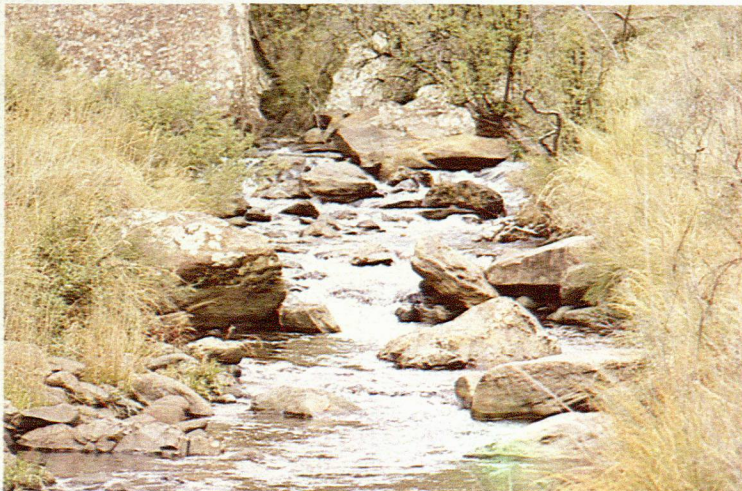




The River Research Programme

A A Ferrar
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**SOUTH AFRICAN NATIONAL
SCIENTIFIC PROGRAMMES**

Report No 146

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A A Ferrar, J H O'Keeffe and B R Davies

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ABSTRACT

The need for a comprehensive, multidisciplinary research programme for river ecosystems is described. The scope of the programme needs to include basic descriptions of systems and biota, the testing and development of functional theory and the solution of practical management and conservation problems. Justification for the programme is centred around the need to determine with greater precision the minimum flow requirements of regulated rivers.

Several topics are addressed: the characteristics of South African rivers, described in terms of headwater, middle and lower reach zones; differences between local rivers and those of well studied areas in the Northern Hemisphere are emphasized; current theories on the functioning of river ecosystems are briefly introduced; a general review of the problems that managers have in resolving the need for water by people and the maintenance of ecological functions is provided; and finally, an administrative context for the management of a Foundation for Research Development rivers research programme is set out, together with an analysis of the general approach of the programme and a list of research priorities.

SAMEVATTING

Die behoefte aan 'n omvattende, multidissiplinêre navorsingsprogram vir rivier-ekosisteme word beskryf. Die omvang van die program moet 'n basiese beskrywing van sisteme en biota, die toetsing en ontwikkeling van funksionele teorie en die oplossing van praktiese bestuurs- en bewaringsprobleme insluit. Regverdiging vir die program sentreer om die behoefte om meer noukeurig die minimum vloeibehoeftes van geregleerde riviere te bepaal.

Verskeie onderwerpe word aangespreek: die eienskappe van Suid-Afrikaanse riviere soos beskryf met betrekking tot boploopwater, middelloop- en benedelloopgebiede. Verskille tussen plaaslike riviere en die van riviere in gebiede wat reeds goed bestudeer is in die noordelike halfrond, word beklemtoon. Huidige teorieë oor die funksionering van rivier-ekosisteme word kortliks bespreek; 'n algemene beskouing van die probleme wat bestuurders ondervind wat betref die waterbehoefte van mense en die handhawing van ekologiese funksies word voorsien. Ten slotte word 'n administratiewe konteks vir die bestuur van 'n riviernavorsingsprogram deur die Stigting vir Navorsingsontwikkeling uiteengesit, tesame met 'n analise van die algemene benadering van die programme en 'n lys van navorsingsprioriteite.

INTRODUCTION

In common with many developed countries of the Northern Hemisphere, South Africa has been brought to the realization of the limitations of its water supplies. Our rapidly growing population and relatively well developed economy is placing demands on water supplies which have already forced planners to look beyond our borders to provide for the needs of the 1990's. All major rivers are already regulated by large impoundments, and periodic water shortages in the main urban complexes have become a frequent feature of urban and industrial life. The established trend of seasonal shortages and increasing costs of water is predictably escalating and is already placing constraints on future development.

The Department of Water Affairs (DWA), charged with the task of providing adequate good quality water to all competing users at acceptable degrees of risk and cost, are fully aware of their challenging task. Current supplies are generally adequate and plans to cater for the midterm future such as the Highlands Water Scheme, are well in hand. However, existing water development projects have been implemented with only cursory attention to the functions and values of the aquatic ecosystems that they alter or destroy.

The findings of the 1970 Commission of Enquiry into Water Matters made scant reference to the ecological needs of aquatic ecosystems. No acknowledgement of any social or economic cost for the degradation of aquatic ecosystems as a result of water abstraction is made in the Commission's report except for certain nature reserves and for recreation. However, in the most recent and comprehensive statement of water management policy (DWA 1986) this omission is recognized. Projections of water demand for "environmental management", for 1990 are set at 2 949 million m³/a which amounts to 15% of the total demand figure, estimated at 19 043 million m³/a. However, this figure is based on simplistic models and a clear need is expressed for research and information that will permit a more accurate assessment to be made (DWA 1986).

South Africa is predominantly arid with a potential evaporation rate in excess of annual precipitation. Perennial rivers occur over only one quarter of the land surface and rivers that flow only periodically are found over a further quarter of the landscape. In the remaining 50%, primarily the western and southern interior, rivers flow only after infrequent storms. This clearly indicates that all rivers carrying useable quantities of water will be intensively managed for human benefit. Most of the scientists and managers who work in this field regard rivers primarily from this utilitarian point of view. However, an increasing awareness of the ecological value of aquatic ecosystems and their role in maintaining supplies of useable water is generating a growing body of expertise in river ecology and the conservation of rivers as valuable ecosystems.

The provision of conservation based management strategies for rivers is fraught with problems. Seen on the one hand as merely the drains of the landscape, rivers have complex and intriguing characteristics. They operate in both linear and cyclic modes. They are simultaneously

renewable and finite as sources of water. They are incredibly dynamic systems that are difficult to measure and predict and yet have strong tendencies of stability and resilience. Two of their most important properties are, that they reflect very precisely the climatic and other physical characteristics of their catchments and, in respect of pollutants, they have distinctly limited powers of self-purification.

To ecologists and conservation scientists, however, rivers are seen primarily as ecosystems, or ecosystem components, that have a larger set of values. These values are in fact subscribed to by everyone but are seldom articulated in any comprehensive way outside of purely economic terms. The amenity or socio-aesthetic values of rivers still defy clear definition and public or political acceptance.

Central to any conservation philosophy for rivers is the concept of naturalness. With South African landscapes being so rapidly modified, a concept of naturalness is only useful if it is linked to an ability to manage rivers towards some hypothetical near-natural state. The predominance of the need for water means that all our substantial river systems will be subject to water regulation and abstraction and to the introduction of pollutants. Conservation management therefore becomes an exercise in mitigation. The principal tools are, legislation, monitoring, land-use planning and the conservative management of catchments, of necessity all of them indirect in their action. Direct management by way of physical protection and reclamation is so costly that it has limited application outside of urban or recreational sites and in conservation areas.

In the absence of appropriate management it has been repeatedly demonstrated that rivers can rapidly degenerate to a state where they lose many of their vital characteristics and functions. Riverine species have become endangered (Skelton 1987); alien species have tended to dominate (Bruton and van As 1986); pest species have become an economic problem (Ashton et al 1986); water purification processes have been lost as a result of pollution; recreational and aesthetic values have been sharply reduced (Thornton et al 1986).

This provides a background to the need for a clearly directed multidisciplinary research programme for rivers. Such a programme should be aimed at providing primarily for the needs of river managers. It must address not only the practical management problems associated with sustaining riverine functions and biotic diversity, but also to provide a deeper understanding of their ecological structure and functional processes.

The purpose of this document is to provide a framework and description of such a programme. It is aimed primarily at two target audiences. The first is the community of public servants and private land owners who have a responsibility for, or interest in managing and conserving rivers and in minimizing the negative impacts of development. The second is the community of research scientists, students and educators who are responsible for improving our understanding of river ecosystems and therefore our capacity to manage them in the long term.

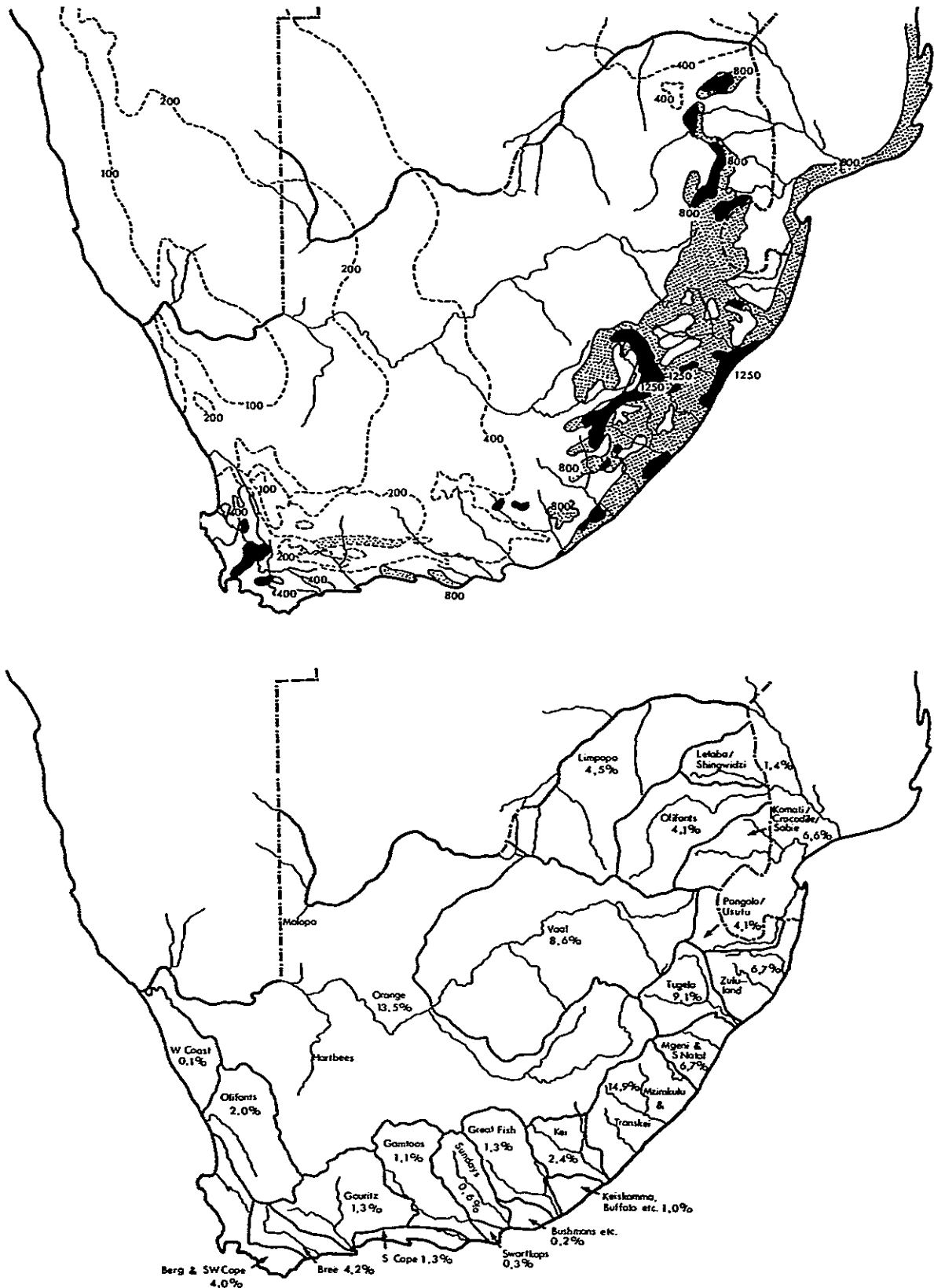


FIGURE 1. Top: Average annual rainfall (isohyets at 100 mm intervals). Bottom: Principal drainage systems and their contribution to total mean annual runoff. (Adapted from Commission of Enquiry into Water Matters 1970).

CHAPTER 1 ECOLOGY OF RIVER ECOSYSTEMS

Aquatic ecosystems are fluid, interconnected systems which have poorly defined boundaries. Rivers, being one of several categories of aquatic ecosystems, are most difficult to separate precisely from the others because they function as the connecting system, from alpine bog to open ocean. The boundaries between these systems are not only indistinct but, like the systems themselves, are highly dynamic both in space and intime.

In spite of these difficulties, the scope of this document is limited to rivers. In this context rivers are seen as distinct from wetlands (floodplains, vleis and pans) impoundments, coastal lakes and estuaries, the research programmes for which are described elsewhere. Rivers therefore comprise the entire length of any watercourse, including the water, biota and substrates associated with it. In practice, river ecosystems are limited to those areas directly influenced by their hydrological characteristics, whether permanent or temporary. Riverine communities include the truly aquatic plants, animals and micro-organisms as well as the terrestrial riparian vegetation and its associated biota.

An understanding of the characteristics of rivers and the processes which govern the way they function is needed to manage them and to limit the detrimental impacts of water exploitation and development. River systems comprise natural drainage networks sculpting the landscape. They may be regarded as dynamic longitudinal ecosystems and they express the type and condition of the land they drain.

Most of South Africa has a semi-arid climate with a highly seasonal rainfall pattern. The average annual rainfall is only 475 mm compared with the world average of 860 mm. In addition, especially 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 per cent in South Africa) and the greater the variability of river flow. In addition, potential annual evaporation is generally in excess of annual precipitation. This climatic picture, together with South Africa's geomorphological history, has created a landscape characterized by small rivers of erratic flow and very few with strong perennial flow.

The average annual runoff into rivers in South Africa is estimated at 53 000 million m³. However, this runoff is very unevenly distributed. These differences reflect principally the differences in mean annual rainfall which varies from approximately 50 mm at 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% 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% 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.

The outstanding example of deficient rainfall is the Molopo River. As far as can be ascertained, despite its tremendous catchment (equivalent to nearly 21% 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 rivers is fluvial sediment. Most rivers carry considerable loads of sediment consisting mainly of particles smaller than 0,2 mm in diameter. When exposed to weathering, the shales and mudstones of the Beaufort and Molteno series of the Karoo system are particularly susceptible to erosion. 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%, due perhaps to a decrease in the amount of easily erodible material in the catchment and the effects of soil conservation (Rooseboom 1978).

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.

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. 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 rain. Average sediment concentration figures are often difficult to obtain and must be interpreted with care as it must be borne in mind that 98% of the annual sediment load of a river can be transported in a single day. If this is missed, the average becomes meaningless.

THE ZONES OF A RIVER

A river usually consists of fast-flowing erosive headwaters; slower-flowing, partly erosive, middle reaches and slow-flowing, low-lying, mature reaches where materials eroded in the upper reaches are deposited. Standing on the banks in each reach, or even analysing the organisms, the physical characteristics of the water chemistry at each site, one will inevitably get three totally different 'snapshots' of the same river. But all three reflect different aspects of a system in which the physical and biological processes in the upper reaches modify and mould processes and features further down. The three major riverine zones are described below.

Headwaters: the mountain stream

The water of undisturbed mountain streams is characteristically clear and free of silt, except when in spate, for the land the stream drains is rocky, steeply inclined and with very little loose soil. The bed is boulder-strewn so that water is well oxygenated. As the mountainous catchment area is largely rocky and resistant to weathering, leaching is minimal so that the water is usually soft and of good quality for human use.

Biologically the stream in this reach is dependent for its energy source on trees, whose canopy causes a perpetual condition of semishade. Large plants rarely occur in the water or close to the stream banks. Algae and mosses are present only in small quantities because little light reaches them. Even where sunlight does reach the water, green plants are still relatively rare because the water is very poor in nutrients. Phyto- and zooplanktonic organisms are rare because they are swept away by the current while fish are highly adapted to maintaining position in the fast-flowing water. These reaches are dominated by insects, including nymphs or larvae of mayflies, stoneflies, caddisflies, dragonflies, midges and craneflies as well as young and adult stages of beetles and bugs.

Although the flow of water within the stream is the driving force, sculpting the channel and dictating the physical form of animals and plants, the velocity of flow drops off rapidly towards the bed of the stream. Thus a diverse array of small streamlined animals makes use of the so-called "boundary effect" where, close to the substratum, flow almost ceases. These organisms use hooks and other adhesive organs together with various behavioural adaptations to maintain position on the stony riverbed.

In the absence of adequate green plant material as food, most of the animals feed on the dead leaves that fall into the water from trees lining the banks. In addition to these primary consumers there is an important decomposer community of fungi and bacteria which themselves contribute to the total food resource. This food-web, unusual in most ecosystems, is common to tree-lined mountain streams worldwide. Thus these ecosystems are driven by, and dependent on, allochthonous or external inputs of food. In this way leaves and other coarse organic debris are steadily broken down into fine particulate organic matter and finally into ultra-fine particulate organic matter that is carried downstream. The quality and quantity of leaves and other plant debris falling into the stream determine not only the number of organisms that can be supported but also the type and complexity of the food-web. This has profound implications for land management, deforestation and river bank clearance. Any disturbance of the catchment, and particularly of the riparian zone, will affect the functioning of the stream ecosystem.

Invertebrates are adapted in many ways to exploit these food sources. Some animals, "shredders", skeletonize or shred the leaves, leaving the tougher veins and stalks, while "scrapers" sweep the layer of bacteria and fungi off the surface of decaying leaves with brushlike mouth-parts. "Grazers" feed on the thin layer of algae living on rocks and other structures while the "collectors" are filter-feeders, erecting nets or strings of saliva that trap small particles of food. Insect predators may feed on any of these types of animals. Because of the large number of whole leaves on the riverbed, the "shredders" form a large proportion of the fauna of mountain streams, while scrapers, grazers and collectors are less common. Food is usually scarce so that the animals in the mountain stream grow slowly and are relatively small even at maturity. These systems are thus said to have a low productivity. Further, because of their slow growth and the relatively constant conditions in which they live, the same set or sets of species are always present. Such species

are able to survive only within a very narrow range of environmental conditions so that even minor disturbances may have profound effects on species abundance. Recovery, if it occurs, is likely to be slow. These species are of great value as indicators of stream condition and levels of disturbance.

The middle reaches

As the stream enters the foothills, its bed widens as more water arrives from tributaries. Although trees still line these middle reaches, occasionally patches of dense river bank vegetation, such as reeds and sedges, occur where sufficient sediment has accumulated between rocks. Water temperatures increase, encouraging the growth of mosses and algae, and some plankton occurs in sheltered backwaters. The water quality is poorer, with turbidity and total dissolved solids being higher than in the mountain stream. The current is slower, because of the reduced gradient, while the streambed tends to be smoother and the water less turbulent, so that oxygen levels may be lower even though rocks in the riverbed may support a more extensive growth of microscopic algae. The invertebrate fauna consists largely of grazers and collectors; shredders are proportionally less important than they are upstream because there is proportionally less terrestrial plant debris. The food-web is now based on autochthonous (self-generated) food, in the form of green plants, rather than on imported detritus. Detritus, in the form of leaf fragments and other organic matter swept down from upstream or from the river banks, still remains a significant source of food, however, so that collectors are present in the fauna.

The organisms in this reach of the river are different from those occurring in the mountain stream, although adaptations for survival are similar because current speeds are still relatively high and the substratum still mainly comprises rocks and stones. The invertebrate fauna as a whole is more abundant and more productive and grows faster, so that insect-eating fish and birds are also far more abundant.

The mature lower reaches

As the river flows on to the coastal plain it continues to widen, while current speeds decrease along with the gradient. The heaviest particles of sediment drop out as the current slows, settling to cover stones and forming a relatively uniform sandy or silty blanket on the riverbed. Closer to the sea finer and finer particles, including organic matter, settle out so that the substratum becomes more and more muddy. The water may become noticeably less oxygenated, particularly at night because it is richer not only in mineral salts such as NaCl, but also in nutrients derived from the banks, infiltrated from groundwater, washed down from upstream or released from dead plants and animals. Increasing levels of nutrients allow a more abundant and luxuriant growth of plants such as reeds and bulrushes. Even if trees still line the banks, they shade only a minor portion of the river's surface. Increased sunlight and the slow flow encourages the growth of phytoplankton and also of grazing zooplankton, both of which can survive for some considerable time before reaching the sea. Filter-feeding collectors sifting the plankton from the

water become far more abundant, as does another group of collectors, the deposit feeders, that consume the rich rain of organic material deposited on the riverbed. Snails and other grazers scraping algae off any available surface increase in numbers, as do the carnivores, which feed on everything else.

In the very lowest reaches, just above the estuary, the substratum becomes very muddy and rich in organic matter and is an excellent refuge and food source. Burrowing bottom-dwellers of many invertebrate groups increase in numbers in these reaches, which also support a diverse avifauna and a diverse array of bottom-feeding fish.

The estuary

The estuary, unlike the rest of a river, is a place where the seaward flow of water may stop entirely during periods of rising tides. In fact instead of a continual loss of material, estuaries may gain particulate matter and nutrients from both the river and the sea. This, together with the extensive tidal flats and shallows developed by successive marine and riverine deposits, means that estuaries are often among the most productive ecosystems known. Descriptions of the functioning of South African estuaries may be found, for example, in Day (1981), and need not concern us here. What is important, however, is that the manipulation of a river, particularly by abstraction or impoundment of its water, will always affect the amount and timing of the freshwater supply to the estuary.

Not all rivers conform to the basic pattern outlined above. Some seep from low-lying areas while others rise high above the tree line in alpine zones. Those rivers that rise in coastal hills may immediately plunge from mountain stream to estuary, as they do along the more precipitous parts of the southern and south-eastern coast. On the other hand, mature rivers are sometimes rejuvenated by cascading down a second mountain range nearer the coast, as with the Orange River at Augrabies Falls (Cambray et al 1985). Rivers also vary widely in mineral content and silt loads, depending upon the substrate over which they flow. The Orange River naturally carried a heavy silt load, well before man increased it through agricultural malpractice. The waters of the southern and south-western Cape are also very different from most of those elsewhere in Africa, for although they are almost free of silt they are exceptionally acid, due to the fact that they drain ancient, weathered and nutrient-poor rock.

Despite these exceptions, rivers conform well enough to the generalizations outlined above that various schemes for river zonation have been included in the ecological literature (see Harrison 1965 for river zonation in southern Africa). J H O'Keeffe and several coworkers are currently working on a new river classification system of particular relevance to river managers in southern Africa.

CHAPTER 2 HYPOTHESES CONCERNING RIVER ECOSYSTEMS

THE RIVER CONTINUUM CONCEPT

The river continuum concept was formulated by Vannote et al (1980), in an attempt to synthesize information, gathered over many years for North American rivers, into a set of general hypotheses concerning river ecosystems. The concept suggests that plant and animal communities are able to make maximal use of resources (particularly food) in a river and this results in variations in community structure down the length of the river. The biological adjustments are evident in (a) the changing balance of production and decomposition (the ratio of photosynthesis:respiration, or P/R; and (b) in changes in community composition, expressed as a downstream succession of "functional feeding groups": the shredders, grazers, collectors. Particulate organic matter is progressively reduced in size by the successive actions of these functional groups or "litter processors". Although there are certain features of the river continuum concept that may not be generally applicable it seems that by and large it provides a very useful way of looking at rivers and its general applicability to South African rivers deserves examination. Further information may be found in Cummins (1979) and Minshall et al (1983).

THE NUTRIENT SPIRALLING HYPOTHESES

This hypothesis refers to one of the salient differences between lake and river ecosystems. In a closed system, such as a lake, nutrients are cycled, being taken up by living organisms and returned to the environment in the process of decomposition. In the stream - a more open system - the cycling nutrients are continually displaced downstream so that they are said to traverse an imaginary spiral (or more correctly, a helix (Figure 4)). Information on the hypothesis is provided by Webster (1975) and Newbold et al (1982).

THE INTERMEDIATE DISTURBANCE HYPOTHESIS

This concerns the processes that maintain diversity in communities of plants and animals. It was first formulated for marine ecosystems but has been applied to many other environments; its application for streams is discussed by Ward and Stanford (1983). The hypothesis suggests that the level of natural "disturbance" or variability in an ecosystem determines the diversity of plant and animal species in a particular environment. Disturbance here refers to the extent of change and need not imply intervention by man. For example, a spring-fed stream may have near-constant flows and temperatures year-round; it would experience a low level of disturbance and consequently it would sustain a relatively small variety of plants and animals. At the other extreme, a seasonal watercourse subject to rapid, unpredictable climatic changes would experience a high level of disturbance and it too would sustain few plants and animals. Maximal diversity would be attained at an intermediate level

of disturbance, where a balance is struck between environmental heterogeneity in time and space and the ecological characteristics of the flora and fauna.

RESILIENCE OF RIVERS

A further consideration of river functioning has not been formally stated as a concept but is nonetheless of great practical importance. Given time (and space), rivers are capable of returning to their equilibrium state if perturbed, as long as the majority of their abiotic and biotic characteristics are not damaged. For example, polluting organic matter such as outfall from a sewage plant will be processed by river organisms, so that the river will return to the condition it was in above the source of pollution, as long as it is not grossly perturbed in other ways. This has been elegantly illustrated by Hynes (1966, 1970). Combinations of perturbations tend to act cumulatively. Canalization, for instance, will destroy any stream's capacity for "self-cleaning" because the natural diversity of the stream and its associated biotic communities will have been completely destroyed.

CHAPTER 3 PROBLEMS IN RIVERS

The term 'problems in rivers' encompasses any influence, trend or disturbance that has its basic causes rooted in the activities of modern industrial man (modern = \pm 150 years BP). It assumes that these man-derived influences will impose potential threats to the conservation or sustainability of rivers. The record shows that many of these threats are real and that sophisticated management activities have to be undertaken in order to limit their detrimental effects. It is useful therefore to consider these problems in the whole context of human needs and the continued functioning of South African rivers. The following list of causes and effects provides a basis for the development of a matrix of interactions which could prove useful in identifying problem-orientated research priorities.

CAUSES OF RIVER PROBLEMS

Instream engineering

1. Major impoundments
 - built for a variety of purposes such as water for urban and irrigation use, power generation, flood control;
 - effects vary with the design and purpose of the structure and its water-release mechanism and pattern; mainly influences physical flow characteristics with consequent influences on water chemistry and ecosystem characteristics.
2. Inter basin water transfers
 - used increasingly to balance water demand deficits; the effects of the impoundments are covered above, but the effects of flow augmentation are separate;
 - affects all aspects of the recipient river by way of enhanced constant flow of water, both physically and chemically different from the natural flow; affects the donor river by way of flow reduction and flood attenuation; potential to cause major biodiversity changes and transfer of alien species.
3. Minor impoundments
 - primarily weirs and farm dams of <250 000 m³ capacity;
 - effects are minimal individually, but because of large numbers their cumulative and synergistic effects on reducing runoff and delaying the onset of river flow can be substantial.
4. Canalization
 - generally limited to intensive water management areas; typically urban rivers for flood management purposes;

- canals completely alter all ecosystem properties and physical flow characteristics of the original river.
5. Bridges and other structures
- all engineering structures in, or across rivers have an impact, often greatest in remote areas where least information on river flows and substrates is available;
 - effects are generally limited to flow constriction, diversion and enhanced flooding.

Catchment effects

1. Afforestation
 - usually in upper catchment high rainfall regions;
 - effects are generally hydrological and indirect, via raised water demand for evapotranspiration, leading to marked flow reduction; direct effects on ecosystem properties occur where afforestation transgresses the riparian zone.
2. Crop production
 - all annually or regularly cultivated crops where vegetation is removed predisposes the soil to accelerated erosion, mostly into rivers;
 - resulting excessive sediment transport affects all the main ecological and physical attributes of rivers; intensive agriculture (irrigation schemes) have potential to markedly influence all aspects of water chemistry and hence the biota.
3. Livestock grazing
 - in most areas particularly the arid and semi-arid regions, overgrazing, vegetation reduction, reduced infiltration, increased runoff and accelerated erosion is the general pattern;
 - effects are as for crop production, less marked but vastly more widespread; effects are most marked in areas of high erosion risk.
4. Riverine or stream bank cultivation
 - a special (worst) case of 2 above; legislated against but widely practiced especially in wetlands and in high production agricultural regions;
 - effects as for 2 above.
5. Urban development
 - in situ effects are obvious and usually totally destructive of river ecosystems; a positive effect is that of providing

an opportunity for management and clean-up activities with great public educational value (urban parks);

- ex situ effects are brought about via the constant flow, eutrophic, often toxic return-flows carrying effluent and industrial waste; all river attributes are affected, especially when pollution controls are lax or the return flow forms a dominant proportion of normal runoff; biodiversity and productivity are unnaturally raised under such circumstances.

Alien species

1. Aquatic fauna and flora
 - fish species, introduced deliberately for angling and floating and rooted aquatic plants which reach pest-plant status especially in eutrophic waters, are the most important;
 - effects are limited primarily to reduction in biodiversity and habitat heterogeneity.
2. Riparian plant invaders
 - river lines in all climatic zones are preferred sites and routes for spread of woody and herbaceous alien plants, lack of water-stress and water borne propagules being two important enabling mechanisms;
 - effects are again changes in species and habitat diversity but in worst cases dense stands of alien plants seriously interfere with natural spates causing flow diversion; local increase in evapotranspiration can reduce runoff in small streams.

Other activities

1. Recreational angling
 - not very important as most angling is for introduced fish, can reach serious proportions in confined estuaries and other localized/special habitats;
 - reduction in biodiversity, usually temporary.
2. Industrial accidents.

Summary of river attributes and functional processes affected by the causes listed above.

1. Ecosystem properties

- Water supply and transport
- Biological or genetic diversity (species richness)

- Habitat diversity or heterogeneity (includes aesthetic values)
- Biological dispersal
- Sediment and chemical transport (removal, deposition, flushing, leaching etc)
- Self-purification of water
- Biological productivity
- Groundwater/lotic system interactions

2. Physical flow characteristics

- Volume and flow rate
- Velocity
- Timing and seasonality
- Water temperature
- Clarity and turbidity
- Erosive capability

3. Water chemistry

- Eutrophication
- Salinization
- Toxins and other pollutants (pesticides, acid rain, etc)
- Microscale changes (eg ion concentrations in headwaters)

CHAPTER 4 PROGRAMME GOALS, STRATEGY AND TERMS OF REFERENCE

The purpose of this section is to provide a conceptual framework for the administration of a directed, multidisciplinary research programme. Such a programme is firmly rooted in the IUCN philosophy for conservation and management of renewable natural resources which defines conservation as:

"The management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations".

If this statement is applied in the context of South African river ecosystems, it is necessary to balance its idealism with practicality. In this regard it is recognized that human needs will have priority in the competing demands for water. What is in question, is whether or not within these priorities, a basis can be found for maintaining the ecological functioning of lotic ecosystems and the diversity of their associated biota.

Rivers are inseparable from their catchments and as such have immense "information" value for terrestrial as well as aquatic ecosystems. Much of this value is inherent in the extent of our knowledge of river biota and their community characteristics, including physico-chemical functioning, patterns and processes. Basic research into these ecological aspects of rivers is part of the balanced research programme being developed; the counter-balance being the more practical, problem-orientated component. This research programme must accommodate the interactive and representative characteristics of rivers relative to their catchments. In addition, there are special attributes of rivers per se, which, in respect of management and conservation activities, present a whole range of real difficulties. How does one manage or conserve these linear ecosystems that are so unpredictably dynamic and interconnected with everything else in the landscape? How does one protect their poorly known ecological values when the economic value of the water they transport is so vital and in increasing demand? Further background to the development of this research programme will be found in O'Keeffe (1986a,b).

TERMS OF REFERENCE FOR THE WORKING GROUP FOR RIVER ECOSYSTEMS

The programme is managed under the auspices of the National Committee for Ecosystem Research, guided by its Working Group for River Ecosystems. The Working Group has as its general mission:

To develop the information, understanding and expertise necessary for the management and conservation of river ecosystems.

These general activities will be focused initially on:

Determining the instream flow needs of rivers, sufficient to maintain their ecological functioning and biotic diversity.

A key perspective of the research approach will be:

To develop a predictive understanding of rivers that is of value to managers and land-use planners.

Principal users of the research products will include:

Development planners, agriculturalists, catchment managers, nature conservation managers and the scientists and engineers responsible for water supply, water engineering design and pollution control.

The specific objectives of the Working Group are:

- to develop understanding of the structure and functioning of river ecosystems sufficient to predict their response to major, natural and man-derived influences;
- to identify rivers or parts of rivers of special scientific or aesthetic value and develop guidelines for their management towards set objectives.

Within these objectives the strategy of the Working Group will be:

- to develop the ecological principles necessary to manage and conserve river ecosystems in South Africa;
- to develop methods of assessing the ecological and cultural values of rivers;
- to develop methods for classifying and monitoring the conservation status of river ecosystems in both the long and short term;
- to develop methods for assessing the ecological and socio-economic impacts of instream engineering and catchment changes that affect river ecosystems;
- to encourage collaboration in this field between conservation scientists, land-use administrators and those responsible for the planning and management of agricultural and development projects involving water resources.

A basic strategy for conducting management orientated research in situations of uncertainty and inadequate knowledge is that referred to as adaptive management. This strategy accepts that decisions that cannot wait for acquisition of sufficient information, are taken anyway. It requires that consequent management actions be integrated with ongoing monitoring and research activities and continuously evaluated and adapted in the light of improved understanding. If necessary, the original objectives of management may also be adjusted through such a feedback process.

PROGRAMME PRIORITIES

Many of the key questions in any river research programme are not likely to be amenable to single answers or research projects. To begin to answer them we have to break them down into manageable subquestions, applied to specific river systems or types of rivers. Twenty-three water researchers/conservationists/managers recently allocated priorities to the subjects listed in Figure 2 and the following is a summary of their main priorities:

The priorities should be seen not in rank order, but as parallel and interdependent.

- (a) River classification - an essential prerequisite for a river research programme, to identify like groupings of rivers, based on criteria relevant to users, and to assign priority uses to them.
- (b) Catchment land use - rivers are a reflection of catchment processes, and management options therefore start with catchment uses.
- (c) Nutrient dynamics and other processes - these are the fundamental driving forces of the river, which must be understood for rational management of rivers.
- (d) River regulation - the main artificial disturbances to rivers, the consequences of which need to be understood in terms of (c) above.
- (e) Instream flow needs and water quality requirements - these are directly applied management concerns which can only properly be evaluated through an understanding of ecological functions and processes.

These priorities show an overwhelming bias toward applied research, which is appropriate, given the urgent need to find answers for river managers now. The success of applied research, however, is dependent on a sound fundamental and conceptual research base. For example, attempts to quantify instream flow needs (for the maintenance of river ecosystem functioning) will continue to rely on educated guesses unless we have a sound understanding of how river ecosystems function. The continued investigation of conceptual models such as the River Continuum Concept and its associated theories, within management-orientated research projects, should remain a priority.

Programme Organization

The scope of these research activities is wide and the available community of researchers is small. The programme would benefit from some degree of administrative subdivision and consequent specialization on the part of the main participants in the programme. This should help to develop new

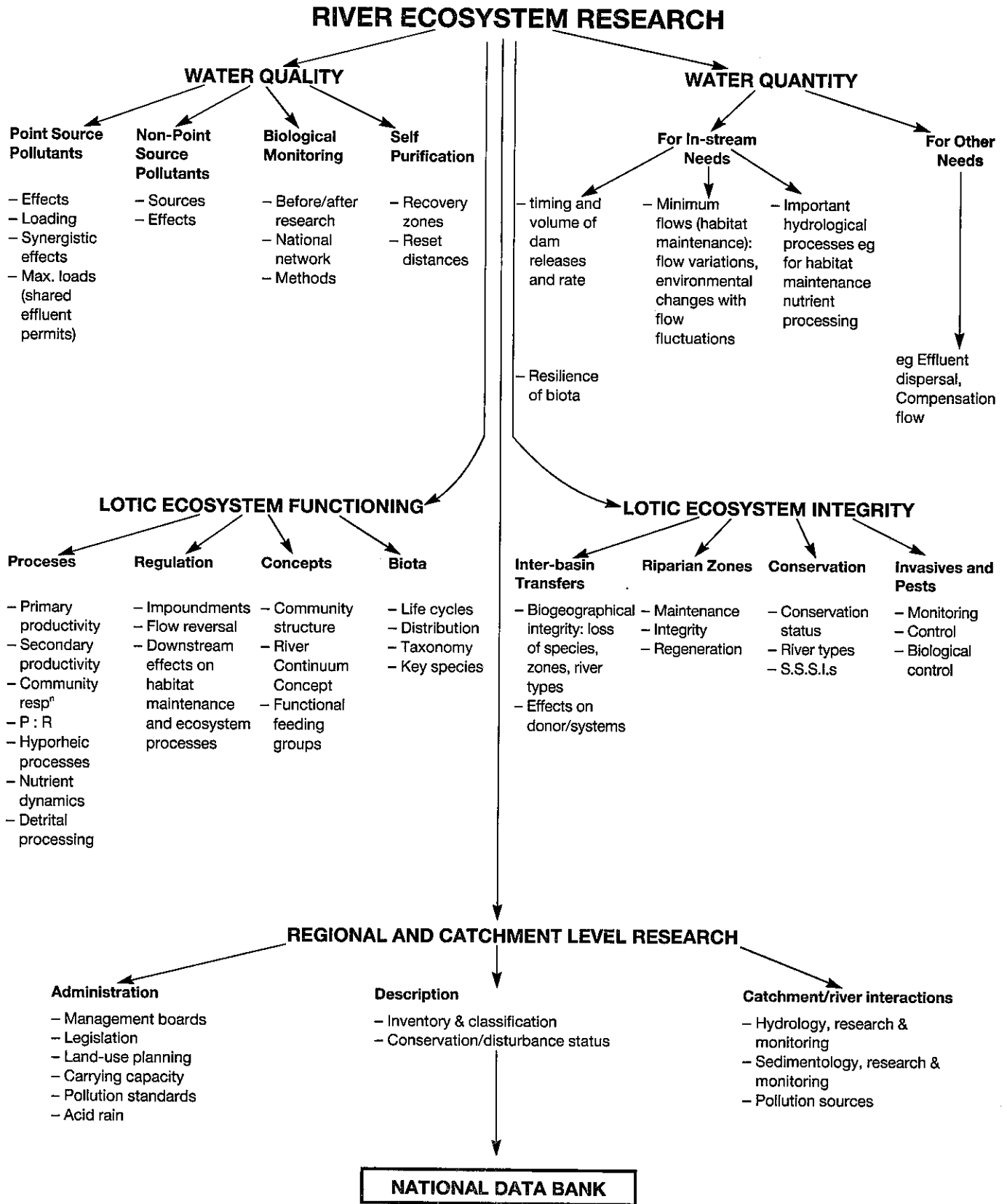
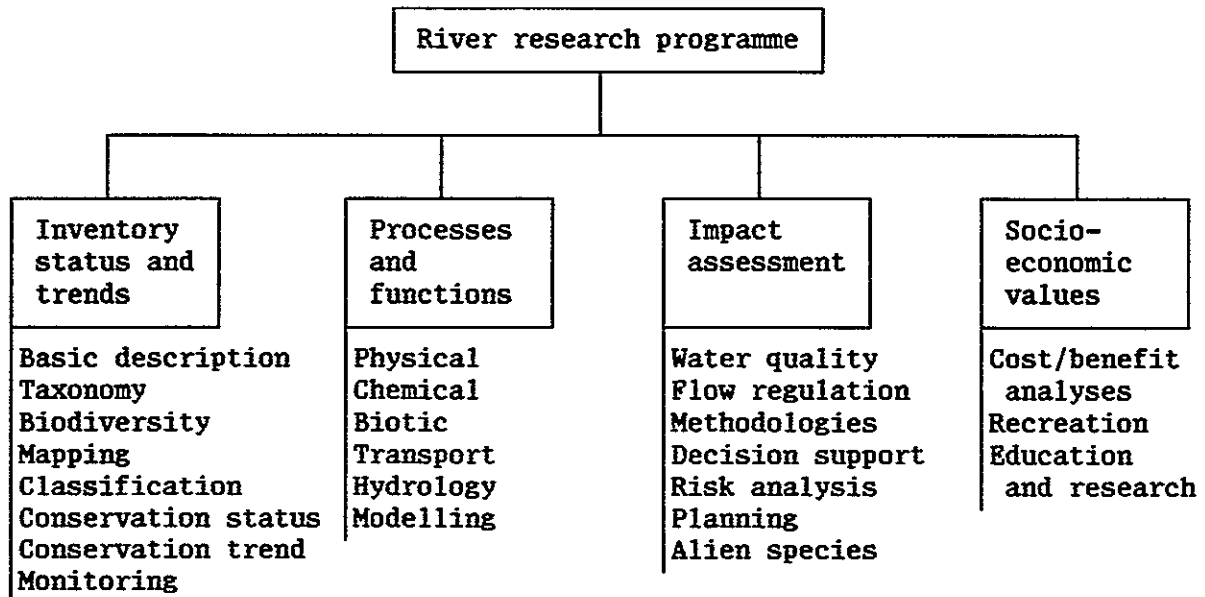


FIGURE 2. A framework for considering research priorities within the River Research Programme.

insights in areas such as testing theoretical concepts, management modelling and review of research priorities. The subdivisions could include the following:



These four sections will operate under small Task Groups set up by leading researchers. Such Task Groups will develop each general topic and assist in determining priorities within them. They will also be responsible for developing the right multidisciplinary mix of participating researchers and managers. The mechanisms used by this diverse community will include:

- the synthesis of existing information;
- the commissioning of research projects within this framework;
- the development of new approaches, skills and understanding by means of interactive meetings (workshops) and visits;
- the publication of research results, workshop products, syntheses etc, aimed at appropriate audiences; and
- the development of guidelines for a national policy on the conservation of river ecosystems, including the implications for long-term monitoring.

RESEARCH PRIORITIES

O'Keeffe (1986a) has identified that in the past a large proportion of research effort has been devoted to the autecology of individual species, and particularly to invertebrates and fish. This has been partly a consequence of the necessary emphasis on taxonomy during the formative

years of river research, partly of the distribution of individual enthusiasms, and partly of the financial and logistical difficulty of mounting holistic or multidisciplinary research projects on even small parts of river systems. Notable exceptions to these trends have been the hydrobiological investigations of the Great Berg, Tugela, Jukskei/Crocodile, Mgeni and Vaal Rivers.

Some current projects are also demonstrating that system studies are possible with limited resources. J M King, J A Day and B R Davies at the University of Cape Town, by limiting the study area to small streams in the Jonkershoek catchment, have been able to devise methods to investigate energy and nutrient budgets, so as to identify the important processes governing stream functions. C J Kleynhans and J Engelbrecht at the Nature Conservation Division of the Transvaal Provincial Administration have developed methods for regional surveys of many aspects of rivers, to provide an initial database for the conservation assessment of Transvaal rivers. K C D Hamman and A H Coetzer at the Cape Department of Nature and Environmental Conservation have begun a multidisciplinary project aimed at identifying habitat requirements for endemic fish in the Olifants River system. R N Porter, of the Natal Parks Board, has developed a protocol for environmental impact assessment of proposed impoundments on the Mfolozi River. These are all attempts to provide an integrated understanding of river ecology, often improvising methods to circumvent the problems of limited resources.

Preservation versus sustainable multiple-use

The lack of an overall conservation policy for rivers in South Africa is a serious impediment to the focusing of research attention on river conservation problems. The importance of such a policy has been underlined by Gaigher et al (1980) and by Allanson and Rabie (1983). The development of such a consensus policy must therefore be a major priority, since the directions for future research will depend crucially on the careful definition of conservation aims for rivers.

There are two approaches to conservation in rivers. The first is concerned with 'preservation', and deals with the desirability of maintaining pristine systems in which the following criteria (modified from Newbold et al 1983) are of greatest importance:

- | | |
|----------------------|-------------|
| - Naturalness | - Rarity |
| - Representativeness | - Fragility |
| - Diversity | - Size |

'Naturalness' implies the extent to which a system has been altered from its state before the arrival of industrial man. A "pristine" river acts as a baseline against which to compare the level of degradation in other systems.

'Representativeness' identifies the desirability of conserving typical examples of all different kinds of systems. A practical river classification system is a prerequisite.

'Diversity' is an uncomfortable criterion for rivers. South Africa's streams and rivers are very diverse and many contain sparse but specialized biota. Regulation may well increase biotic diversity, but not add to the conservation value.

'Rarity' of species or habitats must be taken into account, in terms of the intrinsic interest in rarities, their use as first indicators of degradation, and their contribution to the 'fragility' of a system.

'Fragility' indicates both the resilience of a system to interference, and the level of threat of further interference.

'Size' with respect to rivers, is some combination of length, runoff, catchment area and stream order. Size is important because of the problems of scale. To effectively conserve a portion of a large river is orders of magnitude more difficult than a similar portion of a small river. Threat assessment follows the same exponential trend.

The second approach to conservation has been termed a holistic view. In this case, the underlying criteria are often the same, but the other perspectives and demands on river systems are acknowledged and accepted. The river is viewed as a renewable resource which can be exploited for multiple uses, the overall aim being to maximize its uses with minimal detriment to its essential functions.

River functions

River uses

Water transport (and drainage)
Sediment transport
Nutrient transport
Water purification
Nutrient cycling
Biotic habitats
Biotic dispersal
Vegetation maintenance
Groundwater recharge

Domestic and industrial water supply
Agricultural (irrigation) water supply
Recreation
Conservation of species and habitats
Scientific information
Fisheries

In all large rivers and most small rivers in South Africa, this kind of multiple-use is already a fact of life, and conservation priorities have to be integrated with those of other users. Conservation, however, while receiving considerable lip service, has traditionally been ranked very low down the scale of user priorities. To summarize this view of conservation, the emphasis is not: "No effluent must be allowed in this river", but "How much of a particular effluent can be disposed of in this river without seriously affecting the biota, and breaking down the self-purification capacity of the system".

At present, there is a reasonable understanding, in the specific example used above, of the effects of effluents in rivers, but very little predictive capacity. Similarly, if an impoundment is planned for a river, some of the general consequences can be described, but the severity and persistence of the effects cannot be accurately predicted or quantified.

A practical list of priorities

There are two major impediments to effective research on rivers in South Africa. The first is that rivers are longitudinal, dendritic, and unpredictable, with diffuse inputs and dependent on catchment processes. These are all attributes which cause problems in the planning and logistics of river research. However, the application and adaptation of the conceptual models developed in the United States of America, have made a considerable contribution to overcoming these problems (see Chapter 3 this volume).

The second impediment to river research is the critical shortage of resources, particularly of trained manpower. This has probably been a result of the emphasis on lake and reservoir research in the last twenty years, which has channelled limnologists away from the study of running water ecology. However, shortage of skilled manpower is common to many industries and professions in South Africa and is unlikely to be remedied in the near future.

Noble and Hemens (1978) and Ward et al (1984) have previously identified priorities for research into river ecology, and some of their suggestions have been included here. Each project has been assigned to one of three categories, which indicates the level of training necessary for its accomplishment.

Category 1:

Specialized ecological research. This requires highly trained manpower, although it is not necessarily expensive to do. These projects are aimed at providing a basis for understanding ecological processes in rivers, from which better management decisions may be made.

Category 2:

Monitoring and conservation management projects. This kind of research is often expensive in terms of the number of personnel and amount of travelling required, but methods can be refined to be within the capability of less specialized people than Category 1 above.

Category 3:

Information gathering and 'clean-up' projects. These exercises require only good organizational ability and enthusiasm. Local conservation groups and angling interests are ideal targets for this kind of operation.

1. Specialized ecological research.

- a. Determination of instream flow requirements of regulated and other modified rivers, sufficient to maintain acceptable levels of ecological functioning and biodiversity (in progress: several synthesis documents derived from workshops).
- b. Downstream effects of impoundments, particularly in terms of reset distances required for physical and biological parameters to return to preimpoundment conditions (in progress: work on the Buffalo and Palmiet Rivers).

- c. The measurement of trophic status in rivers using production/respiration ratios, as an integrated measure of biological activity, and calibration of changes in the ratio in response to different perturbations in the river (in progress: work on the Buffalo and Palmiet Rivers).
 - d. Functional classification of river fauna. At present very little is known about the feeding methods and preferences of most riverine species, and these must be understood before functional changes in communities can be related to river processes.
 - e. The role of rivers in nutrient recycling and absorption. The ability of rivers to act as 'nutrient buffers' preventing eutrophication of recipient water bodies, and the length of river required to 'self-purify' after effluent input are both important aspects of nutrient cycling in rivers.
 - f. Quantification of the relationships between time scales associated with hydrological processes and those of the biota.
 - g. Effects of interbasin water transfers on physical, chemical and biological river attributes (in progress: overview, Berg River study).
 - h. Effects of fish populations on energy flow and nutrient cycling in rivers.
 - i. Environmental effects of dam construction projects.
2. Monitoring and conservation management projects.
- a. Drawing up a consensus policy of conservation aims and criteria for South African rivers (see O'Keefe 1986b).
 - b. Development of a protocol for research into river development projects at the planning stage.
 - c. Preparation of a field guide to freshwater invertebrates. At present this important group is often ignored because of the difficulties of identification (in progress: general field guide and Trichoptera handbook).
 - d. Development of methods for the consistent evaluation of the conservation status of rivers (see O'Keefe et al 1986).
 - e. Ordination analysis of existing data (especially on invertebrates), to identify comparable rivers/stretches of river.
 - f. Resurveys of selected rivers to evaluate changes over time (to include or be integrated with general monitoring of rivers).

g. Evaluation of changes in river and catchment conditions by:

- i) Water temperature changes.
- ii) Palaeoecological methods such as pollen analysis, diatom frustules, mollusc shells, and fishbone middens.
- iii) Fixed point photography (and the comparison of historic photographs).

3. Information gathering and "clean-up" projects.

These would include such projects as the efforts of Mrs W Bodman to clean up parts of the Jukskei River (Anonymous 1977) and the organization of angling competitions to gain information about fish stocks and to provide a platform for education about the harmful effects of exotic species. The present need is for an evaluation of the potential for these projects and the development of the methods and infrastructure to make them happen.

Without the more fundamental river process investigations it will be difficult to provide the level of input to development planning necessary for ecological aspects to be taken seriously. However, it has to be recognized that rivers are going to be developed anyway, and that best use has to be made of the present limited knowledge and resources to prevent overexploitation. The less specialized projects are aimed at achieving this, but they are not a substitute for fundamental research.

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