algae or floating hydrophytes. The filling of Vaal Dam was followed by a persistent bloom of toxic *Microcystis* and the filling of Kariba was followed by a damaging release of deoxygenated water through the turbines and an extensive growth of *Salvinia*.

Thereafter, during the subsequent management and maintenance phase, the impoundment stabilizes and some of these problems can disappear or be reduced. For instance, *Salvinia* mats still occur on Lake Kariba, but are not as extensive as they were, no longer obstruct fishing and the passage of boats to any very great extent and have some beneficial effects in providing shelter for young fish.

The filling of an impoundment (as well as associated irrigation) can raise the surrounding water table. Under unusual circumstances, this can have unexpected effects. For instance, when the Kommandodrif Dam was filled, a freshwater spring immediately downstream turned saline. Apparently, the rise in water table caused a displacement of fossil saline underground water for some reason.

No South African dams are large enough to have a detectable effect on the local climate other than possible micro-climatic changes along the shoreline.

Instrumentation has been installed in the vicinity of the Hendrik Verwoerd Dam to monitor tectonic changes but no adverse effects such as local earthquakes have been detected.

The physical configuration of the basin inundated, the surrounding landscape, the inflowing water and the wind regime will largely determine the temperatures and summer stratification, the likelihood of deoxygenation of the hypolimnion and the extent and nature of the littoral belt around the shore. The hydroclimate created in the impoundment will also largely determine the fate of the influent water and its suspended material.

Various biological factors can determine what the effects of the impoundment on the trophic status of the river downstream will be. During the initial stabilization period there will normally be a substantial increase in the concentration of nutrients, algae and zooplankton. Thereafter, depending on the drawoff pattern, the impoundment will still affect the nutrient load of the downstream river system in two ways. In the first place, the riverine drift (bottom-living animals that detach and float some distance downstream) and debris will be replaced by algae and zooplankton drawn off from the impoundment (if the drawoff is near the surface). Thus the Vaal River immediately below the shallow Vaal Barrage contains quantities of algae and zooplankton which evidently form a food base for riverine animals for some distance downstream. More significantly, particulate living matter from an impoundment could provide food for the larvae of Simuliidae in the river downstream. This can lead to outbreaks of these animals, as the larvae are also favoured by the stabilized flow which can be created below a dam.

On the other hand, algae and zooplankters tend to die off and settle to the bottom of impoundments, resulting in an accumulation of nutrients and progressive eutrophication of the impoundment. This accumulation process results in a net reduction in the total nutrient load transported downstream.

The fish population which develops in the new impoundment represents a new natural resource and a potential source of income for the surrounding area. The composition of the fish population is important in this regard and will be determined by a number of factors, including the hydroclimate, the nature of the food sources that develop and the extent to which different species can reproduce to populate the impoundment. Fish species have differing food and spawning requirements. Thus *Barbus* species, the larger of which are attractive angling fish, require clean gravel and flowing water while *Labeo* species, which are not attractive angling fish, can spawn in the impoundment on mud. However, the prediction made at the time of construction that the eroded catchment of the Hendrik Verwoerd Dam would be unable to provide sufficient spawning sites for *Barbus holubi* and *B kimberleyensis* was apparently too pessimistic, as a large population of *B holubi* has since developed in the impoundment.

Many fish species undertake spawning migrations which can be completely obstructed by the construction of a dam wall. There are several instances of migrations of *Barbus* species to upstream spawning sites being blocked. The Pongolapoort Dam, on the other hand, blocks the downstream migration of tigerfish *Hydrocynus vittatus* to its spawning sites on the floodplain and this species has consequently disappeared from the impoundment. Eels migrate upstream from the sea as young elvers and return to the sea as mature adults. Obstructions can be bypassed at a cost through the construction of fish ladders, but the facts are not always readily available to assess needs and possible benefits.

In the impoundment, early planning could assist in avoiding future problems and in making it easier to exploit the fish population by for instance clearing level patches of the future littoral zone for netting. Submerged trees are very persistent and snag seine and other nets. Semi-submerged trees and shrubs can be beneficial in forming a refuge for young fish but can also provide refuge for aquatic weeds which could spread from there, as was the case with *Eichhornia* on Hartbeespoort Dam.

A little-studied aspect related to the management of impoundments is the littoral zone. Irrigation dams have a large seasonal drawoff of water which exposes a relatively sterile beach of sand and gravel. The fluctuations in water level prevent the establishment of reeds or submerged hydrophytes. These fluctuations may be expected to have important effects on the impoundment ecosystem, quite apart from causing other practical problems, such as that of drift sand blown into agricultural lands from exposed beaches as occurs at Brandvlei Dam. Pumped storage hydro-electric schemes can have wide daily water level fluctuations as water is released and then pumped back into the impoundment.

Inter-catchment links

Large water schemes can involve the transfer of water from one catchment to another and the environmental implications of these transfers have been little studied. Existing schemes include the Orange-Fish tunnel, the Fish-Sundays, Tugela-Vaal, Caledon-Vaal and Breë-Berg links, the Usutu-Vaal piped link and the mooted Orange-Vaal link.

Other construction works

A variety of construction works can affect the flow of rivers and tidal exchange in estuaries. These include bridges and causeways, dykes and canals which may be dredged or constructed.

Serious damage can be caused during the construction phase of even fairly minor projects through excavation and other actions. Erosion and sedimentation can take place, sensitive areas can be damaged by access roads, spoil dumping and so forth and changes can be made to water courses without due reference to possible later geomorphological, hydraulic and hydrological implications.

In general the ecological consequences of these structures will be related in the first instance to the physical obliteration of habitats and, secondly and more important, to changing water movement patterns. These are most serious in estuaries, where the reduction in tidal exchange can result in the destruction of salt marshes and mangrove forests and in severe sediment deposition. There are unfortunately many examples of past construction works in South Africa which have caused this kind of damage.

Harbours and marinas

The construction of a harbour is a major development and may be expected to have major effects on any estuary in which it is constructed. However, the surprising fact that remnants of mangrove swamp and prawn beds survive even in Durban Bay suggests that it might be possible through skilful planning and management to reduce the damage.

When the new harbour was built at Richards Bay, the estuary was divided in two in order to create a sanctuary in the southern bay which was given its own artificial entrance. However, the sanctuary area has subsequently been exposed to tremendous sedimentation as a result of damage to the reedbeds of the inflowing Mhlatuze. A large delta has been created and *Zostera* and prawn beds have been obliterated.

A good deal of work has also been carried out at Saldanha Bay to reduce the impact of harbour development and the shallow and estuarine southern area (Langebaan) is to become a nature reserve. Once again, however, severe problems can be expected here in the future and will require continuing attention. For instance, the dredging of the channel from the harbour to the open sea continuously stirs up the bottom and the fine material which finds its way into the southern area is deposited in considerable quantities and smothers the bottom fauna and flora, including the red alga *Gracilaria verrucosa* which was previously harvested for agar production.

Marinas and small boat harbours are becoming an increasingly important form of development in estuaries along the South African coast. These involve extensive dredging, the building of dykes, and urban settlement with attendant pollution problems. The nature of any problems to be experienced will depend to a large extent on the configuration of the new channels and water bodies created and such management practices as water level manipulation and wastes removal. For instance, when stagnant arms are created in an estuary with good tidal exchange, situations are created where organic sediments and plant detritus may accumulate and decompose. Early planning and continuing management are necessary in most instances to avoid weed, algal bloom, odour and other problems.

Recreation and fishing

Water bodies attract both urban and rural holiday development and a large part of their value to man lies in their recreation value. Careful planning based on insight into the ecosystem processes is needed, however, if this value is not to be destroyed through thoughtless though well meaning development. Many estuaries around the South African coast have already been greatly damaged in this way and the same is happening to coastal lakes and other water bodies of the interior.

Some information is available to assess the needs of different activities, including boating, bait collection, fish netting, angling and even prawn, oyster and other aquaculture to make it possible to preserve the conditions necessary for each. Some information is also available, and more could easily be collected, on the effects of different kinds of past development, including housing and different kinds of construction associated with recreation activity to be able to predict the effects of future planned development. Environmental assessment would be made possible and would greatly add to the value of such future development.

Agricultural and other development in the catchment can have marked effects on coastal lakes and estuaries. Management actions such as the opening and closing of estuary mouths and the removal of hydrophytes and emergent plants can have important effects on estuaries and other water bodies and may in many instances be essential to maintain certain conditions. In fact, once even very slight interference with a natural system starts, one starts on a spiralling path of increasing manipulation. One action may solve a problem but will almost undoubtedly cause other problems which will require other actions and so on. The danger is that a series of perfectly rational individual decisions can produce a totally irrational final result. Only clear insight into the workings of the system, good scientific information and long term planning can avoid this kind of situation.

Information required

7.1 Impact of development on river systems

There is a need for information to make the following possible :

- Prediction of the likely hydrological effects of different forms of development, including possibilities of flooding upstream and of alterations to flow regime downstream of construction works.

- Prediction of the effects of construction and different forms of development on the loads of sediments, nutrients and chemical pollutants transported by rivers and on erosion and sedimentation in the rivers.

- Prediction of possible outbreaks of Simuliidae, mosquitoes or snails as a result of the creation of suitable habitats for these animals.

- Prediction of possible effects of construction works or different forms of development on water quality.

- Prediction of possible accumulation or decomposition of organic matter or alterations to algal and macrophyte growth in rivers as a result of construction works or different forms of development.

- Prediction of possible effects of construction works and different forms of development on fish populations and migrations.

- Prediction of possible effects of construction works and different forms of development on threatened species and habitats.

- Cost-benefit analyses of any remedial actions required.

7.1.1 Review of existing information on river pollution in South Africa

Considerable information is available on the past pollution of South African rivers and its impact on rivers. There is a need to synthesize this information and re-assess possible needs for future research.

7.1.2 Synthesis of existing information on the environmental effects of dam construction projects

Considerable experience has been built up in South Africa which should be synthesized both as an aid to future planning and in order to provide information on which to base environmental impact assessments (EIA's).

7.1.3 Effects of development on nutrient loads of rivers

See 1.2.1.

7.1.4 Effects of development on Simuliidae, mosquitoes and snails

See 5.1.2.

7.1.5 Effects of construction works on fish migrations

Existing literature and other information should be reviewed in order to provide a basis for the assessment of possible needs for fish ladders in given situations.

7.2 Impact of development on vlei and sponge ecosystems

Sponge areas are known to be sources of water of high quality and information is to be sought elsewhere (see 1.3) on the possible rôle of vleis in retaining nutrients and sediment. Information is therefore also required on particular vleis in order to make the following possible :

- Prediction of possible effects of physical disturbance on the vegetation and on plant succession in individual sponges and vleis.

- Prediction of possible hydrological and hydraulic effects of construction works and different forms of development on vleis (including the likelihood of possible flooding, erosion and rerouting of channels).

- Prediction of effects of possible changes to vleis upon possible water losses through infiltration and evapotranspiration.

- Prediction of possible effects of construction works and different forms of development on nutrient, sediment and chemical pollutant loads reaching and leaving vleis and of the possible water quality implications of any changes.

- Prediction of the possible effects of burning, cutting of reeds, grazing and extraction of peat on vlei ecosystems.

- Prediction of likely effects on water quality (including nutrients and pathogens) of any changes to vlei ecosystems.

- Prediction of possible effects of vlei destruction on migratory birds.

- Prediction of possible implications for problem animals (mosquitoes, snails and terrestrial pests) of any changes to vlei ecosystems.

- Prediction of possible effects of construction works and different forms of development on threatened species and habitats.

- Cost-benefit analyses of any remedial actions required.

7.2.1 Distribution of vlei ecosystems in South Africa

See 1.3.1.

7.2.2 Surveys of effects of past development on vlei ecosystems

Considerable damage has been done to vlei systems through drainage, burning, clearing and other actions. Surveys should be undertaken to assess the effects of these actions.

7.3 Impact of dams, irrigation and other development on floodplains

Information is required from the research in progress on the Pongolo floodplain and other activities in order to make the following possible :

- Prediction of possible hydrological and hydraulic implications for floodplains of construction works and different forms of development.
- Prediction of water quality implications for floodplains of construction works and different forms of development.
- Prediction of possible geomorphological and sedimentation implications for floodplains of construction works and different forms of development.
- An understanding of the structure and functioning of natural floodplain ecosystems and of the rôle of periodic flooding in these systems.
- An understanding of past, present and possible future utilization of floodplains and of the socio-economic factors involved.
- Prediction of likely effects of planned future development on floodplain ecosystems and of likely socio-economic implications of changes foreseen.
- Cost-benefit analyses of any remedial action required.

7.3.1 Dynamics of floodplains affected by development

Detailed research is in progress on the Pongolo floodplain in relation to the construction of the Pongolapoort Dam and proposed development of an irrigation scheme. A mathematical model is being developed to predict the dynamics of water level fluctuations in the floodplain pans for different hydrological, weather and floodplain management regimes. Water quality changes are being monitored. The rôle of periodic flooding in biological production and nutrient cycling processes and in the life histories of fish has been studied. Information is being collected on the fish productivity and on the demography and social implications of likely future changes for the local population is being collected.

7.4 Impact of development on endorheic pans

Information is required in order to make the following possible :

- Prediction of possible effects of pollution (including eutrophication) on pans.

- Prediction of possible physical damage done to pans by exploitation and other processes.

- Prediction of future trends.

7.4.1 Distribution and status of endorheic pans in South Africa

A survey is required of different pan types, their conservation status, their value to migratory birds and other wildlife and their possible threats.

7.5 Impact of development on impoundments

Information is required in order to make the following possible :

- Estimates of sediment deposition rates in different impoundments and an understanding of differences between sediment types of differing origin.

- Prediction of possible algal growth and aquatic weed problems in impoundments and an assessment of the costs (for instance loss in amenity value, increased cost of water purification) of eutrophication and pollution.

- Prediction of the fish production potential and planning of the management of fish populations for sport (and perhaps commercial) fishing.

- Assessment of the benefits derived from different forms of utilization of different impoundments.

- Cost-benefit analyses of any remedial or other action required.

7.5.1 Assessment of threats to impoundments of excessive nutrient loading

See 1.8.1.

7.6 Impact of development on coastal and estuarine lake systems

A good deal of information is available on Sibaya and the Kosi lake system. An assessment should be made of future information needs, taking into account possible plans for the area, development and human settlement.

A study is nearing completion of the rôle of the *Potamogeton pectinatus* belt in nutrient cycling and primary production in Swartvlei and further research is being initiated both in Swartvlei and the adjacent Wilderness lakes. An understanding of biological production and nutrient cycling is of considerable value in predicting how the ecosystem might react to bridge construction, shoreline development, management and pollution.

Information is required to make the following possible :

- An understanding of the hydrology and hydraulics of important lake systems sufficient to be able to predict water level and salinity dynamics for any given set of conditions (for instance periodic droughts and floods) and to manipulate estuarine lake water levels, where necessary, for instance by opening and closing the estuary mouth or by diverting fresh water into the system.

- Prediction of rates of recovery of lake systems after disturbance.

- Assessment of the rôle of vleis in retaining sediment which might otherwise have been deposited in the lakes.

- An understanding of the rôle of reedbeds in the hydraulics and nutrient budgets of the lake systems sufficient to be able to predict possible consequences of actions affecting the reedbeds.

- Prediction of possible problems of eutrophication and toxic pollution in lakes threatened by development.

- An understanding of the factors controlling the angling and fish netting potential, as well as the numbers of mud and sand prawns and other organisms, in the lakes threatened by pressures of heavy exploitation.

- The planning of strategies for the management of the fish and other biological resources of lake systems.

- An assessment of criteria for the conservation of particular ecosystem functions.

- Cost-benefit analyses of any remedial or other actions required.

7.6.1 Hydrology, hydraulics and salinity dynamics of estuarine lake systems

Information is needed on the hydrology of water supplies to important lake systems, the hydraulics of water movement between different parts of each system and the processes determining salinities. The information should be incorporated into mathematical models to simulate the hydraulic behaviour of the system.

7.6.2 Rôle of reedbeds of coastal and estuarine lakes in relation to water movements, sediment deposition and eutrophication

Information is needed on the flow resistances of reedbeds of different densities in order to make an assessment of the hydraulic and other implications of canalization and other possible actions (see 7.6.1). Information is also required on possible dangers of eutrophication of certain lakes and the possible rôle of the reeds and other aquatic vegetation in this regard.

7.6.3 Assessment of the effects of development and environmental extremes on coastal and estuarine lakes

Short term surveys and investigations are required from time to time to assess possible consequences of planned development (construction works, urban and other development) on coastal and estuarine lake systems.

7.7 Impact of development on estuaries

Estuaries are the aquatic ecosystems in South Africa which have in recent years been placed under the greatest threat from development. A good deal of information on these estuaries and on their ecology is available from research which has been carried out to date and a programme of research on St Lucia is being administered by the St Lucia Scientific Advisory Council (of the Natal Parks Board). However, considerable further information needs exist to make the following possible :

- An understanding of the hydrological and hydraulic processes that take place in estuaries.
- An understanding of the ecological dynamics of estuaries.
- Prediction of the likely environmental consequences of different forms of development and disturbance to estuarine dynamics.
- An assessment of criteria for the conservation of particular estuarine ecosystem functions.

7.7.1 Review of existing information on estuaries

A review of existing information on Natal estuaries is nearing completion. This is expected to prove a valuable aid for planners and researchers. An urgent need exists to carry out a similar review for Cape estuaries and to draw up a classification system for these estuaries.

7.7.2 Preliminary bathymetric surveys of estuaries

An urgent need exists to carry out simple bathymetric surveys of South African estuaries. This information would very usefully complement the reviews described in 7.7.1.

7.7.3 Pollution surveys of estuaries

Pollution surveys of all major South African estuaries receiving pollution are being carried out for the NPES Marine Pollution Section. Certain of these surveys should be repeated from time to time as part of a planned monitoring programme.

7.7.4 Studies of environmental effects of different forms of past development

Short term investigations of the environmental consequences of such forms of development as bridges, dykes, embankments, canals, dredging, villages, recreation, fishing and artificial control of the mouth of water level should be carried out at estuaries where these developments have taken place, in order that the consequences of similar developments at other estuaries can be predicted.

7.7.5 Assessment of effects of development on selected estuaries

Short term surveys and investigations are required from time to time to assess possible consequences of planned development (construction works, urban and other development) on particular estuaries.

SUPPORTING RESEARCH

TAXONOMY AND BIOGEOGRAPHY

No biological research is possible unless the plants and animals collected can be identified. The present advanced level of limnological research in South Africa would have been inconceivable if it had not been for pioneer taxonomic work carried out by K H Barnard, B J Cholnoky and others, for the existence of the National Herbarium, for the extensive collections built up by the University of Cape Town, the NIWR and others and for the systematic study of these collections over many years by specialists all over the world.

Present state of knowledge and of identification services

As may be seen in Table 12, some groups are well known, others are poorly known and a few are scarcely known at all. Several important taxonomic centres exist in the country, where large collections are housed, the otherwise unobtainable literature is available and posts exist for systematists. These include :

- The NIWR, with extensive collections of diatom algae, all of the literature on African diatoms and two diatom systematists both able to identify material for other researchers and currently publishing in parts a systematic index to the 3 000 or so species of southern African diatoms. The NIWR also has algologists and the literature to identify and describe where necessary blue-green algae (Cyanophyta), a much smaller group.

- The National Herbarium, Botanical Research Institute, Department of Agricultural Technical Services, currently publishing in a series of volumes the revised Flora of South Africa and maintaining an identification service and extensive liaison with specialists in South Africa and elsewhere.

- The National Collection of Freshwater Organisms, Albany Museum, with extensive NIWR and other collections, one invertebrate systematist post, maintains extensive liaison with overseas specialists.

- The Snail Research Unit, Potchefstroom University for CHE, with extensive collections, three systematist posts, currently preparing detailed distribution maps for publication, offers an excellent identification service.

- The Albany Museum Freshwater Fish Section, with good collections and one systematist post, able to undertake identifications.

- The JLB Smith Institute of Ichthyology, with good collections and two systematist posts, able to undertake identifications.

- The South African Museum Marine Biology Section, with three systematist posts, able to undertake identifications.

- The University of Cape Town Department of Zoology estuarine reference collection.

Table 12. State of knowledge and identification series for different groups of freshwater and estuarine organisms

Group	Size of group	State of knowledge	Availability of specialists	Identification service	Identification guides
Nannoplankton	medium	poor	one in RSA	none	none
Blue-green algae	small	reasonable	none but probably not needed	algologists do own	good world guides
Diatoms	enormous	good	two in RSA	excellent but limited volume	being published
Red algae	small	reasonable	one in RSA	good	good
Green algae and others	enormous	exceptionally poor	one in RSA	algologists do own; literature permitting	none
Bryophytes	small	poor	two in RSA	none	reasonable
Ferns	small	reasonable	one in RSA	available for occasional identifications	inadequate
Flowering plants	small	good	adequate	good	reasonable
Protozoans	large	very poor, but most probably cosmopolitan	few overseas	none	reasonable world guides
Sponges	small	poor	none	none	none
Coelenterates	small	poor	none	none	inadequate
Turbellarians	medium	poor	none	none	inadequate
Parasitic worms	medium	poor	few overseas	none	inadequate
Nematodes	medium	reasonable	one in RSA	occasional identifications	good world guide
Polychaetes	medium	good	one in RSA	good	excellent
Oligochaetes	large	good	few overseas	none	reasonable
Entomostracans	large	good	one in RSA (estuarine copepods) few overseas (others)	good (estuarine copepods) only overseas specialists (others)	reasonable
Decapods	medium	good	one in RSA	good	good
Molluscs	large	good	group in RSA (freshwater) few overseas (estuarine)	excellent	inadequate
Ephemeropterans	medium	good	few overseas	none	reasonable
Odonates	medium	adults good	one in RSA	none	reasonable for adults only
Plecopterans	small	good	overseas	adequate	reasonable
Hemipterans	large	good	overseas	adequate	inadequate
Megaloptera and neuropterans	small	good	overseas	none	reasonable for adults
Gyrinids and dytiscids	medium	good	one in RSA	occasionale identifications	reasonable for adults only
Other beetles	large	varies according to family	few overseas	none	inadequate in most families
Trichopterans	large	good	one in RSA	excellent	inadequate
Mosquitoes etc	large	good	two in RSA	adults	reasonable for adults
Simuliids	medium	good	one in RSA	none	good
Chironomids	large	adults good larvae poor	none	none	good for adults only
Ceratopogonids	small	adults good larvae poor	none	none	inadequate
Other flies	small	adults good larvae poor	one in RSA	good	inadequate
Fish	medium	good	two in RSA	excellent	excellent
Amphibians	medium	good	six in RSA	good	reasonable

Future needs

8.1 Collections of freshwater and estuarine organisms

Taxonomic study is based on collections and there is a general long term need, with no particular urgency attached to it, to continue and where possible to encourage collecting expeditions and to build up collections in areas and habitats as yet inadequately covered. Wherever possible these collections should be worked upon by an appropriate specialist and then be lodged in the appropriate centre in the Republic of South Africa.

8.2 Taxonomic research

8.2.1 Green algae

There is an urgent need to have a permanent post for a systematist for green algae (Chlorophyta) created at some suitable institution, to ensure that this person is trained and has experience at a suitable centre overseas and to ensure that the literature (including expensive historical literature) is acquired.

8.2.2 Fish parasites

There is an urgent need to have a post for a fish parasite systematist created, preferably at the fish disease centre suggested in the chapter on utilization of inland waters for fish production, to ensure that this person is suitably trained and equipped to provide a routine identification service as well as conduct original research.

8.2.3 Freshwater invertebrates

There is an urgent need to have one or more further posts for invertebrate systematists at the Albany Museum National Collection of Freshwater Organisms and to provide this centre with the technical staff required to provide a routine identification service at least for some groups.

8.3 Identification guides

8.3.1 Flora of South Africa

It is suggested that the Department of Agricultural Technical Services consider ways and means of speeding up the preparation of volumes of the Flora of South Africa, by providing additional posts and involving South African and outside specialists to a greater degree on a cooperative basis. The expansion of the project to include cryptograms should also be considered.

Ways of speeding up the preparation of illustrated identification guides for South African plants, again by the Department of Agricultural Technical Services, should be investigated.

8.3.2 Freshwater invertebrates

Ways of having an illustrated identification guide for freshwater invertebrates, preferably on a cooperative basis involving specialists around the world, should be investigated.

AUTECOLOGY, PHYSIOLOGY AND ECOPHYSIOLOGY

Several excellent studies of the biology of individual species have been undertaken or are still in progress. These include the hydrophytes *Azolla filiculoides*, *Myriophyllum aquaticum*, *Eichhornia crassipes*, *Potamogeton pectinatus* and *P crispus*, insects like *Simulium chutteri*, certain Culicidae, freshwater snails like *Biomphalaria pfeiferi*, *Bulinus (Physopsis) africanus*, *Bulinus (Bulinus) tropicus* and *Lymnaea truncata*, crustaceans like *Pseudodiaptomus hessei*, *Caridina nilotica*, *Callianassa kraussi*, *Upogebia africana*, *Hymenosoma orbiculare* and *Scylla serrata* and fish like *Sarotherodon mossambicus*.

This work has considerably enriched our understanding of inland water ecosystems. It is greatly to be hoped that, quite apart from the priority research initiated through the IWE programme, university and other researchers will be encouraged to undertake similar studies of other species.

EXPLORATORY AND DESCRIPTIVE REGIONAL LIMNOLOGY

Priority is given in the IWE programme to research into the structure and functioning of particular aquatic ecosystems aimed at predicting the consequences of possible human actions, at finding solutions to particular problems or at providing the scientific basis for the rational exploitation of these ecosystems. The programme rests very heavily on the early descriptive surveys of the ecosystem types concerned.

It must be realized that considerable needs still exist for exploratory surveys and descriptive studies of different ecosystem types. Ephemeral rivers in the drier parts of the country and the important river systems of the Limpopo, Letaba, Olifants, Komati and Sabie systems in the northern and eastern Transvaal, for instance, are still poorly known. Vlei and floodplain ecosystems have nowhere been mapped and described. The endorheic pans and unique bodies of water like Fundudzi are extraordinarily poorly known, as are the coastal lakes of the south-western and western Cape and the salt marshes and certain other features of South African estuaries. Almost nothing at all is known of temporary waters, sinkholes and other minor ecosystem types which have been ignored in this document.

It is greatly to be hoped that, quite apart from the priority research initiated through the IWE programme, university and other researchers will be encouraged to undertake exploratory and descriptive surveys so that the remaining gaps can in the course of time be filled.

RELATED RESEARCH AREAS OUTSIDE THE IWE PROGRAMME

HYDROLOGY

South Africa's water resources are severely limited and hydrological research is essential to provide the necessary scientific basis for their optimal management. This research is also necessary for any understanding of the structure and functioning of aquatic ecosystems. These ecosystems are often very sensitive to changes in the hydrological cycle which may affect both the quantities and the quality of the water they receive.

Rainfall in South Africa is strongly seasonal in character and a network of rain gauges has been developed to meet the need for accurate statistics on the distribution, frequency and nature of rainfall. Key questions for research are of moisture in the atmosphere, with the understanding of atmospheric processes necessary to improve weather forecasts and hail and drought predictions and with possible techniques for hail prevention, rain stimulation and the extraction of moisture from the atmosphere.

The proportion of rainfall which reaches rivers as runoff is greatly affected by processes that take place in the atmosphere. Research is in progress on the interception of rainfall, on factors affecting evaporation and evapotranspiration, on plant-soil relations and the effects of different land use practices.

A network of river flow gauging weirs has been built up to provide the statistics on flow fluctuations. These are necessary to plan water utilization and dam construction schemes, as well as to determine flood frequencies, control development on floodplains and detect changes in runoff patterns.

The gauging weir network is also used to determine sediment loads in South African rivers and provide the data necessary to investigate the effects of different land use patterns and other factors on sediment loads. Research is also in progress to determine the transport of suspended material and patterns of sedimentation in impoundments.

Research is also in progress to determine the utilization potential of groundwater, the contribution of groundwater resources to runoff and the possibilities of recharging groundwaters.

Hydrological considerations are vital to most investigations relating to water quality and for the management of rivers, floodplains, impoundments, natural lakes and estuaries. For this reason, close contact between the IWE programme and the Research Coordinating Committee for the Hydrological Cycle is essential.

MINERALIZATION

Mineralization, or gross salt pollution of natural waters, is a problem of increasing importance in South Africa in such rivers as the Great Fish and Sundays Rivers in the eastern Cape and the Berg and Breë Rivers in the western Cape. In rivers such as these, total dissolved salt concentrations are frequently found which are in excess of limits for the uses to which the water is to be put. Knowledge of the processes of mineralization operating in these systems is required in order that river management strategies can be devised to provide water of required quality at the places and times it is required for particular purposes.

Mineralization takes place wherever water comes into contact with soil and rock and leaches inorganic salts released by weathering processes. These natural processes are complex and not completely understood, but the degree of mineralization is determined to a large extent by the geology of the catchment and by the local climate, in particular the rainfall pattern. For example, in the upper Berg River catchment, where the rainfall often exceeds 1 000 mm annually, the rocks are relatively inert (Table Mountain sandstones) and total dissolved solids concentrations of about 60 mg ℓ^{-1} are found in the winter rainy season. In contrast, tributaries in the drier lower catchment having their origin in Malmesbury shale formations typically have winter TDS concentrations of around 3 500 mg ℓ^{-1}.

Mineralization can also result from the percolation of saline soil water from the root zone of irrigated soils, where the dissolved salts in the irrigated water have been concentrated by the evapotranspiration of around 80 percent of the water. Finally, industrial and sewage works effluents can act as point sources of salt pollution.

A study of mineralization processes in the Great Fish and Sundays Rivers in the eastern Cape has demonstrated the importance of natural processes in mineralization and is being used to develop a model to predict salt concentrations and loads resulting from different natural circumstances, such as rainfall, and river management strategies. This study is being expanded to the Berg and Breë Rivers in the western Cape and it is hoped to verify the predictive model for application to these rivers.

This work was initiated within the IWE programme and has now been transferred from the IWE programme to form part of the programme of a new WRC Coordinating Research and Development Committee for Water Quality.

WATER QUALITY

The increase in water consumption in the Republic of South Africa is still rising exponentially and has not yet shown any indication of levelling off. The need for determining water quality is consequently constantly increasing.

A fair amount of information on water quality has already been gathered by different bodies and is being stored at different localities. Difficulties are seen in the establishment of a general monitoring network which will satisfy the needs of all of the user organizations at different localities. It has therefore been generally agreed among the agencies responsible for the collection of water quality data to concentrate first on a small number of specific areas to satisfy specific needs.

Monitoring is of great importance in many research programmes, first, to make possible a preliminary assessment in order to determine research needs, second, in order to detect changes and, third, to collect quantities of data for the verification of predictive models. It is therefore essential that the needs of the IWE and other research programmes be considered when monitoring networks are to be designed.

A Working Group for Water Quality was set up within the IWE programme with an object of promoting and coordinating research relating to water quality, to identify water quality data needs, consider the parameters which should be measured in South Africa, the frequency and distribution of measurements required, procedures for sampling, storage, transport, analysis, standardization and inter-laboratory calibration required, on data control, storage and retrieval required and the assessment and reporting required on water quality in South Africa.

This work has now been transferred from the IWE programme to form part of the programme of a new WRC Coordinating Research and Development Committee for Water Quality.

AQUACULTURE

In the more densely populated countries of both Europe and Asia, aquaculture plays an extremely important rôle in food production. The products include some of the most highly sought after forms of animal protein on the market (such as eel, trout and prawns) as well as some of the cheapest (such as *Sarotherodon, Cyprinus* and *Mugil*). There is a relatively new but rapidly growing demand in South Africa for these products right across the spectrum from the most expensive to the cheapest staple.

Great possibilities exist for aquaculture in estuaries. In the Far East, in countries with extensive coastal wetlands, fish culture in brackish water ponds represents a very important source of animal protein. No equivalent to this exists in South Africa. However, the first successful oyster culture industry has recently been developed by Viskor (Fisheries Development Corporation) at Knysna while attempts have also been made by Viskor to culture prawns in the Matigulu estuary in Natal. Possibilities also exist in the culture of mussels and soles in river mouths in South Africa.

Trout culture is by far the oldest practised form of aquaculture in South Africa and several farms are in operation. In spite of adverse climatological conditions like drought spells and hot weather, the considerable cost of trout feed and competition from imported products, the locally cultured trout sell well.

Carp farming has also established itself to a lesser degree in especially the Transvaal where Aischgrund carp are used and production rates of 1 000 kg ha^{-1} or more in one summer season are recorded. It is said, however, that a lack of marketing facilities as well as high fish feed prices are the principal factors limiting development.

A good deal of research has been carried out on the culture of Mozambique tilapia *Sarotherodon mossambicus* as well as on some other cichlid fish (the plant-eating redbreast kurper *Tilapia rendalli* and various Middle East tilapias). Similar production rates to those of carp have been obtained experimentally, especially in single sex culture (which avoids the overproduction of juveniles). No real cichlid fish farm is as yet in operation in South Africa.

Research undertaken for Viskor at Rhodes University has overcome many of the disease and other problems experienced earlier in the pond culture of eels and possible export of elvers.

Mullet (*Mugil* spp) are cultured very successfully in saline waters in many parts of the world and some work has been done on their culture in South Africa.

Research on the production potential and growth of catfish *Clarias gariepinus* has shown that this hardy fish might also be a local candidate for aquaculture as crops of more than 3 000 kg ha^{-1} have been harvested. Work in the Orange Free State suggests that moggel *Labeo umbratus* might also be a promising candidate for aquaculture.

Three fish widely cultured in Asia have recently been introduced and are being bred and studied by Provincial Administrations with a view to their possible use in fish culture or control of water plants. These fish are the plankton eating silver carp *Hypophthalmichthys molitrix*, the grass carp *Ctenopharyngodon idella* and the bighead carp *Aristicthys nobilis*.

Recent research by the Transvaal Provincial Administration has shown that considerable potential exists for the intensive culture of fish in low cost raceways constructed in irrigation canals. Exceptionally high production figures per unit of surface area and per unit of water volume are obtained in the systems because the water flows through them and the same water is re-used several times.

Highest fish production rates have been obtained in culture systems where species utilizing different food resources are stocked together. No systematic attempts to develop polyculture methods in South Africa have yet been made.

A real need for relative inexpensive animal protein exists in South Africa's developing areas, with their large rural populations. Efforts to introduce fishery techniques and fish farming have only recently begun and already there are signs that freshwater fish are an acceptable form of protein food. Fish farming could also be introduced where it can be developed in association with an intensive agricultural project - e g irrigation and pig, chicken or cattle farming.

The greatest potential for protein production is offered by algal culture. Preliminary experiments at the University of the Orange Free State have confirmed that prodigious production rates are possible. However, while considerable practical problems remain, such as harvesting, control over the species to dominate the culture and the economic viability of algal culture, methods for the mass culture of algae on sewage have been developed and the algae can be harvested. The NIWR is currently evaluating an algal culture and harvesting system and the uses to which the product might be most favourably put.

WASTE WATER TREATMENT

Research relating to effluent quality and treatment has a vital bearing on the interests of the IWE programme in that the quality of effluent discharges has in many cases a significant effect on aquatic ecosystems.

Sewage effluents treated to presently accepted standards are rich in nitrogen and phosphorus compounds, and effluents from the larger population centres contribute a significant nutrient load on the receiving waters. Several research programmes coordinated by the WRC are directed at the development of treatment processes capable of increased removal of N and P compounds and form an obvious complement to the activities of the IWE programme in the area of eutrophication.

Many industrial effluents are discharged to sewers for treatment in municipal sewage treatment works and have no significant effect on the environment after discharge. Others have effects that persist through the treatment process, either because the volume and strength of the industrial effluent is such as to exceed the capacity of the treatment works or because they are unaffected by the treatment process. In certain cases industrial effluents are discharged directly into watercourses often with significant effects.

Research programmes on effluent treatment in several industrial areas are being coordinated by the WRC. Examples of these are the following :

- Tanneries and fellmongers
- Abattoirs
- Textile industries
- Fruit and vegetable canneries
- Pulp and paper industries.

A well known example of an industrial effluent with profound effects on the environment is the highly mineralized and often acidic effluent from the Transvaal and Orange Free State goldmines. Research is being carried out on these effluents by the Chamber of Mines Research Laboratory, and again the WRC has a coordinating research committee.

A related activity of direct interest to IWE is the research that has been carried out by NIWR and others on the inhibition of algal growth in sewage effluent maturation ponds. While this does not form a part of the IWE programme the phenomena are obviously of considerable relevance to eutrophication research.

PRIORITIES FOR ACTION

Basis for allocating priorities

The funds and skilled manpower available in South Africa for limnological research are limited. It is therefore highly desirable that every effort be made within the IWE programme to use these resources to the greatest advantage. Attempts have been made in this document to identify the problems of the future relating to inland water ecosystems, especially those problems caused by development and involved in the management and utilization of these ecosystems. Attempts have also been made to identify the information which will be needed for planning, management and the prediction of problems. Suggested priorities have been allocated to all of these needs from the point of view of the IWE programme. Some fall within fields for which State departments, provincial administrations or other bodies are responsible. They may assign quite different priorities to these items.

Priorities may be determined by scoring on the basis of criteria as follows :

Importance criteria	A Score	Urgency criteria	B Score
Essential. The information is required at all costs. Significant economic, scientific or other benefits are certain to be made possible as a result.	1	Very urgent. Immediate action is essential. Delay could be costly.	1
Very important. Every effort should be made to obtain the information. Significant economic, scientific and other benefits are likely (and at least some benefits are certain) to be made possible as a result.	2	Urgent. Action should be taken now (manpower and funds permitting) and must take place within two years otherwise expected benefits could diminish.	2
Important. It is highly desirable that the information be obtained. Significant economic, scientific or other benefits could (and at least some benefits are likely to) be made possible as a result.	3	Less urgent. Action should be taken as soon as manpower and funds permit and must be taken within the coming five years.	3

Priorities have been calculated as A + B - 1, providing the following priority categories :

Priority	1	2	3	4	5
Description	Essential and very urgent	Essential and urgent or Very important and very urgent	Essential but less urgent or Very important and urgent or Important and very urgent	Very important but less urgent or Important and urgent	Important but less urgent

In this chapter, priorities are suggested for the following categories of future action :

- Synthesis of existing information on priority planning regions.
- Synthesis of existing information on selected topics.
- Short term surveys and investigations.
- Monitoring.
- Detailed research.

Within each of these categories, the items in the three highest priority categories are seen as the items which must receive attention within the coming three years if the IWE programme is to achieve its purpose. The full list of priority items should be reviewed annually in the light of new knowledge and changing circumstances.

Synthesis of existing information on priority planning regions

A good deal of information already exists on many drainage systems and aquatic ecosystems in South Africa. This information is not always readily available, especially to decision makers, and is essential both for the planning of the IWE programme and for the planning and management of development relating to inland water ecosystems. It is seen as a function of the IWE programme to assemble, review, synthesize and evaluate such information and to assess present and possible future environmental problems in these regions and the catchments within which they fall for use by limnologists, planners and decision makers.

The following NPDP planning regions (where necessary expanded to include missing pieces of the catchments in which they fall) require synthesis as a priority :

Planning region and catchment		Remarks	Priority for synthesis
27	Witbank-Middelburg Olifants	prototype for synthesis in light of existing problems and envisaged development	1
6	George-Knysna-Wilderness southern Cape catchments	prime recreation area	1
42	Pretoria-Witwatersrand-Vereeniging (1) Crocodile (Limpopo) (2) Vaal (part)	metropolitan area	1
28	Bethal-Ermelo Vaal (part)	rapid development fore-seen	2
40	Port Elizabeth-Uitenhage Swartkops, Sundays plus minor catchments	metropolitan area	2
21	East London Keiskamma, Buffalo, Nahoon, plus minor catch-ments	metropolitan area	2
41	Durban-Pietermaritzburg Mgeni plus minor catch-ments	metropolitan area	3
39	Cape Town Berg (part), Diep, Eerste plus minor catchments	metropolitan area	3
17	Upington Orange (part)	rapid development fore-seen	3
3	Saldanha-Vredenburg Berg (part)	rapid development fore-seen	4
4	Worcester Breë	rapid development fore-seen	4

Synthesis of existing information on selected topics

Existing literature and other information needs to be synthesized for various purposes :

- To make it possible to assess certain research needs and possibilities for management action.
- To make the information available to decision makers.
- To make it possible for the IWE Committee to offer advice on certain topics.

The following topics require synthesis as a priority :

Synthesis required	Remarks	Priority
1.1.1 Social and economic costs of eutrophication	Required in order to assess the importance of eutrophication	1
1.1.2 Criteria to assess trophic status of impoundments	Will be assisted by findings of the NIWR 22 impoundment study	1
1.1.3 Procedures for the prediction and assessment of eutrophication	Based on 1.1.2, required to determine where control or rehabilitation may be required	1
1.9.1 Assessment of eutrophication prevention techniques	Required in order to assess research needs and be able to advise on possibilities	2
1.9.3 Assessment of techniques for the rehabilitation of eutrophic impoundments	Required in order to assess rehabilitation possibilities	2
4.3.1 Procedures for the identification of representative ecosystem types and habitats for conservation	A new approach to the siting of nature reserves and management needs outside reserves is required	2
6.1.1 Sources and rates of release of chemical pollutants into the environment	At least a first attempt required to identify possible problem chemicals	2
7.1.1 Review of existing information on river pollution in South Africa	Required to assess future needs	2

Synthesis required	Remarks	Priority
7.1.2 Synthesis of existing information on the environmental effects of dam construction projects	Synthesis of past experience upon which to base impact assessments	2
7.7.1 Synthesis of existing information on estuaries	Natal synthesis nearing completion and Cape synthesis required, required for impact assessments	2
1.4.3 Nutrient availability, algal growth and energy flow in impoundments	Required to assess research needs relating to availability of different nutrients	3
1.5.1 Nutrient uptake and release from sediments	Required to determine research needs	3
2.1.1 Identification manual for aquatic weeds	Required to make monitoring possible	3
2.1.3 Criteria for the assessment of aquatic plant problems	Required to assess the importance of different species and to determine research needs	3
2.3 Factors influencing algal succession	Required to determine research needs and assess possibilities of manipulation	3
2.5.1 Methods of determining hydrophyte production rates	Required to predict field growth rates from recent data	3
2.6.1 Biological control of aquatic weeds	Required to assess possible research directions in South Africa	3
2.9 Algal control	Required to assess possibilities	3
3.1.1 Autecology of important fish species	Required for interpretation of fish production studies	3
4.3.2 Assessment of conservation requirements in estuaries	Implementation of 4.3.1 for a neglected ecosystem type	3

Synthesis required	Remarks	Priority
6.2 Environmental forms and pathways of chemical pollutants	Required to identify potentially dangerous forms and critical pathways to man	3
6.4.3 Toxicity criteria for chemical pollutants	Criteria are required to determine safe conditions for man and ecosystems	3
1.7.1 The rôle of nitrogen-fixing algae	Required to determine research needs	4
1.9.2 Requirements for the rehabilitation of eutrophic impoundments	Required to recommend strategies in the light of 1.9.3	4
4.1.2 Red Data Books for threatened species	Periodic updating required	4
2.6.2 Mechanical control of aquatic weeds	Required to assess possibilities	5
2.6.3 Chemical control of aquatic weeds	Required to assess possibilities	5
2.7 Utilization of aquatic plants	Required to assess possibilities	5

Short term surveys and investigations

Although it is highly desirable through detailed research to collect reliable information before making predictions on the possible consequences of planned development or effectiveness and side effects of a planned management action, this is often not possible in practice. In a majority of instances, there is either no time to carry out the research that would be required or insufficient manpower or funds available to do the research. When this happens, a short term survey or *ad hoc* investigation is often the only way to assemble information to assist planners and decision makers.

The following is a list of short term surveys and investigations required as a priority :

Survey required	Remarks	Priority
1.3.2 Retention of nutrients and other pollutants in vlei ecosystems	Do vleis hold back nutrients and what happens during floods?	1
7.7.2 Preliminary bathymetric surveys of estuaries	Required for environmental assessments	1
7.7.3 Pollution surveys of estuaries	First surveys nearing completion	1
1.3.1 Distribution and status of vlei ecosystems	What kinds of vleis, where, and what waterfowl and other wildlife do they support?	2
1.8.2 Assessment of the trophic status and requirements for rehabilitation of eutrophic impoundments	Required in order to initiate rehabilitation trials	2
2.1.2 Questionnaire and field surveys of aquatic weeds	Where are problems being experienced?	2
3.4.2 Experimental netting in selected impoundments and natural waters	What is the commercial netting potential of these impoundments?	2
6.4.1 Short term toxicity tests of chemical pollutants	Required for screening purposes	2
7.6 Impact of development on selected coastal and estuarine lake systems	Assessment of extremely complex environmental effects	2
1.4.1 Nutrient loading of selected impoundments	Required for eutrophication studies and assessments	3
1.8.1 Limnological investigation of oligotrophic impoundments threatened by excessive external nutrient loading	Nutrient dynamics and factors influencing algal growth	3
3.4.1 Creel analysis in selected impoundments and natural waters	What mass of fish of different species do anglers remove?	3
3.5.3 Fish population estimates in important impoundments	Mark-and-recapture estimates to confirm creel and experimental netting data	3

Survey required	Remarks	Priority
7.3.1 Fisheries potential of the Pongolo floodplain	Required to improve utilization	3
7.7.4 Studies of environmental effects on estuaries of different forms of past development	Required as data base for impact assessments	3
1.3.4 Retention of nutrients and other pollutants in artificially established vlei ecosystems	If 1.3.2 is successful, can beneficial vleis be established?	4
1.9.4 Field trials of lake rehabilitation techniques	Required to check on effectiveness and side effects	4
1.11.2 Short term eutrophication studies of selected estuaries	Required to plan prevention strategies	4
3.4.3 Effectiveness of different fishing gear, techniques and strategies in impoundments	Required in relation to proposed commercial fishing	4
4.1.1 Field surveys of the conservation status of threatened aquatic species	To place Red Data Books on sounder footing	4

Monitoring programmes

Monitoring is the long term observation of selected constituents and properties to detect trends and possible changes. Monitoring only achieves its purpose if the findings are assessed by specialists and appropriate action is taken where necessary. Certain limited monitoring is required in order to identify problems to which the IWE will have to address itself. These are :

Monitoring required	Remarks	Priority
1.2.1 Monitoring of nutrient loads in selected South African rivers	Catchments of impoundments	1
2.1.2 Questionnaire and field surveys to monitor aquatic weeds	Monitoring eutrophication symptoms	2

Monitoring required	Remarks	Priority
7.7.3 Pollution surveys of selected estuaries	Monitoring on basis of earlier surveys	2
6.5 Monitoring of chemical pollutants	Monitoring possible problem chemicals to detect changes	3
1.8.3 Monitoring of rehabilitation and eutrophication control programmes	Long term observations of effectiveness and side effects	4

Detailed research programmes

Detailed research is often required both at particular sites where planning or management problems occur or at suitable sites where important ecosystem processes or problems and their solution or consequences can conveniently be studied and the findings can be extrapolated to other water bodies.

The following is a list of priority research topics :

Research required	Remarks	Priority
1.4.1 Techniques for estimating nutrient loading of selected impoundments	Detailed estimates required for 1.4.2	1
1.4.2 Nutrient cycling and eutrophication processes in selected impoundments	Understanding required for predictive purposes	1
1.4.4 Development of models to predict the response of impoundments to changes in nutrient loading	Based in first instance on existing data, later on 1.4.2	1
1.5.1 Nutrient uptake and release from sediments in impoundments	Conditions under which recycling will occur (part of 1.4.2)	1
1.6 The rôle of suspensoids in impoundments	In relation to nutrient availability and primary production (part of 1.4.2)	1
2.8.1 Factors responsible for the development of toxic *Microcystis* blooms in eutrophic impoundments	The conditions responsible, the processes involved, identification of the toxin	2

Research required	Remarks	Priority
3.5.1 Limnology of a major impoundment in relation to its fish production	The effects of hydroclimate on fish biology and production (for 3.5.2)	2
3.5.2 Fish population dynamics, migrations, production and possible exploitation in a major impoundment	Understanding required for predictive purposes	2
5.1.2 Biology of problem Simuliidae and the effect of flow manipulation and other control measures	Understanding required on which to base control	2
1.7.1 The rôle of nitrogen-fixing algae in impoundments	Necessary for the success of eutrophication control programmes	3
2.2.1 Autecological and growth kinetics studies of selected aquatic weeds	Work in progress	3
2.2.3 Growth kinetics of selected algae	Some work already in progress	3
2.3.1 Factors responsible for algal succession in impoundments	To examine possibilities of manipulating to avoid undesirable species	3
2.6.1 Biological control of aquatic weeds	To examine potentially very valuable possibilities, even if the likelihood of success is small	3
3.3.1 Food availability, daily ration and growth rates of important fish species	Important background to fish production studies	3
3.6.1 Fish population studies in selected estuaries	Work on juvenile fish in Cape estuaries being begun	3
5.2.1 Life histories and environmental requirements of mosquito species	Work in progress	3
6.2.1 Speciation of metals in the environment	Required to know which potentially harmful species may be present	3

Research required	Remarks	Priority
6.2.2 Factors influencing the remobilization of metallic species in sediments	Under what conditions can potentially harmful metals be released?	3
6.4.2 Sublethal toxic effects of chemical pollutants	Required to determine which chemicals may be potentially harmful	3
1.10.1 Nutrient budgets and internal nutrient cycling in coastal lakes threatened with eutrophication	A further development of work being carried out at Swartvlei	4
2.4.1 Flow resistance measurements of emergent hydrophytes	To predict hydraulic behaviour of vleis and floodplains	4
3.1.2 Autecology of estuarine fish and fish entering estuaries	Required for fish production predictions and management	4
3.2.1 Lethal limits for freshwater fish	Required for considering introductions and investigating fish kills	4
3.2.3 Effects of environmental conditions on fish growth rates and other functions	Required for predicting production	4
3.7.1 Taxonomy and life histories of fish parasites	Some work in progress, of considerable practical importance	4
3.7.2 Fish pathogens and pathology	Required for diagnostic purposes	4
4.2.1 Autecology of threatened fish species	Required in order to plan conservation measures	4
5.1.1 Simuliidae taxonomy	Required for identification of problem species (some morphologically identical to harmless species)	
5.3.1 Systematics and distribution of freshwater snails	Being carried out	4
6.3 Analytical procedures for the identification and quantification of chemical pollutants	Development of methods and inter-laboratory calibration, work in progress	4

Research required	Remarks	Priority
1.11 Estuary eutrophication protection studies	Required to plan control measures	5
2.2.2 Growth kinetics, nutrient uptake and water relations of emergent marsh plants	Required to predict effects of change on reed-bed growth	5
2.4.2 Water relations and evapotransporative water loss by floating and emergent plants	Required for hydrological models and to assess impact of weed and vlei growth	5
2.5.2 Measurement of primary production rates by hydrophytes	Some work in progress, required for energy flow studies	5
2.5.3 Measurement of hydrophyte reproduction rates	Required for predictive purposes	5
3.1.1 Autecology of freshwater angling and food fish	Required for fish production predictions and management	5
3.1.3 Biology of fish being considered for introduction	Some work in progress, essential if introductions are to be considered	5
3.2.2 Physiological effects on freshwater fish of exposure to lethal and sublethal conditions and concentrations of toxic substances	Will aid understanding and could suggest symptoms of sublethal effects	5
5.3.2 The ecophysiology and experimental ecology of freshwater snails	Much past work done, required to predict problems	5
5.3.3 Effects of temperature and other factors on the life cycles and transmission of parasites	Required to understand epidemiology	5
5.3.4 Effects of parasite infestation upon resistance of snail intermediate hosts to environmental extremes	Required to understand epidemiology	5

TITLES IN THIS SERIES

1. *A description of the Savanna Ecosystem Project, Nylsvley, South Africa. December 1975. 24 pp.

2. *Sensitivity analysis of a simple linear model of a savanna ecosystem at Nylsvley. W M Getz and A M Starfield. December 1975. 18 pp.

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6. *Recycling and disposal of plastics waste in South Africa. R H Nurse, N C Symington, G R de V Brooks and L J Heyl. June 1976. 35 pp.

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11. South African Red Data Book - Small mammals. J A J Meester. November 1976. 59 pp.

12. Savanna Ecosystem Project - Progress report 1975/1976. B J Huntley. March 1977. 41 pp.

13. Disposal and recovery of waste paper in South Africa. G R de V Brooks. April 1977. 35 pp.

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