The conservation of South African rivers

J H O'Keeffe (editor)

A report of a workshop convened by the Nature Conservation Research Division,
Foundation for Research Development, CSIR, at Midmar Dam, Natal,
from August 19 to 21, 1985

SOUTH AFRICAN NATIONAL SCIENTIFIC PROGRAMMES REPORT NO

131

1986

Issued by
Foundation for Research Development
Council for Scientific and Industrial Research
P O Box 395
PRETORIA
0001
South Africa

from whom copies of reports in this series are available on request

Printed in 1986 in the Republic of South Africa

ISBN 0 7988 3820 5

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PREFACE

To most scientists and managers who work in this field, rivers are seen primarily as sources of water for people. As such they 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. However, to non-biologists, the bottom line is that they provide water in economic quantities, beyond that there is rapid loss of interest.

To ecologists and conservation scientists however, rivers are seen primarily as ecosystems, or ecosystem components, that have a larger set of values. It is these that are elaborated in this volume. They 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. It is intended that this publication should help establish these values in the minds of scientists and decision makers.

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.

These brief comments provide a background to the interest that FRD's Ecosystem Programmes has in promoting research into river ecosystems. This report is the product of a workshop held in August 1985 at Midmar Dam Public Resort, as part of a project to synthesize what is known about the status and functioning of South African rivers. The workshop was held under the auspices of the Nature Conservation Research section of the National Programme for Ecosystem Research. Along with the text that follows, a map of the conservation status of the major rivers of South Africa has been prepared, and will be published separately. The map, at a scale of 1:2,5 million, identifies four different conservation categories of river, together with a long list of sites of special scientific or conservation importance. Together, this text and the river conservation map, provide the best current statement available on the conservation status of South Africa's rivers. The Rivers Working Group of the Nature Conservation Research Committee, which is responsible for the river research programme, has supervised the production of these publications with the understanding that they will be criticized and reviewed to enable more comprehensive statements and maps to be produced in the future.

ABSTRACT

The report presents the proceedings of a three-day workshop at Midmar Dam designed to establish a consensus view of river conservation and to provide professional conservationists, managers and planners with a set of guidelines. These indicate what is known about the ecology of South African rivers, what options are available for monitoring and managing them, what legislation is available for controlling the exploitation of rivers and what research priorities should be implemented to increase our understanding of river ecology.

Chapter 1 is an overview of ideas on river ecosystem functioning, emphasizing the view of a river as a continuum in which changes in the biotic community are a reflection of changes in the physical environment, and of the nature and amount of energy and nutrients supplied by the catchment or produced in the river.

Chapter 2 summarizes the views of the workshop participants on aims and criteria for river conservation, emphasizing an holistic approach to conservation and aiming for the maintenance of diversity of function within the framework of essential exploitation of this vital resource.

Chapter 3 examines the uses to which rivers are put and the impact which these uses have on rivers. The importance of avoiding over-exploitation by any one user, to the detriment of all, is stressed.

Chapter 4 derives a set of management options for rivers based on the conservation aims and values elaborated in the previous two chapters. Three categories of activity are proposed, namely, the protective, manipulative and legislative approaches. The need for public education and acceptance of compromise in the use of diminishing resources is stressed.

Chapter 5 explains the interactions between a river system and its catchment, the river being dependent on and sensitive to land-use changes in its catchment.

Chapter 6 discusses the aims and methodology of river monitoring programmes, examining the options for physical, chemical and biological methods. A considerable amount of legislation relates to the exploitation of South African rivers, but much of it is inadequately administered.

Chapter 7 lists the relevant sections of river-related acts and concludes that there is a need for legislation governing the overall management of rivers on a catchment basis.

Chapter 8 describes progress in river research to date, discusses research organization, and suggests specific areas and projects which should be given priority for future research.

Appendices define research priorities and a conservation classification system for South African rivers.

SAMEVATTING

Hierdie verslag verteenwoordig die handelinge van 'n drie-daagse werksessie te Midmardam om 'n eenvormige sienswyse oor die bewaring van riviere te bewerkstellig. Daar is ook gepoog om aan professionele natuurbewaarders, bestuurders en beplanners, 'n stel riglyne te voorsien wat aandui wat oor die ekologie van Suid-Afrikaanse riviere bekend is, watter keuses vir die monitering en die bestuur daarvan beskikbaar is, watter wetgewing vir die beheer van die benutting van riviere beskikbaar is, en watter navorsingsprioriteite geïmplementeer behoort te word om ons kennis van rivierekologie te verbreed.

Hoofstuk 1 gee 'n oorsig van idees oor die funksionering van rivierekosisteme en beklemtoon die sienswyse dat 'n rivier 'n kontinuum is waarin veranderinge in die biotiese gemeenskap 'n weerspieëling is van veranderinge in die fisiese omgewing, asook van die aard en hoeveelheid energie en voedingstowwe voorsien deur die opvanggebied of geproduseer in die rivier.

Hoofstuk 2 som die sienswyses van die werksessiedeelnemers oor doelstellings en kriteria vir rivierbewaring op, en beklemtoon 'n holistiese benadering tot bewaring. Die doelwit is die handhawing van verskeidenheid van funksie binne die raamwerk van noodsaaklike benutting van hierdie lewensnoodsaaklike hulpbron.

In Hoofstuk 3 word die gebruike van riviere en die impak wat hierdie gebruike op riviere het ondersoek. Die noodsaaklikheid om oorbenutting deur enige enkele gebruiker wat vir almal nadelig is, te voorkom, word beklemtoon.

Hoofstuk 4 stel 'n aantal bestuurskeuses vir riviere voor, gebaseer op die bewaringsdoelstellings en waardes wat in die vorige twee hoofstukke beskryf is. Drie benaderings word voorgestel, naamlik beskermend, manipulerend en wetgewend. Die behoefte aan openbare opvoeding en die aanvaarding van 'n kompromie in die gebruik van verminderende hulpbronne word beklemtoon.

Hoofstuk 5 verduidelik die interaksies tussen 'n riviersisteem en sy opvanggebied, aangesien die rivier afhanklik en gevoelig is vir bodembenuttingveranderings in sy opvanggebied.

Hoofstuk 6 bespreek die doelstellings en metodologie van riviermoniteringsprogramme en ondersoek die keuses vir fisiese, chemiese en biologiese metodes. 'n Aansienlike hoeveelheid wetgewing het betrekking op die benutting van Suid-Afrikaanse riviere, maar baie hiervan word ontoereikend geadministreer.

Hoofstuk 7 gee 'n lys van die betrokke afdelings van rivier-verwante wette en kom tot die slotsom dat daar 'n behoefte bestaan vir wetgewing wat die algehele bestuur van riviere op 'n opvanggebiedbasis beheer.

Hoofstuk 8 beskryf vordering in riviernavorsing tot hede, bespreek navorsingsorganisasie, en stel spesifieke gebiede en projekte voor wat voorkeur vir toekomstige navorsing behoort te geniet.

Die aanhangsels omskrywe navorsingsprioriteite asook 'n bewaringsklassifikasiesisteem vir Suid-Afrikaanse riviere.

ACKNOWLEDGEMENTS

The organization and successful completion of this workshop was the result of considerable work by Tony Ferrar, who also chaired the workshop plenary sessions, and Fifi Bierman, who also coordinated the production of this report.

The production of draft manuscripts during the workshop was due to the exceptionally fast and accurate word-processing skills of the late Margaret Orton and Marie Breitenbach. Lynette van Niekerk and Lorraine Horn continued the process after the workshop.

The voluntary efforts of the chapter conveners (Jan Heeg, Niels Kleynhans, Jan Bosch, Mark Chutter, Andrew Stone, Jim Cambray and Piet le Roux) in preparing their subjects, leading their group discussions and finalizing the manuscripts are greatly appreciated. Thanks are also due to Jenny Day, Bryan Davies and Jackie King for contributing the opening chapter, in addition to their participation in their respective groups.

The workshop was financed through the Ecosystem Programmes section of the Foundation for Research Development, CSIR.

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CHAPTER 1 RIVERINE ECOSYSTEMS

J A Day, B R Davies and J M King

1.1 INTRODUCTION

As well as acting as drains for the land and thus as major sources of surface water, rivers are highly complicated longitudinal ecosystems. In South Africa, where there are very few permanent standing waters of any size, rivers provide almost all the surface water that can be exploited by man.

Since water will soon be the factor limiting the economic prosperity of South Africa, it is clear that this country's rivers will continue to be exploited to the greatest possible extent. It is necessary, therefore, to consider the effects that this will have on the rivers themselves. Not only are rivers ecologically, aesthetically and recreationally important parts of the landscape, but their biota is able to cleanse their waters, making them available for further human use. As yet there is no policy for the conservation or preservation of any South African rivers and no legislation directed specifically at preventing their abuse as functioning ecosystems (see Chapter 7).

This chapter describes the physical and ecological properties of rivers in order to set the scene for subsequent chapters that discuss the uses and abuses of rivers, the need for their conservation and how this might be brought about.

1.2 THE ZONES OF A RIVER

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.

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 or 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.

1.2.1 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 semi-shade. Large plants rarely occur in the water or close to the edges because, amongst other things, the abrasive movements of the riverbed boulders during spates destroy any newly-established seedlings. Algae and mosses are present only in small quantities because little light reaches them so that photosynthesis is slow. Even where sunlight does reach the water, green plants are still relatively rare because the water is very poor in the nutrients they need for growth. 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. Collectively, their numbers may reach hundreds or thousands of individuals per square metre and some groups may be represented by several different species.

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 banks (Figure 1.1a) and towards the bed of the stream (Figure 1.1b). Thus a diverse array of small streamlined animals (eg Figure 1.2a) virtually escapes the fast-flowing water by making use of the so-called "boundary effect" where, close to the substratum, flow almost ceases. These organisms use hooks, suckers or friction-pads to maintain position on the stony riverbed; bodies are flattened and streamlined to take advantage of the boundary layer; silky and sticky secretions may attach the animals to underwater boulders; ballast is used to increase body weight. In addition to the boundary layer, regions of turbulent flow occur on downstream-facing surfaces, while particles may accumulate in interstitial spaces with no flow (Figure 1.2b). Behavioural adaptations to these micro-habitats include a tendency to live on the underside of stones or between boulders, or to burrow as much as a metre down into the streambed in gravel and sandy substrata.

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. This food-web, unusual in most ecosystems, is common to tree-lined mountain streams world-wide. Thus these ecosystems are driven by, and dependent on, allochthonous inputs of food: food material manufactured outside their own boundaries. 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, for any disturbance of the catchment, and particularly of the riparian zone, will affect the functioning of the stream ecosystem.

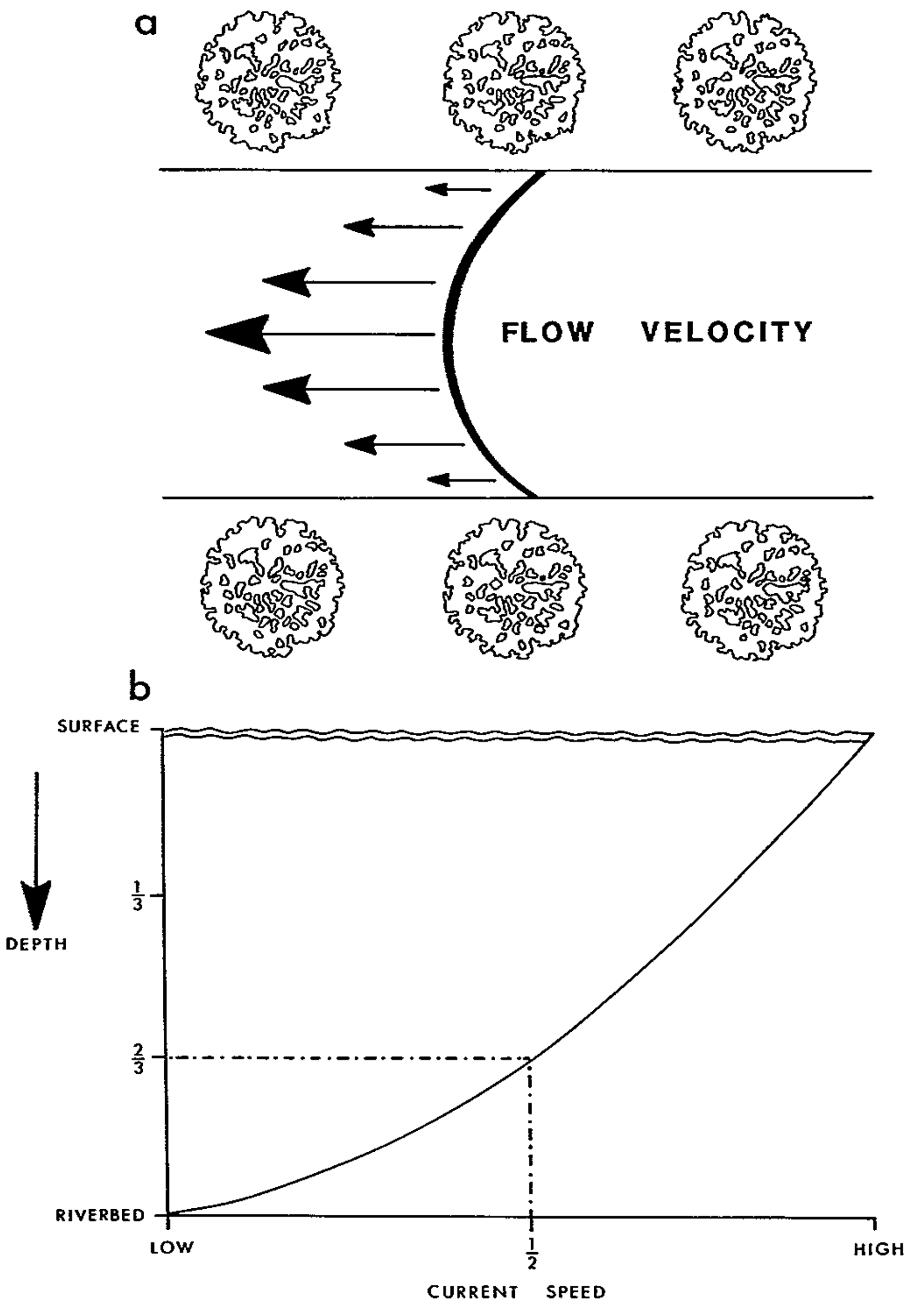

FIGURE 1.1 Diagrammatic plan (a) and cross-sectional view (b) of a river showing changes in flow velocity across a stream due to bank friction (a) and vertically through a stream due to bed friction (b). In the lower diagram, note that the mean velocity of the stream in vertical profile occurs at a point approximately 2/3 of the way below the surface and that near the bed of the stream there is very little flow, while the surface waters may be flowing very quickly. Indeed a "shear" in the water column may develop near to the bed creating a so-called "boundary layer" on the bed, where there is virtually no flow (from Davies and Day 1986).

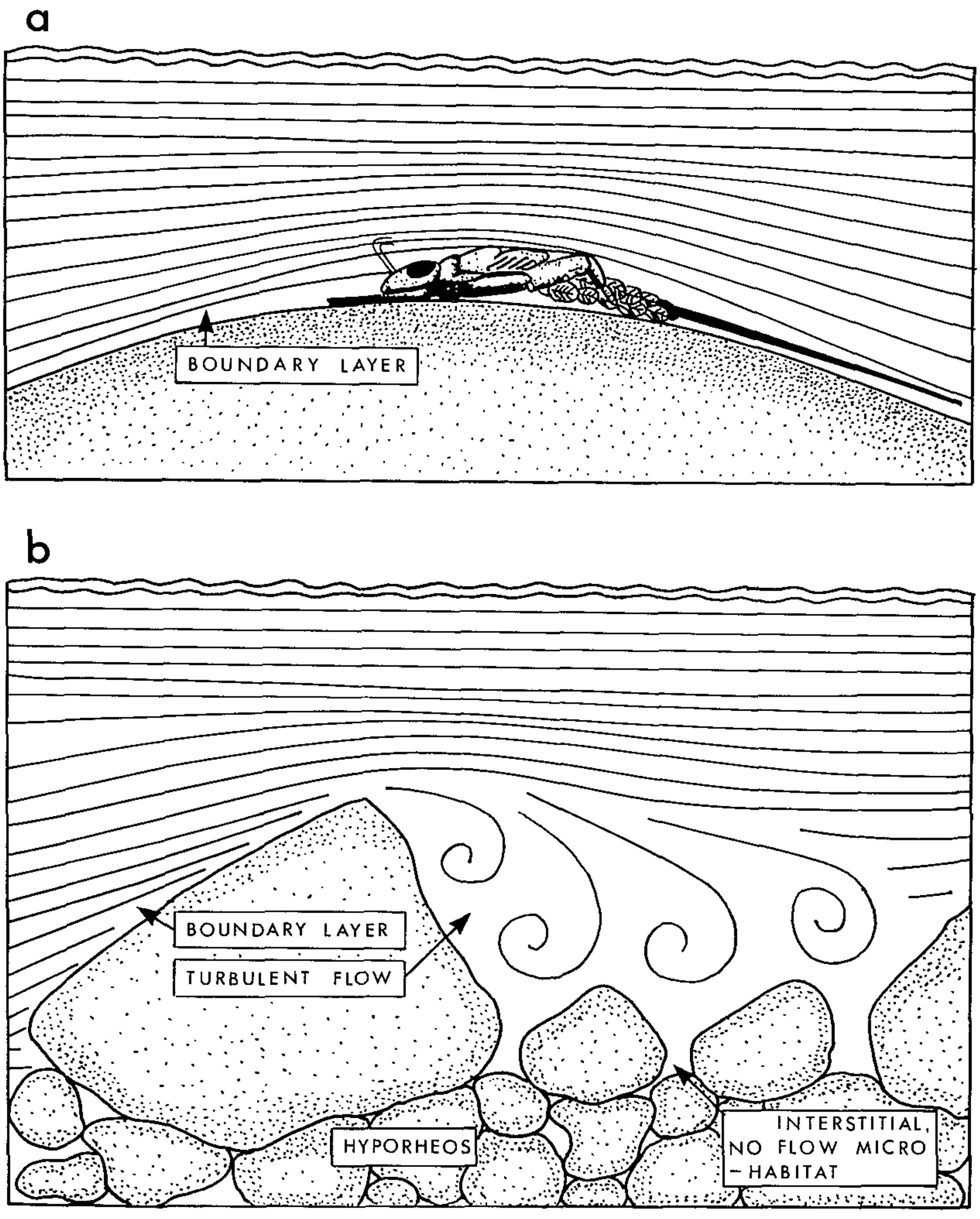

FIGURE 1.2 Organisms living on the surface of exposed boulders in fast-flowing headwater streams are streamlined and dorso-ventrally flattened. Living in the boundary layer, the water moving above them will force them down onto the substratum (rather than sweep them away), allowing them to move over the substratum with relative impunity (1.2a). There are additional microhabitats in headwater streams which can be colonized by other specialists (see text): the turbulent flow regions, the interstitial spaces between boulders and the hyporheos (the regions deep down - as much as one metre or more - in the streambed) (1.2b) (from Davies and Day 1986).

Leaves falling into the water are decomposed by fungi and bacteria. These, together with the decaying leaves, form the food for larger animals, the indigestible material being voided as faeces that are in turn eaten by other organisms. In this way leaves and other coarse organic debris (CPOM: coarse particulate organic matter) are steadily broken down into FPOM (fine particulate organic matter) and finally into UFPOM (ultra-fine particulate organic matter) that is carried downstream.

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 brush-like mouth-parts ("taking the peanut butter off the bread", as one American river biologist eloquently described it). "Grazers" feed on the thin layer of algae living on the surface of rocks and other structures while the "collectors" are filter-feeders, erecting nets or strings of saliva that sieve the water, trapping 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, a new generation annually replacing those that emerge as aerial adults. Such species are able to survive only within a very narrow range of environmental conditions so that even minor disturbances in mountain streams may have profound effects on the ecosystem as a whole, and recovery, if it occurs, is likely to be slow.

1.2.2 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, occasional patches of vegetation, such as the palmiet reed *Prionium serratum*, 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 than in the mountain stream because of the longer stretches of rock and soil over which the water has flowed en route from the mountains, allowing more leaching, and because of water-borne organic debris flowing in from upstream. Thus turbidity may be higher. 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 falling into the water. 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 FPOM swept down from upstream or in 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.

1.2.3 The mature lower reaches

As the river flows on to the coastal plain it continues to widen, while current speeds continue to drop as the gradient decreases. The heaviest particles of sediment drop out of the water column 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 FPOM and UFPOM, settle out so that the substratum becomes more and more muddy. The water column may become noticeably less oxygenated, particularly at night because the water is richer not only in mineral salts such as NaCl, but also in nutrients that have been leached in 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 bullrushes. Even if trees still line the banks, they shade only a minor proportion 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.

1.2.4 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 wide banks developed by successive marine and riverine particulate deposits, means that estuaries are often among the most productive ecosystems known. Details of functioning of South African estuaries may be found in Day (1981), for example, and need not concern us here. What is important, however, is that the manipulation of a river, particularly by extraction or impoundment of its water, will almost always have severe effects upon its estuary.

1.3 HYPOTHESES CONCERNING RIVER ECOSYSTEMS

Not all rivers conform to the basic pattern outlined above. Some seep from low 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-western Cape coast. On the other hand, mature rivers are sometimes rejuvenated by cascading down a second mountain range nearer the coast, as does the Orange River at Augrabies Falls (Cambray et al 1985) or the Zambezi River at the Victoria Falls and (prior to the construction of the Cabora Bassa Dam) at the Cabora Bassa Rapids in Mozambique (Davies 1985). Rivers also vary widely in mineral content and silt loads, depending upon the types of rock and soil over which they flow. The Orange River naturally carried a very heavy silt load even before man increased its load through agricultural malpractices. Many of 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).

1.3.1 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. Vannote et al (1980) suggest 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. Coarse particulate organic matter (CPOM) is progressively reduced to fine particulate organic matter (FPOM) by the successive actions of these functional groups or "litter processors". The changes are gradual and depend on longitudinal changes in the physico-chemical conditions of the river's catchment. Although there are certain features of the river continuum concept that may not be generally applicable (for example the apparent inability of animal communities, in Australia, New Zealand and South Africa at least, to time their activities to make maximal use of their food resources (cf Ward et al 1984)), 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. The continuum may be visualized as a "sliding scale" which is shifted upstream or downstream depending on large environmental forces, or reset following the application of more localized ones (Minshall et al 1983). Some general features of the river continuum concept are shown in Figure 1.3, while further information may be found in Cummins (1979).

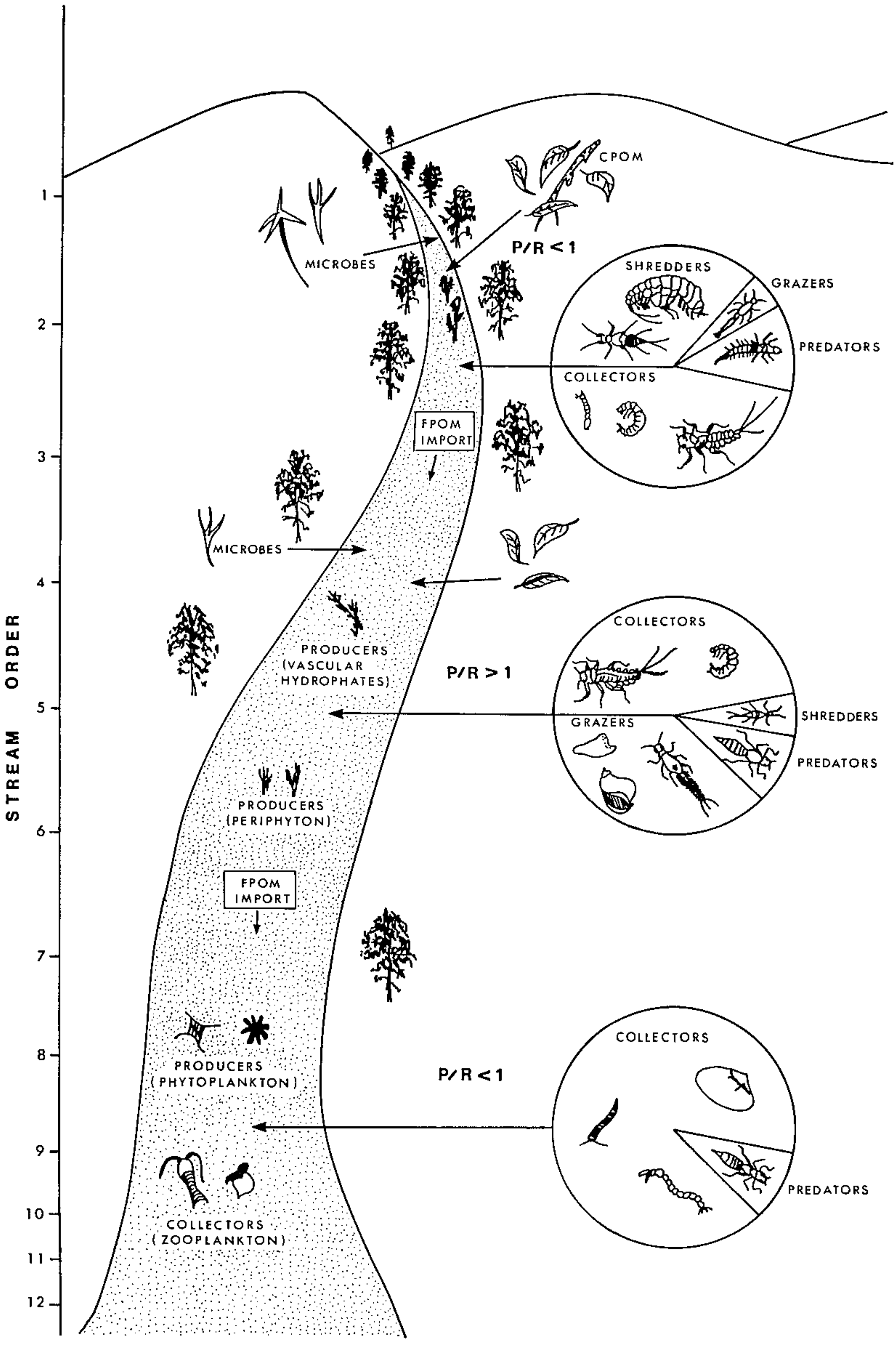
STREAM ORDER
1
2
3
4
5
6
7
8
9
10
11
12
CPOM
MICROBES
P/R < 1
SHREDDERS
GRAZERS
PREDATORS
COLLECTORS
FPOM IMPORT
MICROBES
PRODUCERS (VASCULAR HYDROPHATES)
P/R > 1
COLLECTORS
SHREDDERS
GRAZERS
PREDATORS
PRODUCERS (PERIPHYTON)
FPOM IMPORT
PRODUCERS (PHYTOPLANKTON)
P/R < 1
COLLECTORS
PREDATORS
COLLECTORS (ZOOPLANKTON)

FIGURE 1.3 A pictorial representation from Cummins (1979) of the river continuum concept (modified from Davies and Day 1986), showing the downstream gradient of physical factors and the corresponding biological adjustments. The diagram represents the river continuum as a single stem of increasing stream order. General range of stream widths (in metres) is given, and orders have been roughly grouped into headwaters (orders 1-3), mid-sized rivers (4-6) and large rivers (7-12), considering the Mississippi River as order 12 at its mouth. The headwaters and large rivers are shown as heterotrophic (ratio of gross photosynthesis to community respiration P/R less than 1) because of restricted light in the headwaters and attenuation from depth and turbidity in the large rivers. The mid-sized rivers are depicted as autotrophic, with a P/R greater than 1, through a combination of reduced riparian shading and relatively shallow and clear water. The importance of terrestrial inputs of CPOM decreases and the transport of FPOM increases down the river. The downward macro-invertebrate functional feeding groups shift from shredders and collectors in headwaters to collectors and grazers (scrapers) in mid-sized rivers and to collectors in large rivers, which also develop plankton communities.

1.3.2 The nutrient spiralling hypothesis

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 1.4)). Information on the hypothesis is provided by Webster (1975) and Newbold et al (1982).

1.3.3 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 applications for streams are discussed by Ward and Stanford (1983a). 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 stream 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.

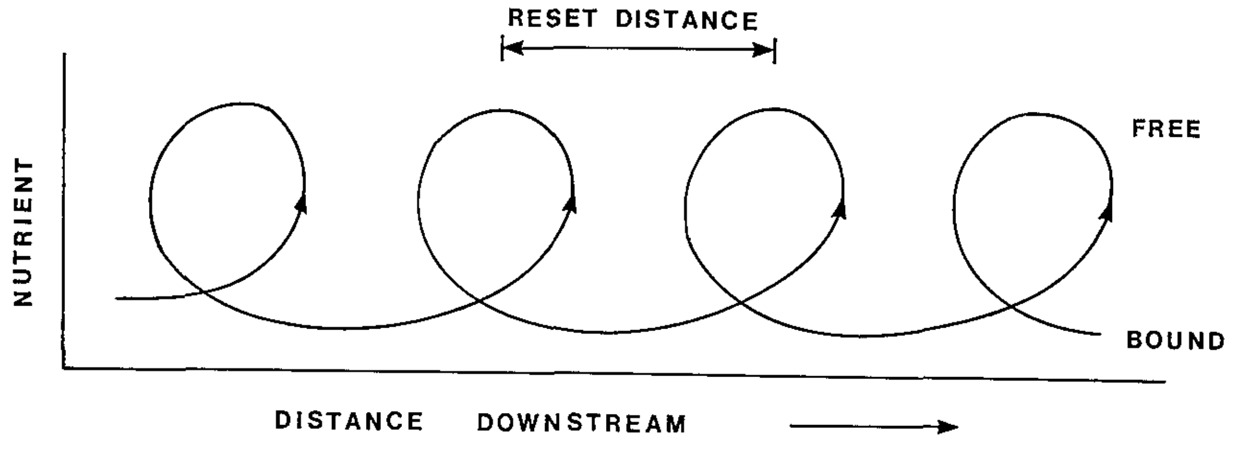

FIGURE 1.4 A simple representation of nutrient spiralling in a stream. Nutrients are taken up and released by the stream biota, in the course of metabolism. The spiralling distance refers to successive points along the stream, where a given amount of nutrient begins and completes the cycle.

1.3.4 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) and Figure 1.5 graphically depicts the "self-cleaning" process using a typical river in the United Kingdom as an example. 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 disrupted.

1.4 MAN-INDUCED CHANGES IN RIVERS

It is clear from the previous section that rivers have a considerable ability to recover from change, be it natural or anthropogenic, short-term or long-term. But it is also clear that rivers are not infinitely adaptable and that they will continue to be more and more seriously perturbed in South Africa as populations grow and more and more water is required. This section discusses the major human-induced impacts on rivers and their consequences for the effective functioning of riverine ecosystems.

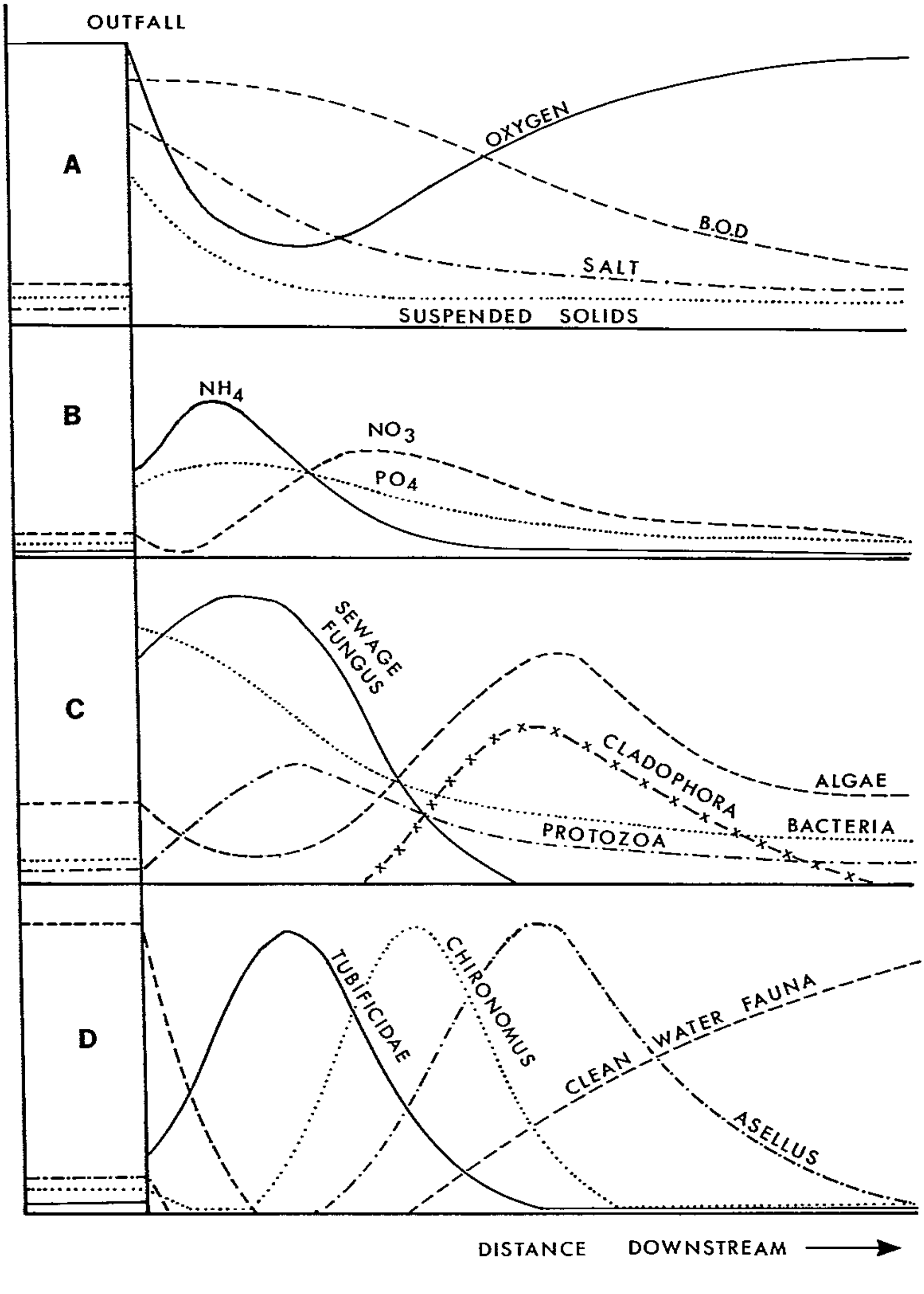

FIGURE 1.5 Diagrammatic representation of the effects of an organic effluent on a river and the changes as one passes downstream from the outfall. A and B, physical and chemical changes; C, changes in micro-organisms; D, changes in larger animals. (Modified after Hynes 1966).

1.4.1 Perturbations in the catchment

A catchment is all the land drained by a river right down to the sea. Since the water in a river comes either from groundwater that has percolated through from the surface, or directly from surface runoff from rainfall, the geology, soils, vegetation and land use of the entire catchment will have an effect on the quality of water in the river. The riparian vegetation will determine, particularly in the upper reaches, the quantity and quality of food in the form of allochthonous detritus and hence the FPOM loading of lower reaches and the types of organisms processing the material.

Salinization. One of the most serious problems in several South African rivers is the increase in salt (usually NaCl) content of the water associated with excessive irrigation under arid conditions. Even though irrigation water may contain only very small quantities of dissolved salts, evaporation occurs when this water is sprayed or flooded onto the land and the remaining water, now containing proportionally more salt, is ultimately returned via groundwater or surface flow to the river. The ecological effects are very poorly understood, although severe salinization will undoubtedly result in a loss of most of the species of plants and animals normally associated with the river and hence eventually reduce its self-cleaning abilities. The agricultural and economic effects of salinization are considerable. A detailed discussion is to be found in Williams et al (1984).

Eutrophication. Just as salts such as NaCl can be vastly concentrated by spray irrigation, nutrients such as phosphates, nitrates, ammonia and potassium in fertilizers eventually find their way into rivers. The other major source of these nutrients is effluent from sewage treatment works: this inevitably has high levels of phosphates but usually less elevated levels of nitrogen-containing compounds. The problem with nitrogen-containing nutrients may be minimal, since these are often converted into atmospheric nitrogen by certain micro-organisms. But phosphates are not volatilized and must accumulate either in the vegetation or in the water. High levels of nutrients in the waters of mountain streams do not seem to be particularly damaging, since flow rates are high. In the lower reaches, however, especially where planktonic algae are found, high levels of nutrients result in eutrophication - the excessive growth of plants due to an excess of nutrients. These plants, usually algae, change the trophic structure of the entire ecosystem, sometimes causing the water to be so green as to look like pea soup and can be extremely expensive to remove from drinking water.

Such algae may have very short life-spans so that there is a continual "rain" of dead algal cells onto the bottom. Similarly, in turbid reaches where little light penetrates the water, plants cannot survive below the uppermost layers, so that those swept down from upstream die and sink to the bottom. In both cases such reaches are rich in bottom-feeding animals if sufficient oxygen is present. Where organic matter on the riverbed encourages micro-organisms to thrive, oxygen is usually lacking and noxious substances such as hydrogen sulphide and methane may be generated. Under these circumstances very few species of animal can survive although those tough enough to withstand the harsh conditions may be present in astronomical numbers (cf Cullen et al 1984 for a review of eutrophication problems and management strategies).

Pollution. The topic of pollution is reviewed by MacDonald et al (1984). Toxins such as heavy metals, organic solvents and biocides can obviously be extremely damaging to riverine organisms but once again the consequences for man are more dramatic: as well as many of these substances being toxic in very small quantities and difficult to remove from drinking water, they will prevent the normal functioning of the river's biota in purifying the water that they live in.

Land-use practices. The normal functioning of the stream biota is the result of evolution acting on countless generations of each species. The organisms are adapted to a particular regime of water flow, water chemistry and food resources. Practices such as afforestation, clear-felling, or ploughing and planting of short-lived commercial crops, may alter the riverine environment in a number of ways. Firstly, they will change the available food resources in the form of allochthonous detritus. Secondly, they may well alter the water balance by increasing or decreasing runoff and/or evapotranspiration. Thirdly, they may increase erosion, thereby increasing the amount of soil entering the river. This last effect will result in increased quantities of sediment settling out on the riverbed, smothering bottom-dwelling organisms or remaining in suspension and clogging the gills of fish, or preventing them from being able to see their prey. Many South African rivers are naturally turbid so that these effects are not always obvious. What is quite clear, however, is that many estuaries in Natal, where silt has been identified as a major problem in 30 estuaries (Begg 1978) and in the south-western Cape (eg Milnerton, the Bot River estuary, Kleinmond), are rapidly silting up as a result of excessive erosion, often due to irresponsible farming practices such as planting sugar cane right to the edges of rivers.

1.4.2 Manipulation of water in rivers

Essentially the water of a river can be deliberately manipulated by impoundment, by extraction, by transfer from one catchment to another or by reversing the flow of the river. This last is a new phenomenon and nothing is known about its effects, although they must be dramatic for the riverine biota. Direct extraction of water has similar consequences to those discussed below for impoundments, while no work has been done in South Africa on the transfer of water from one catchment to another. There is no doubt that this results in transfer of many different organisms with considerable biogeographical consequences and is hence of major conservation interest. The deleterious effects include the transfer of pest species, such as blackflies and mosquitoes, fish that may eliminate the less robust endemic fishes and invertebrates from thus-far isolated streams.

Impoundment of rivers and river regulation. The flow regime of regulated streams is strongly influenced by the type of impoundment holding back the water (cf Ward and Stanford 1979; Ward et al 1984). Indeed, flow regulation is probably the most serious effect of stream regulation, with ramifications through the entire river food chain and repercussions for river functioning and self-cleaning processes. Hydro-electric and irrigation dams can lead to short-term fluctuations (on a daily basis in summer below the Vaal-Hartz Diversion Weir, for example and on a seasonal basis in the Lower Orange River below the P K le Roux Dam). The major result is reduction in the natural annual variations in flow of South African rivers. Where once there were winter low flows and summer floods (or vice versa in the western Cape), the original flow peaks and troughs have been evened out, while there is a general reduction in the annual flow in rivers below storage dams except during the largest floods. Thus summer floods are smaller and winter low flows are much higher. The river is regulated.

The low sediment loads in waters released from many impoundments increase the erosive capacity of the water (Simons 1979) and lead, together with a modified flow regime, to degradation of the river channel downstream of the impoundment (cf Ward et al 1984). Decreased turbidity also leads to greater water clarity, with consequent development of benthic algal mats (Chutter 1968), while permanently turbid waters in some South African and Australian impoundments lead to perennially high turbidity levels in the downstream regions, a factor that might not have been encountered prior to impoundment. High mortalities in fish juveniles follow increased silt deposition in the early summer season.

Discharge from the hypolimnion (the deepest waters) of waters containing high levels of H_2S but devoid of dissolved oxygen can have short-term toxic effects on the downstream fauna of regulated rivers. The reduced frequency and severity of floods can either increase or decrease salinization of floodplain pans (eg Davies 1979; Ward 1982), while the levelling out of flow peaks can increase pest species by reducing natural population control through desiccation (eg de Moor 1982; Ward et al 1984).

Standing waters become warmer than running waters and the release of warmed epilimnetic water into a river below a dam can lead to severe disruption of the life cycles of organisms or even to the elimination of species, since each species has an optimum temperature regime or equilibrium at which maximal development and fecundity is attained (Vannote and Sweeney 1980).

In summary, modifications of stream flow lead to an alteration in the general riverine habitat and in the functioning of the river as a dynamic ecosystem by altering the temporal and spatial heterogeneity of the environment in which the biota has evolved.

Effects on estuaries. Generally the physical impact of impoundments on the downstream stretches of a river is a function of distance from the dam since rivers, being linear systems, can eventually recover from such disturbance and reach a new equilibrium determined by the new flow regime. Reduction in flow may, however, have serious consequences for an estuary even if long stretches of the intervening river have otherwise recovered from the effect of the impoundment upstream. This is particularly true in arid regions, where flow may be minimal or highly variable (eg Alexander 1985; Ward et al 1984). The effects of stream regulation on the biota of an estuary are generally similar to those on the downstream reaches of a river (see above). In particular it is worth noting that, as flow is reduced, the system depends more and more on marine influences: there is a change in the relative importance of marine and estuarine food-sources in the form of detritus and particulate organic matter imported into the system, also in the relative abundance of marine organisms.

It is worth noting that these biological effects in the estuaries of regulated rivers often have more impact on the man-in-the-street than do similar effects in regulated rivers per se because estuaries are prime recreational areas. Thus reductions in the number of angling fish and bait organisms or dramatic increases in nuisance organisms such as mosquitoes or the alga Cladophora, may have an obvious and immediate social and economic impact.

The most serious economic impact, however, concerns commercial and recreational estuarine fisheries. Nursery areas in the estuary are important for recruitment of many marine fish species. Reduced flows can drastically alter these areas and fish kills can occur due to a build-up of industrial effluents while temporary closure of the mouth can interrupt movement in and out of the estuary, to the detriment of certain fish species.

The serial discontinuity concept. The serial discontinuity concept, formulated by Ward and Stanford (1983b), builds directly upon the river continuum concept. Given that river communities do represent a continuum, the construction of a dam creates a discontinuity. In the case of the dam, the pre-impoundment conditions are not restored for some distance downstream. The "reset distance" is that distance downstream from a dam that is needed for the river to recover from the effects of impoundment.

Assuming that the aim of the manager is to retain conditions in a regulated river as close as possible to those pertaining before impoundment, then the primary goal would be to reduce this reset distance as much as possible. This requires research and a basic understanding of the way in which each river (and indeed, each river reach) functions.

1.4.3 Other physical alterations in a riverbed

Like living organisms, rivers tend to be unpredictable. Particularly in South Africa, a country prone to drought and flood (Alexander 1985), it is difficult to calculate or even to imagine the force of a raging flood or its effects on man-made structures (vide Cyclone Demoina in 1984 and its effects upon northern Natal/KwaZulu systems). For this reason one is often struck by apparently incongruously large bridges over apparently timid streams or even over dry riverbeds. But the construction of bridges, causeways, diversions and weirs may have subtle effects on a river that are not immediately obvious. During the period of construction there is inevitably a good deal of disturbance of the riverbed and consequently an increase in silt being carried by the river, while the exact design of structures such as bridges may be of considerable importance since they can alter the river channel, causing aggradation in some areas and erosion of the bank in others. This is of particular consequence for estuaries, whose shifting sand- and mud-banks are naturally unstable and the movements of which are difficult to predict, even in the absence of man-induced changes.

1.5 RIVERS: THEIR VALUE AND CONSERVATION

Rivers provide South Africa's only large-scale resources of fresh water. The topography of the country is such that there are virtually no natural standing waters that can supply water for potable, irrigation, stock or industrial use. We have to use rivers. We have to dam them and, in doing so, we inevitably alter the characteristics of rivers: their flow rate, their volume and their temporal features, their temperature, erosive nature, particulate material and their chemistry. As such, we profoundly alter the ability of river systems to clean themselves, to adapt to additional perturbations, to support fisheries, to supply water to floodplains and estuaries, to flush pollutants and sediments from lower reaches and to fertilize estuaries, floodplains and coastal regions. Although water is a renewable resource, it is definitely limiting and limited. The in-stream flow needs ie the minimal requirements for river reaches below dams to function correctly, must be met and this requires very careful husbanding as well as research. No single river has exactly the same requirements as its neighbouring system.

The recent suggestion of Roberts (1983) that an allocation be made for the maintenance of river systems, is not only welcomed but essential. What is needed now is an attempt by managers and river biologists to reach consensus on how much water should be allocated and for which systems. A global figure (11%) is a start, but only a point for discussion and negotiation. We must now scientifically quantify the needs of individual rivers and then implement them.

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CHAPTER 2 CONSERVATION AIMS, CRITERIA AND GOALS FOR RIVERS

J H O'Keeffe

The purpose of this chapter is to try to synthesize a general statement about the basis of river conservation, which will act as the theme for the following chapters intended to describe the methods for the achievement of these aims.

In order to achieve a consensus view of these fundamental aspects of river conservation, all the workshop participants were asked to prepare short statements under the following headings:

- A philosphy of river conservation
- Important criteria to be taken into account for river conservation.
- Conservation goals for rivers.

This chapter is a synthesis of these statements and should therefore be the inclusive view of those best qualified in South Africa to define river conservation.

2.1 A PHILOSOPHY OF RIVER CONSERVATION

The IUCN World Conservation Strategy (1980) 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". Thus conservation is positive, embracing preservation, maintenance, sustainable utilization, restoration and enhancement of the natural environment.

A number of respondents used this statement as their basis and others made use of concepts such as sustainable utilization and the maintenance of essential ecosystem functions, which are embodied in the IUCN text. The important implications of this statement are that conservation is for people, and that it is an holistic concept, embracing use of resources as well as their preservation. In the context of South African rivers, which constitute a limiting resource for expansion and development in most of the country, this is particularly important.

The IUCN statement also emphasizes a range of conservation priorities, from the preservation of pristine habitat in areas of special nature conservation importance, to the wider view of conservation, which can be summed up as the maintenance of diversity of function in rivers. This implies a recognition that water supply is and will continue to be the main priority for river management and that rivers will also continue to be used for effluent disposal and recreation. Within this framework the important conservation aims are to ensure that rivers are not overexploited to a stage where essential functions such as the supply of good quality water, nutrient recycling processes and recreation potential are lost. The Black/Liesbeek River in Cape Town is an extreme example of this kind of overexploitation.

The conservation of rivers can therefore be seen as a continuum in which there are rivers, or stretches of river, which have been little modified and which incorporate features such as endemic fish species which are of extreme nature conservation importance. In these systems nature conservation priorities should be paramount, and other uses, such as water supply, must be restricted within nature conservation requirements. At the other end of the continuum, where rivers must be exploited for essential water supplies, the conservation role is likely to be restricted to mitigation of the effects of exploitation, for instance through advice as to the least damaging sites for regulatory structures, and the magnitude and frequency of modified flows which will cause least perturbation to the system.

Attempts to accommodate multiple use priorities inevitably lead to conflict between short-term economic needs and the less obvious benefits of long-term ecological maintenance. Where a decision is taken to sacrifice conservation priorities, the onus should be on the developer to bear the costs of mitigation of effects, or of the protection of alternative ecological resources.

It has by now been generally accepted that passive preservation of habitats is not possible because of the influence of adjacent areas and this is particularly true of stretches of river, which are subject to influences from upstream, and which reflect events in their catchments (see Chapter 5). The emphasis must therefore be on active management to conserve rivers and the management unit must be the whole catchment.

The characteristic plant and animal community of a river is also a reflection, not just of conditions in the river channel, but of events in the catchment as a whole. Chapter 5 examines the major ways in which catchment processes can affect the state of a river. The conservation of the biota is therefore largely dependent on the management of the whole system. Efforts to conserve important species should therefore be aimed at the maintenance of their habitat rather than the species themselves.

Finally, the importance of conserving rivers simply for their own sake should not be ignored.

2.2 CONSERVATION CRITERIA FOR RIVERS

The Oxford English Dictionary defines a criterion as "A characteristic by which something can be judged", so that conservation criteria for rivers are those characteristics of rivers by which their conservation should be judged.

Newbold et al (1983) have identified a number of standard criteria for nature conservation and these were also suggested by many of the workshop respondents. They are:

- Naturalness
- Representativeness
- Diversity
- Rarity
- Fragility
- Georaphical position
- Size

'Naturalness' implies the extent to which a river system has been artificially altered from its natural state (ie its condition before the arrival of industrial man).

'Representativeness' identifies the desirability of conserving typical examples of different kinds of river systems.

'Diversity' refers to the natural genetic and/or species diversity of the biota of a river system, as well as to the diversity of habitat in the system.

'Rarity' of species or habitat is important both in terms of the intrinsic value of rarities and their use as first indicators of degradation.

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

'Geographical position' is also important because it affects the threat status of a river (for instance if it is near a major urban/industrial area), and because different use priorities are applicable to heavily populated catchments compared to remote ones.

'Size' of rivers is some combination of length, runoff, catchment area and stream order. Size is important because of the implications of a viable ecological unit and because a large river is a more valuable conservation resource than a small river, if they are in the same relative condition. Size is also important because there is a clear distinction between the threat status and management possibilities for large and small rivers in South Africa. Large rivers, without exception, represent vital parts of the economic infrastructure and will always be managed primarily for water supply. Small rivers and streams are often under less pressure for exploitation; the logistics of their management for conservation priorities are obviously simpler.

These criteria apply largely to priorities for nature conservation in the narrow sense and are incomplete in terms of an holistic approach to conservation - the concept of the maintenance of diversity of function, identified in the previous section. The idea that a properly conserved river will carry out a number of functions which are relevant to both the natural ecosystem processes and to human requirements, as described in Chapter 3, is potentially a useful concept. Some of these functions which are immediately identifiable are:

- Water supply
- Sediment transport
- Nutrient transport and recycling
- Biotic dispersal
- Vegetation maintenance
- Water storage
- Effluent transport
- Flood buffering capacity

Other functions which apply only to human requirements of rivers might be:

- Recreation
- Land value enhancement
- Aesthetics
- Information value

The level of degradation of a river system could be judged in terms of which of these functions have been broken down or diminished and similarly, the ecological costs of planned developments should be looked at in terms of loss or changes to these functions.

As in the previous section, the use of these two sets of criteria should not be seen as mutually exclusive, but rather as complementary, to achieve a balanced view of the status of a river.

2.3 CONSERVATION GOALS FOR RIVERS

The definition of a philosophy and criteria for river conservation has immediately identified the general goals which should be aimed at:

- The maintenance of diversity of function
- The sustainable utilization of resources
- The maintenance of ecosystem functioning
- The preservation of representative types of rivers.

To be able to maintain the diversity of function of rivers requires the achievement of a number of specific goals. First of all, the functions must be identified and their controlling processes understood, so that the effects of perturbations can be predicted and mitigation methods suggested. The development of methods for the assessment of the conservation costs of river exploitation schemes is therefore a primary goal. Because of the difference in emphasis on the use of different rivers it will be necessary to formulate a number of different management policies to take account of the continuum from pristine to degraded and small to large rivers. It may be most effective to formulate individual river management plans.

The sustainable utilization of river resources requires research for the prediction of exploitable levels as well as the development of alternative technologies, such as water recycling, to ease the pressure for over-exploitation. In addition, the inclusion of ecological expertise and the identification of conservation priorities as a matter of course, at the earliest planning stage of development projects, is an overriding priority.

The maintenance of ecosystem functions underlies any attempt to preserve diversity of function. Once again the preliminary necessity is research to identify and understand basic controlling processes. In the river itself the dominant controlling variable is the flow level, and an urgent priority is to identify flow requirements for the acceptable maintenance of essential functions. However, as has been stressed in Chapter 1, conditions in the river are fundamentally dependent on events in the catchment and one of the primary goals for river conservation should be the establishment of management policies based on whole catchments.

The preservation of representative types of rivers requires the classification of rivers by geographical region, by physical environmental type and by conservation status.

The definition of goals for the conservation of rivers is a simple matter compared to their achievement. At present it is doubtful whether the work has been done to gather sufficient fundamental information on South African rivers for many of these goals to be tackled effectively. Chapter 8 provides a detailed examination of methods of improving our knowledge base, and perhaps the highest priority goal should therefore be to identify where our knowledge is inadequate, and fill the gaps.

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CHAPTER 3 USES OF, AND HUMAN IMPACT ON RIVERS

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3.1 INTRODUCTION

Rivers can be regarded as the natural water reticulation system of any land mass, draining the land, concentrating runoff and seepage into water masses usable by human populations and transporting such water on the surface from often inaccessible high rainfall areas to other regions where it is less plentiful. By virtue of their self-cleansing ability (see Chapter 1) rivers are capable of delivering water of a high quality, provided that this ability is not impaired. The rapidly increasing population of South Africa has resulted not only in an increased water demand, but also greater human impact on the country's river-borne water resources. This impact, which results from the need for increased agricultural production, urbanization and industrialization, has given rise to rapid lowering of the conservation status of many rivers through partial or total destruction of the natural river biota, alterations to river functioning (see Chapter 1), overloading of self-cleansing mechanisms and a concomitant drastic lowering of water quality.

The inestimable value of our rivers should be obvious to all, yet the alarming degradation which they continuously suffer is testimony to the need for a brief statement of the main uses to which they are put and the consequences of thoughtless exploitation. These aspects are discussed below, stressing the urgent need for strictly enforced river conservation measures.

3.2 RIVER USES

3.2.1 Agriculture

With an estimated abstraction of 73% of the total amount of water used in South Africa, the agricultural sector makes the greatest demand on the country's water resources. Crop irrigation and stock watering account for almost the whole of this, with some multiple use in the form of fish culture being practised on a limited scale.

The ability of a country to feed its population without recourse to food imports is of inestimable value to its prosperity. Rivers are essential to agriculture for maintaining food production on a sustainable yield basis, but can only fulfil this function while an adequate yield of water of suitable quality is assured. In areas of highly seasonal rainfall, which includes the whole of South Africa, this depends on land-use practices within the catchment, which are most often under the direct control of the agricultural industry. Disregard of the principles of sound catchment management and river conservation, whether through ignorance or wilful neglect, has an immediate detrimental effect on downstream users and causes irreparable damage to both catchment and river. However gainful such neglect may be to the individual farmer in the short term, it is the effect on future food production potential that must be the primary consideration.

Agriculture must perforce have a vested interest in the perpetuation of rivers as sources of a sustainable water yield. This interest does not necessarily take cognisance of rivers as dynamic ecosystems (see Chapter 1). A river may appear irrelevant as long as an adequate quantity of water is delivered. It is, therefore necessary to inform farmers through extension in all rural communities, whether engaged in cash crop or subsistence agriculture, of the essential nature of river ecosystem processes in maintaining water quality and to enforce legal requirements (see Chapter 7) to protect the rights of all users.

The mere fact that agriculture makes demands on river water resources in itself implies that the river is in some way affected. Conservation of rivers must, therefore, be aimed at minimizing this impact within the constraints of legitimate and necessary water needs to maintain agricultural production. Unnecessary damage, which will exacerbate the effects of essential exploitation, must be prevented at all cost. Agricultural malpractices which have done much to degrade South African river systems are set out below.

3.2.1.1 Indiscriminate abstraction. All abstractions from a river for irrigation purposes reduce the flow, since return flow does not equal abstraction as a result of evapotranspiration. Extreme cases have led to perennial rivers being reduced to seasonal rivers, where all flow ceases during the dry season, as for example, in the case of the Letaba, Crocodile and Levubu Rivers in the Transvaal Lowveld. In order to maximize abstraction, some farmers temporarily impound rivers during low flow or channel water for direct abstraction.

The effects of these practices impinge upon downstream users, the river biota and the physical stability of the watercourse, and can only be effectively countered by an equitable partitioning of a river's water resource. Consideration needs to be given to establishing the amount of abstraction the river can withstand without losing its viability as a functioning ecosystem. Land-use practices and agriculture should be required to operate within these constraints if the needs of all users are to be met.

3.2.1.2 Destruction of riparian vegetation. Natural riparian vegetation, which forms an integral part of any river ecosystem, plays an important role in river bank stabilization. It is frequently destroyed in order to extend grazing or to allow the planting of crops, this despite the existence of legislation which prohibits the removal of natural vegetation from the riparian zone (see Chapter 5, section 5.7). Other reasons for destruction of riparian vegetation include the installation of extraction plants, giving livestock direct access to rivers for drinking and to facilitate movement of people.

Apart from the direct effect of these practices in destroying a wildlife refuge, they also deprive the riverine fauna of its primary energy resource, particularly in upper and middle reaches (see Chapter 1). The effect on downstream users is, however, much more tangible. Shallow rooting grass and crops such as sugarcane cannot stabilize river banks even against normal summer flow and the effects of floods become disastrous. The result is continuous bank erosion with considerable siltation and also substantial crop and soil losses during floods. Enforcement of existing legislation can prevent an aggravation of this problem but rehabilitation will be a slow process. The losses suffered by farmers on the Mfolozi floodplain, following Cyclone Demoina, would have been considerably less if riparian vegetation had been conserved, even if only to the legal limit.

3.2.1.3 Increased silt load. All causative factors of bank destabilization mentioned above will lead to an increase in the suspended solids in river water. To this must be added catchment mismanagement. Overgrazing, which leads to vegetation denudation, results in increased turbulent runoff, accelerated erosion and an increase in silt loads. Cultivation of wetlands and destruction of sponges further aggravates the problem, as well as destabilizing flow patterns through removal of the catchment's natural storage capacity. All these factors taken together can transform a perennial river into a seasonal flow of muddy water, in which natural refuges of the biota, such as pools, become filled and impoundments on the river have their capacity, and thus their value, severely reduced.

Enforcement of soil conservation legislation (see Chapter 7) in all catchments will go a long way towards ameliorating this effect. The conservation of wetlands, sponges and riparian vegetation could almost totally eliminate it.

3.2.1.4 Deterioration in water quality. Silt loads are not the only consequence of agricultural malpractices which affect rivers. Intensive irrigation, together with the destruction of riparian and adjoining watershed vegetation lead to high runoff rates, increased seepage, changes to the structural and chemical characteristics and altered water conducting properties of the soil. This ultimately also affects the water table. The return of seepage and runoff to river systems frequently contains excessive fertilizer and other salts leached from the soil, thus causing salinization and enrichment of the river (Williams et al 1984). More serious pollution (see MacDonald et al 1984) results from biocides (herbicides, nematocides, insecticides and fungicides) entering the river, killing off much of the biota and thus destroying its self-cleansing ability. The result is a river in which algae and bacteria thrive as a result of increased plant nutrients and a reduction in species richness and diversity of the fauna.

Should such a river be impounded to supply potable water for urban communities, these problems are compounded, since impoundments act as nutrient traps. Water purification costs are increased as a result. These effects can be minimized by irrigation practices appropriate to the soils, avoiding over fertilization and not exceeding recommended biocide dosages. Biocides with long residual effects are, for the most part, no longer permitted and this ban should be rigorously enforced.

3.2.1.5 Spread of waterborne diseases. In most farming and rural communities little or no control is exercised over the spillage of stock and/or human waste into rivers. This promotes the spread of waterborne diseases such as cholera, typhoid, bilharzia and fascioliasis (liver fluke) to name but a few (Davies and Day 1986). The careful siting and proper design of human latrine and ablution facilities and the provision of drinking troughs for stock can greatly reduce, if not totally eliminate, these health risks.

Overflow or seepage water from irrigation schemes may provide the shallow, predator-free habitats in which mosquitoes breed and so contribute to the problem of "man-made malaria". An example occurred in Tongaland in 1983 when overflow irrigation water created just such habitats and resulted in an outbreak of mosquitoes belonging to the Anopheles gambiae complex (Sharp et al 1984). Over irrigation may also be at least partly responsible for the heavy load of infective larvae of the citrus nematode Tylenchulus semipenetrans in some rivers. Cohn (1976) reports loads of up to 120 larvae per 200 litres of water in the Crocodile River, the equivalent of 7 million every hour, passing down the river. These are then spread through downstream abstraction for citrus irrigation.

3.2.2 Urban complexes

Concentrations of people into urban centres can only occur where there is an adequate water supply for domestic purposes. Although at eight per cent of the total water use in the country, domestic water consumption is low compared with that abstracted by agriculture, it does have a considerable impact on rivers, since the effects are concentrated into a much smaller area. Urban complexes usually require some form of water storage, most often impoundments which also have considerable value as recreational venues, but have marked downstream effects. In addition, urban communities generate large quantities of organic and inorganic wastes, much of which finds its way into rivers.

In all urban complexes of significant size, control is exercised over the abstraction and reticulation of water, and over the water returned to source via sewage purification works. Despite this control, such complexes have considerable impacts on the conservation status of downstream tracts of rivers. These impacts are briefly discussed below.

3.2.2.1 Reduced river flow. The presence of an impoundment on a river must, of necessity, affect the biota and thus the conservation status of that river. The magnitude of this effect varies with position on the river continuum (see Chapter 1; Ward et al 1984) and can be ameliorated by water releases from the impoundment. Such releases must be timed to simulate the natural flow regime (Heeg and Breen 1982; Ward et al 1984).

Where the demand for water by an urban complex increases beyond the assured yield of the catchments in its immediate vicinity (eg PWVS metropolitan area), the impact of such a growth point extends to other catchments through inter-basin transfer (eg the Tugela-Vaal scheme). In such instances close liaison between conservation authorities and those responsible for distribution of the water is imperative, particularly where more than one province is involved.

3.2.2.2 Stormwater drainage. Urban complexes enhance runoff through the hardening of surfaces (eg tarmac, concrete, roofs). Such runoff, which is nearly always seriously polluted by oil, traffic deposits, chemical spillages and general diffuse wastes, is carried away through stormwater drains which discharge into rivers. Many rivers in urban areas are canalized, mainly because urban developments have extended onto flood-plains, with a consequent need to carry floodwaters rapidly and safely through these areas. Such canalized rivers already have a seriously impaired self-cleansing ability and with the discharge of the stormwater reticulation into them, become little more than open drains which often discharge directly into estuaries or bays (eg Mlazi River, Durban; the Black-Liesbeeck River, Cape Town).

The effect of pollutants in urban runoff is greatest following light rains, when only a small volume of water flowing in the river receives a small but concentrated pollution load without the benefit of dilution by floodwaters (see Chapter 1). This renders the conservation status of most rivers passing through urban areas low, a situation which is frequently worsened by industrial effluents. Short of channelling such runoff through purification works, which, because of the intermittent nature and the amounts involved is impractical, there is little that can be done about this problem for existing systems: more careful town planning will perhaps reduce impact upon systems which are not yet severely degraded.

3.2.2.3 Sewage effluent. Stringent regulations govern the return of water contaminated by human wastes to source. The development of sewage treatment works, however, does not always keep pace with population growth, giving rise to effluents high in plant nutrients (phosphates and nitrates) which, particularly under low flow conditions, can give rise to eutrophication, increased biochemical oxygen demand and a drastic reduction in faunal diversity (Nash et al 1972). Untreated sewage is likely to have been the source of the human bilharzia eggs recovered from the droppings of seagulls at the mouth of Mbokodweni River, Durban (Appleton and Eriksson 1983). Extension of sewage works to include tertiary effluent treatment (Mason 1981) can do much towards the amelioration of this problem. Rogers et al (1985) have reviewed the potential use of natural and artificial wetlands for tertiary wastewater treatment. Such wetlands provide good refuges for many species of birds and could thus enhance the conservation staus of areas associated with sewage effluent inputs into rivers.

3.2.2.4 Urban refuse. Urban refuse is concentrated at garbage tips which are usually of the land-fill type. Valleys (and in many instances, wetlands) are ideal sites for such land fill operations. Seepage from such disposal sites is, by virtue of the diverse nature of urban refuse, highly polluted, often containing pathogens and toxins. Such seepage most often finds it way into rivers causing a variety of environmental problems ranging from eutrophication to the poisoning and extermination of the flora and fauna. Like sewage effluent inputs, such seepage almost always poses a health risk in rivers near and often within the boundaries of urban complexes. The aesthetic and recreational potential of the river is thereby lost in areas where it is most needed.

3.2.3 Population concentrations in rural areas

The availability of water is always a determining factor in the distribution of human populations, and in South Africa many rural populations live under quasi-urban conditions near watercourses. These people make the normal demands on rivers for domestic water and usually also practise subsistence agriculture. In such communities water abstraction is uncontrolled and sewage and wastewater is untreated. Under these conditions points of contact with the river are frequently found to be foci of bilharzia transmission, counts of coliform bacteria are high and the general indications of organic pollution are manifest to varying degrees. Where such foci are isolated, the disease transmission potential and ecosystem degradation probably does not extend for more than a few hundred metres downstream (Rowan 1965; Hynes 1959) but where they are strung out along the river, as is so often the case in Africa, the effects on human health and on the overall conservation status of the river can be considerable. The impact of these communities is a compounding of the effects of agricultural practices and of human density without the safeguards and controls applied in proclaimed urban areas. Such impacts can only be reduced through health education, planned regional development and through extension services to guide land-use practices.

The above conditions also occur in squatter communities. Here, because the people involved have entered a cash economy in place of subsistence agriculture, they are aggregated in extremely high densities in localized areas without ready access to watercourses. Faecal and detergent pollution of groundwater can reach serious proportions under these conditions, with dysentry causing pathogens such as Salmonella (typhoid) and cholera (Vibrio cholerae) constituting a high risk. Such groundwater may, through seepage, also contaminate nearby river systems.

3.2.4 Industry

Industrial development is dependent on energy, labour and water. No matter how abundant the raw materials may be, without these resources little growth in the industries of a region is possible. The distribution of electricity through the national grid makes the siting of industries independent from the location of the primary energy source, coal. However, urbanization, and thus the labour supply is dependent upon water resources, as is industry generally, resulting in urban complexes and industrialization becoming almost synonymous. In such centres the impact of urbanization on rivers is exacerbated by that of industry per se. Industry accounts for some four to six per cent of the total national water use, but its impact is disproportionately high because the discharge of effluents containing toxicants and other pollutants (MacDonald et al 1984).

Although many industries utilize water directly for the processing of commodities, and river systems provide avenues of supply, an additional value of a river to industry is that of disposal of solid, liquid and heat wastes. Such waste discharges vary from large volumes of cooling and rinsing effluents to small concentrated effluents containing organic wastes and heavy metals (zinc, copper, iron, nickel).

Discharges of industrial wastes into river courses have severe effects on the ecology of the receiving waters. Physical, chemical and biological characteristics are affected, a deterioration in water quality occurs, aesthetic and recreational values are diminished and the overall conservation status of the river is lowered. The influence of industrialization on river ecology in South Africa is not well documented (see MacDonald et al 1984). The specific effects of the main industrial sectors on river ecology are summarized below.

3.2.4.1 Power production. Most of South Africa's power supply is generated in coal based power plants, which require water for their cooling towers. Water is abstracted from nearby rivers, passed through the towers and returned to the river with an increased heat load, thus raising the temperature of the river by several degrees. Such maintained elevated temperatures can have a marked effect on the river biota, particularly if the river is already perturbed in other ways, and may inhibit the free movement of fishes resident in the river.

Although limited in South Africa at present, hydro-electric power generation, particularly when serving the national grid on a demand basis, can through wide unpredictable fluctuations in downstream flows, create a maximally disturbed environment which greatly reduces the diversity of the biota (Ward and Stanford 1979; Ward et al 1984). Important here too is the demonstration by Pitchford and Visser (1975) that the water released from the sluices of the H F Verwoerd Dam on the Orange River has altered the temperature regime of the downstream river in such a way that bilharzia transmission could now be encouraged rather than excluded as was previously the case.

3.2.4.2 Mining is one of South Africa's major industries and the economic gains from the exploitation of mineral resources (gold, platinum, manganese, coal, diamonds) far outstrip other natural resources in terms of contribution to the gross national product. The provision of water to mining is, therefore, vital to the South African economy, not only because of the revenue derived from the sale of minerals but also provision of employment.

Most mining concerns require water as a medium for mineral extraction processes, which often involve highly toxic chemical compounds. This renders mining effluents extremely hazardous in terms of their pollution and toxicant status. Seepage water from mines, particularly coal mines, can have extremely detrimental effects if they enter river systems. High levels of sulphuric and nitric acids, formed from oxides of sulphur and nitrogen in disused mines can drastically increase the acidity of such seepage water and of rivers in mining areas. The Olifants River in the eastern Transvaal has stretches where the acidity is so high (pH 2-3) that no life is possible. Such acid waters can also cause considerable corrosive damage to downstream installations.

3.4.2.3 Manufacturing industries. The effluents generated by such manufacturing industrial complexes are many and varied, and all have an impact on water quality and river biota, with a concomitant lowering of the river's conservation status. Stringent controls over effluents is essential where downstream users or recycling are involved. A list of the more commonly encountered pollutants and their sources is given by MacDonald et al (1984).

3.2.5 Recreation

The recreational industry in South Africa is substantial, with considerable investment in boats, fishing tackle, caravans, tents, and supports a large number of hotels, caravan and camping sites. This can only be sustained by sufficient acceptable venues. Much recreational activity is centred on inland waters, and these activities require high quality water for obvious aesthetic and health reasons. Favoured recreational sites are impoundments which, as modified rivers, are directly affected by the state of their river inflows. Rivers per se are extensively used by anglers and canoeists, while power boating and sailing is practised on slow-flowing, deep river stretches.

All the activities described above bring people into direct contact with the river, thus the state of the river has an impact on recreational users and vice versa. Canoeing and swimming almost inevitably result in participants swallowing some river water, and it is well known that a number of participants in the annual Duzi canoe marathon suffer gastro-intestinal complaints after the race. Similarly, swimming in streams, a popular pastime in rural areas, is considered to be the single most important activity exposing children to bilharzia infection (Kvalsvig and Schutte 1985).

The angling fraternity has had a profound effect upon the conservation value of most, if not all, South African rivers. Destruction of riparian vegetation, leading to bank destabilization, together with littering, are probably the main physical consequences of angling. The introduction of exotic fish species for angling purposes also has a detrimental effect on the indigenous biota. For instance the distribution of endemic redfins (Barbus species) in the Olifants River system of the south-western Cape has been greatly reduced by introduced small-mouth bass predation. Lead poisoning from sinkers has recently been found in swans and other waterfowl in the United Kingdom, but we have no information on whether the problem is serious anywhere in South Africa.

3.3 SCIENTIFIC, EDUCATIONAL AND AESTHETIC VALUES OF RIVERS

Rivers have intrinsic scientific, educational and cultural values which, like their aesthetic values, cannot be assessed in monetary terms. Few South African rivers have been extensively studied, and many have not been studied at all. Our knowledge of the distribution of our riverine fauna and flora is, therefore, scant and patchy, and the opportunity for the very limited scientific manpower to gain an understanding of this biota diminishes as more of the country's rivers become progressively degraded.

Streams and rivers are also ideal outdoor classrooms, in which many fundamental biological principles can be demonstrated. However, owing to health risks involved, particularly in urban areas, many cannot be used by educationists for any purposes other than to demonstrate environmental degradation (sometimes at a judicious distance).

The aesthetic value of rivers, which can make a considerable contribution to the enhancement of urban environments, is something which is seldom exploited. Most often the river is canalized, riparian vegetation is destroyed and the system is used to augment stormwater and waste disposal. The asset values set out here cannot be realized without maintaining the streams and rivers concerned in a state where both water quality and the riparian environment are maintained.

3.3.1 Need for a social ethic

Because of the continuous nature of the river ecosystem, it is essential that every user minimizes his adverse impact on that ecosystem. If this simple rule is not observed, everyone loses. Multiple use of rivers is inevitable and conflict of interests unavoidable, as illustrated by some particularly pertinent examples set out below.

The Vaal River, which is utilized for domestic, industrial, recreational and agricultural purposes, provides perhaps the best example in South Africa of the problems caused by industrialization (Bruwer et al 1985). Mining activities, major and minor manufacturing industries, sewage treatment works and upper catchment agricultural activities have given rise to a river system subjected to heavy metal pollution, salinization, sediment blanket pollution and many water quality problems associated with eutrophication. This has major cost implications for other users, both domestic and agricultural, and has considerably reduced the conservation status of the river. The heavy pollution of the Msunduze River (Breen et al 1985) is likely to have a profound effect on the cost of purifying water from the proposed impoundment on the Mgeni River at Inanda.

Hydro-electric power generation on the Orange River has so stabilized flows that the downstream population of blackflies reached epidemic proportions, resulting in major stock losses (see Ward et al 1984). Encroachment by fringing reed beds, also resulting from low stable flow rates, is causing concern as well.

The proliferation of irrigation canals and night storage dams as a consequence of agricultural development has greatly increased the incidence of bilharzia amongst the population of the Transvaal lowveld.

Many more exmples in similar vein can be given and the list of specific effects of user practises extended. Readers requiring further details are referred to Hart and Allanson (1984) in the first instance. What has been given here, though, should stress the need for a social ethic, which safeguards the legitimate rights of all water users and which must ultimately be sought in the application of a sound conservation policy for all river systems.

3.4 THE VALUE OF RIVER CONSERVATION

Sound conservation practices, based on current knowledge of river ecosystem functioning and reinforced by the results of ongoing research into the applicability of this knowledge to all categories of South African river systems, holds benefits for all users. In principle this involves that the following requirements be met:

1. Ensuring the integrity of the river course through maintaining riparian vegetation which stabilizes banks.

2. Ensuring continued flow on a normal seasonal pattern through maintaining sponges and wetlands as well as controlling abstractions of water along the course.

3. Ensuring that catchments are managed in such a way as to minimize impacts on river systems.

4. Ensuring continued inputs of allochthonous organic material, particularly in the headwater regions, where the biota is totally dependent upon such inputs.

5. Ensuring that the quality of return flow into the river, whether through runoff, seepage or canalized disposal, is of a quality which will have minimal effect on the biota and on downstream users. This involves the improvement of all land-use practices, ranging from agriculture (biocides, disease, erosion products through recreational (litter), and domestic (sewage) to industrial (chemicals).

6. Maintaining the self-cleansing ability of rivers in order to restore water quality where degradation from the above sources, though minimized, is inevitable.

The requirements outlined above will, if met, hold advantages for all water users, which ultimately implies the whole population of the country. This country's water resource must be regarded as its primary national asset, the one which makes life possible. As such, it cannot be regarded as the property of any one sector or individual, nor can the actions of any user or user agency be allowed to impinge on others in a detrimental manner. In our use of rivers, it is not even a case of "greatest good for the greatest number" but rather "survival for all". The argument does not stop here: a river mirrors the state of its catchment, a degraded river reflecting bad land-use practices, and, by implication, the destruction of another national asset, the soil.

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CHAPTER 4 CONSERVATION MANAGEMENT OPTIONS FOR RIVERS

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4.1 INTRODUCTION

Conservation management involves an interference with rivers to produce desired changes or to prevent undesirable changes. In order to decide whether management is necessary and what measures must be taken in different instances, rivers need to be classified on two scales, ie in terms of their conservation status and their conservation importance. Different parts of a river system could be given different gradings. Rivers which have a high conservation importance but a low conservation status need the most urgent attention, and the aim will be to raise their conservation status to the highest practical level (Figure 4.1).

Conservation importance	HIGH IMPORTANCE LOW STATUS	HIGH IMPORTANCE HIGH STATUS
	LOW IMPORTANCE LOW STATUS	LOW IMPORTANCE HIGH STATUS
	Conservation status	

Figure 4.1. Hypothetical diagram of conservation importance versus conservation status of rivers. The highest priority is to move points in the high conservation importance bracket to the right.

The river and its biota in the pristine state reflect the most stable utilization of its catchments precipitation. Interference with the catchment and or river alter the natural functioning of the river and ultimately lead to the degradation of the river and its annual natural flow regime and an alteration of its biotic components.

For any management decisions to be made, it is important to have a fundamental understanding of the way in which a river functions, the consequences of perturbations, and a value system which allows judgements to be made about priorities. Unfortunately, the knowledge base and predictive potential for South African rivers is often rudimentary. Nevertheless, judgements have to be made, based on the available information.

The manipulation of water in a river, including abstraction and altered flow regimes, is easily quantified and the effects are beginning to be understood. But the effects on a river of manipulations in its catchment are highly complex and often difficult both to quantify and to understand. This topic is dealt with in Chapter 5 but here it must be stated that options for managing rivers themselves are essentially constrained by events in the catchment and these too have to be managed. The most efficient way of managing the catchment together with the river itself is by the creation of catchment management authorities (Breen 1984), none of which have been established in South Africa as yet. A recent development has been the formation of advisory committees for river catchments, eg the Mfolozi Catchment Planning Committee and the Upper Tugela Catchment Planning Committee. In addition, numerous private organizations (eg Kowie Trust, Swartkops Trust, Siyayi Project Committee) and research committees have been formed to plan research and recommend management options for rivers or parts of rivers eg Pongola Floodplain Steering Committee.

4.2 KEY QUESTIONS

There are certain key questions which must be asked in order to decide on management options:

a) Is management necessary? If modification of a system due to man's activities has caused an imbalance in the system, management is necessary in order to improve the conservation status. It may be uneconomical to rehabilitate some rivers, such as those which are used as sewers, have concreted channels or are otherwise highly manipulated, although rehabilitation may be possible if there are good social or ecological reasons. Although these rivers no longer function as natural systems, they perform an important role in the overall scheme as they absorb the bulk of man's impact and relieve other rivers of such impact.

It is important to use 'conservation' in its modern, holistic sense, as defined by the IUCN (1980) (see Chapter 2). Conservation is not synonymous with preservation, but entails the protection and development of natural resources for the long-term benefit of man. There is a clear need to grade rivers according to the amount of management necessary in order to achieve the conservation goals.

b) What should the conservation goals of river management be?

The primary aim would be to maintain essential ecological functions eg capacity for self purification, biotic diversity and the sustainable utilization of species and resources. This approach should be basic and applicable to all rivers (especially those developed and utilized extensively by man). Every system operates within a range of abiotic and biotic parameters. In an undisturbed system, the pristine range will apply, but in most systems a new set of ranges will have been established. In order to be able to sustain use of resources such as water and fish, certain characteristics of the river will have to be maintained within acceptable limits ie water quality (organic and inorganic), hydrological and physical characteristics (flow, temperature), input from the catchment, and various biotic processes.

It is felt that, if an irreversible change has been effected in a river, eg a large impoundment or permanent interbasin connections, then management would aim to maintain the river within the 'disturbed' range, as a compromise. If, however, the man-made perturbation which caused the change in ranges is reversible, then the aim of management could be to approximate the 'pristine' regime. The extent of change, and the management option, may differ for different parts of a river or for different rivers. An important point to remember is that the biota of a river evolved over thousands of years in the pristine system, and may not be as well adapted to the disturbed system.

The second aim, which is also applicable to all rivers, is to apply management in order to prevent the disappearance of rare species and endemics as well as ecologically and commercially important species. Endangered species which live within a permanently disturbed system in which the pristine regime cannot be re-established may need particular attention. Prevention of domination of the biota by pest species more adapted to the altered environment than the natural fauna and flora of the river in its unperturbed state, may also be necessary.

The third aim, applicable to rivers with a high conservation importance, is to maintain an undisturbed, near-pristine state. These rivers can serve as a baseline against which to judge the success of management on the impact of changes in ecosystem functioning.

4.3 TYPES OF MANAGEMENT

Management options nearly always have to be related to particular types of ecosystem modification and types of rivers, and can be of various kinds: manipulative, legislative and passive. We prefer not to use the terms positive and negative management because of their undesirable connotations.

Manipulative management refers to the manipulation of the system for conservation objectives. The reintroduction of species, stabilization of banks, excavation of sediment traps, the removal of alien species, removal of threatened species to suitable refugia, the construction of weirs (to maintain water supply or as a barrier to the invasion of aliens), and of fish ladders, are all examples of manipulative management. Legislative management consists of the prohibition of activities and developments in defined areas. Litigation is the final option for legislative management, and should be used very sparingly, since the effects in terms of loss of goodwill are often counter productive. Passive management implies the protection of areas either in reserves (where manipulative and legislative management practices also apply) or by failing to provide facilities for, access to and information about an area, to prevent its exploitation.

The assessment of trends and understanding of a system are fundamental to its effective management. The dissemination of information, including public relations and personal contact between land owners and conservation officers through extension services, is also essential. Lack of understanding of the value of rivers and thoughtlessness are particularly important causes of river degradation, since the level of awareness with respect to rivers tends to be much lower than for large-animal communities and terrestrial ecosystems. Mitigation refers to management options in a system where development and exploitation have been or are being carried out. Where a dam is required for an urban water supply, the option may not be whether the river is dammed, but which dam site is chosen, and how the reservoir is eventually managed.

Although all kinds of management could ideally be applied to all kinds of rivers, the options for large rivers are more restricted than for small streams, both because of the economic importance of the former, and because of the logistical difficulties of large river management.

4.4 MANAGEMENT OPTIONS

Three basic alternatives exist as far as management options are concerned. Firstly, a river can be given protection as a type of formal reserve. Usually this approach is not practical due to the longitudinal nature of rivers, the dependence of the open water system on the catchment and the different properties under the control of different authorities through which they flow. Some headstreams with a relatively limited catchment and a very high conservation importance are already included in conservation areas, or should be included. These streams could be managed as 'pristine' systems without making any allowances for development.

Few reserves have been established for downstream parts of rivers, although reserves established for other purposes may contribute to the conservation of an enclosed river eg the Umlalazi Public Resort Nature Reserve, Blyde Rivierspoort Nature Reserve, Mohlapitse River in the Wolkberg Wilderness Area, Sterkspruit Nature Reserve and the Fish River Canyon in South West Africa/Namibia.

A second alternative exists when rivers with a high conservation status and importance cannot be protected in reserves for practical reasons. In these cases the river can be conserved as part of a Natural Area or Natural Heritage Site, or parts of a conservancy established by riparian land owners in collaboration with the local conservation department. In such situations the landowner is allowed to continue his normal farming and other land-use practices but must do so according to a management plan which has the conservation of the area (or the river specifically) as the primary objective, although some compromise will probably have to be made. This form of participatory conservation is regarded as very important in river management and could be extended to include catchment authorities which have jurisdiction over river systems. South Africa has recently introduced a Natural Heritage System and rivers could be included as living national monuments, in a similar way to the Canadian Heritage River System, the American Blue Ribbon System and the British Sites of Special Scientific Interest. Several South African rivers have outstanding natural attributes and could qualify as heritage systems eg Olifants River in the western Cape and the Mtamvuma and Mkomanzi Rivers in Natal. In addition, the reaches of certain rivers have outstanding natural attributes and should have a special status eg reaches of the Palala River (Limpopo system) the Tyume River of the Buffalo River (eastern Cape) and the lower Ifafa River (south Natal). The conservation of Barbus treurensis in the Blyde River is an example in which the landowner was willing to proclaim the habitat of a fish as a natural heritage site (Kleynhans 1984). Silviculture was included but in such a way that the trees did not affect river ecology (minimum planting distance from stream bank: 50 m) and all alien plants and animals were removed from the stream.

The third alternative is applicable to most situations and involves conservation in a more generalized way and by compromises with development. Development is an inevitable consequence of progress and it is necessary in such situations to develop management options which minimize the adverse effects of development.

Different modifications to rivers require appropriate management actions. Impoundments impose new flow regimes on rivers and require consideration not only during the planning phase of water projects but especially during their operation. Dams also interfere with the movements of fishes, and fish ladders and multiple valve outlets should be constructed when necessary to allow fish free upstream migration.

The effect of an impoundment on the ecology, morphology and hydrological regime of a river will depend both on fixed attributes such as geographic position, size and design and on the timing and volume of water released during normal operation of the dam. Apart from the destruction of lotic habitats when an impoundment is built, significant changes in flow volume and regime are inevitable and can have very profound effects on the biota (Ward and Stanford 1979; Hart and Allanson 1985). For example, discharge in South African rivers may vary dramatically from season to season and from year to year (Midgley 1983). Organisms adapted to fluctuating but seasonally predictable conditions may be replaced by others when the flow becomes much more evenly distributed through the year due to discharge from an impoundment. A particularly clear example of this was shown by plagues of blackflies due to the higher than normal winter flow of the Vaal River near Warrenton (de Moor 1982). The solution was to manipulate the flow to more closely resemble the flow of the river during dry periods, eg winter and early spring. This prohibited Simuliid populations from building up to pest proportions during summer.

Given that impounding a river will necessarily alter the flow regime, and that the river will no longer be undisturbed, a decision will have to be made as to whether pre-impoundment conditions should be closely simulated or whether a new flow-pattern might be of greater economic or recreational value (Roberts 1983; Porter in press). Obviously the final decision will depend on, amongst other things, the conservation importance of the downstream stretch of the river. Whatever the decision, the precise timing and the quantity of water released from an impoundment provide a management tool for determining with some degree of certainty the biota likely to dominate the downstream reaches of a regulated river.

The storage of water in impoundments can also have an effect on the quality of water released downstream. The retention time and vertical positioning of outlets from an impoundment are options that should be considered both in the planning stage and during operation of a dam.

Thus determining the extent to which water quality and flow regime will be altered by a proposed dam, allows an assessment of the effect of various strategies of water release on the river. This in turn should influence the final positioning and design of the dam. Where necessary and feasible, translocations of rare and/or endemic species might be considered (Kleynhans 1984).

Intercatchment transfers of water are very common in South Africa and form an important part of the overall strategy for the manipulation of this country's limited water supplies. Thus the options are limited to where such schemes should be developed and how they may be developed to minimize the impact on the receiving streams. The result is often an improvement in water quality from a human point of view (for example the dilution of Fish River water with Orange River water) but intercatchment transfer almost inevitably results in transfers of plants and animals, sometimes to the detriment of rare endemic species (Skelton 1977). For example Barbus bergi, a small redfin minnow known only from the Berg and Eerste Rivers, is under threat from alien species introduced via the Berg, Eerste and Theewaterskloof schemes in the south-western Cape.

Intensive agricultural development (eg ploughing) should, as far as possible, be avoided in headwater streams. The water-producing sources in mountain catchments should have the highest conservation status. As these streams are generally small, the construction of dams or development of large human settlements is not very likely. Extensive farming (eg grazing) can be allowed on condition that it is well within the carrying capacity. Burning of veld should be regulated and should simulate the natural occurrence of fires as far as this is known (refer to locally applicable burning guidelines). In the lower sections of rivers, limits should be placed on the minimum distance which ploughing is allowed from river banks. Aquaculture must also be considered and where alien and translocated indigenous species are farmed, care should be taken to prevent their escape into rivers or their translocation from one catchment to another (Safriel and Bruton 1984). Streams where farming with exotics presents no problem should be identified.

The water-producing characteristics of mountain catchments should be realized when plantations are established. Where plantations are allowed, restrictions should be placed on the distance they are situated from stream banks. Roads in plantations should be planned so as to minimize erosion and prevent water runoff from roads flowing directly into streams.

Alien species that cause river degradation or endanger indigenous species, especially rare species and endemics, should be removed if possible or prevented from entering streams by creating obstructions. Alien plants (especially those which have invasive characteristics) would be removed from streams where possible.

Although the conservation of estuaries is the subject of discussion by other working groups we should not lose sight of the fact that the ultimate fate of an estuary depends on the quantity and quality of water arriving from the river. Except in the case of the most seriously degraded rivers, the chemical quality of the river water is not of serious concern, while the sediment load and the quantity of water will largely determine the rate of sedimentation (and thus the equilibrium between aggradation and erosion) of the estuary itself, of the adjacent coastline and sometimes even of dune systems some distance away from the river mouth (eg the apparent feeding of the dunes of the Namib Desert by sediment from the Orange River). Thus the management strategies used in upstream areas, particularly the construction of dams, should take into account the effects that these may have in the coastal zone. Such studies have been undertaken on the Palmiet, Guela Orange and Mgeni Rivers for the Department of Water Affairs and on the Mfolozi River by Natal Parks Board.

4.5 DISCUSSION

Optimum use of a scarce resource such as water requires an effective policy that prevents continually increasing the amount of the resource being distributed. Scarcity is a constraint that cannot be ignored if ultimate social and economic collapse is to be avoided. Two possibilities for the management of a scarce resource such as water have been proposed in the literature (Ophuls 1977; Bowers and Bradley 1983):

a) The first is the maximum feasible sustainable state which essentially relies on continued technological advancement to maximize the resource as the solution to the scarcity problem. This solution is unwise because at some future point the resource will once again become scarce. Therefore such a policy would be self defeating because it will only defer and greatly exacerbate the ultimate ecological crisis.

b) The second alternative is the frugal sustainable state in which no goals of maximizing the amounts of the resource that will be used are set. Instead the goal is one of ample sufficiency. This policy would be ecologically viable, and would depend on the success of the national population development programme ie improving the quality of life in order to reduce the rate of human population increase.

There is a need to pay more attention to improving the conservation status of urban rivers. In this respect participatory conservation can also be very effective as shown by the example of the Braamfontein Spruit which was rehabilitated through the CARE campaign. A healthy river is an asset to any community and it should be part of an urban development plan. There is no need to accept lower river quality standards because a river is flowing through an urban area.

The general public as well as riparian land owners, tribal authorities, industrialists and developers should be informed of the value of rivers and the essential role they play in the well-being of man. The fact that a river is more than just a conduit and that it constitutes the habitat for a characteristic community of plants and animals should be pointed out. This educational programme should take place through provincial and regional authorities as well as at grass roots level.

Although the success of conservation management will depend largely on education, provision must also be made to prosecute those who willfully contravene the standards set for the conservation of rivers. Legislation related to rivers and the aims of river conservation should, however, be widely publicized so that the community at large is well informed of their rights and responsibilities with respect to rivers.

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CHAPTER 5 RIVER RESPONSE TO CATCHMENT CONDITIONS

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5.1 INTRODUCTION

A catchment is the drainage basin of a river. Bounded by other catchments, its geographical area covers all the land that drains into one river system, from the source to the estuary. For purposes of management, a catchment may be divided into subcatchments, and thus include areas specifically associated with water storage (mountain catchments) and with the drainage of a particular lake or section of river.

When water precipitates into a catchment, much of it is lost into the atmosphere by evapotranspiration. Most of the remainder moves downhill through the catchment, either as ground or surface water, and eventually drains into the river system. The speed with which this water moves through the catchment is dependent on the geology and topography of the area, whilst the impurities it collects along the way are characteristic of the types of bedrock, soils and land use within the catchment. Thus by the time the water reaches the stream, its quality has changed from that of rainwater, in a manner that reflects the nature of the catchment. In general, this change in quality will be least near the river's source, because the rocks of a mountain source-area will be hard and resistant to leaching, while land disturbance in such areas will be minimal. Water entering the lower reaches of the river will show the greatest change in quality from rainwater, because of the softer more easily leached rocks of the coastal plain through which it has drained. Additionally, land use and other developments of the catchment will be extensive in this area, with pollutants such as eroded soil, bioscides and fertilizer mixing with the draining water. Because of this, not only the character of the river (width, gradient, flow rate), but also the quality of its water, changes continuously along its length, with all adjacent and upstream parts of a catchment exerting an influence upon the river at any point.

With the river playing such a central role in the catchment, it follows that many catchment characteristics will have an important influence upon it. These characteristics will vary from those that directly affect only particular portions of a river (eg a point-source pollutant), to those that affect the complete river system (eg the pattern of stormflow into the river). Nevertheless, because the river exists as a longitudinal ecosystem in its own right (see Chapter 1), as well as part of a catchment ecosystem, disturbances within the catchment should be recognized as potentially disruptive to all of the river system downstream of that part and also occasionally (as with an in-stream dam) to the upstream section.

Some relevant catchment characteristics are identified and discussed below.

5.2 GEOLOGY

The precise influence that the geology of a catchment has on a river is difficult to define and few attempts have been made to do so. The hydrological function of bedrock can be summarized as its potential to control water transmission and storage in the catchment. This potential is determined by the hydraulic conductivity and porosity of the rock matrix and by structural features such as fissures, cracks and joints. Variation in these properties will influence 1) the seasonal flow patterns in a river; 2) individual stormflow characteristics; 3) subsurface flow patterns; 4) water quality; 5) erosion and sedimentation.

5.2.1 Seasonal flow pattern

Rivers in South Africa are characterized by a seasonal flow pattern. Flow duration curves show the percentage of time that certain volumes of streamflow are equalled or exceeded, and are frequently used to depict the long-term flow pattern within a catchment.

Figure 5.1 is an example of flow curves for two equal-sized catchments one on basalt and one on sandstone. A generally flat curve indicates that streamflow is derived mainly from delayed, slow flow, while a steep curve indicates erratic flows where flow is derived mainly from rapid flow. Impoundments in the river would affect the flow as indicated in Figure 5.1.

Although the seasonal flow pattern is mainly controlled by the rainfall pattern and variability, the type of bedrock will tend to either dampen or amplify the effects of rainfall. Bedrock with a high hydraulic conductivity, for example, will tend to transmit water quickly to the rivers or to groundwater/deep seepage.

The seasonal flow pattern of a river has a profound influence on its biota. Rivers which experience severe spates, for instance, tend to have an impoverished fauna, as do those that dry out for part of each year. The predictable seasonal changes in flow of perennial rivers have led to the evolution of aquatic faunal communities that can cope with the environmental extremes of very fast flowing or almost stagnant waters. Although adaptations at the individual species level are many and varied, an interesting adaptation at the community level is the presence of two quite different sets of animals in such rivers - one set for each environmental extreme. The animals that are not present at any one time, are usually dormant or present as tiny juveniles deep in the riverbed, awaiting favourable conditions (King 1981). The flow pattern greatly influences the presence of plants also. Most mountain streams are poor in aquatic plants, partly because the abrasive action of spates and moving boulders would destroy new seedlings. Stands of reeds and aquatic plants which establish themselves in the lower reaches during low flow, may be destroyed during high flow, and planktonic forms, being by definition at the mercy of currents, can only become abundant during low flow periods.

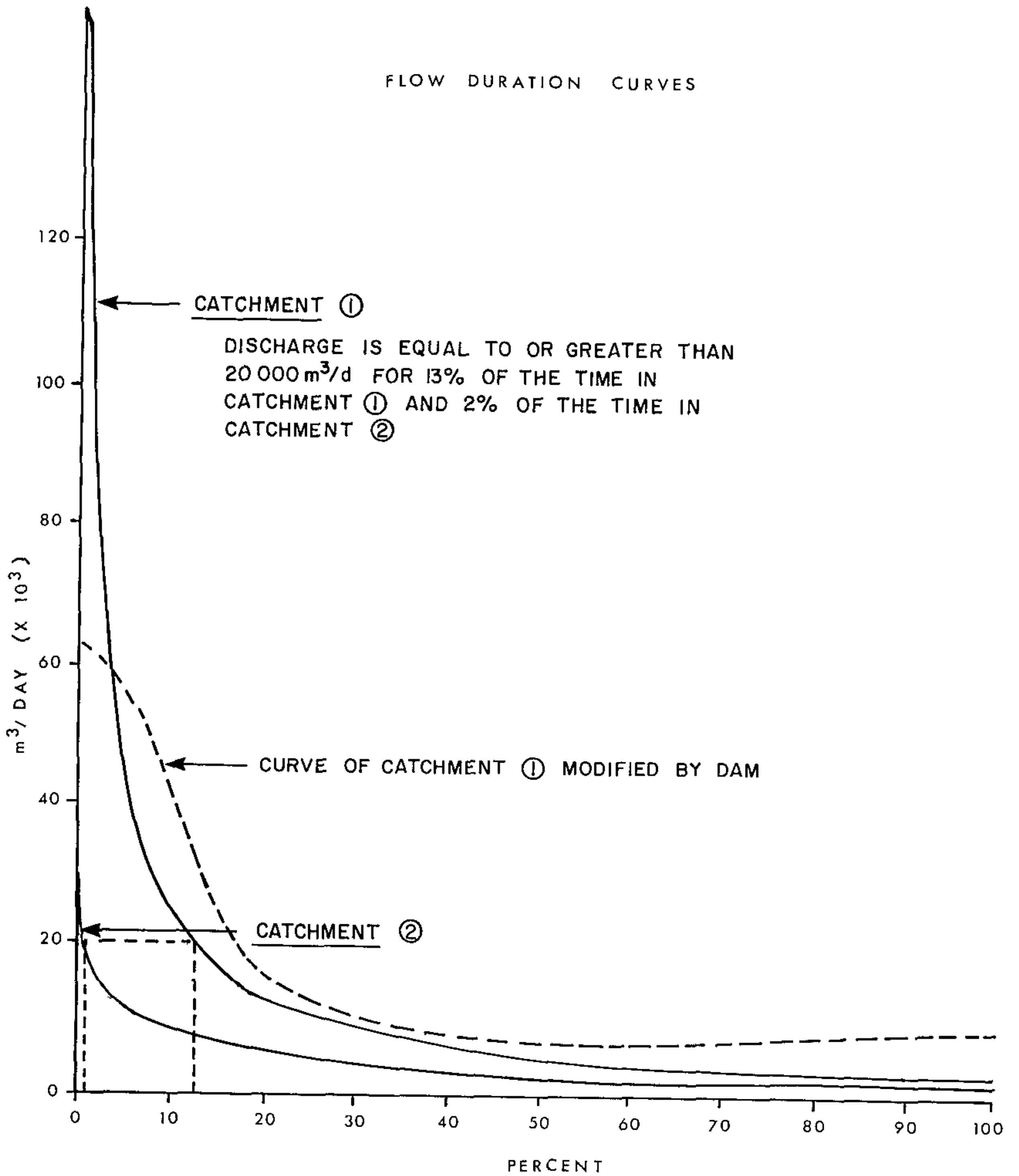

FIGURE 5.1 Flow duration curves for two small catchments. Catchment 1 is on sandstone and catchment 2 on weathered basalt.

5.2.2 Individual stormflow characteristics

The characteristics of individual storm events is best described by the hydrograph shape. The hydrograph (Figure 5.2) is the stage height of a river as measured by a water level recorder, plotted over time. Hydrographs provide valuable information about the characteristics of storm events. One important characteristic as far as downstream flooding is concerned, is the total volume of the flood event (depicted as the area above the separation line in Figure 5.2). It is this quantity in the headwaters that produces downstream floods and not the peak discharge (Hewlett 1982).

Few efforts have been made to relate the hydrograph shape to geology although Woodruff and Hewlett (1970) indicated that the hydrological response of catchments in the eastern United States of America showed a pattern that paralleled the major topographic and lithological features. They showed that mean response is controlled more by geology than land use and other catchment attributes. The hydrological response is a simple measure of the hydrograph shape following rainstorms. It is calculated as follows:

$$\text{Hydrological Response} = Qs/Pg \qquad (1)$$

Where Qs = stormflow volume
Pg = storm rainfall

Mean response factors for some small South African catchments are shown in Table 5.1. From this table it appears that response factors of catchments with the same basic bedrock type do not vary much, despite differences in catchment size. Variations do occur between lithological areas. For instance Langrivier at Jonkershoek in the south-western Cape has an exceptionally high response which is probably a result of there being a large proportion of sandstone cliffs in the catchment.

5.2.3 Subsurface flow pattern

The way in which rainfall is dissipated through the soil, the pathways which it follows to the river and the time it takes to get there is an extremely complex process, and has an important bearing on the water chemistry including the nutrient load (see Crabtree and Trudgill 1985).

The origin of streamflow has traditionally been explained in terms of a fixed channel system and an arbitrary division of the hydrograph into components of surface runoff, interflow and base flow (Horton 1945). On the other hand Hewlett (1961) organized later ideas, which originated from research work, into a definition of streamflow generation called the Variable Source Area Concept (Figure 5.3).

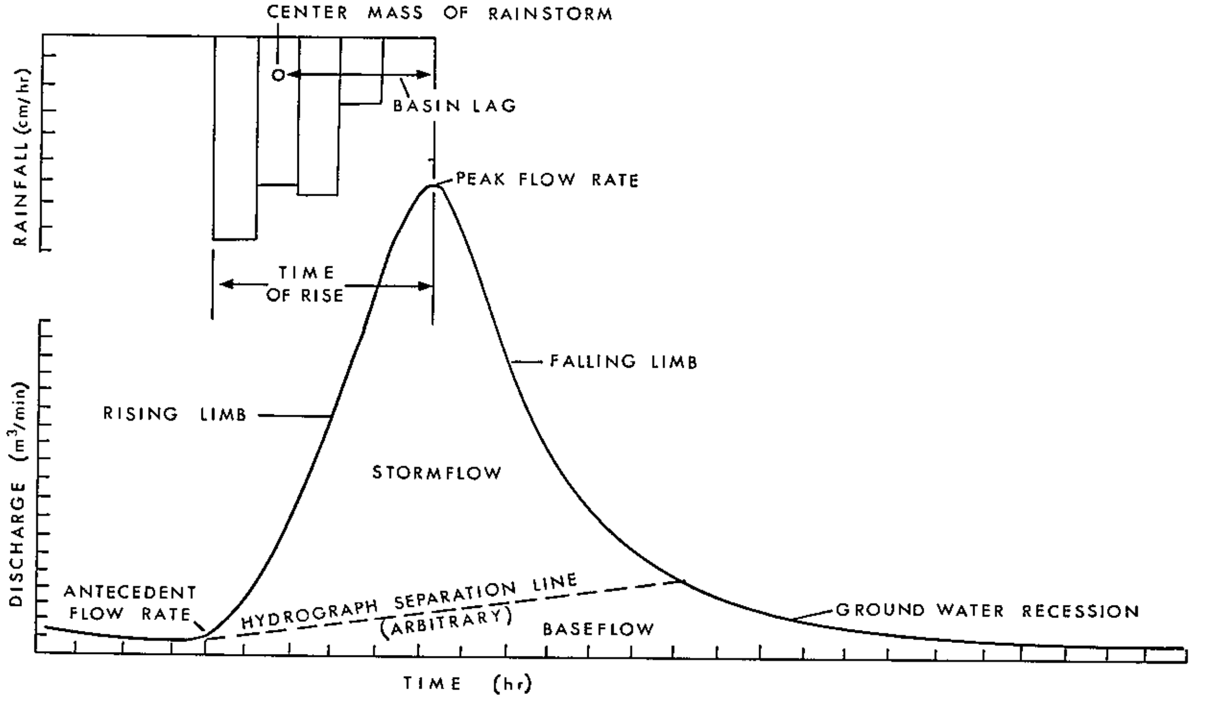

FIGURE 5.2 This diagram defines terms normally used to describe a storm hydrograph. From Hewlett (1982).

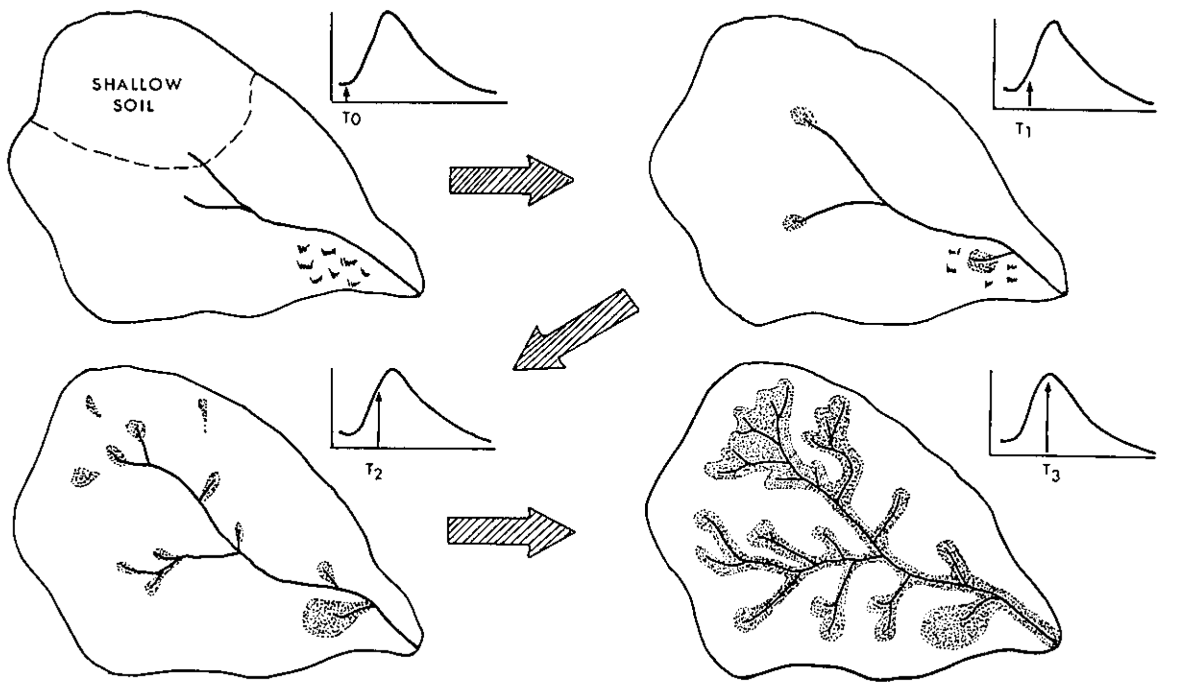

FIGURE 5.3 The small arrows in the hydrographs show how streamflow increases as the variable source extends into swamps, shallow soils and ephemeral channels. The process reverses as streamflow declines. From Hewlett (1982).

TABLE 5.1 Hydrological response factors for some comparable small catchments in South Africa. (Qs = stormflow volume; Pg = storm rainfall)

Place	Area (ha)	Lithology	Mean response (Qs/Pg) (%)
Cathedral Peak		Deeply weathered basalt	
CP 4	95		4,1
CP 2	195		2,6
CP 9	61		3,6
Mokobulaan		Shale	
CA	26		1,8
CB	35		3,7
CC	37		5,8
Zululand		Biotic granite gneiss	
W1M15	1365		12,2
W1M16	322		15,7
W1M17	67		18,7
Cedara		Shales	
U2M20	25		5,3
De Hoek		Mudstone	
V1M28	41		8,8
V7M03	45		10,3
Jonkershoek		Sandstone	
Bosboukloof			2,2
Langrivier			30,9

This concept is based on the fact that streamflow is not generated uniformly over the entire catchment surface but rather by a dynamic, expanding or shrinking source area (Hewlett and Hibbert 1967). The depth and porosity of soil and weathered bedrock help determine whether water remains in the soil, or re-emerges quickly to become streamflow. It may be, for example, that stream channels, surrounding saturated areas, and zones of low hydraulic conductivity are the main source of storm flows. It could also be that rainfall which enters the soil in the upper parts of the catchment, remains in the soil for many years, whilst source areas close to streams supply water to the streams. Very wet years could cause source areas to expand and tap soil zones in which nutrients have accumulated for years. Spates of nutrients will be exported from the catchment. The Variable Source Area Concept has far reaching implications for explaining and predicting the behaviour of water, minerals, nutrients, pollutants and eroding soil. Unfortunately very little work has been done in South Africa to clarify these processes and their consequences for river flow, river quality and to relate them to catchment conditions.

5.2.4 Water quality

Many factors affect the quality of stream water, including geological factors such as the source area, the types of rock and their weathering pattern.

Rocks weather as a result of, inter alia, chemical reactions when they are in contact with water. Minerals are released from the rocks and transported by the water toward the stream. The factors controlling the type and amount of soluble matter transported to the rivers are listed by Tordiff et al (1985) as: "the type of geological formation; the structural features of the area; the temperature of the water; the salinity concentration and the abundance of particular ions and compounds in the water; the amount of water moving through the particular rock-type; and the velocity with which the water flows through the rock". They also discussed the relationship between the geology and water quality aspects in the Great Fish River catchment and showed how constituents of water quality are derived from certain geological formations.

Kemp (1963) hypothesized that certain geological formations would yield streamwater in which ions display near constant ratios and that significant deviations in such ratios would signify ecological disturbances.

Absolute concentrations of NO_3-N are commonly used as an indication of ecological disturbance since composition and decomposition of NO_3-N is mainly a result of biological activity and not a product of weathering bedrock.

As a general rule the main cations in water are taken to be derived from chemical weathering of bedrock, whilst anions are derived mainly from non-geological sources.

5.2.5 Erosion/sedimentation

Erosion is the process by which soils and minerals are detached and transported by water, wind, gravity or man's activities. The deposition of detached particles in streamwater is termed sedimentation.

The type of erosion which is mostly affected by geology or bedrock type is mass wastage (Bosch and Hewlett 1979). This is the process by which detachment and transportation takes place by gravity only. Soil slips and soil creep are familiar forms of mass wastage. Mass wastage is also directly related to rock type and is a common phenomenon in steep sandstone areas. Its affect on the quality of stream water is virtually unrecorded.

Sheet erosion depends largely on the availability of detached soil. The various ways in which soil particles are detached are discussed later. Sediment yields for South African rivers are given by Rooseboom (1978). Annual sediment yield varies from less than 10 tons per km^2 to more than 1000 tons per km^2. The total annual sediment yield from South Africa is estimated to be 100-150 million tons (Rooseboom 1975).

5.2.6 Human activities

Man can do little to change the bedrock itself, but he can alter, perhaps in localized areas, some of the geological features that affect streamflow quality. Physical structures such as roads, quarries and mines may not only cause erosion and sedimentation but may also interfere with downward percolation and lateral subsurface water movement. This could result in changes in the flow pattern of both surface and subsurface waters, possibly affecting boreholes and vegetation some considerable distance away. In localized areas mining can have detrimental effects on the water cycle. For example, diamond mining in Lesotho has caused destruction by prospecting of bogs based on Kimberlite pipes (Jacot Guillarmod 1963).

Man can also drastically influence the vegetation cover in catchments. Degradation of vegetation could result in exposure of bare rock and consequent increases in erosion and sedimentation. Too dense vegetation on unstable slopes can result in mass wastage causing serious sedimentation problems.

5.3 SOILS

Depending on depth, surface conditions and layering, soils may dominate certain components of the hydrological cycle. The infiltration capacity at the surface controls subsurface water supply and hence the runoff processes. The infiltration rate is dominated by properties of the soil surface such as organic matter content, initial wetness, texture and structure.

The principles of streamflow response to bedrock conditions, described in Section 5.2 pertain to soils as well. In summary, the hydrological properties of soils are related to the capacity of the soils to absorb, store and redistribute the water which they receive either as precipitation or from lateral soil moisture movement.

An effort to categorize South African soils according to their hydrological properties was made by Schulze (1985). Although his categorization of over 500 soil series in South Africa is based on their hydrological response in terms of a particular hydrological model, it serves as a good general basis for describing certain hydrological characteristics to soils in South Africa.

Soils can be affected by certain forestry and agricultural practices and may be changed in various ways. Vegetation generally improves the hydrological properties of soils in that it protects the soil from compaction of the surface and degradation due to exposure to sun and rain, provides organic material and improves the structure. However, management practices, such as burning and harvesting of timber may have detrimental affects on hydrological properties of soils. Experimental results on the effect of burning on rainfall infiltration vary but most indicate that under normal conditions fires in natural veld do not change the soil properties that regulate infiltration. Under certain conditions fires may, however, cause residual ash dust and condensation of volatilized organic matter which could result in water repellency and consequent increased overland flow (Bosch et al 1984).

The effects of forest harvesting practices on the properties of soil, such as bulk densities and porosity have been extensively studied, but little work has been done to show how these changes in soil properties affect the hydrology of catchments. Such harvesting influences the hydrological characteristics of the soil mainly by compaction which influences hydraulic conductivity, infiltration and physical soil factors, such as bulk density and air-filled porosity. These in turn cause concentration of overland flow in wheel ruts, lower rates of vegetation recovery and different vegetation types. Some of these aspects are discussed by Riley (1984), Taylor and Gill (1984), Carter (1980), and Warkentin (1971).

It is generally found that well-vegetated undisturbed catchments have infiltration capacities that exceed rainfall intensities and soil surface is thus not a controlling factor in water movement into the soil. In such catchments subsurface flow determines the flow pattern and streamflow mechanisms are explained in terms of the variable source area concept.

In semi-arid catchments, urban catchments or catchments with the phenomenon of repellancy, infiltration may become a controlling factor. In such catchments surface flows may dominate the runoff process.

Farming practices are all too often deleterious in their effects on the hydrological properties of soils. Unless care is taken the proportion of organic matter in the soil decreases, with a loss not only of soil texture, but also of the soil's capacity to hold water. This can result in increased flow to the river, which must be counteracted by increased levels of irrigation in an endless cycle. Another major problem is ever-increasing soil erosion due to bad farming practices. Much work has been done on this aspect (eg McPhee et al 1984).

5.4 TOPOGRAPHY

Topography is primarily a reflection of the underlying geological formations and the climatic regime, with the plant communities playing an important but lesser role. Its form is dependent on the rate of weathering of the parent rock and the rates of soil genesis and loss, these latter in turn being dictated by the action of transporting agents such as water and wind. Certain topographic features of catchments, including size, shape, relief, gradients, and drainage density and pattern, significantly influence the hydrological performance of the basin and the river, as well as its status as a living system. These are discussed briefly below.

5.4.1 Size

All other things being equal, the water yield of a catchment will increase with its size. Other factors, such as conservation and management, are also related to size, since smaller catchments, while being more susceptible to damage, are easier to manage and conserve. This property, as with many others, need not be applied to a whole drainage basin but may deal with one section of a large system.

5.4.2 Shape

The shape of the basin affects the flow pattern of the river. The timing of peaks from sub-basins and thus the shape of the hydrograph and the volume of stormflows discharged at the mouth of the basin, are factors which are controlled by basin shape. Double peaking hydrographs could also be attributed to basin shape. See Figure 5.4.

5.4.3 Relief and gradients

Relief and gradient are of the utmost significance in controlling the hydrological characteristics of a catchment. The presence of steep gradients can result in a large proportion of overland flow and hence become a potentially erosive force. Streams on steep terrain will tend to be torrential with water that is highly oxygenated but, because of the low residual time in or on the ground, is poorly buffered. Deposition of sediments will be low and pollutants tend not to accumulate. However, the flora and fauna of such areas tend to be slow-growing and adapted to a very narrow range of environmental conditions. They are thus very vulnerable to disturbance and their recovery time is thought to be long. This fragility, coupled with the fact that in South Africa areas of steep gradients generally have a high rainfall, imply that such areas have great significance in water and nature conservation. Any development in such areas must be very carefully assessed and planned.

Lesser gradients allow more of the precipitation to enter the soil and hence storage is higher and transport to the river is slower. Generally the water will be more highly mineralized and buffered. Dissolved oxygen may be below saturation levels and the local flora and fauna will be more resilient to environmental extremes. Sediments and pollutants will accumulate more readily in the slow-flowing waters. These accumulations are of great significance as they can drastically change the low-river ecosystem, preventing fish migrations, causing flooding and even rendering the water unfit for animal and plant life or for human use. The effect that relief may have on the hydrograph is illustrated in Figure 5.5.

5.4.4 Drainage density and pattern

Drainage density is a reflection of geology, relief and climate. It is an expression of the length of stream per unit area of catchment. While it is not a feature that is normally affected by human activities, it reflects the average distance water must travel to the nearest water channel in the catchment. As such it is of significance in dispersing the effects of human activities. For example, activities such as road construction or quarrying will have a greater effect on a river in areas with a dense drainage network. Thus developments which involve major soil disturbance should be planned in areas where drainage density is low. Figure 5.6 illustrates possible effects of drainage density on the shape of the hydrograph.

5.5 CLIMATE

The influence of climatic factors and their interactions on the catchment and river ecosystem is extremely complex. The driving forces of the hydrological and energy cycles are precipitation and solar radiation (light and temperature) respectively. Minor influences on these major forces could have serious effects on all processes within the catchment.

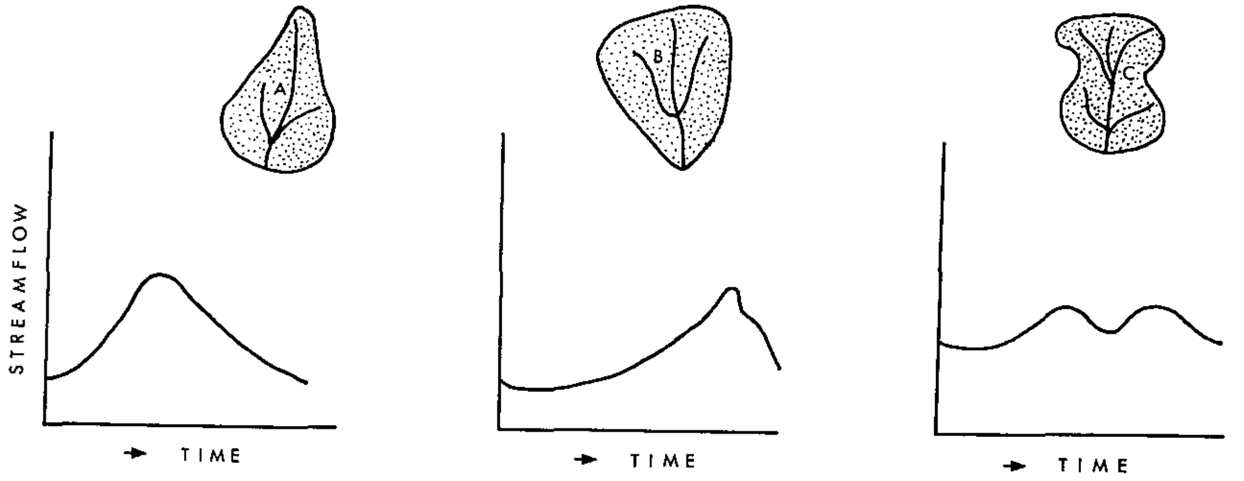

FIGURE 5.4 Possible effects that basin shape could have on the hydrograph form.

5.5.1 Precipitation

Both the quantity and quality of precipitation, be it in the form of rain, mist, hail or snow, can be influenced by man. Techniques of cloud seeding to change the rainfall patterns are improving, but too little is known about its consequences to warrant discussion here.

It has been shown that man can markedly influence the quality of precipitation, which in turn can affect catchment processes and ultimately the river ecosystem. Howard-Williams and Alexander (1984), for example, listed the following sources of pollution:

- Atmospheric dust following extensive ploughing or overgrazing.
- Smoke, generated by burning of vegetation or solid fuels.
- Volatilization of urea and ammonia compounds in the farming practice of heavy fertilization.
- Atmospheric sulphur, phosphorus and nitrogen oxides originating from industrial development.

In Table 5.2 concentration of ions in atmospheric fallout are given for some areas in South Africa. Very little is known about the effects of changes in the quality of fallout on catchment processes, but they may have deleterious effects. Acid rain, for example, is an increasingly significant threat to river ecosystems. This may only be evident at great distances from the origin of pollution. Sampling of atmospheric fallout at

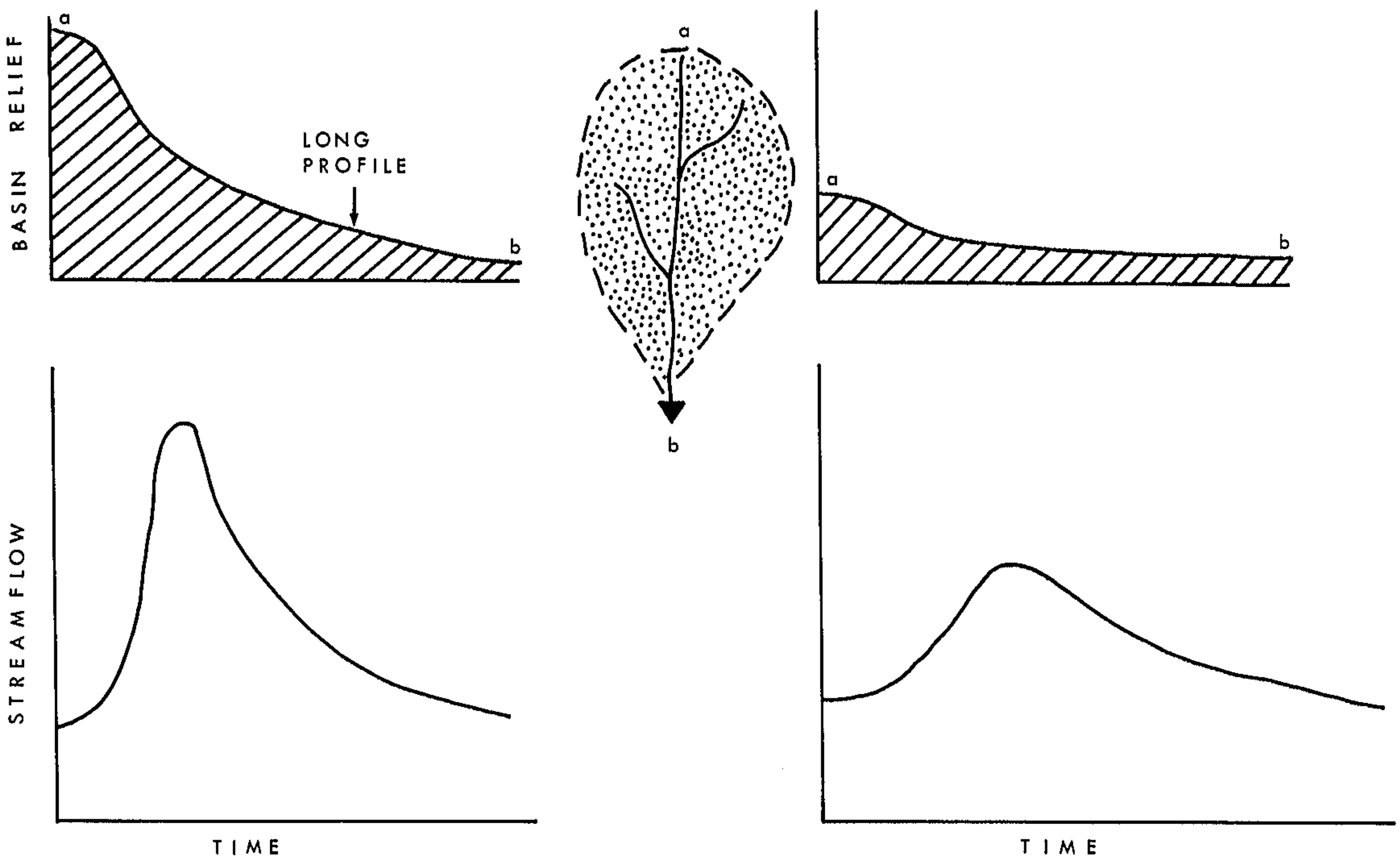

FIGURE 5.5 Different gradings on the same length of slope would generally influence the hydrograph form as shown above, but it must be emphasized the river profile and slope of the river flanks may override the effect of gradient.

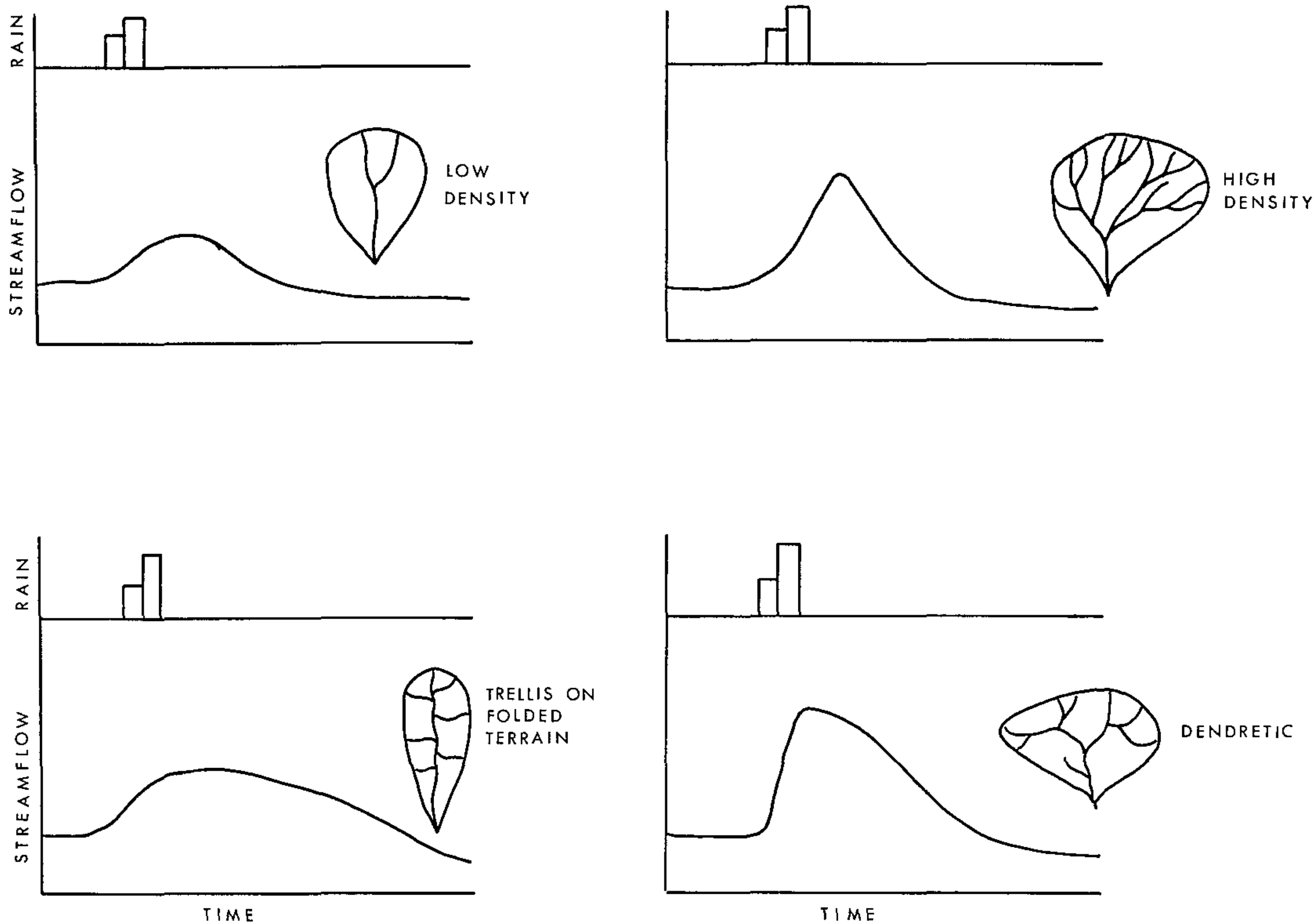

FIGURE 5.6 General affects of stream density and pattern on the hydrograph.

Witklip State Forest near White River in the eastern Transvaal has shown high levels of SO_4^{2-} and NO_3-N and Cl^- which probably originated in the highveld industrial areas (van Wyk 1985). It is not known if acid rain can directly affect the riverine biota, but it may affect them indirectly by, for example, increasing the solubility of aluminium above levels tolerated by fish populations. Hornbeck (1981) gives an overview of acid rain problems in ecosystems. Undisturbed lakes and streams may well respond quickly to polluted rain because they receive precipitation directly and are often poorly buffered.

5.5.2 Temperature

Temperature can have an indirect effect on rivers in that it causes or accelerates processes of erosion and hence the concentrations of sediment and dissolved solids in streamwater. Low temperatures at high altitude cause frost heave in some of the upper catchments in South Africa (Jacot Guillarmod 1969), while diurnal variation in temperatures also can cause accelerated weathering of bedrock. There is little or nothing that man can do to influence these processes, but if aware of them, sensitive areas can be avoided for development.

In contrast to terrestrial systems where low temperatures present great problems for survival of many living forms, high temperatures appear to be a greater threat to aquatic animals. Adaptations of the aquatic fauna, to cope with normal seasonal fluctuations in temperature, have already been mentioned. Abnormal changes in temperature, such as exposure of a mountain stream to sunlight following clear-cutting of timber, or discharge of a heated effluent into a river, can have serious effects on the animal life. Mountain stream fauna, adapted to cool, dark environments, simply cannot survive in water of greatly elevated temperature, while the additional possible effect of blooms of algae in the brightly-lit water might be to blanket their food, footholds and refuges. High temperatures anywhere in the system, but particularly in the lower reaches, can encourage massive growth of plants, resulting in the water being super-saturated with oxygen by day. But because water holds less oxygen as its temperature increases, and because plants do not release oxygen into the water during the dark but only use it in respiration, oxygen levels can fall critically low overnight in warm, nutrient-enriched systems. In artifically-warmed systems (as from a heated effluent) there is the additional problem that metabolism of animals increases with increase in temperature, and life-cycles will thus be speeded up. The consequent emergence of aerial adults at times too early for their food supply, into air of the wrong temperature, could have a profound effect on the success rate of their reproduction and the return of the species to the river.

5.6 BIOSPHERE

Many aspects of the living communities of a river have already been touched upon. We have mentioned the response of riverine communities to seasonal changes in discharge and temperature, the fragility of the mountain stream communities and the comparative adaptability of the lower-river communities. Changes within the catchment that could have a detrimental affect on the river have also been mentioned: the lowering of pH levels by acid rain, interference with the groundwater regime and disturbance of the

TABLE 5.2 Weighted mean annual concentrations in atmospheric fallout (ie precipitation and dust fallout collected at weekly intervals over a number of years) in urban and mountain catchments (after Howard-Williams and Alexander 1984)

Parameter	Urban	Mountain
Suspended solids mg l^{-1}	25-50	-
Orthophosphate-P mg l^{-1}	0,007-0,026	0,006
Soluble-P mg l^{-1}	0,009-0,032	-
Total-P mg l^{-1}	0,047-0,103	0,019
Nitrate-N mg l^{-1}	0,184-0,438	0,091
Ammonia-N mg l^{-1}	0,207-0,434	0,093
Soluble Organic-N mg l^{-1}	0,151-0,247	-
Total Kjeldahl-N mg l^{-1}	0,562-1,096	0,204
Chloride mg l^{-1}	5,0-5,7	5,1
Sulphate mg l^{-1}	3,5-5,9	6,5
Fluoride mg l^{-1}	-	0,02
Sodium mg l^{-1}	-	2,8
Potassium mg l^{-1}	-	0,2
Calcium mg l^{-1}	-	0,4
Magnesium mg l^{-1}	-	0,2
Bicarbonate (HCO_3) mg l^{-1}	-	5,6
Conductivity mSm^{-1}	7,4-9,1	-

land during farming and timber-cutting. These are all parts of a larger picture however, which can only be appreciated at the ecosystem level. A catchment is usually accepted as such a unit and, because by definition it is the drainage basin of a river system, the role of the river within that ecosystem automatically gains prominence. Many of the topics that we have mentioned in this chapter have the same underlying message: That events within a catchment affect each other, and all have the potential to affect the river. From planting of forests to fertilizing of crops, from replacement of veld with tarmac to turning on a tap - all activities that interfere with the living components of a river. The most important biotic characteristic of a catchment is its vegetation, for this affects the catchment's climate, its ability to cycle water, minerals and energy, and the quality of water reaching the river.

Vegetation holds soil in place, provides additional soil water storage potential and enhances infiltration of water; it protects soil against eroding forces such as rainfall and wind and absorbs and emits solar energy. Changes in the vegetation are thus likely to affect many processes and the influences on the river of various catchment management practices have been studied intesively. For example, it has been shown that afforestation causes large decreases in water yield from catchments (Bosch and Hewlett 1982; van Lill et al 1980) and invasion by woody exotics is expected to have similar effects. Afforestation and normal forest practices may not cause major changes to water quality. Increases in NO_3-N were observed (Van Wyk 1986). Catastrophic phenomena in plantations, such as fires and large scale deforestation can have serious effects on rivers. Van Wyk (1986) has shown severe sedimentation and extremely high levels of nitrogen in streams after a pine forest burnt down at Cathedral Peak in the Natal Drakensberg and Graynoth (1979) lists the extensive effects of logging on streams in New Zealand.

The effects on streamflow and water quality of fire in grassland and fynbos have been well researched (Bosch et al 1984; van Wyk 1981, 1985b). In summary these results show that in fynbos, small increases in all determinants of water quality occur only during the first four significant floods following burning of the catchment. Increases in sediments (from 43 g m^{-3} to 143 g m^{-3}) occurred following a burn in grassland in the Natal Drakensberg, but this effect was short lived. Total dissolved solids were apparently not influenced by burning.

It was also found that stormflow in small catchments of the western Cape, Natal Drakensberg and eastern Transvaal Highveld were not materially affected by burning and by afforestation (Hewlett and Bosch 1984). Soil depth, texture and layering dominate flooding and stormflows, rather than vegetation.

Grazing and, in particular, overgrazing can cause changes in processes such as infiltration and interception. Sediments and nutrient levels are also bound to be seriously affected in overgrazed areas. Too little research has been done in this respect but some aspects of grazing in upper catchments are discussed by Jacot Guillarmod (1962).

Application of fertilizers and biocides in catchments can seriously affect the quality of streamwater. There is no control (other than financial) over the total amount of fertilizers and biocides applied to a catchment. This is leading to increasing amounts of these pollutants draining into rivers. In three agricultural shires in England, for instance, the level of nitrates in drinking water are now above EEC limits, because of the excessive application of this fertilizer to the land. High nutrient levels in rivers cause problems other than to the quality of drinking water eg eutrophication and blooms of aquatic weeds; while pesticide residues may, apart from their destructive action in the lotic system, be of significance if the river water is reused in any way.

5.7 RIPARIAN ZONES

Riparian zones include the phreatic, bank and floodplain areas. These zones are of utmost importance in river conservation because they form part of the catchment which has a direct effect on the stream ecosystem, and on streamflow quantity and quality. The vegetation of these zones plays a vital role in the river ecosystem, by supplying food to the aquatic fauna, controlling the drainage of water, nutrients and other minerals to the stream, providing shade to decrease the deleterious effects of warm water on the biota, and stabilizing the banks, thereby keeping the water silt-free. The riparian zones probably comprise the source areas in most catchments. Disturbance of these zones has occurred by removal of riparian vegetation in order to increase farmland or, supposedly, to increase water yield. Trampling and erosion of banks through the activities of humans and animals cause bank erosion. When shallow-rooted trees fall, rivers may be blocked and cause flooding. Many introduced species are unsuitable as food for riverine fauna (King 1982). Coarse, fine and very fine particulate organic matter (see Chapter 1), derived from riparian plants, float downstream to become a major food source for lower-river communities. Removal of the trees therefore must have a marked effect on the energy supplies not only of the animals in the immediate vicinity but of the downstream communities as well. However, Bosch and Hewlett (1979) have pointed out that roads and road crossings are perhaps the major source of disturbance in riparian areas.

A major current need is for objective guidelines to define and to manage riparian zones. The new Forest Act makes provision for the protection against afforestation of certain areas within a catchment that are regarded as source areas or hydrologically sensitive areas. Previous policy, which prohibited plantings to within 20 m of streams resulted in irregular, digitate boundaries in the catchments. These open zones were seldom well managed and became invaded by alien plants which in turn caused several management problems.

At present research is being aimed at defining riparian zones in upper catchments and obtaining qualitative understanding of the hydrological and biological role of riparian zones in maintaining water quality, as a wildlife habitat, and as a recreational amenity.

Development of land too close to inland waters and sometimes below the 50-year flood line has often led to urgent flood control measures having to be implemented. Flooding of waterside properties in the Cape Town area has led to reed-beds being removed to facilitate fast-flow of flood waters, while erosion of cleared banks has forced some stretches of rivers to be canalized.

Developments of waterside areas should include maintenance of the integrity of bankside vegetation not only to avoid erosion and to preserve the riparian aquatic habitat, but to act as a trap to fertilizers and other pollutants.

5.8 CATCHMENT IMPLICATIONS IN LONGITUDINAL STREAM ECOSYSTEMS

At this point it is worth reinforcing the fact that a river is a longitudinal ecosystem, and that its condition at any point is a reflection not only of all upstream activities within the river but also of all activities in the adjacent and upstream parts of its catchment. Obvious changes to a river system, such as the erection of a dam, have been dealt with, but many more subtle changes may have quite far-reaching effects on the river. Vegetation changes in the upper catchment can alter the amount of water in the downstream river, while the unseen but very real connections between surface and ground waters mean that extraction of water from one can have serious implications for the other. The insidious underground drainage of fertilizers, biocides and sewage (eg from septic tanks) places an ever-increasing stress on the receiving rivers and represents the major non-point source of pollutants entering them. These, together with point source pollutants such as factory effluents, may overload river systems that thus become incapable of processing the loads dumped in them because of reduced flow for damming and water extraction. The proposal that 11% of a river's flow be allocated for conservation purposes (Roberts 1983) is a great step forward in that it recognizes the right of the river to exist, but this or whatever allowance is ultimately decided upon will be wasted if draining pollutants increase in developing catchments to the point where stream functioning falters anyway. Of the remainder of a river's flow, much will presumably be stored in in-stream reservoirs. It therefore becomes important, when a new river-dam is being planned, to consider land use and all other activities in the upstream catchment, since each new reservoir created on a river, either in or downstream of a developed area, is at the mercy of upstream land-users and potentially requires very expensive management. The non point-source pollutants in the river may well be more important and more difficult to control than the point-source ones and those from agricultural areas will probably be a significant portion of the whole.

Thus, investigations should be carried out at an early stage of the planning, to identify all upstream activities that result in significant levels of point- and non-point source pollutants in the river. Such investigations would best be associated with a full-scale ecological assessment of the status of the catchment, in order to give an overview of prevailing conditions and problem areas. The assessment should include recommendations for revised land-use practices in the catchment where necessary and should identify which of these revisions would offer the greatest improvement in water quality for the least cost.

Only if rivers are considered at this catchment level can we hope to manage them wisely and perhaps conserve some of their natural character. Piece-meal management will benefit neither the rivers nor us, since the need for their waters is greater now than ever before.

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CHAPTER 6 MONITORING AND SURVEILLANCE

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6.1 INTRODUCTION

The words survey, surveillance and monitoring are often used more or less interchangeably. This is not desirable and Hellawell (1978) made the following distinctions between the three activities:

- Survey: an exercise in which a set of standardized observations (or replicate samples) is taken from a station (or stations) within a short period of time to furnish qualitative or quantitative descriptive data.

- Surveillance: a continued programme of surveys systematically undertaken to provide a series of observations in time.

- Monitoring: surveillance undertaken to ensure that previously formulated standards are being met.

In an activity such as an investigation on an ongoing basis of the conservation status of lotic systems, for which standards have not been defined, it is obvious that, in terms of the above definition, the activity is surveillance and not monitoring.

Streams, rivers and other lotic systems are as distinctive ecosystems as are many of the more commonly recognized major ecosystems, such as the savannas, grasslands and forests of the terrestrial world, and the rocky or sandy shorelines and the open sea of the oceans. As such, lotic systems are worthy of conservation as much as our other ecosystems. The need to define standards for lotic system conservation is urgent.

6.2 PURPOSES OF SURVEILLANCE

The purpose of the surveillance of lotic systems is the timely detection of ecosystem change beyond the normal range of variability, so that remedial actions may be taken before such change becomes permanent. Remedial action might involve the removal or elimination of the cause of change where the whole ecosystem is involved or, perhaps in more desperate circumstances, the removal of an endangered species and its establishment in a less threatened habitat where it was previously unknown. The separation of real and permanent ecosystem change from change within the normal range of dynamic variability, is of crucial importance in the management of lotic systems.

6.3 NATURAL VARIABILITY AND PERMANENT CHANGE

The natural variability with time of lotic systems has two broad causes. The first is brought about by the fact that in lotic systems water is travelling in one direction and dissipating energy as it does so. A major component of the dissipation of the kinetic energy of water in a head-water stream, as it flows down to the sea, is the work done in transporting particulate material from the riverbed. All other things being equal, a stream or riverbed therefore varies with time as the stream cuts down into the underlying geological strata and transports the eroded material, depositing it temporarily in places and then transporting it on again. For further details of the processes involved, the reader is referred to books such as Hynes (1970), Leopold et al (1964) and Petts (1984).

The second major cause of natural variability in lotic systems, which is particularly applicable in South Africa, is the long-term drought cycle. Through its effect on riverflows, there are cycles of streambed disturbance, of water chemistry and, as a consequence of these changes in the physical and chemical environment, no doubt changes in stream biology, such as vegetation encroachment into stream beds. Unfortunately, the pioneering surveys of lotic system ecology in South Africa (Harrison and Elsworth 1958; Oliff 1960; Allanson 1961; Chutter 1970) were completed at a time when the regularity of the drought cycle in South Africa was not appreciated. The consequence is that no river system has been surveyed for a period long enough to achieve an understanding of the impact of the longterm drought cycle on the nature of rivers. This represents a real gap in the background knowledge against which surveillance of the conservation status of lotic systems in South Africa needs to be assessed. It is pertinent in this context that hydrologists insist that data records over a period of at least twenty years are necessary for the understanding of relationships such as that between rainfall and runoff under South African conditions (P J Roberts personal communication). Some idea of the difficulty in distinguishing between permanent change and natural variability may be obtained by considering findings in studies not related to those concerned with lotic systems. For instance, in considering the problem Sors (1984) reported on the natural, temporal and spatial variability in stratospheric ozone. To quote Sors "..... it has been estimated that if there were an effective two per cent depletion of ozone per annum, an additional ten years of observation would be required before the event could be confirmed from measurements with 95% confidence." In the light of this type of finding, it could be argued that in South African rivers the natural variability is so great that it would be impossible to detect change of a more subtle nature, such as that which might arise through the impact of increased soil erosion or changes in land-use patterns. However, there are examples of drastic and permanent change of which it is timely to remind ourselves. In Pietermaritzburg, the Dorpspruit is now a shallow stream flowing over a rubble-filled bed. Many years ago, probably at the turn of the century, the schools in Pietermaritzburg held their swimming galas in the Dorpspruit which had pools of a sufficient size to mark them off into swimming lanes for a number of competitors (the late A W Bayer personal communication). Another example of permanent change is the Tongaat River. When the first sugar mill was built at Tongaat, the machinery was floated up the river to the mill site on barges (F L Farquharson personal communication). Today one can literally step across this stream at its usual flow. These two examples illustrate an important point about South African lotic ecosystems. Many of them have been drastically changed and the change has only been recorded through the long memories of certain individuals. The causes of such change and whether timely action could have been remedial, remain areas for speculation.

6.4 THE COMPONENTS OF A SURVEILLANCE PROGRAMME FOR A LOTIC SYSTEM

In this section an attempt is made to describe the major components of an ideal surveillance programme and relate them to what is usually practically feasible. Ideas are offered on matters such as how surveillance should be undertaken; what is involved in the choice of sampling sites and frequency of sampling; the expression of results; who might be responsible for surveillance programmes; and what the costs of surveillance programmes might be.

6.4.1 An idealistic surveillance programme

The major factors influencing the biological status of a lotic system are the quantity of flow and its variation in time, the temperature of the water, the particulate material transported by the river, its nature and distribution in time, and the soluble compounds in the water and their distribution in time. The combined effects of these environmental variables are expressed in a variation of the biota of the lotic system. It should be borne in mind that there is always the possibility that the composition of the insect fauna of streams and rivers may be affected by events outside of the river, when insects with an aquatic developmental stage and an aerial or terrestrial adult stage are involved. The ideal surveillance programme would provide information on the changes taking place in all these components of a lotic system with time. The analysis of such information would allow for the detection of long-term trends of change as opposed to inherent natural variability and would reveal the impact of such change on the composition and dynamics of the biota. However, to record all the parameters involved would be prohibitively expensive and management decisions usually have to be made on far less information.

6.4.2 Practical surveillance programmes

In practice, a person initiating a surveillance programme will find that flow records are sometimes available from Department of Water Affairs gauging stations. Water temperature is unlikely to have been recorded continuously. Methods for the direct measurement of suspended and bed loads of particulate material are prohibitively expensive. In fact, bed loads can usually only be inferred from the rates of loss of storage in downstream impoundments, from extensive, active erosion in the catchment or sometimes from changes in the river channel. There may be monthly analysis of the chemical quality of snap (grab) water samples. These analyses will be concerned mainly with the major anions and cations and the plant nutrients nitrogen and phosphorus. It is unlikely that there will have been previous biological studies.

The biota of a lotic system reflects the long-term abiotic conditions of the system. For example, if the system has been contaminated by a biocide, the chemical detection of the passage of that biocide down a river will depend on a snap water sample being taken to include the biocide and the chemical analysis of that water sample including an analysis for that particular biocide. If the invertebrate benthic fauna of the lotic system were being surveyed at monthly intervals, the effect of that biocide through killing susceptible species would be indicated by the disappearance of these species from one month to the next. Similarly, a marked change in the dissolved oxygen content of the water, or the temperature of the water, or of the flow, would be reflected in the composition of the fauna and other components of the stream biology. On this basis, the minimum requirements for a surveillance programme should be the routine sampling of one or other component of the biota.

Hellawell (1978) considered the question of what component of the entire biology of lotic systems is best to use to monitor changes in the chemical quality of the water. He concluded that the benthic macro-invertebrate fauna should be the first choice when selecting a component for general surveys. Next most useful were algae and fishes. In South Africa, the benthic macro-invertebrates have been more intensively studied than other components of the biota in relation to water quality, followed by the diatoms. Macro-invertebrates have been shown to vary, following changes in water quality and this variation has been codified into a biotic index of water quality which has been found useful in classifying macro-invertebrate communities (Chutter 1972, 1984; F C Viljoen personal communication). The biotic index is applicable to the fauna of hard bottoms in fast flowing water (commonly known as stones in current) and this fauna has generally been shown to be the most responsive to water quality and environmental change. Diatom studies are promising but have not yet progressed as far as macro-invertebrate studies. Potentially, diatom studies may ultimately yield better information on chemical variation in the water quality. Against this advantage is the disadvantage that diatoms are not as long-lived as macro-invertebrates. Macro-invertebrate and diatom studies complement one another. For general purposes, it is recommended that the minimum surveillance programme should be based on the benthic macro-invertebrate fauna of stones in current. It is recognized that this recommendation is made in the face of the fact that stones in current habitats do not always occur where it is desired to site sampling points.

The shortcoming of such a minimum sampling programme is that if a change is found in the macro-invertebrate fauna, it may be necessary for intensive follow-up studies of environmental factors such as flow and water chemistry to establish the causes of such change. At the present state of knowledge of natural variability in the South African lotic macro-invertebrate fauna, it is also necessary to establish whether the observed change represents real change or change due to natural variability. The latter decision is often unlikely to be as difficult as may appear at first glance. The change may be observed at only one sampling point, in a series of sampling points down a river, in which case it is almost certainly due to a local and real change. If it is observed at all sampling points in the river, it is more likely to be due to natural variability or to a real change in the upper catchment.

There are special circumstances, such as cases where ecosystem degradation through contamination by biocides or heavy metals may be involved, where recommendations for the minimum surveillance programme would change. The environmental impact of low concentrations of such substances should be surveyed through the examination of the accumulation of these substances in higher organisms, such as predatory fish.

In addition to this minimum sampling of the fauna of the lotic system, the minimum surveillance programme should include careful observation and recording (photographically if necessary) of the general environmental conditions at sampling points. Features such as the amount and type of macrophytic bank and aquatic vegetation, the observable nature of the streambed (sand, mud, algae), evidence of recent large changes in flow, should be recorded. The common property of these features is that they can help explain the composition of the invertebrate fauna and the general conservation status of the lotic system.

6.4.3 Initiating a surveillance programme

When initiating a surveillance programme, it is almost always necessary to make a preliminary survey of the lotic system which it is desired to keep under surveillance. The preliminary survey should start with the gathering of all existing information on the lotic system and the geography and human activities within its catchment. All past records relating to the flow, water chemistry, sediment transport and biology of the lotic system should be gathered and evaluated. Against this background, the preliminary survey should concern itself with identifying the sampling points at which the routine surveillance should take place.

6.4.4 Choice of sampling points

Factors governing the choice of sampling points are related to a number of properties of the system. Most lotic systems will have a mountain source and then flow through a number of gradient zones on the way to the sea. These zones are described, for instance, by Harrison and Elsworth (1958) for the Great Berg River; by Oliff (1960) for the Tugela River; by Chutter (1970) for the Upper Vaal River; and by Harrison (1965) for South African rivers in general. While scientific perspectives of zonation have changed over the years and today rivers are regarded as continua (Vannote et al 1980), it nevertheless remains true that, regardless of catchment use and urban development which will themselves have impact on lotic systems, it is desirable to have a basic network of sampling points spaced out along the course of a river. In addition to this basic network, sampling sites should be chosen in relation to different catchment usages which might include primarily grazing, arable agriculture, intensive orchard or forestry development, areas of mining activity, informal settlements and towns. Sampling sites should be sited below such potential sources of interference with the conservation status of a river. In the initial survey, it would perhaps be prudent to over-sample the system rather than to under-sample it.

6.4.5 Frequency of biological sampling

Many of the surveys of the invertebrate fauna and water quality which have been undertaken in the past in South African rivers, have been based on year round monthly sampling of the fauna and water chemistry. This sampling frequency is unnecessary in surveillance programmes whose object is to detect long-term trends of change. Monthly sampling of South African rivers produces highly variable results in the rainy season when widely fluctuating flows tend to bring about an apparent disruption of the benthic fauna. This disruption is more apparent than real and comes about because benthic samples can too easily be drawn from parts of the riverbed which have been under water for only a short period; or again if the river flow has dropped after a prolonged period of high flow, benthic fauna may become concentrated in the smaller available habitat area. It is suggested that surveillance programmes should be based on sampling lotic systems in the early to mid-part of winter in the summer rainfall area, and in the spring or early summer in the winter rainfall area. In the summer rainfall area, the growth of filamentous algae in streams tends to be greatest in the late winter/spring period. Such algal growths support special elements of the fauna, but also considerably complicate and excessively prolong the sorting of benthic samples.

6.4.6 Biological sampling method

Hellawell (1978) has given a full analysis of the sampling methods involved in the biological surveillance of rivers, of their limitations and of their advantages, and it can be most strongly recommended that this book be studied at the initiation of any South African surveillance programme. In South Africa most recent work on the macro-invertebrate fauna has been undertaken using various types of sampling apparatus all fitted with netting with a space between parallel threads of 300 microns. For purposes of comparison of new results with old, it is desirable that this standard netting be used in the future. The most commonly used and versatile sampling apparatus has been a circular hand-held net of 250 mm diameter, supported on a brass ring mounted on a broom handle. In South Africa, the tendency has been to hold this net downstream of the stones as they are individually lifted from the river bottom and then to wash the clinging animals off the stones into the net. This particular point is of some importance because in some overseas studies, the so-called kick sampling method has been used in which the hand net is held downstream of stones which are then kicked to disturb the fauna from them. This kicking method ignores the fact that many animals adhere strongly to the stones on which they are living. Hence kick sampling is not recommended. The particular usefulness of the hand net is that it can be used in almost all types of habitat including sand and muddy bottoms where it can be scraped across the top of the sediment. The other sampling apparatus commonly used in South Africa is the Surber sampler for stones in current habitats (Surber 1936; Hellawell 1978). Its limitations are that it cannot be used where the stones are larger than about 150 mm and that it should not be used in water deeper than 200 mm. Although apparently a quantitative sampler, more faith is placed in the faunal density revealed by the sampler than is justified by the results (Chutter and Noble 1966; Hellawell 1978).

The size of the benthic sample to be taken is addressed at length by Hellawell (1978). The general conclusion is that, in order to arrive at density estimates of the fauna with any reasonable degree of accuracy, an inordinately large number of samples needs to be taken. It is better, therefore, in analysing and comparing samples, to make use of the quasi-quantitative figure where each taxon is represented as a percentage of the total number of animals in the sample.

6.4.7 Analysis of benthic samples and presentation of results

The animals collected in benthic samples have to be sorted as to the species present and the number of animals belonging to those various species. A stereo microscope is used for this. In South Africa there are unfortunately no comprehensive local taxonomic accounts of the freshwater macro-invertebrate fauna. Biologists new to the fauna of lotic systems are likely to experience considerable difficulty in identifying the taxa they may find in samples. Their best approach is probably to get in touch with biologists who have previously worked on the invertebrate fauna of lotic systems and in this connection the Curator, Freshwater Invertebrates, at the Albany Museum in Grahamstown, and the Head of the Limnology Division, National Institute for Water Research, can at the present time be recommended. When once the animals collected in the benthic samples have been sorted and counted, it is necessary to present these results in a form that can be used to make comparisons with other sampling sites or other sampling occasions. The benthic biologist will usually be interested in the complete results and his fellow benthic biologists would prefer to be provided with the full information to allow them to confirm the interpretations placed on the results for themselves. However, this results in cumbersome tables of results which non-biologists find confusing and pedantic. It is necessary to summarize the tabulated results. Sometimes, as simple a piece of information as the total number of taxa found will be sufficient to convey conclusions to non-biologists, but a word of caution is necessary here. Obviously the larger the area from which the sample is collected, or the larger the number of individual organisms, the greater the likelihood of a higher number of taxa. In other words, the diversity of the fauna in the sample is directly related to sample size. This should be taken into careful account in drawing conclusions about differences reflected in species diversity. In spite of its many ardent supporters (reviewed by Hellawell 1978), diversity can also be misleading in other ways. For instance, if a benthic sample is taken from a place of particularly fast current, the fauna may be restricted to a small number of species which can tolerate this environmental extreme. Archibald (1972) showed this type of variation in diatom populations. There is no clear linear relationship between species diversity and water quality or, probably for that matter, conservation status. In the Highveld regions of the Transvaal and in Natal, Chutter's (1972) biotic index has been shown to vary consistently with the organic pollution of water. A consistent value of this index above 6 can be taken as a clear indication that there is considerable deterioration in the conservation status of a stream, most probably due to a change in water quality.

In South Africa, a major concern for the conservation status of rivers is the impact of the high rates of soil erosion on ecosystem structure, functioning and species composition. Preliminary analyses of the effect of increasing loads of silt and sand on macro-invertebrate communities of streams and rivers in the Highveld have been made (Chutter 1969, 1970). These analyses should be taken into account in analysing the biological results of surveillance programmes.

There are methods for making objective comparisons between benthic samples. For instance, similarity may be measured as the similarity in the species present or as the similarity in the dominant animals. Methods to compare these two types of similarity and for handling the information from any number of samples compared simultaneously is given in Kemp et al (1976). The results of such comparisons may be expressed in the form of dendrograms which visually display the similarity between samples. From the biologists' point of view, it is always advisable to look beyond the dendrogram for those components of the biota which have resulted in the degree of similarity or dissimilarity. A knowledge of the species concerned can reveal information about the causes of the differences.

6.4.8 Sampling and analysis of water

Methods for the collection and chemical analysis of water samples are comprehensively dealt with in the publication Standard Methods for the Examination of Water and Wastewater (APHA 1985). In the South African context, the methods adopted by some of the major analytical laboratories should also be considered. These laboratories are those of the Hydrological Research Institute (Department of Water Affairs, Private Bag X313, Pretoria 0001), the National Institute for Water Research (P O Box 395, Pretoria 0001), and the South African Bureau of Standards (Private Bag X191, Pretoria 0001). The Department of Water Affairs has a large data base on river flows and the Hydrological Research Institute is developing a chemical monitoring system covering the whole country. Obviously during the preliminary survey stage of the surveillance programme, these organizations would be approached for information and advice on sampling and analytical methods were there no existing information available.

6.4.9 Responsibility for surveillance

An important component of the surveillance of the conservation status of lotic systems is to decide who should be responsible for conducting the surveillance, and who would then take any follow-up action arising from the surveillance revealing that such action was necessary. It is suggested that the routine surveillance should be undertaken by the Provincial Nature Conservation Divisions and, within the areas under its jurisdiction, by the National Parks Board. The authorities which would be concerned with the management steps necessary to maintain the conservation status of lotic systems would be primarily the Department of Water Affairs and, perhaps less frequently, the Departments of Mining, Agriculture and Cooperation and Development.

6.4.10 Costs of surveillance programme

The costs of a surveillance programme will depend very largely on the extent of the programme and the intensity with which it is undertaken. In fact, it is more probable that the costs will dictate the programme rather than the programme dictate the costs. However, in biological surveillance of the type which has been described above, it is usually staff costs that make up the major component. Capital equipment requirements for biological surveillance are low consisting mainly of stereo microscopes. In relation to other activities, running expenses will be low and consist mainly of transport and subsistence.

6.5 RECOMMENDATIONS

Arising out of this consideration of the surveillance of the conservation status of South African lotic systems, there are a number of recommendations, as follows:

1) Organizations thinking of initiating a surveillance programme should regard Hellawell (1978) as required reading for biological surveillance. They will find a wide survey of the methods of surveillance and their accuracy and representativeness.

2) There is a need in South Africa for top quality revisions of the known South African species of aquatic invertebrates. These revisions should include keys to the species in the aquatic stages, with adequate illustrations of the important taxonomic characters. They could be prepared along the lines of the British Freshwater Biological Association keys to various groups. It is particularly important that such keys be prepared for the mayflies and the caddis flies.

3) There is a need for the definition of conservation standards for lotic systems.

4) Intensive long-term surveillance of selected representative lotic systems is needed to gather basic information on the effects of the long-term drought cycle on the physics, chemistry and biology of the systems. The information would give the essential background on natural variability against which the importance of variation observed in routine surveillance can be assessed.

5) It is suggested that the research activities implicit in points 2, 3 and 4 above, be undertaken by universities and the CSIR/NIWR through the Nature Conservation Section of the Foundation for Research Development, and that such activities be clearly identified as research rather than surveillance activities.

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CHAPTER 7 RIVER CONSERVATION – IMPLICATIONS FOR LEGISLATION

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This chapter is presented in two sections. The first, (7.1), is introductory and is intended to serve as a background statement of the problem. The second section (7.2 to 7.8) is intended to deal more specifically with legislation aspects.

7.1 INTRODUCTION

7.1.1 Rationale for concern

Present demands for the resources of South African rivers have put severe strains on river systems. The stress on a natural system results in a progressively less productive resource base. Future demands for water from the river systems will be greater than at present as population numbers and expectations rise. In order to maximize the benefits of river systems for the present and future population of South Africa there must be effective control, management and education in all aspects of the hydrological environment.

One of the greatest problems in South Africa is the paucity of water resources as well as an unequal distribution of available sources. Consequently there is a potential conflict in priorities between the need to develop a river system as a water source and the need for ecological conservation. There is therefore a need for careful planning and effective management. Legislation provides the framework for all decision-making related to abstraction, engineering works, and the allocation of water resources.

7.1.2 River systems

1. In as much as a river is an expression of the interaction of climate and land use on the hydrological cycle, legislation to conserve river systems must of necessity encompass all land use in the catchment.
2. River systems may be considered in terms of fluvial and biological aspects, and/or in terms of water resources and biological resources.
3. There is a link between fluvial and biological aspects.

7.1.3 Present problems

1. A reduced and stressed hydrological resource potential.
2. A degraded ecological conservation status.

7.1.4 Principal causes

1. Change of flow volume (ratio of runoff from rainfall).
2. Change of temporal aspects of flow (decrease in flow days/seasonal volumes).
3. Change of water quality eg (salination, nutrients, sediments)

Contributory factors are:

a) Dams, diversions, abstractions.
b) Land-use changes, overgrazing, bush clearing, afforestation, inefficient use of water, land drainage and erosion.
c) Urbanization (effect on hydrograph and water quality).
d) Channel modifications (temporal and quality effects).
e) Agricultural pollution
   - irrigation return flows
   - fertilizers, biocides
   - sediment concentration.
f) Urban and industrial pollution:
   - effluent disposal
   - waste dumps
   - mining activities
   - atmospheric precipitation (potential long-term problem)
   - feedlots
   - storm water runoff.

7.1.5 Problems of achieving effective management

1. Lack of public awareness of the condition of rivers.
2. Lack of public awareness of the need for river and catchment conservation.
3. Lack of control over utilization of rivers because of insufficient staff to undertake policing and enforcing of legislation.
4. Fragmented control by different authorities and states.
5. Conflicting interests and priorities for development from the point of view of water resource development and ecological conservation.

7.2 ACTS OF PARLIAMENT RELATING TO RIVERS

7.2.1 Principal Acts:	Major department concerned:
1. Water Act No 54 of 1956	Department of Water Affairs
2. Forest Act No 122 of 1984	Department of Environment Affairs
3. Conservation of Agricultural Resources Act No 43 of 1983 (includes old Soil and Weeds Acts)	Department of Agricultural Economics and Marketing Department of Agriculture and Water Supply

4. Mountain Catchment Areas Act No 63 of 1970	Department of Environment Affairs
5. Health Act No 63 of 1977	Department of Community Health and Population Development
6. The Environment Conservation Act No 100 of 1982	Department of Environment Affairs

7.2.2 Partially relevant Acts:

1. The Physical Planning Act No 88 of 1967	Department of Constitutional Development and Planning
2. The National Road Act No 54 of 1971	Department of Transport
3. The National Parks Amendment Act No 57 of 1976 (Includes lake areas)	Department of Environment Affairs
4. The Nuclear Energy Development Act No 92 of 1982	Department of Mineral and Energy Affairs

7.2.3 Provincial Ordinances

In terms of river conservation the main areas of concern are:

1. Planning (townships).
2. Nature conservation (fish and aquatic biota).
3. Roads.
4. Public resorts (many riverine resorts are not under Provincial control).

7.2.4 By-laws

Matters relating to health and to access to rivers and dams are probably the most relevant.

7.3 ASPECTS OF MANAGEMENT AND CONSERVATION OF RIVERS COVERED BY EXISTING LEGISLATION

7.3.1 Abstraction and use of water

The Water Act, 1956 (Act 54 of 1956 as amended). Administered by the Department of Water Affairs (S. refers to the section of an act).

S.7 Any person lawfully at a place where he has access to a public stream may use water for primary purposes (stock drinking and household). Provincial administrations and divisional councils may use water for construction, maintenance and repair of roads.

S.9 Every riparian owner is entitled to his rightful share of the normal flow of a public stream provided water is not used wastefully.

S.9B A permit is required for construction operation or enlargement of any water work on any land which will enable more than 110 litres per second of water to be abstracted or diverted from a public stream.

S.10 Every riparian owner can use as much surplus water from a public stream as he can beneficially use.

S.11 Use of water for industrial purposes is subject to permission of a water court, except where water is supplied by local authority, by the Minister from a Government scheme, or water is allocated from a Government water control area.

S.12 If use for industrial purposes exceeds 150 cubic metres on any one day, a permit of authority is required for the use of the water regardless of the source of the water. This permit must accompany application to a water court as provided for in S.11.

S.13 A local authority requires a permit to construct, alter or enlarge any waterwork by means of which more than 5 000 cubic metres per day could be abstracted or diverted from a public stream.

S.30(2) The minister can control the abstraction of subterranean water in a subterranean water control area (eg BoMolopo Subterranean Water Control area). Note, excessive abstraction may reduce river baseflow.

S.30(5) Mines require permits to dispose of surplus underground water beyond the boundaries of the land on which it was abstracted.

S.56(3) The Minister may supply water from a Government waterwork.

S.62(2) The Minister may allow the abstraction from a Government water control area for any purpose.

7.3.2 Impoundments

The Water Act, 1956. Administered by the Department of Water Affairs.

S.9B A permit is required for an impoundment of more than 250 000 cubic metres in a public stream.

S.13(3) A local authority requires a permit to construct, alter or enlarge any waterwork by means of which more than 125 000 cubic metres of public water can be impounded.

S.19 A riparian owner to a public stream may apply to a Water Court if he is aggrieved by an upper riparian owner storing a greater quantity of surplus water than he could be reasonably entitled to use.

S.25 In the case of impoundment of any quantity of public water for soil conservation purposes, the Minister can prescribe specifications and conditions to ensure that the public water is not wastefully impounded.

7.3.3 River deviations and modification of river banks

The Water Act, 1956. Administered by the Department of Water Affairs.

S.20 No person shall alter the course of a public stream, except under the authority of a permit issued by the Minister (not applicable in the case where the course of a public stream is altered in accordance with a Water Court Order, by or under the authority of an irrigation board, by a local authority within its area of jurisdiction, or by the construction of a soil conservation work in terms of the Conservation of Agricultural Resources Act No 43 of 1983).

The Conservation of Agricultural Resources Act. Administered by the Department of Agriculture.

S.6 Control over diversion of runoff water from one water course to another as well as over the obstruction to natural flow pattern.

7.3.4 Winning or washing of sand, gravel or stone

The Mines and Works Act 1956 (No 27 of 1956). Administered by the Department of Mineral and Energy Affairs.

Authority required from a Government mining engineer (these activities are defined as mining activities).

Physical Planning Act, 1967 (Act No 88 of 1967). Administered by the Department of Constitutional Development and Planning.

S.6B Permit required for winning or washing of sand, gravel or stone.

The Water Act, 1956. Administered by the Department of Water Affairs

S.11(1A) The Minister can authorize by permit anybody who has the right to use water for agricultural purposes to use part of that water for the winning or washing of sand, gravel or stone.

S.12 A permit is required if water use exceeds 150 cubic metres on any one day.

S.21 An exemption permit is required if the effluent returned to source does not comply with gazetted standards.

7.3.5 Effluent discharges and prevention of water pollution

The Water Act, 1956. Administered by the Department of Water Affairs.

S.21 All effluents occasioned by the use of water for industrial purposes must be purified to gazetted standards and be returned to the source of origin of the water at point of abstraction.

Non-compliance of any one or both basic requirements requires an exemption permit. This section also controls illegal discharge of industrial effluents down municipal stormwater drains and pollution by feedlots and the breeding of fish or any mollusc.

S.22 Prevention of pollution of any private or public water on or under any land including stormwater drainage across any property, including feedlots (regulations in draft).

S.23 Any person who wilfully or negligently does any act which could pollute public or private water, including underground water, shall be guilty of an offence.

S.23A Prevention of pollution of water through farming operations. The Minister can prescribe steps to be taken to prevent pollution of public or private water, including underground water by farming operations.

S.24 The Director-General can issue directions for additional works to be constructed to prevent the pollution of water (including pollution from feedlots).

The Conservation of Agricultural Resources Act 1983. Administered by the Department of Agricultural Economics and Marketing.

S.6 The Minister may prescribe control measures regarding the protection of water sources against pollution on account of farming practices (regulations outstanding).

The Health Act. Administered by the Department of Health.

S.20 Local authorities shall take steps to prevent the pollution of any water intended for its inhabitants.

S.33 The Minister may make regulations relating to the prevention of the spread and eradication of vectors of any communicable disease.

S.36 Regulations for intensive animal feeding systems as well as mollusc nurseries and fish-farming activities including the purity of water issuing therefrom (regulations controlling feedlots are being drafted).

S.38 Regulations in respect of the provision for night soil and rubbish removal, and sewage treatment.

The Environmental Conservation Act, Act 100 of 1982. Administered by the Department of Environment Affairs.

S.12(2(a)) Control over solid waste disposal (regulations published for comment administration to be delegated to Water Affairs)

7.3.6 Access to river

The Water Act, 1956. Administered by the Department of Water Affairs.

S.70 The Minister can make regulations to control access to any area submerged or to be submerged (regulations pending).

S.141 Any person entitled to use public water or water found underground shall be entitled to claim under the Water Act, temporarily or in perpetuity, such servitudes of abutment, aquaduct, drainage or storage as may be necessary for, or incidental to, be exercising of his rights. Access may be allowed through common law/servitude rights.

7.3.7 Construction of bridges

The Water Act, 1956. Administered by the Department of Water Affairs.

S.59(4) The State President can proclaim dam control areas irrespective of whether public or private streams are involved. No permanent structures may be constructed without a permit from the Minister. (Under section 23 one may be prosecuted if pollution occurs).

7.3.8 Water sports and boating

The Water Act, 1956. Administered by the Department of Water Affairs.

S.70 The Minister can make regulations to control the use of boats on submerged (impounded) areas. (Regulations exist for those dams not handed over to provincial authorities eg Vaal Dam).

S.164 (bis) The State President can proclaim any area a water sport control area.

7.3.9 Floodplain planning and catchment control

The Water Act, 1956. Administered by the Department of Water Affairs.

S.59(2) The State President can proclaim a catchment control area:

- if the flow of a public stream should be controlled for the prevention or control of silt or the purpose of lessening the possibility of flood damage.

- if any land is required for the protection of any portion of the catchment area.

S.59(4) The Minister may proclaim dam control areas. No township development or permanent structures may be established without a permit from the minister.

S.70 The Minister may make regulations to provide for the preservation of any area within a government water control area, a subterranean control area or a catchment control area.

S.169A Certain flood lines, namely one in twenty years if catchment exceeds one square kilometre, one in fifty if catchment exceeds five square kilometres, should be shown on township development plans.

The Physical Planning Act. Administered by the Department of Constitutional Development and Planning.

S.4 Land can be reserved for the utilization of a specific natural resource or as a nature conservation area.

S.6A Guide plans can be prepared (eg the Vaal River guide plan) which can inter alia prohibit township development close to rivers or below certain floodlines (not binding on mining activities).

The Conservation of Agricultural Resources Act 1983. Administered by the Department of Agricultural Economics and Marketing.

S.6 Control over cultivation of land within the floodplain as well as on the drainage and development of vleis.

The Forest Act 1984 (Act No 122 of 1984). Administered by the Department of Environment Affairs.

S.8 Control of the planting or replanting of trees in any given area (for the protection of natural water sources).

S.13 Protection of trees on private land as well as the prevention of erosion and the reclamation of drift sands, maintenance of the natural diversity of species and the preservation of tree-dominated biomes.

S.18-27 Deals with the prevention and combatting of veld, forest and mountain fires.

7.3.10 <u>Sinking of boreholes (relevant to rivers where baseflow may be affected)</u>

The Water Act, 1956. Administered by the Department of Water Affairs.

S.30(2) The Minister can make regulations to control the sinking of boreholes as a subterranean water control area. (Subterranean water control areas were proclaimed in terms of the Water Conservation and Irrigation Control Act of 1912 or can be proclaimed in terms of section 28 of the Water Act of 1956).

S.30 The Minister may authorize the drilling of boreholes or acquire a right to existing boreholes, or abstract water from such boreholes and supply to other parties in the national interest (applicable only to boreholes on Government property or on boreholes on property to which the Minister acquired rights by agreement with owner).

7.3.11 Soil conservation and veld management practices

The Water Act, 1956. Administered by the Department of Water Affairs.

S.25(2) The Minister can prescribe specifications and conditions subject to which any soil conservation works may be constructed to ensure that public water will not be wastefully impounded or detained or used for the flooding of veld to the prejudice of lower riparian owners or any owner of a waterwork within a legal water right.

The Conservation of Agricultural Resources Act 1983. Administered by the Department of Agricultural Economics and Marketing.

S.6 Control over excessive soil loss in the catchment including:

- cultivation of virgin soil
- utilization and protection of sloping land
- utilization and protection of vleis and watercourses
- utilization and protection of vegetation (grazing land)
- prevention and control of veld fires
- restoration or reclamation of eroded land

This section also provides for control over the construction, maintenance or removal of soil construction works, and the spread of noxious weed and invader plants.

7.3.12 Control authorities and offices other than State employees

The Water Act, 1956. Administered by the Department of Water Affairs.

S.68 The Minister may in respect of any government waterwork or a subterranean water control area, a government water control area or a catchment control area or any catchment area or areas, appoint an advisory committee to advise him on matters connected with the preservation, conservation, utilization, control, supply or distribution of water resources, and water, or any other matter which he may from time to time refer to such committee. (This can also include ecological considerations of rivers within catchments). At least one half of the members appointed shall be selected from amongst public persons nominated by members of the public. (Members of all committees/boards are financially assisted).

Chapter 6 Irrigation boards

These boards are delegated with powers and duties to protect the sources of water of any public stream and to control water abstraction from streams, and usually consist of a group of farmers nominated by the local community and appointed by the Minister.

Chapter 7 Water boards

These boards can be established to control and to provide water for urban, industrial or agricultural purposes in given areas. Authority also includes the operation and control of waste water treatment plants. Members are appointed by the Minister from nominations submitted by the public within the area of control.

The Conservation of Agricultural Resources Act 1983. Administered by the Department of Agricultural Economics and Marketing.

S.4 The executive officer may appoint employees of both local authorities and irrigation boards established in terms of the Water Act as honorary weeds inspectors.

S.14 The Minister may establish a conservation committee for an area to promote the conservation of the natural agricultural resources as well as to advise the department on any matter in the application of the Act.

The Forest Act. Administered by the Department of Environment Affairs.

S.6(1) The Director-General may appoint any person as an honorary forest officer (with most of the same powers as a forest officer).

S.19 The Minister may establish a fire control committee comprising landowners in the relevant area.

S.82 A court which imposes a fine for an offence in terms of this Act may order that a maximum of one quarter of the fine imposed be paid to any member of the public (excluding honorary officers) as remuneration for providing the information leading to the conviction.

The Environmental Conservation Act, 1982. Administered by the Department of Environment Affairs.

S.2,3 Council for the Environment. The Minister may appoint any experts as members of the Council to advise him on coordination and recommend priorities in connection with conservation of the environment.

S.9 The establishment of management committees in proclaimed nature areas, comprising owners, users and authorities involved in the area to see to conservation management.

S.11 The Director-General may appoint honorary environment officers to perform such functions as relate to conservation of the environment.

The Mountain Catchment Areas Act. Administered by the Department of Environment Affairs.

S.6 Advisory committees may be established by the Minister to advise him on matters relating to conservation, use, management and control of land and prevention of soil erosion within a proclaimed mountain catchment area. Within five kilometres of a mountain catchment area they can advise on control of invasive vegetation.

S.7 The Minister may establish fire protection committees.

7.3.13 Information relating to floods and polluted water

The Water Act, 1956. Administered by the Department of Water Affairs.

S.168A The Minister may at any time in respect of any public stream or a government waterwork, make available to the public information relating to:
a) a flood which has occurred or which is expected to occur; and
b) the presence of any pollutant in the water.

7.3.14 Environmental impact studies

The Water Act, 1956. Administered by the Department of Water Affairs.

S.58 The construction of a government waterwork of which the estimated cost exceeds R10 million is subject to approval of a White Paper by Parliament. The Act prescribes particulars to be contained in the White Paper. Over and above technical information relating to the works and the use of water, the Minister may report on any other matter. It is the Department of Water Affair's policy to include environmental impact statements under this provision. An EIS is however, not obligatory.

7.4 SUGGESTIONS FOR ADDITIONAL LEGISLATION AND/OR CONSOLIDATION OF EXISTING LEGISLATION

1. There is a need for a clear definition of responsibility for educating and informing the public about the importance of river conservation.

2. A useful addition to existing requirements for environmental impact analysis of river development projects would be an obligatory comparison of the costs and benefits of allocating scarce water resources for the downstream ecosystem.

3. For effective use of resources, and the maintenance of river systems, the only sensible management unit is the whole catchment. The establishment of catchment authorities, comprising specialists from all relevant disciplines, and with full responsibilities for catchment control, should therefore be a priority goal.

7.5 SHORTCOMINGS IN THE ADMINISTRATION AND APPLICATION OF EXISTING LEGISLATION

1. There is a lack of sufficient catchment control areas proclaimed with a view to controlling activities affecting river systems.

2. There are few incentives to the public to report pollution incidents and other contraventions of existing acts.

3. Legislation controlling water sports and boating should be extended to all public waters.

4. There is a shortage of staff to police water abstraction and effluent discharges.

5. The promulgation of regulations in terms of the various existing acts must be expedited so as to activate relative clauses in the acts.

6. Environmental conservation generally, and river conservation in particular, is not considered a high enough priority for funding and organization to allow the most effective management and conservation of rivers and their catchments. This may largely be solved through promotion of public awareness leading to pressures which will render the above a high priority.

7.6 ASPECTS RELATING TO THE EFFECTIVE MANAGEMENT AND CONSERVATION OF RIVERS NOT COVERED BY EXISTING LEGISLATION

1. Permission for dams with a capacity smaller than 250 000 cubic metres is not required outside of government water control areas.

2. Outside of subterranean water control areas no permission is required for sinking boreholes (overexploitation of groundwater can lead to progressive reduction of baseflow of rivers).

3. There is no legislation pertaining to control of river systems in totality.

4. There is no limitation to the aggregate storage capacity that may be provided in any catchment or part of a catchment.

5. No control exists over rivers flowing through self-governing or national states.

7.7 SUGGESTIONS FOR ADMINISTRATIVE CHANGES NECESSARY TO ACHIEVE EFFECTIVE ENFORCEMENT OF EXISTING LEGISLATION

1. Staff and funds should not be cut any further from authorities responsible for enforcement of laws relating to the conservation of rivers.

2. Air and water pollution should be administered by the same authority.

3. Objectives and functions of authorities involved in matters related to the conservation of rivers ironment need to be re-evaluated and redefined to prevent duplication and fragmentation of responsibility and function, and wasteful use of trained manpower.

4. Control over rivers should extend their full length and not end at political boundaries.

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CHAPTER 8 RESEARCH AND INFORMATION NEEDS

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8.1 PREAMBLE

It is not difficult to produce a list of potential research projects which need to be done to provide essential information on rivers. One has only to consult several of the more recent works which include such lists as Noble and Hemens (1978), Anonymous (1984), Ward et al (1985) and O'Keeffe (1986). The emphasis of this chapter will not be on listing but on identifying the research and information needs, stressing the need for long-term ecological research with predictive capability, and discussing the creation of the necessary research climate to stimulate creative science and develop a cooperative, interdisciplinary approach. Hence an holistic view is taken of research needs. The term "holistic" as used by us in this chapter means all the factors (biotic, abiotic, climatic, anthropogenic) which have an influence either directly or indirectly on the river environment. A list of research project proposals is provided in the Appendix to this Chapter.

8.2 INTRODUCTION

Historically western science has operated mainly on the basis of reductionism (Talbot 1980). The complex functioning of river systems has been divided into a number of individually researched simpler compartments as they are easier to understand individually than collectively. A more profitable approach is to shift the emphasis away from reductionism to reassemble the components of the system, ie a synthesis approach. At the ecosystem level of study, stream ecologists have led the way internationally by recognizing that the catchment is the basic unit of study taking into account the role of geomorphology, terrestrial-riparian and aquatic linkages as well as climatic influences on the functioning of the ecosystem (Barnes and Minshall 1983). In other words we must not canalize our research approach to the river only, but must take an holistic view of rivers as their conservation is part of a multiple-use management plan aimed at conserving river functions within a framework of essential exploitation (O'Keeffe 1986). To offer advice on the permissible levels of exploitation of rivers requires a thorough understanding of the biota and the fundamental processes governing the function of the system. This leads us to an interdisciplinary research and information gathering approach, which should allow the specialists enough freedom to pursue and advance in their own fields of fundamental research yet encourage them to report their findings in a way suitable for holistic syntheses. Information and research findings should also be disseminated to libraries and other sources of data capture where they can be abstracted and become readily available and easily retrievable. Furthermore, the implementation of research findings should be followed up and the outcome monitored where feasible.

Since environmental issues extend across scientific disciplines, there is a need for a cooperative climate to enable coordination of interdisciplinary research. The value of basic fundamental research as opposed to applied or problem-orientated research should also not be overlooked in the funding of research. Sustained long-term research must be encouraged and cognisance should be taken of long-term periodic phenomena such as rainfall patterns (Vines 1980).

River conservation in South Africa has mainly been a two-sided process of reacting or not reacting to environmental problems, which in most cases are anthropogenic in origin. This approach has little chance of lasting success in conserving the environment. The reactive approach is usually carried out in a disjointed ad hoc fashion. A problem is perceived, usually a threat to a species, and conservationists react. This approach focuses on effect rather than cause and cure rather than prevention. Vallentyne (1978) calls this type of approach "fire-fighting" and considers it to be counterproductive, detracting from the ability of scientists to contribute real solutions to the prevention or cure of the problem. One way of overcoming the reactive approach to conservation is to include river conservationists at the initial planning stages of development projects thus allowing them to investigate alternatives which will be less disruptive to the ecosystem. Furthermore, ecologists should have an active participation in development and decision-making stages of the planned project. Conservationists must also ensure that developments carried out to improve man's living standards are economically and ecologically sustainable and not only beneficial in the short term. Ecologically unsound development which is not sustainable eventually lowers the human carrying capacity of the environment and therefore ultimately defeats the original purpose of the development (Talbot 1980), (Figure 8.1).

8.3 HISTORICAL REVIEW OF RIVER CONSERVATION RESEARCH

Barnes and Minshall (1983) state that stream ecology is coming of age, having progressed through descriptive studies and experimental testing to the formulation of new concepts in less than 25 years. O'Keeffe (1986) reviews ecological research in South African rivers and identifies the lack of an overall conservation policy for rivers in South Africa. He proposes an holistic view of river conservation in which external influences in the river system as well as multiple uses of the river are incorporated. O'Keeffe's holistic approach aims at managing river utilization and integrating conservation with other priorities to maximize the use of the river and to minimize detrimental effects to its essential functions (Chapter 2). Professional advice, ecological planning and conservation policy must become an integral part of river development projects.

The emphasis on research needs for inland water ecosystems in South Africa (Noble and Hemens 1978), was previously on impoundment studies (Table 8.1) and this has been the direction taken by Inland Water Ecosystems since 1978 (Anonymous 1984).

TABLE 8.1 A summary of the research needs for inland water ecosystem outlined by Noble and Hemens (1978)

Categories of future action	Flowing water	Impoundments	Coastal lakes	Estuaries	Vleis	System	Other+
1 Synthesis of existing information on priority planning regions	-	-	-	-	-	11	-
2 Synthesis of existing information on selected topics	3	11	-	1	-	1	10
3 Short-term surveys and investigations	2	8	-	5	3	-	2
4 Monitoring (long-term)	1	1	-	1	-	-	2
5 Detailed research (includes fundamental research)	2	12	1	2	2	-	22
TOTAL	8	32	1	9	5	12	36

+Other - is catch-all section including pollution, autecological, taxonomic, parasites, pathogens studies, which could occur in any section of the river system.

TABLE 8.2 Institutes where river-related research was carried out, type of research and biota studied as reported in the National Register for Scientific Projects 1984

Institutes	**No.**
Universities	44
Museums	3
NIWR (CSIR)	9
Provincial Administrations	5
Other	8
TOTAL	69

Biota studied	**No.**
Fish	22
Fish parasites	2
Invertebrates	7
Snails	3
Pest species (Simulium)	1
General ecology	14
Other	20
TOTAL	69

Type of Research	**No.**
Management	10
Surveys/Monitoring	2
Taxonomy/Genetics	3
Developmental biology/Physiology	4
Autecology/Synecology	12
Distribution	10
Systems ecology	3
Hydrology/Chemistry	8
Reviews/Syntheses/bibliographies	3
Environmental Impact Assessment	6
Pollution monitoring	5
Parasitology	3
TOTAL	69

According to the National Register of Scientific Projects 1984, 69 out of 422 projects listed were on river-related research (Table 8.2). Although some completed projects were included and other projects already in progress were not, the list provides an overall view of where most research was carried out and indicates the major types of research as well as biota covered by these projects. Universities are the institutes where the majority of river-related research projects are carried out and fish are the group on which most research was conducted (Table 8.2).

An analysis of the literature reviewed by O'Keeffe and O'Keeffe (1986) reveals a steady decline in the percentage of literature related to taxonomic studies and a gradual increase in the literature related to other disciplines such as ecology, or reviews and syntheses (Table 8.3). Viewed in the international context this is a logical progression of science but if one considers that Pennak (1978) stated that taxonomic research in the United States was at least 10 to 30 years behind that of Europe then we can appreciate how far behind the taxonomic state of research in South Africa must be. As an example, Coaton (1974) reported a serious lack of taxonomic research in southern Africa and pointed out that the majority of our insect fauna was studied by overseas specialists. The whole of the extremely biologically rich Afrotropical region attracted only 7,08% of the world's available interest in insect classification. In the ephemeropteran family Baetidae to date, 41 species have been described in the adult stage but only 29 of these are known in the aquatic nymphal stage. A further 22 species of Baetidae are known from the aquatic nymphal stage only. Scott (in press) states that only 14% of the known adult Afrotropical Trichoptera (an insect group that is considered as better known taxonomically than most other insects with aquatic developmental stages) are described in the aquatic larval stage. Both Ephemeroptera and Trichoptera spend more than 95% of their life cycle duration in water, which illustrates the serious lack of basic knowledge which we need to understand the ecology and functioning of our aquatic environments and rivers in particular.

Even on this limited basis of taxonomic and biological information available there has, however, been a steady increase in the literature pertaining to the synthesis of data and development of predictions and management options available to river and conservation administrators.

In summary the emphasis of river research in South Africa has swung from a descriptive phase of the biota through an ecological and functional study of the biota in the system to a management and predictive phase over the last 30 years. Figure 8.1 encapsulates these three phases.

8.4 PHILOSOPHY OF RESEARCH

8.4.1 International approach

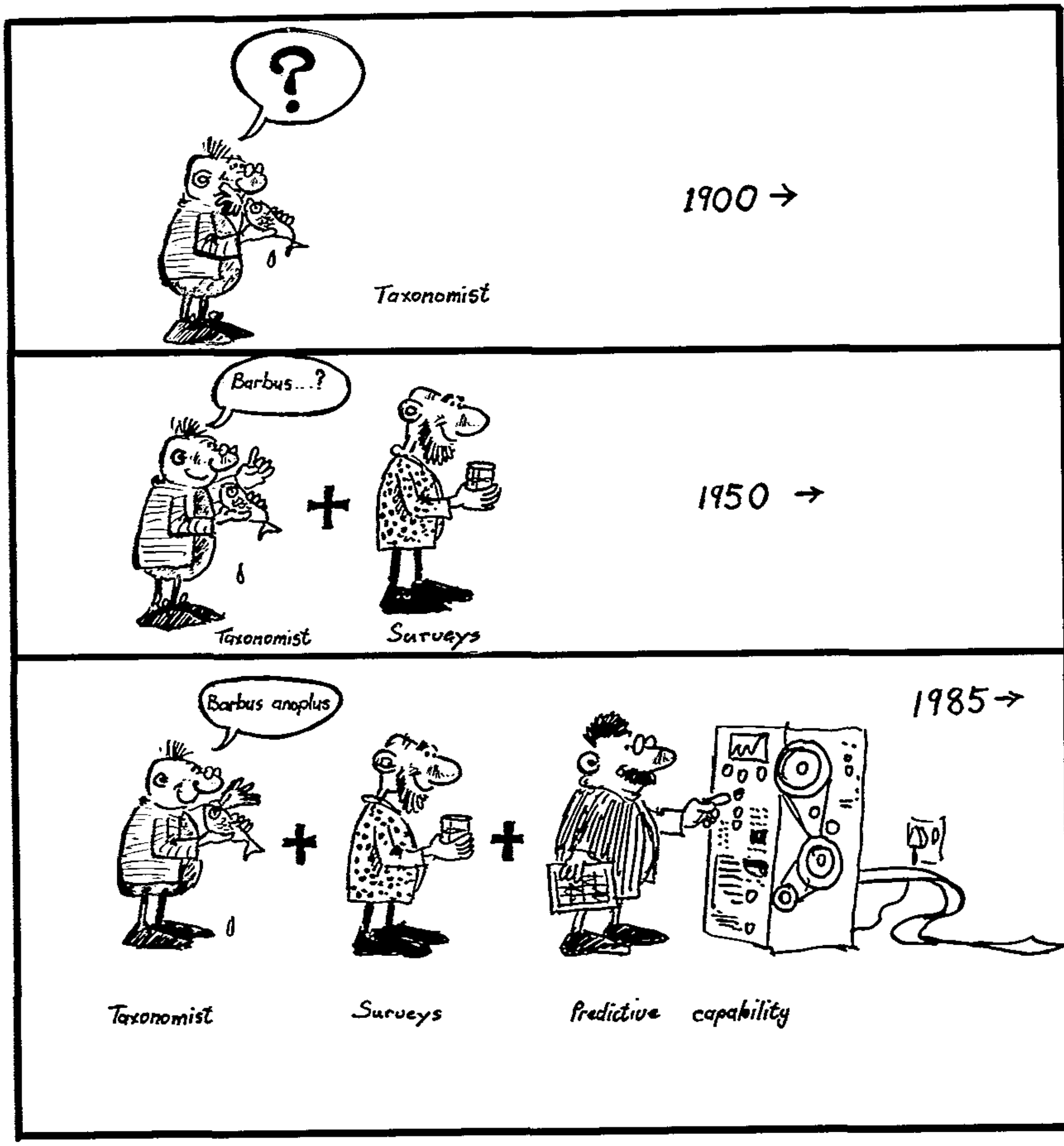
Each river basin is unique in terms of administrative, demographic, resource distribution (Pantulu 1983). Therefore each one must be studied and subjected to individual and intensive river quality assessment to provide a proper basis for management of the land and water resources (Weaver 1981). Cairns (1981) has stated that the most important need is the development of predictive capability and validation of prediction accuracy. Ecology has advanced from a largely descriptive discipline to a predictive science of considerable importance to nature conservation (Siegfried and Davies 1982).

TABLE 8.3 Summary of literature published on various aspects of river related research and the percentage of literature in each category between 1850 and 1984*. (Data extracted from O'Keeffe and O'Keeffe 1986)

A. Number of references	pre 1900	1900-1930	1931-1950	1951-1970	1971-
	%	%	%	%	%
Conservation	-	-	-	1,5	5,9
Distribution	-	8,6	2,8	13,3	13,0
Survey	-	-	-	1,3	1,9
Bibliography	-	-	-	0,3	2,1
Review	-	2,9	2,8	4,5	9,5
Pollution	-	-	-	10,0	8,7
Taxonomy	100,0	80,0	75,0	32,3	12,3
Ecology	-	8,6	20,0	37,0	46,8
TOTAL	4	35	36	400	633
B. Number of pages					
Conservation	-	-	-	0,4	3,5
Distribution	-	0,8	1,6	12,7	10,5
Survey	-	-	-	2,7	1,0
Bibliography	-	-	-	0,2	0,9
Review	-	0,1	0,7	1,9	8,3
Pollution	-	-	-	8,9	8,4
Taxonomy	100,0	98,2	91,6	36,2	18,1
Ecology	-	0,8	6,1	37,1	49,4
TOTAL	95	1481	1103	8337	10003

*Publications where pages were not cited are categorized as:

Report = 5 p.
Hons Thesis = 15 p.
MSc = 50 p.
PhD = 150 p.
Books = 200 p.



HISTORICAL REVIEW OF RIVER CONSERVATION

FIGURE 8.1 An analysis of the literature pertaining to river studies in South Africa, reveals a steady decline in the percentage of literature related to taxonomic studies. As the cartoon shows the taxonomist was joined by people conducting surveys and today we have the systems approach, based on long-term studies, from which we can predict any future changes (perturbations) to the river system. You will note that the taxonomist still plays an important role, but is now part of an inter-disciplinary team of scientists.

Pantulu (1983) listed six human failures in water management projects, which are applicable to river conservation in South Africa: short-sightedness of planning; lack of perspective on the part of development planners; imperfect coordination with co-basin countries, inadequate research on immediate and long range effects; poor scheduling and implementation of relevant activities; and inadequate supply of technically trained manpower.

The trend is to manage the environment holistically as everything is interrelated ecologically (Talbot 1980). In river conservation the systems approach (as defined by Patten and Auble 1981) which has predictive capability gained through long-term research and high quality data accumulations should be used. All user agencies involved must have effective liaison and coordination and there must be a central environmental policy. O'Keeffe (1986) notes that there is an urgent priority to define a consistent policy embracing conservation objectives and management strategies for South African rivers.

The World Conservation Strategy clearly points out that to be successful, development must not only succeed in the short term, but must also be sustainable, economically and ecologically in the long term (Talbot 1980). The international approach to river conservation research has tended to correlate studies and data into a common user pool. Monitoring and research data has been synthesized and can be used to advise multiple basin users on how to manage the river and its catchment to ensure conservation of the whole system.

8.4.2 Basic or fundamental research

Historically, scientific research and development has been a type of free enterprise system with small laboratories throughout the world following their pursuits of new and promising lines of enquiry (Wallace 1981). The researchers determine, in collaboration with their peers, the direction of research.

Fundamental (basic) research is research aimed at extending the frontiers of knowledge and is usually academic in nature. Unfortunately some managers equate this to "curiosity-orientated research" - or science for science's sake. Vallentyne (1978) has pointed out that "curiosity-oriented" research is a fiction: scientists do not collect facts or study relations randomly. The most influential facts and relations have a chance of recurring and it is in this recurrence that the great practicality of science lies. Unfortunately governments sometimes fail to appreciate the long-term practical importance of sound basic research. Comroe and Dripps (1976) found that "basic research" pays off in terms of key discoveries almost twice as handsomely as all other types of problem-oriented and applied research and development combined. In contrast, applied research is short-term crisis-oriented with the research component designed to answer questions originating from management which usually deal with the effect and not the cause.

Stream ecologists have only recently realized the opportunities that exist in streams to test hypotheses and develop principles which have broad applicability to ecology (Barnes and Minshall 1983). Williams (1983) has stated that river ecology has become one of the most exciting and active areas of modern scientific research. Therefore fundamental research, if one believes in separating it from applied research, is necessary to provide solutions in the short and long term for many of the problems which occur or will occur in the river systems of South Africa.

Some suggested research programmes (see Appendices to this chapter) would improve the understanding of how rivers function, which is necessary for the resolution of possible long-term problems.

There are at least two serious drawbacks to the political drive for greater relevance of scientific and technological research. The first is a failure to distinguish the time frame of application and the second is an uncritical acceptance, because if it is "applied" research it is funded whereas "basic" research is not funded (Vallentyne 1978).

8.4.3 Training of researchers in the right direction to meet future needs

Most of the funds and manpower of the Committee for Inland Water Ecosystems during the past five years have been directed towards the investigation of the effect of eutrophication, sediments and suspensoids on biological production in impoundments (Anonymous 1984). This would imply that universities have trained people in these fields during the course of their programmes. We therefore suggest a switch of some of this training to producing stream ecologists.

Vallentyne (1978) has suggested that we need a new breed of scientists. Traditionally, the graduate student in universities is trained to work alone. However, when he joins the work force he is expected to join a cooperative, interdisciplinary team of scientists. His training has not prepared him for this change. Vallentyne (1978) even suggests that cooperative graduate theses be initiated on a joint pass-fail basis. Traditionally this 'rubs against the grain', but researchers are innovative and this suggestion should be investigated.

We need an inventory of our available research expertise for studying river conservation, so that we can identify fields where there is a shortage and plan the training of scientists in the appropriate direction.

8.4.4 Research centres

Wallace (1981) noted that the trend towards larger more centralized centres for good research is a reflection of an overall increase in the national, institutional controls over research science. Stankiewicz (1979) found that there was an increase in productivity and research effectiveness at centres where groups did not exceed three to seven scientists, and that when these groups grew larger, productivity and research performance declined. The proposed Institute for Fundamental Biological Research, which would house up to 70 researchers (Potgieter 1985), would be unproductive according to Stankiewicz (1979). There is an attractive cost effectiveness of large institutions, but the consequences for productivity of research may be profound. We recommend that the existing institutes, museums, universities and government departments, which are dotted around the country, and in many cases understaffed, would be in a better position to provide good research on river conservation and other fundamental biological research than one big centralized institute.

The mere fact that these institutes are scattered all over the country makes field research in local areas cheaper and more effective. With modern communication and computer facilities the exchange of information has become more efficient. Wallace (1981) came to a similar conclusion after reviewing large research institutes in Canada. It is better to establish more, smaller, stable research laboratories than to concentrate funds and attention on fewer, larger institutional facilities. In the case of museums, too, it is not merely the institute and its people, but the vast collections of material that are needed for fundamental taxonomic research that have to be considered. A list of where reference and research collections of fauna and flora are housed would indicate the extensive distribution of research centres. Such a list would also indicate where researchers can send their material to make it internationally available to the scientific community; as an example we mention the National Collection of Freshwater Fish and Invertebrates at the Albany Museum, Grahamstown.

There is also the problem with large centres that too much attention is devoted to the concerns of the organization, administration and management instead of the facilitation of research.

8.4.5 Research climate

The research climate is defined as the sum of psychological and physical factors affecting creativity in research. It is the relationship between the scientist and the external forces that impinge on his performance in research. If the researcher is constantly shunted from trying to solve one crisis after another, instead of conducting long-term research, which would prevent crises, or at least predict them, the research climate will be unstable, and the morale of the researcher will be eroded.

Social research studies show that organizations that allow for effective, meaningful worker input into policy and administrative decisions are much more productive than those that follow autocratic approaches (Wallace 1981).

A scientist is programmed by his training and occupation to think in the long term, unlike a manager whose role demands short-term decisions and therefore pushes researchers into unimaginative 'quick-and-dirty' research (Vallentyne 1978).

A scientist has usually chosen his career because of a particular line of interest. It is therefore in his chosen specialist field where he will make the most significant scientific contributions. Hence it will be most productive to encourage the pursuance of a scientist's chosen field of research rather than channelling his talents into a marginal field of interest.

In smaller well-established institutes such as museums and universities where researchers are free to follow their chosen line of research and where research material and equipment have been accumulated over a long period, there is a good research climate and a tradition of fine research. The contributions museums have made toward South African science is out of all proportion to their limited size and the time their staff can devote to research (Crompton and Talbot 1964).

8.4.6 Long-term ecological research ("fire-fighting" is the antithesis of science)

Research in ecology has traditionally been funded for short periods of time and conducted at isolated localities or at a few sites at most. Such research data are not conducive to answering problems posed by the ecosystem, which spans a much greater temporal and spatial scale than the duration and coverage of the research projects (Callahan 1984). The principal objective of the Nature Conservation Research Section of National Programmes for Environmental Sciences (NPES) is to stimulate and coordinate the research needed for the development of ecological hypotheses and testing of principles and practices necessary for the conservation of indigenous species and communities together with their habitats and life support processes for the long-term benefit of mankind (Anonymous 1984). Similarly the committee for Inland Water Ecosystems (IWE) has realized the need for sustained research into the fundamental aspects of the functioning of our freshwater resources (Anonymous 1984). These clear policy statements are a relief to the scientific community. They ensure that researchers will not all be quickly and abruptly shifted into research programmes which are short-term and crisis-oriented (fire-fighting) and are supposedly designed to answer management-derived questions. In some countries governments have stated that they cannot fund long-term research, but this can be seen as simply an erosion of responsibility (Vallentyne 1978), and really the question is, can they afford not to fund long-term research?

Many managers see aquatic environmental research as short-term research with the promise of immediate, site-specific benefits (Vallentyne 1978). Because of this short-term approach in which there is inadequate preparation time, continuity and moral support, the research climate can be harmed. Traditional patterns and rules for planning of research and competing for funding have been counterproductive to a science that deals with many phenomena occurring over decades or centuries. Also in asking for funding one has to clearly define the research proposal and suggest where the research is going as well as set target dates for completion of various proposed sections of the work. By definition this is no longer research because if one has a preconceived idea, it no longer means that a new source of information to science will be the product. Long-term studies must be orientated towards question/hypothesis formulation and testing.

Environmental biology deals with processes occurring over long periods of time, yet there is a serious contradiction between the time scales of many ecological phenomena and the support to finance their study (Callahan 1984). For example, the effects of clear-cutting on a river basin cannot be evaluated in less than 5-10 years, and thus it would be inappropriate to fit this research into a typical two to three year research funding cycle.

A research group needs a firm assurance of continuity of the research programme, and that it will not be terminated for more immediate, here-and-now information needs. Scientists tend to view any investment of time in crisis research, except under the most urgent conditions, as counterproductive to the increase of overall scientific knowledge and that it detracts from their ability to contribute generalized solutions to the prevention and cure of the crisis and also acts as a detraction or break in their planned research programme.

The trend of short-term gain must be arrested and reversed or many ecosystems are likely to become less resilient to perturbations and hence also less diverse and variable in their biota (Siegfried and Davies 1982). Fortunately, there is an emerging public recognition in some countries that many of our present environmental problems stem from a past lack of attention to the long term.

Proposals for long-term river conservation work would take major efforts to compile. The scientists and institutes would be making considerable commitments for example in terms of time and facilities for the long term. Several other constraints on long-term research are staff turnover and the requirements that researchers must get results and publish constantly to satisfy research funding agencies. In America, most proposals for long-term ecological research were orientated towards testing hypotheses or answering questions on ecosystem structure and function (Callahan 1984). This is exactly what is required for river conservation in South Africa. Botkin et al (1982) have noted that to define permissible limits of 'natural' change within which the ecosystem remains 'safe' (ie it will not change irrevocably or to such a degree that major efforts are needed to restore it) requires long-term, detailed studies to which there are no short-cuts. The main weakness of many environmental impact studies has been the lack of predictive capability (Callahan 1984) which can only come from long-term work.

The six recommendations made by Callahan (1984) for long-term ecological research are very applicable to river conservation projects:

1. Actively promote well researched sites to make their availability and potential known to the scientific community at large.

2. Guarantee continued site security and availability.

3. Provide mechanisms to resolve possible conflicts in use of the sites by different projects.

4. Provide bibliographies and libraries of publications related to each site.

5. Provide reference collections of locally obtained biological and physical specimens.

6. Develop on-line systems for data storage, retrieval and manipulation.

The ultimate value of the long-term programme approach is that it should lead to new and also improved ecological theories which will aid in diagnosing and solving the increasing array of fundamental ecological problems in our river systems. Both IWE and the Nature Conservation Research Section of NPES have promised support for the long term and therefore should be willing to receive proposals. It is now up to the scientists to make the proposals.

8.4.7 Holistic approach

We must not 'canalize' our approach to river conservation. A central problem facing modern conservation is basing research on individual, isolated objectives, which is not well adapted to approaching environmental problems from a realistic, holistic perspective. The management of our environment needs to be done holistically because everything is interrelated ecologically. Many research programmes are fragmented and deal largely with isolated problem solving. This simplistic approach works on the assumption that one part of the environment is separate from and can be dealt with apart from the rest (Talbot 1980). Since many environmental questions are complex they require an interdisciplinary approach. In South Africa, the Foundation for Research Development enables scientists from different backgrounds, institutions and parts of the country to work together to identify problems requiring attention, to contribute ideas, to plan joint action and to synthesize findings (Anonymous 1984). However, vested departmental interests and competition for funding can make effective, interagency, interdisciplinary research impossible. In addition limitations in manpower, time and funds are restrictive and are real hurdles to the holistic approach.

In river conservation in South Africa we cannot neglect the fact that the human species must be regarded as an evolutionary force. There is an increasing realization that holistic planning is appropriate whenever man exploits ecological systems and in particular water systems (Allanson and Rabie 1983). They also note that there is a lack of a systems approach to freshwater problems. Since there are innumerable variables, with the interactions between soil, water and vegetation, there is a need for systems analysis and simulation modelling (Pantulu 1983). Freshwater systems need to be recognized as integrated dynamic ecosystems in need of ecologically orientated planning and management. There is no provision which allows an entire river from source to sea to be considered as a single system (Allanson and Rabie 1983). Since ecosystems are linked interdependently the goal of conservation is the conservation of the ecosystem mosaic which makes up the biosphere (Siegfried and Davies 1982).

Patten et al (1982) recognize that changes in any one part of an ecosystem will ultimately be reflected in all or most of the other parts of the ecosystem. They furthermore stress that an holistic systems approach to an ecosystem is the only way in which we can hope to understand its functioning. They illustrate that indirect influences were in actual fact far more significant than the usually measured direct causes, and that the direct causality in a model they developed accounted for only a fraction of the total causality. Patten et al (1982) have some overwhelming evidence for the value of the holistic approach to ecological studies. Ecosystems undergo mostly cyclical changes which over the long term, however, appear as persistent steady states. Whereas short term direct effects may appear to be of paramount significance, over the long term it was the interaction of the many indirect effects which overwhelmingly predominated in the functioning of the system. Their paper reported on twelve out of thirty-three interacting parameters which they studied, and as indirect effects tend to increase with system order it is apparent that real ecosystems with many more interactions would be governed to an even larger extent by indirect effects over the long term.

8.4.8 Literature availability

The availability of literature is a problem which faces all researchers and the fact that valuable data are often recorded in departmental reports (grey literature) only poses a further problem in that duplication of research is often the result. O'Keeffe and O'Keeffe (1986) have recently compiled an annotated bibliography on river conservation in South Africa. This bibliography will be of immense value to all river ecologists. Fortunately, it has included the grey literature of unpublished theses and government reports.

We recommend that this computerized, annotated bibliography is constantly updated, and that this project be considered on a long-term basis. In river conservation there are many examples of research work which remain unpublished in reports and theses. To prevent duplication it is important that these studies are brought to light, as they have been in the present annotated bibliography. There is also the problem of work reports solely in Afrikaans without an English summary. It is recommended that all reports and theses in Afrikaans contain an English summary so that these works are at least partly available internationally.

The LSSA bibliography from the Limnological Society of Southern Africa, WATERLIT and FISHLIT available through the CSIR and the JLB Smith Institute of Ichthyology are also valuable sources of references available to river ecologists in South Africa.

8.4.9 Communication and consultation with user groups

There is a need for a policy within the research community to facilitate communication with the public and senior managers on long-term issues. Imaginative science writing on environmental issues is needed. It must first interest and then inform, since this is the key to the development of an aware public attitude in the long term (Vallentyne 1978).

River conservationists and ecologists need to take a firmer and more positive approach to the promotion of their expertise and general public image (Siegfried and Davies 1982). Overall information dissemination is hampered by poor communication between decision-makers, scientists, managers and the public. The researcher must communicate with all these groups as well as his own peer groups. Recommendations of workshops such as this one should be assessed to establish whether the document produced was of any value to the managers, the researchers, the public and steps should be taken to get the information distributed appropriately.

In South Africa we must accept that there are many demands on the river system. Water is however, a renewable resource which can be exploited for multiple uses. O'Keeffe (1986) has noted that conservation traditionally has been ranked very low down in the scale of user priorities. To overcome this low ranking, river conservationists must define their aims clearly and precisely to decision makers and offer clear predictions about the consequences of any river perturbations. Resources are commonly divided into renewable (living) and nonrenewable (mineral) categories. However, chemicals and minerals can be synthesized in the laboratory if they are lost in their natural state, but living species cannot and we hence have the paradox that "renewable" resources become nonrenewable and vice versa (Talbot 1980). Several successful case histories will add weight to the river conservationists cause (eg Pongolo River Studies, Heeg and Breen 1982) and provide decision makers with the reasons why ecological aspects should be integral parts of river development projects. User groups will learn to view conservationists in a favourable light, once they are seen as realists with the expertise to predict limits of exploitation, so that the resource is sustainable over the long term. Critical peer review is also a necessity of science and this ensures that the quality of published literature is kept at a premium. Quick-and-dirty research will rarely enable a local scientist to obtain an entry into the international literature.

8.4.10 Coordination

Figure 8.2 summarizes the role of coordination in directing conservation research. The diagram has three main sections highlighting limiting factors, the coordination of research and information, and the determination/implementation cycle.

8.4.11 Information gathering and distribution

It is important to have data easily available in a format where trends can be seen easily. Many research man-hours can be wasted, for example, in obtaining reams of computerized tables of daily flow data, when all that was necessary was a graph of the mean and monthly minimum and maximum flow regime for a specified period. The people involved with collecting data should ascertain how this data can best be disseminated to other users working on the system. O'Keeffe (1986) has noted the great potential of the database of hydrological records for detecting historical changes in rivers caused by water abstraction or catchment degradation. Is this data base readily available in an easily interpreted format?

There is also a large data base on the water chemistry of many rivers. This includes measures of minerals, nutrients, TDS and pH. There is a further need for water temperature and data on suspended solids (O'Keeffe 1986). These data should also be reducible in a summarized format, ie graph, to prevent a wastage of man-hours. It is suggested that all abovementioned data are recorded on a centralized computer in such a way that researchers can write simple programmes (eg SPSS) to extract the relevant data and condense it in a format which will be useful for their research purposes.

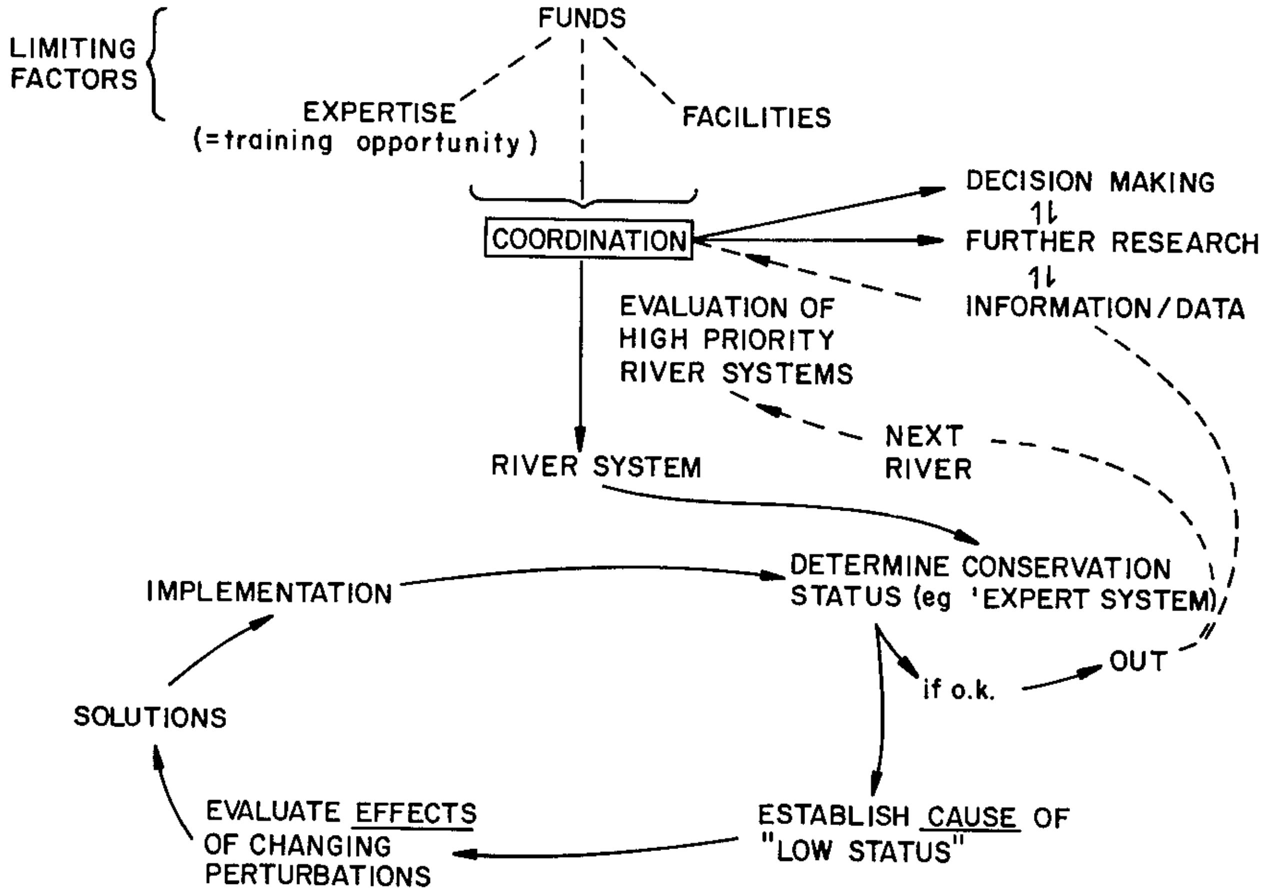


FIGURE 8.2 Schematic diagram illustrating research needs for river conservation in South Africa.

If there is no data base on a river, one can obtain historical information from several sources. Sediments can be analysed for pollen types to obtain information on previous catchment vegetation. In addition mollusc shells, fish bones and diatom frustules provide information about water quality, chemistry and biological communities. One can compare historic photographs or paintings of catchments with present conditions, from which vegetation land-use changes and erosion levels can be assessed. The use of fixed and/or aerial photographs, also provides a method to monitor gross catchment changes (O'Keeffe 1986).

The maintenance and curation of existing research collections in museums and herbaria should also be ensured and sufficient funding should be provided to allow expansion of existing collections.

8.5 RECOMMENDATIONS

O'Keeffe (1986) has suggested that there are five main aims of ecological research on rivers, these are:

1. Initially to locate and identify the types of organisms present. In many areas of stream ecology there is a scarcity of routine and specialist identification facilities. It is recommended that more funds be diverted to training and funding in these fields. The taxonomic work provides the framework for all further research, and the lack of identifications can easily become a stumbling block in holistic studies. Inadequate taxonomic knowledge is possibly one of the greatest limiting factors to the further development of accurate and reliable ecological research in South Africa (Du Plessis 1985).

2. To measure and describe the environmental conditions in different rivers.

3. To relate species and communities to environmental conditions. There is a need for a better understanding of the functioning of our biota in aquatic systems. Detailed autecological studies will go a long way to understanding the community structures of river systems.

4. To discover and quantify the important processes and interactions between the biotic and abiotic parts of the system it is important that both perturbed and unperturbed rivers be studied. See Chapter 1 for definitions of important processes.

5. To make accurate predictions about the effects of perturbations to the system. Interbasin transfer and stream regulation are two examples of major perturbations to South African rivers worthy of study.

In addition to the abovementioned five aims:

1. The need for effective dissemination of the knowledge gained. Since large rivers flow through areas under the jurisdiction of numerous landowners and other authorities, coordination of all these groups is essential for a research group studying the system. Cooperation and dissemination of initial plans and research findings, should constantly be made available to everyone who has a 'share' of the river. This should make it easier to initiate solutions to existing perturbations as well as preventing or at least minimizing future perturbations to the system.

2. The decision-making process also needs to be researched as it is considered that our ability to translate knowledge into action has fallen far behind the technological awareness of knowledge itself (Weaver 1981). We need to know the best method for transforming our scientific information into management action.

3. There is a need to initiate long-term stream ecological work. The collection of high quality data over the long term will allow generalization of ecological research results to develop theory over scales of time and space great enough to evaluate perturbations, and enable a

predictive capability of long- as well as short-term changes in the system. The review and funding systems must be made available for this approach.

4. Research into the conservation of the catchment should be initiated as we cannot hope to conserve the river on its own. Hence an emphasis on an holistic conservation research approach is needed.

5. Previously Red Data Books outlining endangered species have been produced by conservationists. The time has now come to look at the endangered habitat or system and we should now produce a Red Data Book on endangered or vulnerable river systems or possibly all natural inland aquatic systems.

8.6 SUMMARY AND CONCLUSIONS

O'Keeffe (1986) has noted that process-orientated research aimed at achieving a predictive understanding of the interactions between the biotic and abiotic components of rivers still remains to be tackled in South Africa. Work such as that done on the Pongolo floodplain is a good example of the approach. One of the aims of the Committee for Inland Water Ecosystems is to develop the understanding necessary to predict the effects of natural events, planned development and management actions on inland water ecosystems. To achieve a predictive capability, there needs to be a coordination of scientists into teams taking interdisciplinary approaches, and they must investigate the whole system holistically. Provided it is carried out for an extended time span, this kind of approach should provide the knowledge to predict the consequences of natural as well as anthropogenic perturbations of rivers and catchments. This knowledge will permit planning of appropriate management strategies to cope with the perturbations. In the long run environmental protection and economic development are not only compatible but interdependent and mutually reinforcing. There is a need to coordinate all user groups along the river system and to disseminate appropriate information to the different groups when it becomes available. The users should be made aware of the anthropogenic perturbations the river has undergone and what the possible effects of future perturbations will be. The Olifants River System in the Cape is a good example. Farmers are constantly bulldozing stretches of river. If they were made more aware of the consequences of these actions, some farmers might stop these destructive activities.

As river ecologists we deal with rivers while most users deal with the water that comes out of a tap. With the increased emphasis on urban living and technological aids, most people are becoming further removed from the origins of the natural resources which they use. To prevent this divorce from rivers and how they function we need imaginative science writing and other media portrayal on river conservation issues, to bring them 'to life' and influence public attitudes, so that we are 'allowed' to conserve rivers.

If we approach river conservation strictly from the idealist's view, that is maintaining the pristine system, we will only isolate ourselves from the mainstream of conservation. We have to take an holistic and realistic view, and accept that the river is a renewable resource which can be exploited for multiple uses. The maintenance of genetic diversity should also be taken into consideration as this makes living biota nonrenewable resources which are worthy of conservation. It is up to stream ecologists to predict the limits of exploitation and point out the consequences of over exploitation.

It is important that river conservation managers think in the long-term, not only for the here and now and that funds are made available for long-term river conservation studies in South Africa.

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APPENDIX 1

RESEARCH PROJECT PRIORITIES

Research priorities for rivers as listed by Noble and Hemens (1978), Ward et al (1984) and O'Keeffe (1986) are included in no particular priority order.

1. A comparison of pre- and post impoundment environmental characteristics and biota in downstream reaches.

2. Synthesis of existing information on the environmental effects of dam construction projects.

3. The validation of the River Continuum Concept and Serial Discontinuity Concept in South African conditions.

4. The development of methods for the efficient and rapid evaluation of the conservation status of stream systems.

5. Quantification of the relationships between time scales associated with hydrological processes and those of the biota.

6. Monitoring of nutrient loads in selected South African rivers.

7. Preparation of a field guide to South African aquatic invertebrates.

8. The drawing up of a consensus policy of conservation aims.

9. The investigation of functional groups in river fauna.

10. The development of predictive models for recovering stream length following different perturbations. (By organic effluents, by mining runoff, by impoundments).

11. Investigations of the ecological effects of interbasin water transfers, including pollution of gene pools.

12. The development of a protocol for research into river development projects at the early planning stage.

13. The potential for evaluation of changes in river conditions by various methods that might include:

    - water temperature changes,
    - palaeological methods (pollen analysis, diatom frustules, mollusc shells, fish bone middens), and
    - fixed point photography and comparison of historic photographs and paintings of selected river sites.

14. Resurveys of selected rivers to evaluate changes over time.

15. Ordination analyses of existing data (especially on invertebrates) to identify comparable rivers/stretches of river.

16. Methods for low-level conservation monitoring and clean-up campaigns employing nonspecialists and volunteers.

RESEARCH PROJECT PRIORITY QUESTIONNAIRE

RESPONSE FREQUENCY
Priority ranking

RESEARCH PROJECT NO see page 112

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	3	1	1	3	2	3	2	2	3	-	-	-	-	-	-	-
2	1	-	4	-	1	5	2	4	-	-	-	-	-	-	1	-
3	-	2	1	-	3	-	-	-	1	1	-	1	-	-	1	-
4	7	4	1	5	-	1	-	1	1	-	-	-	-	-	-	-
5	1	1	2	1	1	-	1	1	1	3	-	-	1	-	1	-
6	-	1	1	1	1	1	1	2	1	1	-	1	-	-	-	-
7	-	1	2	2	4	-	-	-	1	2	-	-	-	1	-	1
8	7	4	1	-	2	-	-	1	1	-	1	-	-	-	-	-
9	-	-	2	1	-	-	-	1	2	1	1	-	-	1	-	1
10	-	-	-	3	-	-	2	2	2	-	1	1	-	1	-	-
11	-	1	2	-	2	3	4	-	2	4	-	-	1	-	-	1
12	1	2	5	1	2	1	-	-	1	-	-	2	1	-	-	-
13	-	-	-	-	1	1	2	2	1	2	3	1	2	-	1	-
14	1	-	2	2	-	3	4	-	2	-	-	1	1	-	1	-
15	-	1	-	1	-	2	1	2	-	-	-	-	1	1	1	1
16	-	-	-	1	2	1	-	-	-	1	2	1	-	3	-	1

Workshop participants were asked to complete a questionnaire ranking the above sixteen projects in order of their relative importance. The boxes in the matrix indicate the number of respondents ranking each project (left column) at a particular priority (top row).

Analysis of research priority questionnaire

Twenty-three people completed this questionnaire. Only six people ranked all 16 research priorities, nine people ranked the top 10 and others ranked between five and 15.

When the first five priority ranking groups were added together, the top research priorities, in order, are 4, 8, 12, 1 and 7. An example of number 4, is the expert system. Number 8 was the purpose of the workshop, and the document emanating from the workshop. With regard to research project number 13, five people indicated only C as a priority.

Other suggestions which have not been ranked in the table.

1. Development of methods to determine the minimum quantity of water required to maintain conservation status of a river, (respondent ranked this number two).

2. Revision of Jubb's book on the freshwater fishes of Southern Africa (respondent ranked this number seventeen).

3. Monitoring of pesticides (respondent ranked this number ten).

4. Life history adaptations of lotic invertebrates, (respondent ranked this number one priority).

5. Effect of a dam and its discharge on downstream reaches (respondent ranked this number two).

APPENDIX 2

A NATIONAL CLASSIFICATION SYSTEM AND MAP OF THE CONSERVATION STATUS OF RIVERS

P J le Roux (convener)
A H Bok, A H Coetzer, M M Coke and J S Engelbrecht

The following definition of "conservation status" was accepted:

"The extent to which a river has been modified from its natural state"

This limited the consideration of conservation criteria to that of naturalness of a river, which was considered in two categories, ie biotic and physical. Both were divided into five groups, one of which was reserved for streams about which insufficient was known. The other four groups were used to indicate the level of degradation in order of severity:

A. In this group, both the biotic and physical elements of the system are in a pristine state and are not subject to immediate threats from outside.

B. Significant changes can be detected. Exotics, either plant or animal, may be present but are not dominant, both within the stream itself, or riparian to it. Slight pollution may occur but the ability for self-purification is not substantially impaired. Water abstraction and impoundment do not permanently impair streamflow regime. The channel is largely unaltered and silt load is moderately increased.

C. Substantial, and in many cases practically irreversible changes are apparent. Exotics are present and locally even dominant or form an important component of the biota, both animal and plant. Pollution is prevalent and may even be severe, but not sufficient to totally overtax the ability for self-purification. Impoundments and/or water abstraction result in major changes in the stream flow. Stream banks are denuded and rendered unstable, and silt load is considerably or severely increased.

D. All natural aspects are badly degraded resulting in only a few hardy species surviving in the stream or even total elimination of naturally occurring biota. Stream banks are severely degraded or extensively altered by canalization. Aesthetic aspects altogether destroyed.

Rivers were then classified according to the status of both biotic and physical factors as follows:

	Biotic	Physical
CLASS I	A	A
CLASS II	A B B	B A B
CLASS III	B C C	C B C
CLASS IV	C D D	D C D
CLASS V	UNKNOWN	

A map is being compiled using this classification, drawing on the combined expertise of participants in the workshop. This will be distributed to recipients of this report, and will be freely available to anyone interested in having a copy. Extensive areas exist where present knowledge is inadequate to allow valid classification of streams. The major areas are situated in regions whence there were no representation at the workshop, such as Swaziland and Transkei, as well as a large part of the northern Cape where many streams are seasonal.

The primary purpose of the rather coarse classification arrived at during the workshop was to collate as much information as possible in order to provide a national overview of the conservation status of South African rivers. This could serve as a basis for additional, and more detailed, classification by relevant authorities, ideally resulting in complete coverage of every region. The regional conservation authorities would seem to be the logical focal point for such activities.

It is to be noted that the conservation status of a river does not necessarily reflect its conservation importance, or its need for conservation management action. These would be dictated by other considerations such as the ecological values contained in the endemism, rarity and diversity of the biota, the demands upon or threats to the river as a system - now and in the future. Aspects such as size of the river and the fragility of the system would also need to be considered in this context.

During the course of the workshop, several streams were identified as being of outstanding conservation importance, requiring urgent action. These will be indicated on the map. It was also pointed out that some streams, or biogeographical groups of streams, with populations of particularly important species, such as rare endemics, should receive special attention from conservation authorities.

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