# A PRE-IMPOUNDMENT STUDY OF THE SABIE-SAND RIVER SYSTEM, MPUMALANGA WITH SPECIAL REFERENCE TO PREDICTED IMPACTS ON THE KRUGER NATIONAL PARK

## VOLUME THREE

## THE EFFECTS OF PROPOSED IMPOUNDMENTS AND MANAGEMENT RECOMMENDATIONS

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The name of the region where this work was done was changed from
EASTERN TRANSVAAL
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MPUMALANGA
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Where the name Eastern Transvaal appears in the text, please read Mpumalanga

# EXECUTIVE SUMMARY

Section numbers in the executive summary relate to the chapter headings and subsections in the main report.

## 1. INTRODUCTION

This project was begun in January 1990 in response to a need to characterise the fauna of the Sabie-Sand River system for which plans were already advanced to build impoundments. During the cource of the project, the region was subjected to the worst drought on record. As a result the scope and duration of the project was extended. This volume is the first of three which describe the results.

Volume 1 describes the ecological status of the Sabie, the Sand and other major tributaries of the system, including the diversity and distribution of the fish and macro-invertebrate faunas, and their habitat requirements. The second volume describes the results of a drought monitoring programme in which three reaches of the Sabie and one in the Sand River were intensively sampled throughout the worst drought on record, from 1991 to 1992.

The purpose of this volume is to assess the probable effects of proposed impoundments in the Sabie-Sand River (both positive and negative) on the ecology of the downstream reaches, and to draw on the information from volumes one and two to make recommendations for the management and monitoring of the flows in the river.

## 2. EFFECTS OF PROPOSED DAMS

Chapter 2 begins with an extensive review of the effects of dams on the downstream reaches of rivers, including reduction of water temperature ranges; delayed seasonality; changes in water quality; and in the type of organic material. The concept of recovery distance, the distance downstream necessary for the effects of impoundments to dissipate, is explained. Studies on the effects of dams on the Buffalo River (eastern Cape), and the Palmiet River (western Cape), are also reviewed, and summarised as follows:

1. there were no effects common to all six dams;
2. the position of any dam was of over-riding importance, governing the types of downstream effects, while perhaps surprisingly, the marked differences between the physical and chemical features of the two rivers appeared to have very little influence on the types of effects caused by impoundment;
3. larger impoundments caused more intense downstream impacts, and these impacts took longer to recover;
4. release mechanisms were less important than the position of a dam along the river, but bottom-releases consistently reduced temperature ranges, increased TSS, and increased all nitrogenous compounds measured, and
5. reservoirs were more effective than equivalent lengths of flowing water, at "*resetting*" grossly polluted systems.

2.3 Existing and potential dam sites within the Sabie-Sand system

There are at present 7 dams on the Sabie-Sand system, although one of them - the Zoeknog Dam, has collapsed and presently forms no barrier to water flow. The Edinburgh, Orinoco, Acornhoek, and Casteel Dams are all small (1.1 to 3.3 x $10^6$ $m^3$) dams in the upper tributaries of the Sand River. The Da Gama Dam is a medium-sized dam (14.3 x $10^6$ $m^3$) on the White Waters tributary of the Sabie River. The Corumana Dam is a very large impoundment (1200 x $10^6$ $m^3$) on the Sabie River in Mozambique, which backs up to the eastern border of the Park.

The upper dams all have the effect of reducing runoff to the KNP, but if we can extrapolate from the previous studies of the effects of dams on rivers in other parts of South Africa, then they are too small and too remote from the Park to have significant effects on the water quality, temperature regime, sediment transport and species composition in the main rivers within the Park boundaries. Any such effects will have recovered within a few kilometres downstream of the dam wall. The Corumana Dam, downstream of the Park, represents a major barrier to upstream migration of fish such as the Tigerfish, and may be the main reason for the scarcity of this species in the Sabie within the Park.

Seven potential new dam sites have been identified on the Sabie and Sand Rivers: Arthur's Seat, Dingleydale, and an enlargement of the Casteel Dam, are all sites situated in the upper reaches of the Sand system, and would be 14, 59, 73, and 39 x $10^6$ $m^3$ respectively. Two potential sites have been identified on the Marite tributary of the Sabie River: the Inyaka site (101 x $10^6$ $m^3$), and the Waterval site (109 x $10^6$ $m^3$). The Madras site is the largest (230 x $10^6$ $m^3$), and is situated on the main Sabie River only some 5 km from where the river joins the western KNP boundary.

### 2.3.2 Potential effects of the dams

The Madras site is the only proposal which would dam the main Sabie, and could potentially reduce the flow in the Sabie to less than 20% of its virgin MAR (O'Keeffe and Davies, 1991). This would turn the Sabie into a temporary river, in which low-flows would be completely intercepted for five months of most years. The most likely of the dam sites to be developed is the Inyaka site on the Marite tributary. If the dam were exploited to its maximum potential for water supply, runoff would be reduced to less than 20% of virgin conditions during dry years, and the Sabie River could stop flowing altogether during droughts. Mid-Sabie River peak flows would on average be reduced by 50%, while base-flows would approximate those seen during the 1990/91 drought (1.4 $m^3$ $s^{-1}$; Table 2.4). A compromise proposal: "Inyaka Dam - Limited use scenario", would require a compensation flow to be released from the dam which would ensure that the flow in the KNP would never be allowed to fall below un-impounded worst drought conditions. In addition, there would be gradual increases in compensation flow with increases in the inflow to the Dam. As a result, lowest flows would be a rare event, unlikely to occur in consecutive years. This scenario would result in nearly natural flows in wet months during wet years, and flows between 40 - 60% of virgin condition in both wet months during drought years, and dry months during wet years. During the critical dry months during drought years, flows in the Park would be between 20 - 40% of virgin conditions.

Dam sites in the upper Sand River and the Marite are likely to cause significant temperature increases downstream, but these should recover within 20 km at the most - well before the water from these dams reaches the Park. The Madras Dam, if it were to be built and operated with a bottom release valve only, would have a major effect of reducing temperatures downstream, possibly by as much as 18 - 20°C, and this effect would extend well into the Park, perhaps for as far as 40 km. Such an effect would have far-reaching consequences for the riverine biota, and could exclude, for example, most of the lowveld fish community.

Dams are sediment traps, and it can be expected that any of the planned impoundments would have local effects in intercepting sediments, leading to clear "sediment-hungry" water downstream. Only the Madras Dam would affect the rivers in the Park.

As the dam are situated in the middleveld close to the FHZ and LZ transition, the potential for complex range extension/reduction of species is great. A further consideration is that the characteristic FHZ and LZ fish assemblages would respond differently to impoundment.

Downstream of the Marite Dam, FHZ species sensitive to water temperature would decreases. The dominant FHZ species *Chiloglanis anoterus* is unable to survive any period of no-flow and would suffer local extinction as would other less numerous and localised Amphilius catfishes and *Opsaridium zambezense*. In the LZ, the more resilient assemblage would show less species composition shifts, but rather proportional shift in the importance of species. The alternating seasonal dominance of cyprinid to cichlids could be offset with impoundment reduced or no-flow, as seen during drought. Cichlids and other drought species would dominate the assemblage, with *Oreochromis mossambicus* replacing *Barbus viviparus* as the most abundant in the LZ. Decreased water temperature in the LZ such as predicted with the building of the Madras dam, would significantly alter distributions of LZ fish in the KNP.

The biotic effects of both the Inyaka and Madras dams at limited and maximum use are discussed.

2.4 Zoeknog dam

Zoeknog dam, on the Mutlumuvi River, was 29% full when it failed with the first rains of the 1992-93 wet season. Approximately $3x10^6$ $m^3$ of water and an estimated $0,2x10^6$ $m^3$ of earth was discharged into the Mutlumuvi River over a few hours (Plate 1a).

During the construction phase of the dam there had already been major changes in the occurrence and abundance of species. The turbidity in the Mutlumuvi was some 57 times above previous measurements (1300 NTU, TSS 0.85 $gl^{-1}$) (Table 2.5).

The effects of construction on the biota were masked by the 1992-93 drought, and progressively downstream in the mid Sand River reaches, but cannot alone explain the drastic reduction of the biota recorded. Immediately downstream of the dam, the most abundant fish species *Chiloglanis anoterus* and *Barbus eutaenia* were reduced by 60 and 80% even though the Mutlumuvi remained perennial at this elevation. Both these species are most numerous in the clear-watered foothill streams of the catchment and may have been affected by high turbidity.

The collapse of the dam resulted in a flow equivalent to a 1:10 year flood in the Mutlumuvi, but flows attenuated downstream. Gross microhabitat alteration occurred within the reaches downstream of the dam. At 2 km, over a meter of coarse sand had smothered riffle and run sequences (Plate 1c). At New Forest, some 16 km downstream of the dam, there was evidence of a 2-3 meter flood and a layer of fine sediments deposited in and out of the channel. Fine red silt was evident all the way to the Sabie-Sand confluence. Two days after the event the turbidity at Londolozi was still 1900 NTU (2.652 g/l of silt) (Table 2.5).

The lowest fish densities during the project were measured for all stations after dam failure. Effects were greatest in the Mutlumuvi with CPUE immediately below the dam reduced halved from post drought/construction catches. Following the dam burst CPUE was recorded at its lowest for any site during the entire study period, catchment-wide, in the mid-Mutlumuvi (site 19)! Cichlids which had come to dominate the catches in the stressed Mutlumuvi River were themselves scoured during the high flow event, contributing to the low CPUE seen.

Following dam failure, low invertebrate numbers were found as far downstream as site 14, the furthest downstream site in the Sand River. Invertebrates appeared to recover from the effects of the drought and the collapse of the dam more quickly than did the fish.

In the Mutlumuvi, recovery may have been hampered because it is isolated from the upper Sand River by the mid-Sand River reaches, which are often impacted by drought. Little meaningful recovery was evident below the dam site after 5 months. Sediments within the highly modified reach had however started being resorted (Plate 1d).

Fish density and diversity was still very low at the New Forest site 5 months after the collapse of the dam, but recovery was well under way at Londolozi (site 14).

Three months after the dam failure, both diversity and total numbers of invertebrates showed an apparent recovery. All four sites showed recovery to pre-drought and pre-dam failure conditions (Fig. 2.20 - 2.23).

In summary, the collapse of the Zoeknog dam had the following effects:

- A severe reduction in the density and diversity of the instream fauna
- Modification of the instream habitats

- The Mutlumuvi River was generally heavily impacted, while the lower Sand River impacts are masked by more powerful drought effects.
- The upper reaches at Zoeknog show gross modifications in channel structure with course unsorted substrates smothering typical riffle reaches.
- In the mid-Mutlumuvi at New Forest, the already severely drought stressed fish assemblage was almost totally destroyed.
- At Londolozi, clear impacts of the Zoeknog event were masked by drought effects on the mid-Sand River.
- Although difficult to assess, high turbidities impacted off-stream pool fish assemblages in the mid-Sand River floodplain.
- The degradation of the upper lowveld fish refuge reach may reduce the resilience of the lower reaches of the Sand River.
- The ichthyofauna of the Mutlumuvi had recovered very little five months after the event.

# 3. INSTREAM FLOW REQUIREMENTS OF THE SABIE-SAND RIVERS IN THE KRUGER NATIONAL PARK

3.2 Previous assessments of the environmental water requirements for the Sabie river.

To date, three independent methods have been used to assess the environmental water requirements of the Sabie River:

a) Davies *et al.*, (1991) used a water budget method in which the consumptive and non-consumptive water uses were estimated, to provide a seasonally-distributed flow requirement.

b) Gore *et al.*, (1992) used the PHABSIM model to provide preliminary estimates of hydraulic habitat requirements for four key species in the Sabie River.

c) The third assessment of environmental flow needs used hydrological simulations of natural, present and various future impounded conditions of the Sabie River to predict possible ecological conditions (O'Keeffe and Davies, 1991). Ecological consequences of successive reductions in discharge were then assessed using the River Conservation System (O'Keeffe *et al.*, 1987), an expert-system based model, to determine the conservation status of the river under different management conditions.

Table 3.4 compares the recommendations of the three methods. Bearing in mind that these assessments each used different methods, based on different data, analyzed by different teams, the recommendations are very similar, and give some basis for confidence that they are appropriate base flows for the maintenance of the riverine ecosystem. Seen as a percentage of the present MAR of the Sabie River, they are not unreasonable requirements, and should be accepted as targets for management of the river's water resources.

3.3 Lessons from the 1991-92 drought.

If the LZ rivers stop flowing, even for a short time, a number of species will disappear from the static reaches. These will include *Chiloglanis anoterus* and *Opsaridium zambezensis*. In addition to these disappearances, the community structure will change considerably, mainly as a change from dominance by cyprinids to cichlids.

As a general rule, low or no-flow sequences of longer than two months are likely to cause changes to the community from which species will take a year or more to recover. If the river were to be managed to maintain flows at a survival level, species would disappear gradually but permanently due to lack of recruitment. Management of the flow regime should therefore concentrate on the maintenance of natural proportions of all species in the assemblage, rather than on the dangers of the immediate disappearance of species from the system.

The rate of flow reduction is very important, and should be as slow as possible. High flows (greater than bank-full) are important for replenishing and recolonising off-mainstream pools, which proved to be important refuges during no-flow periods.

Finally, the maintenance of permanently flowing reaches is of the utmost importance to ensure that there are survivors in the system from which recolonisation can take place. The upper reaches of the Sand and Mutlumuvi Rivers are such refuges, as is the main Sabie River.

### 3.4 Summarised flow scenarios

The consequences of different flows on habitat availability, water quality, and the instream fauna are addressed in Tables 3.5 to 3.7. Predictions are partly quantitative and partly qualitative. The tables are designed to provide a structured summary of the effects of a series of flow scenarios of varying duration, during the wet and dry seasons. We envisage that these tables will be useful to scientists, conservationists, and managers in assessing the effects of modified flows as a result of impoundment and increased water abstraction.

## 4. FUTURE MONITORING REQUIREMENTS

The objectives of a monitoring programme for the Sabie-Sand would be as follows:

- To measure the relative density and diversity of the fish and invertebrate communities of the rivers, so as to document changes at different spatial and temporal scales.
- To document the size and shape of the river channels and the variety of habitats within them, so that long term changes in channel morphology and the availability of suitable habitat in response to changing flow patterns can be quantified.
- To measure the changes in important physico-chemical attributes of the rivers, so as to recognise seasonal and long term changes in the water quality of the rivers.
- To gauge the flow of the rivers so that the natural patterns of seasonal, drought/flood, and wet/dry sequences can be recognised, and the effects of impoundment and increased abstraction can be followed.

### 4.2 Present monitoring activities

The present long term monitoring activities on the Sabie-Sand can be summarised as follows:

- Continuous flow gauging at 12 gauging weirs, with record lengths varying from 47 to 5 years.

- At these gauging weirs and 3 other sites within the KNP, water samples are collected on average every 2 to 3 weeks, and are analysed for a suite of major ions, salinity, phosphates, nitrates + nitrites, and ammonium.
- Irregular fish surveys have been carried out on all parts of the Sabie-Sand since 1963 (Gaigher, 1969).
- Benthic invertebrates have similarly been sampled sporadically since the early 1960's, but at present there is no regular programme to update previous surveys.
- Aerial photography coverage of the Sabie-Sand catchment has been updated every 10 years since 1940. Within the KNP colour aerial photography surveys have been flown over the river at a scale of 1:5k - 1:10k.
- Fixed point photography sites on the Sabie and Sand Rivers within the KNP have been recorded in recent years, but there are no sites on the rivers outside the Park.

4.3 Additional monitoring requirements

To ensure an adequate database from which to assess long-term changes in the rivers, and to act as warning systems should particular problems arise:

- Regular invertebrate sampling, using the SASS4 rapid biomonitoring system. At least once per year, and preferably twice a year in the wet and dry seasons.
- Resurveys of existing rated transects to check on channel changes, approximately every 10 years.
- Initial surveys to measure the ecological integrity of the rivers, using the methods of Kleynhans (in press), followed by resurveys every 10 years.
- Transect surveys through the riparian vegetation, to check on species changes over time, regeneration, and mortality amongst mature trees. (Details to be provided by the researchers at the Centre for Water in the Environment, Wits University).

In addition, the following activities should be extended from the Park to be carried out throughout the catchment:

- Regularly fish sampling, at least once a year, using the Index of Biotic Integrity approach presently being developed by Dr Andrew Deacon of the National Parks

Board. Samples should be collected at the same time each year, to allow for seasonal changes in fish communities (described in Volume one of this report).

- Regular fixed point photographs, once a year at the same time of year (preferably in winter during low-flow conditions).

Eight sites have been identified as the realistic minimum number of monitoring sites through which to characterise the Sabie-Sand system:

- Upper Sabie, site 3, downstream of Sabie town.
- Sabie River at Mkhuhlu, site 6.
- Sabie River below the confluence of the Sand, site 9.
- Sabie River at Mlondozi, near the Mozambique border, site 20.
- Upper Sand River at Rooiboklaagte, site 11.
- Mutlumuvi River at New Forest, site 19
- Sand River at Londolozi, site 14.
- Marite River downstream of the proposed Inyaka dam, site 21.

## 5. CONCLUSIONS, AND MANAGEMENT OPTIONS TO MAINTAIN THE CONDITION AND COMMUNITIES OF THE SABIE-SAND SYSTEM

The results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the Sabie River. If low-flow conditions become the norm, the communities in the Sabie will change considerably. Water quality in the Sabie is still excellent.

The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the communities are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation.

## 5.4 The effects of dams

Most of the proposed dams are probably too small and too remote from the Park to provide effective low-flow augmentation. However, the Madras Dam, on the Sabie mainstream and very close to the Park's western boundary, would have severe effects on the water quality, temperature and sediment transport within the Park, and is also large enough to intercept all but the largest floods. The option of choice, from an environmental point of view, would be the Inyaka Dam in the Marite tributary. This would have consequences for the Marite, but is far enough from the Park for conditions downstream in the Sabie to recover. It is large enough to provide compensation flows to the Park, and would not intercept high flows, since the site is in a tributary of the system. Compensation flows be linked to the dam inflows, as suggested by O'Keeffe and Davies (1991). The conclusions of O'Keeffe and Davies (1991) should be seen as part of an ongoing assessment of the flow requirements for the rivers.

Existing and proposed impoundments on the Sand River are all remote from the Kruger Park and associated private reserves, but affect the important perennial upper tributaries of the Sand, which act as refugia during droughts.

## 5.5 The effects of consistently reduced flows

The effects of flow reductions on the fish communities of the Sabie-Sand have to be seen in the framework of the different zones of the rivers, and during the wet and dry seasons. In the Foothill Zone (FHZ), there are less seasonal effects, and the consequences of reduced or no-flow would be the reduction or disappearance of flow-sensitive species (such as *Chiloglanis anoterus*). Pool and marginal species will continue to survive and will dominate the fish assemblages. In the Lowveld Zone (LZ), where seasonal changes are marked, a permanent reduction in flow will result in the continued dominance of the dry season assemblage, dominated by cichlids, and the permanent reduction of cyprinids and other flow-dependent species. Lower flows in the dry winter season will result in stressed communities, no breeding and the disappearance of flow-dependent species, especially in rivers which cease to flow.

Generally, mean water temperatures will increase as flow is reduced, and there will be a shift of some of the more flow- and temperature- sensitive elements of the LZ communities further upstream.

Many invertebrate species are extremely sensitive to flow conditions. During drought conditions in 1992 the average number of taxa was half that during the wetter conditions in 1990, and densities were reduced by an order of magnitude. The loss of biodiversity in these circumstances is not confined to invertebrate species, since they form a crucial part of the food base for other organisms, particularly fish and amphibians, and make significant contributions to the processing of organic matter.

The change from flowing water to static conditions will also provide opportunities for the increase of those species which favour stagnant water. These unfortunately include mosquitoes and Bilharzia host snails. The Sand River is already a centre for bilharzia transmission, but it is unlikely that the Sabie is at present.

Up to the present, reduced flows have not resulted in water quality deterioration beyond acceptable limits, except in isolated pools during drought conditions. Reduced flows will however result in less dilution of the effluents and irrigation return flows that reach the river. The presence of dams provides the option of making releases to dilute effluents during critical periods.

The maintenance of refuge areas is crucial to the continued ecological integrity of the system. From the point of view of perennial flow, the most important remaining refuge reaches in the LZ are:

- The main Sabie River, which has always been perennial throughout its length.
- The upper reaches of the Sand and Mutlumuvi tributaries

In the FHZ, the most important refuge is the Marite River.

## 5.6 Recommendations

- The overriding priority for the Main Sabie River is to maintain a perennial flow to the Mozambique border.
- Throughout the system, the maintenance of perennial flows in refuge areas is crucial to the ability of the fauna to survive critical low-flow periods.
- Flow management policy should attempt to build in as much of the natural between and within season variability as possible.
- Education and information: There is an urgent need to inform people in all parts of the catchment about the values of maintaining the resources of the rivers in the long term.
- Following the development of the national biomonitoring programme, a coherent monitoring programme
- As a matter of general policy, all new dams should incorporate multiple release ports at different levels, to provide options for water quality and temperature mixing.
- The adoption of the "Inyaka Dam, Limited Use" policy (see section 2.3.2) will cause only minor ecological disruption to the Sabie River ecosystem, and will provide new options for low-flow augmentation.
- The Inyaka Dam will, however, have significant effects on the unique fauna of the Marite River, unless care is taken during construction, perennial flows are maintained, and the temperature of water releases is controlled within natural limits.
- Madras Dam, if it is built, would have very severe effects on the downstream riverine ecosystem, through flow reduction and changed water quality, unless a strict water release policy was ensured. In the latter case, it could provide the best options for environmental flow releases into the Kruger Park.
- To provide for augmentation of low-flows in the Sand River, the building of the New Forest Dam on the Mutlumuvi, and a transfer facility to the Dam from Inyaka, could be considered. In addition, the repair, or at least stabilisation of the broken Zoegnog

Dam should be a priority, since further high flows will tranport more sediments from the wall down river.

- Strict control of any fish stocking in Inyaka dam will be necessary, especially to prevent the introduction of cool-water-tolerant bass species, which would have a catastrophic effect on the smaller indigenous species in the upper rivers.
- It would be possible to reintroduce the fish species that are missing from the upper middle reaches of the Sabie River (upstream of site 3) due to historic mining effluent.
- Even in temporary rivers during the dry season, it is necessary to ensure some base flow from time to time, to top-up pools and improve water quality.

### 5.6.3 Further information required

- Model development to predict the effects of changes in abiotic driving forces (such as flow) on the riverine biota.
- Breeding requirements of fish.
- Migration and local movement patterns of fish, and their importance to the life-cycles of different species.
- A socio-economic analysis of the long-term values of the natural resources of the rivers.

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dominates the assemblage in all seasons (59-81%). Cichlids are characteristically poorly represented (3-4%) while cyprinids make up 15-32% of the catch.

**Figure 2.12:** Changes in the relative abundance in the Lowveld Zone (LZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species see Figure 7.8 (Volume 1). By early summer (November), cichlids have bred independently of the first rains increasing from 7 to 53%. By February and at the height of the seasonal rains, cyprinids have increased from 31 to 58%. During the dry winter season, no breeding takes place while recruitment of the numerous young-of-the-year swell cyprinid numbers (84%).

**Figure 2.13:** Catch per unit effort (CPUE) for fish below the Zoeknog dam site between May 1991 and May 1993 and above the dam for May 1993. Fish grouped as lotic (solid bars) or lentic (hatched bars) breeders (see text). Between May 1991 and 1992 and during construction, total CPUEs decreased from approximately 7 to 4 fish per minute. By January 1993, post dam failure, CPUEs were recorded as less than 2 fish per minute while lentic species increased with backwater species absent from the reach. CPUE had not recovered by May 1993, being less than half those recorded immediately above the dam.

**Figure 2.14:** Catch per unit effort (CPUE) for lotic (solid bars) and lentic fish (hatched bars) between August 1990 and May 1993 at New Forest on the Mutlumuvi River, some 16 km downstream of the Zoeknog Dam. CPUEs between 6 and 7 fish per minute were obtained with a slight decrease over the summer of 1991-92. By the end of the dry season (November 1992) the CPUE had increased considerably. This was attributed to an explosion of the lentic breeder *Oreochromis mossambicus* in drought conditions. The post-dam flush in January 1993 drastically reduced fish in the reach to a remnant particularly the lentic *O.mossambicus*. Three months later CPUE was still very low.

**Figure 2.15:** Catch per unit effort (CPUE) for fish at Londolozi on the mid-Sand river between May 1990 and May 1993. A CPUE of between 3 and 6 fish per minute was recorded before the 1991-92 drought with lentic species (hatched bars) typically making up more than 90% of the assemblage. By May 1992 the Sand river had ceased to flow concentrating the fish in pools and resulting in artificially high CPUEs. Lentic breeders continued to dominate the assemblage. The river was flowing again by December 1992, the November flush having reduced the lentic species noticeably. CPUE after the Zoeknog collapse, the sixth flushing-flow of the season, measured below 2 fish per minute and were almost exclusively of lotic species 9 (solid bars). Recovery had started by May 1993.

**Figure 2.16:** Catch per unit effort (CPUE) for species below the Zoeknog dam site between May 1991 and January 1993. In May 1991, 11 species were recorded with the rock catlet *Chiloglanis anoterus* particularly numerous (CPUE at 4.7), and the

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| | |
|---|---|
| CPUE: | Catch Per Unit Effort |
| DO: | Dissolved Oxygen |
| DWAF: | Department of Water Affairs and Forestry |
| FHZ: | Foothill Zone |
| GIS: | Geographical Information System |
| IBT: | Inter Basin Transfer |
| IFR: | Instream Flow Requirement |
| mASL: | Meters Above Sea Level |
| KNP: | Kruger National Park |
| KNPRRP: | Kruger National Park Rivers Research Programme |
| LZ: | Lowveld Zone |
| MLA: | Maximum Level of Acceptability |
| NOEL: | No Observed Effect Level |
| NT: | Number of Taxa |
| NTU: | Nephelometric Turbidity Unit |
| PSI: | Proportional Similarity Index |
| SL: | Standard Length |
| SRP: | Soluble Reactive Phosphorous |
| TMS: | Table Mountain Sandstone |
| TDS: | Total Dissolved Solids |
| TNI: | Total Number of Invertebrates |
| TSS: | Total Suspended Solids |
| YOY: | Young of the Year |

# 1. INTRODUCTION

This is the third of three volumes of a report which contributes to the ecological knowledge base for the Sabie-Sand River system in the eastern Transvaal. Volume one described the present ecological status of the main rivers of the system, reporting on the results of a three year field study of the fish and invertebrate communities and the water quality, from the headwaters on the escarpment to the eastern boundary of the Kruger National Park at the Mozambique border (Fig. 1.1).

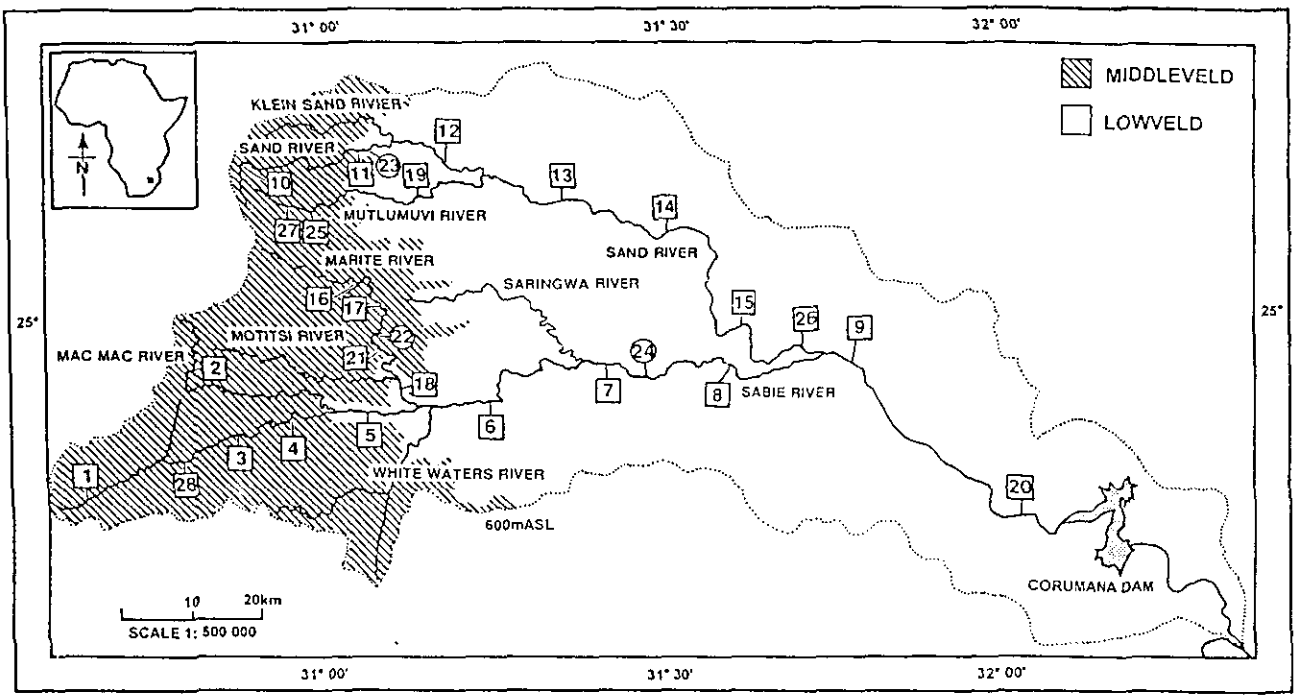



**Figure 1.1:** Station locality map for all sites sampled over the study period, including annual survey, quarterly monitoring and once-off sites. Gill-net stations shown as circles.

During the course of the field study, the catchment experienced the worst drought on record, with the failure of the 1992 wet season. Flows in the main Sabie within the KNP were reduced to 0.5 $m^3s^{-1}$, and the middle reaches of the Sand River ceased to flow for more than

5 months. The effects of the drought were magnified by the abstraction of water upstream of the KNP, mainly for irrigation. Ecologically and socially disruptive as this drought was, it provided a unique natural experiment through which to investigate the effects of low flows on the biota of the system.

The second volume of this report describes the results of a drought monitoring programme in which three reaches of the Sabie and one in the Sand River were intensively sampled throughout the drought. Because the fieldwork was started in 1990, a year of average rainfall, and ended in May 1993, 7 months after the drought was broken by good rains, the effects on the biota could be followed from a year of good conditions, through the drought, and back into the beginnings of a recovery period. The first two volumes of this report document these changes, and draw conclusions as to the short-and long-term effects of very low (or no) flow on the biota of the rivers. Separate studies, by researchers from the KNP and the University of the Witwatersrand, investigated the effects of the drought on the riparian vegetation, and the large terrestrial and aquatic animals associated with the river. A further separate study during the same period investigated the biota of the Letaba River (Chutter and Heath, 1993), and volume 1 of this report also contains a comparison of the biota and conditions of the Sabie and Letaba Rivers.

At present, the Sabie River has no major impoundments on its mainstream, and only one (the Da Gama dam on the White Waters River) on its major tributaries other than the Sand. The Sand River has four small dams on the upper reaches of its tributaries, of which only the Edinburgh had a significant effect on low flows during the drought. Within the next few years, the Inyaka Dam will be built on the Marite tributary of the Sabie, and it is likely that further dams will also be necessary for the supply of water to the increasing number of people in the catchment, and to ensure that sufficient water reaches the Kruger Park to maintain the ecological functioning of the Sabie-Sand River system - biologically the most diverse in the country.

The purpose of this volume is to assess the probable effects of the proposed impoundments in the Sabie-Sand River (both positive and negative) on the ecology of the downstream reaches, and to draw on the information from volumes one and two to make recommendations for the management and monitoring of the flows in the river. Since there are at present no major dams in the system, it has been necessary to infer the probable effects from our knowledge of impoundments on other rivers. The volume begins with a review of the present ecological knowledge of the effects of dams, and relates this to the size and position along the river of the proposed dams on the Sabie, and characteristics of the river compared to those of the rivers in which the effects of dams have been investigated.

The Zoegnog dam, recently built on the Mutlumuvi tributary of the Sand River, was the object of monitoring during the project, but the central section collapsed in January 1993, sending a pulse of sediment-laden water down the Sand River and into the Sabie. The monitoring report therefore covers the effects of the construction of the dam and its subsequent collapse, rather than assessing the effects of the operation of the dam on the downstream reaches.

In the past 12 years, the idea that water flowing to the sea is wasted has been superceded by the realisation that it is necessary to leave some water in rivers to maintain them as functioning natural resources. This idea was adopted by the Department of Water Affairs and Forestry (DWAF) in the form of the environment as a separate water user, competing with other users (agriculture, industry etc.) for water allocations. This policy is now being challenged by the view of the river as the resource, from which users should motivate their needs (O'Keeffe, 1994). The DWAF White Paper on "Water Supply and Sanitation" has accepted this concept, expressed in the following extract: "The environment should not therefore be regarded as a 'user' of water in competition with other users, but as the base from which the resource is derived and without which no development is sustainable".

Section 3.4 discusses the instream flow requirements (also known as ecological flow requirements, or environmental water allocations, King and Tharme, 1993) for the Sabie-Sand River. The instream flow requirement (IFR) of a river is the volume of water needed in the river channel to maintain the biota and ecological processes in the river in a "desired state", which may be its natural state, or some modified state required by the users of the river. This volume of water should be quantified in terms of the magnitude, timing, duration and frequency of different flows (King and Tharme, 1993). Basically, this comes down to answering the question: "How much water of what quality should be left in the river to maintain it in a condition required by the users of the river?".

The question may be a simple one, but the answers are extremely complex to come to, as researchers and managers have discovered over the past 12 years. The details and philosophy of the IFR process, and methods by which it may be assessed have been extensively discussed by King and Tharme (1993), and are also covered in appendix 1 of volume one of this report. Section 3.4 does not attempt to prescribe an IFR for the Sabie-Sand, since this is to be addressed extensively at several levels by the Kruger National Park Rivers Research Programme (KNPRRP), but presents a matrix of the consequences for the instream biota of different flows for different periods of time. The predictions are restricted to the fish, invertebrates and water quality of the river, since these were the components of the system addressed in this project.

It is envisaged that this information will be combined with that on the riparian vegetation, the hydrology, hydraulics, channel morphology and sediment dynamics, currently being assembled by researchers in the KNPRRP. This will provide a comprehensive picture of the modified flow regime following impoundment, the changed sediment regime and channel morphology, the availability of different types of hydraulic habitat, and the consequences for the riverine biota, including the riparian vegetation and associated large mammals. How far this can be achieved, and at what resolution, has yet to be discovered.

The last two chapters of this volume address the management of the rivers from an environmental point of view, including the need for an integrated monitoring system for the Sabie-Sand catchment. The information collected during the project is interpreted into a form that will hopefully be useful to those who have to manage the rivers for the benefit of all the different users of the many resources which the rivers provide, and will continue to provide, if we can manage them sensibly.

# 2. EFFECTS OF PROPOSED DAMS

## 2.1 RIVER REGULATION BY DAMS: A REVIEW OF ECOLOGICAL RESEARCH

The complexities of the impacts of river regulation on receiving reaches of rivers are adequately summarised in Figure 2.1; but to analyze them all would take another Monograph, and we intend to concentrate on only a few aspects, with special reference to the arid/semi-arid nature of our subcontinent. In a dryland region like southern Africa, the effects of flow regulation are ecologically catastrophic at every level, simply because the biota of dryland rivers is **adapted to an unregulated régime** (see e.g. Fig. 2.2). Indeed, our rivers inherit much of their character from the climate, and their flow behaviour especially mirrors the erratic patterns of rainfall, with variable periods of drought punctuated by flooding that may be equally variable in timing, duration, and in magnitude. The significance of a single *flood pulse* (Junk *et al.*, 1989) must be judged against the history of inundation at one place, and the flood régime, describing variations in both space and time (Puckridge *et al.*, 1993). Hydrological variability strongly influences the evolutionary character of the biota - for example, many resident species are highly tolerant of environmental extremes and are **reproductively opportunistic**; where flooding is modified, as for irrigation, the character of the ecosystem is likely to change. Moreover, the high degree of spatial and temporal variability suggests that the times for dryland river ecosystems **to respond to and recover from environmental changes will be prolonged** - the *raison d'être* for this section.

The hydrological character of a number of arid regions has been studied by McMahon (1979) and Finlayson & McMahon (1988). These studies, based upon annual flow records and peak discharge series, concluded that:

1. arid zone rivers *are* more *variable* than those in humid regions (Table 2.1);

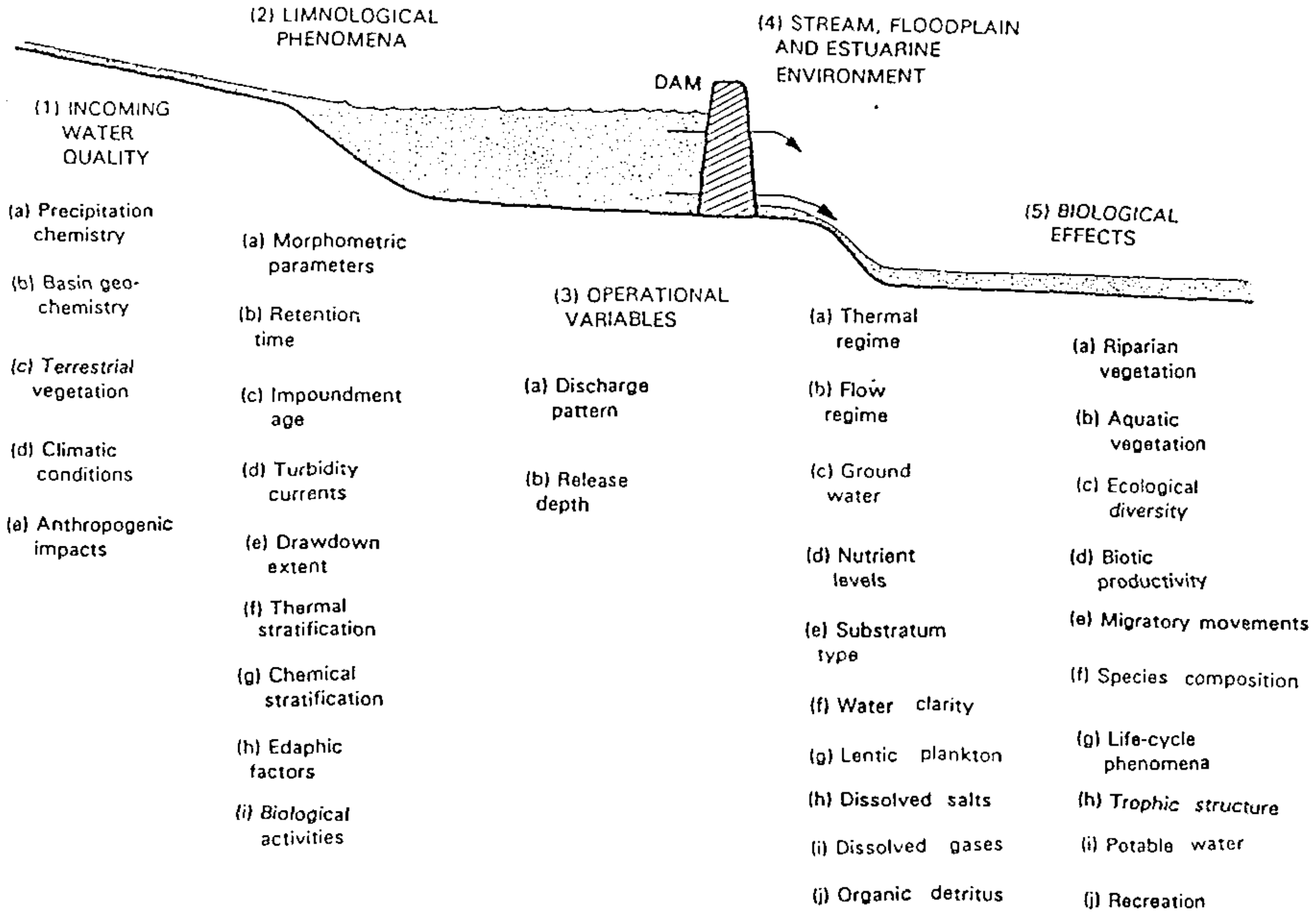



**Figure 2.1:** Major factors and phenomena influencing the receiving reaches of rivers below impoundments, and resultant effects on the biota. (Modified from Ward *et al.*, 1984).

2. hydrological characteristics based upon humid-region data *cannot be extrapolated to arid regions*, and;
3. the maximum potential flow regulation in arid regions is generally 10% of the mean annual flow, except in North America, where up to 40% regulation is possible.

The Coefficient of Variation ($C_v$) expressed as a percentage, is a useful measure of hydrological variability (Table 2.1). Arid regions have a mean $C_v$ of 99 for annual flows, in

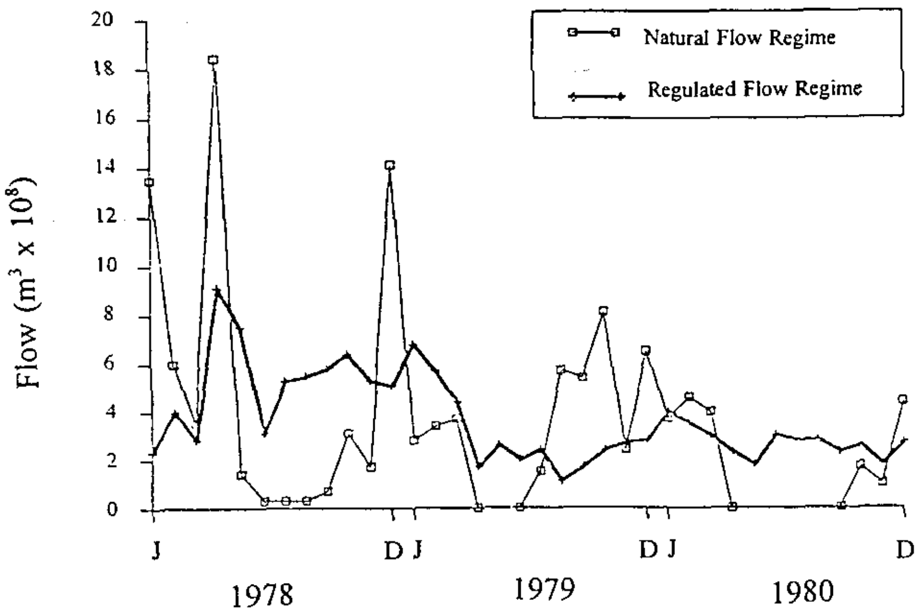



**Figure 2.2:** Natural (thin line) and regulated (thick line) flow regimes of the Orange River. (After Cambrey *et al.*, 1986).

comparison to humid regions in North America (30), Europe (20) and Asia (20). Maximum $C_v$'s for individual arid regions are in Australia (127), southern Africa (114) and the Mediterranean (125) (although see Table 2.1 from Van Biljon & Visser, in manuscript). Finlayson & McMahon (1988) state that, generally, areas of low precipitation (hence low runoff) exhibit high flow variability, with $C_v$'s being twice those of humid regions, irrespective of drainage basin size.

Flood flows in arid regions are also more highly variable than those in other climatic regions. For example, the widely used measure of flood variability, the ratio $O_{100}/O$ (the 100 year recurrence flood interval divided by the mean annual flood), is on average >1.5 times higher in arid regions than elsewhere (Finlayson & McMahon, 1988). Flood flows in both arid Australia and southern Africa exhibit the *greatest degree of variability* with values **>12** (Davies *et al.*, 1993).

**Table 2.1:** (a): Characteristics of representative South African rivers arranged by Province (from north, through central, to the coast, working west to east).
(b): Mean variability for rivers in other parts of the world as a comparison, using the coefficient of Variation ($C_v$) of MAR. (Modified from Van Biljon & Visser, in manuscript). Data for the last 4 rows of section (b) generated by C. Stewart.

(a).

| RIVER | LOCALITY | Catchment area | Mean precipitation | Runoff MAR | $C_v$ |
|---|---|---|---|---|---|
| | | ($km^2$) | (mm) | ($m^3 x 10^6 a^{-1}$) | (%) |
| Crocodile | Hartbeespoort | 4 112 | 688 | 154 | 78 |
| Hennops | Zwartkops | 808 | 709 | 13 | 148 |
| Great Marico | Marico-Bosveld | 1 219 | 613 | 32 | 118 |
| Luvuvhu | Albasini | 509 | 706 | 24 | 108 |
| Olifants | Kromdraai | 3 989 | 693 | 139 | 99 |
| Vaal | Standerton | 8 193 | 726 | 550 | 82 |
| Harts | Taung | 10 990 | 546 | 52 | 158 |
| Orange | Aliwal North | 37 075 | 725 | 5 131 | 56 |
| Dorpspruit | Victoria West | 280 | 216 | 1 | 162 |
| Olifants | Clanwilliam | 2 033 | 396 | 394 | 53 |
| Doring | Melkboom | 24 044 | 214 | 1 | 73 |
| Berg | Wellington | 713 | 1 034 | 547 | 64 |
| Steenbras | Steenbras | 67 | 1 076 | 45 | 33 |
| Hermitage | Swellendam | 9 | 773 | 8 | 35 |
| Brak | Bellair | 558 | 288 | 2 | 107 |
| Kammanassie | Kammanassie | 1 505 | 637 | 39 | 110 |
| Sundays | Vanryneveids Pass | 3 681 | 337 | 35 | 154 |
| Kubusi | Thornhill | 491 | 786 | 54 | 79 |
| Mzimkulu | F.P. 160 | 545 | 1 050 | 225 | 30 |
| Tugela | Colenso | 4 176 | 889 | 944 | 47 |
| Slang | Vlakdrift | 676 | 786 | 131 | 53 |
| Pongolo | Intulembi | 7 081 | 787 | 1 059 | 59 |
| Bonnie Brook | Broadholms | 119 | 844 | 13 | 39 |
| Komati | Hooggenoeg | 5 499 | 670 | 528 | 62 |
| Noortkaap | Bellevue | 126 | 1 123 | 43 | 42 |
| Sabie | Sabie | 174 | 1 268 | 67 | 41 |

Mean coefficient of variation in discharge for 83 South African rivers (including those listed above): 89%.

(b).

| COUNTRY / REGION | Number of rivers in the analysis | Coefficient of variation (%) |
|---|---|---|
| USA | 72 | 38 |
| Canada | 13 | 20 |
| Europe | 37 | 22 |
| Victoria State (Australia) | 10 | 53 |
| Australia and New Zealand | - | 50 |
| Africa | - | 23 |
| Asia | - | 27 |
| South Africa | >83 | 117 |

In terms of physical responses to flow regulation, the transfer of energy and mass is a governing influence in all rivers. Depending upon local geomorphology, these transfers may affect all parts of the physical environment of a fluvial system (Walker & Thoms, 1992). Their significance, in terms of physical and ecological functioning, is accentuated in semi-arid rivers because of their enhanced variability and unpredictable nature. Thus, increasing human control over semi-arid rivers is extremely serious in that the regulated flow régime is so **different** from the natural régime that *the environmental impact on these systems is probably very much greater than for rivers elsewhere.* The consequences of flow regulation on the transfer of energy and mass, and the related morphological adjustments are well documented (e.g. Petts, 1984). Most of these examples are, however, from humid regions and recent work by Thoms & Walker (1992) and Walker & Thoms (1992), for instance, indicates that the environmental response to flow regulation in arid regions may differ from responses recorded elsewhere, and may be catastrophic.

The concept of *dominant discharge*, defined as the increment of discharge that transports the largest fraction of the annual sediment load over some years, has been used by Thoms & Walker (1992) to illustrate the impact of flow regulation on semi-arid rivers. It is calculated as the product of the frequency of occurrence and the sediment transport rate. Wolman & Miller (1960) have argued that in the long-term it is the relatively frequent *intermediate* flows that transport the greatest volume of sediment and that, therefore, such flows govern the morphology of the channel. This magnitude-frequency concept is, however, climatically dependent (Graf, 1985), and semi-arid rivers have high dominant discharges in comparison to humid and temperate systems. Ecologically, this implies that the disturbance régime is characterised by *high magnitude-low frequency* events. Flow regulation *reduces* the dominant discharge of semi-arid rivers (e.g. Fig. 2.2), thereby *decreasing the variability* of hydrological, sediment transport, and disturbance régimes (e.g *sensu* Reice, 1984, 1987; Resh *et al.*, 1988). This decrease in variability, or *increase in predictability*, has implications for both the physical and the ecological functioning of these systems.

Figure 2.3 highlights the impact of flow regulation on flow and sediment transport in semi-arid rivers (Thoms & Walker, 1992). The impacts of flow regulation, and hence the model (Fig. 2.3), depend on at least three factors:

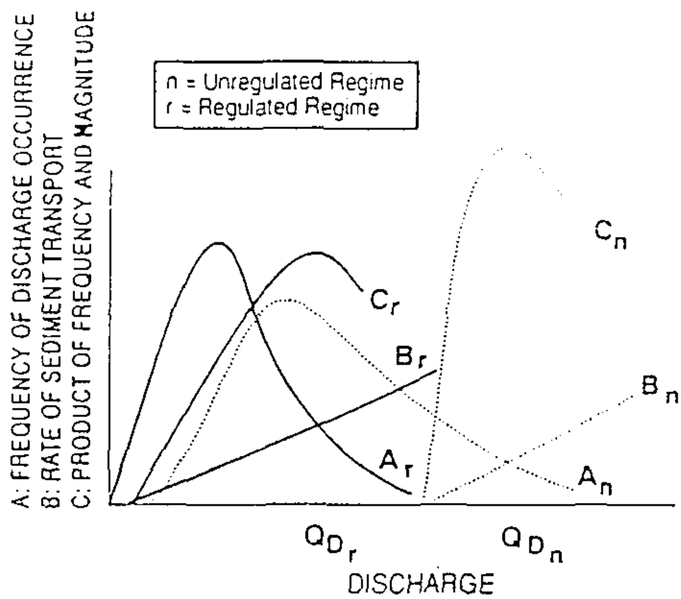



**Figure 2.3:** A conceptual model of the impact of flow regulation on water and sediment transport. (Courtesy of M Thoms, University of Sydney and K Walker, University of Adelaide).

## 2.1.1 CHANGES IN THE FLOW RÉGIME

Curves $A_n$ and $A_r$ represent discharge frequencies for particular periods. The subscript $_n$ denotes the unregulated or semi-arid condition, and $_r$, the regulated condition. Reservoir operations generally decrease the magnitude and increase the frequency and duration of downstream flows. Thus, the regulated discharge-frequency curve has a pronounced peak which is displaced to the left of the pre-regulation curve (Fig. 2.3).

## 2.1.2 THE SEDIMENT TRANSPORT RATE

The curves $B_n$ and $B_r$ (Fig. 2.3) represent transport rates derived for the same periods. The position and slope of the curves depend on the competence and capacity of flows and the availability of sediment. A reduction in flow decreases the ability of a river to transport large quantities of sediment, particularly coarser sediment (*cf* Petts & Thoms, 1986). Reservoirs isolate upstream source areas, restricting sediment availability to downstream reaches. Furthermore, a reduction in the size and frequency of flood events restricts sediment entrainment from floodplain sources.

### 2.1.3. INTERACTIONS BETWEEN THE FLOW AND SEDIMENT RÉGIMES

The product of the two preceding factors is represented by the curves $C_n$ and $C_r$ (Fig. 2.3). Each curve is peaked, with the apex denoting the magnitude of the dominant discharge. The post-regulation curve ($C_r$) is located left of the pre-regulation curve ($C_n$). Thus, discharges which occur relatively more frequently now dominate the sediment transport régime.

This model is incomplete, as it deals only with suspended sediment, but in its current form it does describe the impact of flow regulation on semi-arid rivers in terms both of a reduction in the magnitude of dominant discharge events and the overall variability of the sediment transport régime, or disturbance régime. As such, it may provide a useful framework for investigating the physical impact of catchment disturbances on semi-arid fluvial systems. (**Note:** we are indebted to Martin Thoms - Sydney - and to Keith Walker - Adelaide - for permission to incorporate the model and their discussion of it in this Monograph).

## 2.2 BRIEF REVIEW OF REGULATED RIVERS RESEARCH IN SOUTH AFRICA

Early evidence on the effects of impoundment on South African rivers was collected by Chutter (1967), who investigated the benthos below the Vaal-Hartz Diversion Weir in order to understand the reasons for plague outbreaks of the mammalophilic simuliid, *Simulium* *chutteri*. This work provided an excellent background for later efforts at control. Concentrating on the stones-in-current fauna, Chutter noted that the densities of *S. chutteri* peaked when flow fluctuations were greatest (the weir operated on a *weekly flow variation*, supplying irrigation water). The larvae were better able to invade newly flooded habitat than their predators and competitors (predation mainly from hydropsychid Trichoptera - competition from other simuliids). Large populations persisted for up to 50 km below the weir, and Chutter ascribed this last observation to the *seasonal reversal* of the flow rate. Later, Chutter (1969), reported that the benthic invertebrate community below the Vaal Barrage had **recovered** some 8 km downstream, from the effects of the reservoir.

It was Pitchford & Visser (1975) who provided one of the rare pre- and post-impoundment studies of a southern african river. They compared water temperatures downstream of the Verwoerd Dam on the Orange River, with a view to predicting the possible spread of schistosomiasis vector snails in the system. They found that the range was reduced from 19.6°C (before), to 12.8°C (after), and that seasonal effects were delayed by the thermal inertia of the reservoir water mass, such that winter temperatures were elevated, and summer temperatures decreased. They concluded that in this system, at least, the disease vectors, *Biomphalaria pfeifferi* and *Bulinus* (*Physopsis*) sp., could find conditions more favourable for them than hitherto, and that there was the possibility of the summer transmission of bilharzia. However, and fortunately, this finding has not been borne out; no incidence of the disease has yet been reported in the system.

Only two other studies of "pre-impoundment" conditions have been carried out on southern african rivers: Cahora Bassa, built on the Middle Zambezi, and the Epupa Scheme on the Cunene River in Namibia. However, even these studies have come **AFTER** the construction of other impoundments, upstream on the same system: Kariba, on the Middle Zambezi, some 200 km above Cahora Bassa, and the Ruacana Diversion scheme on the Cunene in Namibia, as well as the Caluéque and Gové dams (amongst others) upstream in Angola - this makes interpretation of any results somewhat difficult!

Recent studies on South African rivers have concentrated on the effects of existing dams, comparing conditions upstream of the impoundments with those downstream. Transported material as well as other physico-chemical variables were examined in relation to the Elandsdrift Dam on the Great Fish River in the eastern Cape (R W Palmer & O'Keeffe, 1990b). Physico-chemical variables and riffle-dwelling benthic invertebrates were sampled above and below the reservoir over one year, and differed markedly. Typical taxa above the impoundment included Ephemeroptera, hydropsychid Trichoptera, Chironomidae, Nematoda and the pest blackfly *Simulium chutteri*, while immediately below, the numbers of benthic invertebrates were reduced, and typical taxa included Chironomidae, *Hydra* sp., Oligochaeta, and non-pest species of Simuliidae. Surface-released water contained high levels of chlorophyll-*a*, and low concentrations of suspended material compared to in-flowing water, while bottom-releases contained low levels of chlorophyll-*a*, but high concentrations of $NH_4$, illustrating the impact of different release régimes. Conditions took between 25-86 km to *recover* to "above impoundment" levels. Draining of the reservoir produced water with high concentrations of suspended material (2829 $mgl^{-1}$), caused fish kills for 3.5 km downstream, and depleted benthic invertebrate population densities for over 200 km, the latter recovering within two months.

## 2.2.1 THE BUFFALO AND PALMIET STUDIES: A COMPARISON OF CONTRASTING SYSTEMS

On a much larger scale than those studies cited above, a very detailed collaborative study of the downstream effects of six impoundments on two contrasting rivers commenced in 1986, between the Freshwater Research Unit, University of Cape Town - Palmiet River - and the then Institute for Freshwater Studies, at Rhodes University - Buffalo River. The systems were carefully chosen to contrast in almost every aspect, other than that both were multiply regulated by dams. Every effort was made to ensure compatibility of approach, and techniques were standardised as far as possible. The results of this study, together with separate reports on each system are variously covered by Byren & Davies (1989), Davies *et* *al.*, (1989), O'Keeffe *et al.*, (1990), C G Palmer (1991), C G Palmer *et al.*, (1991, 1993a,b), R W Palmer & O'Keeffe (1990a,c), R W Palmer (1991), and Gale (1992). The objectives of the programme were the development of a predictive capability for the effects of impoundments on southern african rivers, the measurement of the intensity of those effects, and the estimation of associated "*recovery distances*" (**discontinuities**) for a wide variety of variables, based on the ideas of Ward & Stanford (1983a,b) - respectively, the *Serial Discontinuity Concept* (SDC), and the *Intermediate Disturbance Hypothesis* (IDH).

Table 2.2 lists the major attributes of each river, together with the physical attributes of the six study dams - two on the Palmiet and four on the Buffalo (Davies *et al.*, 1989; O'Keeffe *et al.*, 1990).

The Palmiet River rises in the Hottentots-Holland mountains within the Nuweburg State Forest Reserve. The headwaters are surrounded by the typical open canopy of the Mountain Fynbos of the region. The middle reaches flow through intensive fruit-farming areas and, before widening into its estuary, the lower reaches flow through a second reserve, the Kogelberg State Forest, which is under threat from a highly complex and controversial group of proposals to impound the lower reaches and elsewhere in the valley (see Rothmann, 1992).

The system is short (74 km), steep, clear, cool and acid, and the underlying geology consists almost exclusively of Table Mountain Sandstone (TMS) (Byren & Davies, 1989; Gale, 1992). The river is impounded five times within the first 40 km, mostly irrigation storages, but including a pumped-storage hydro-power scheme. Loosely controlled water abstractions include private irrigation and domestic water supply to the local towns. Of the five existing dams, two were extensively studied by Byren & Davies (1989), Davies *et al.*, (1989), and O'Keeffe *et al.*, (1990), in the context of their impacts, namely: the upper-reach Nuweburg Dam (P1), and Arieskraal Dam (P2) built on the mid/lower reaches. Both are bottom-release dams (Table 2.2). Eleven study sites above and below the two dams, and one on a pristine

**Table 2.2:** Physical attributes of the Palmiet and Buffalo river systems, and the six impoundments studied by the collaborative regulated rivers research programme of the Freshwater Research Unit (UCT), and the Institute for Freshwater Studies (Rhodes University) (After Davies *et. al.*, 1989)

| | BUFFALO | PALMIET |
|---|---|---|
| Catchment Size ($km^2$) | 1 230 | 500 |
| Length (km) | 140 | 74 |
| Stream order | 4 | 4 |
| MAR ($10^6m^2$) | 85 | 228 |
| Source altitude (m) | 1 300 | 1 133 |
| Number of dams | 4 | 5 |
| Rainfall | summer | winter |
| Turbidity | turbid | clear |
| pH | alkaline | acid |
| Temperatue | warm | cool |
| Pollution | severe (mid-reach) | mild (mid-reach) |

| | BUFFALO | | | | PALMIET | |
|---|---|---|---|---|---|---|
| | Maden B1 | Rooikrans B2 | Laing B3 | Bridle Drift B4 | Nuweburg P1 | Arieskraal P2 |
| Distance from source (km) | 8 | 12 | 66 | 109 | 8 | 35 |
| Capacity ($10^6m^3$) | 0.3 | 5.4 | 22.1 | 75.5 | 3.9 | 5.9 |
| Catchment area ($km^2$) | 31 | 48 | 913 | 1 176 | ? | ? |
| Altitude (m) | 525 | 518 | 310 | 109 | 500 | 200 |
| Release type (surface/bottom) | S | S | S | S/B | B | S/B |
| Compensation flow (yes/no) | N | Y | N | Y | Y | Y |

tributary of the Palmiet, were sampled between April 1986 and September 1987 in order to assess recovery distances for a variety of physico-chemical variables. In addition, between February 1987 and April 1988, the benthic communities at seven of these sites were sampled (Gale, 1992).

On the other side of the Cape, the Buffalo rises in virtually pristine, indigenous forest, and then flows through intensive agricultural land, before entering the urban/industrial complex of King Williams Town/Zwelitsha, and is impounded four times (dams B1-B4). Laing Reservoir (B3), immediately below Zwelitsha, receives very poor quality water, which is purified and returned to the towns. The lower reaches of the river are impounded at Bridle Drift (B4), and this reservoir supplies Mdantsane and East London. Sewage effluent from Mdantsane enters the river below the Bridle Drift Dam (B4), considerably reducing water quality. The system supplies 80% of the water requirements for a population of *ca* 730 000 - present demand is 53x106 $m^3$ $yr^{-1}$, while the four impoundments provide a firm yield of 57.7x106 $m^3$ $yr^{-1}$ (South African Department of Water Affairs, 1986). The river is therefore being exploited near to its sustainable limit, although an IBT from the neighbouring Great Kei River will augment the dependable yield by 36.1x106 $m^3$ $yr^{-1}$ (South African Department of Water Affairs, 1986).

These studies are unique for the continent from two angles. Firstly, they comprise *entire rivers*, from headwaters to estuary, and secondly, they were designed to allow for direct comparison. In terms of the impacts of regulation on the physico-chemistry of the two rivers, the major spatial findings are summarised for selected variables in Figure 2.4 (SRP, $NO_3$, $NO_2$, and $NH_4$), and Figure 2.5 (flow rate, spot temperatures, and annual temperature ranges), while Figure 2.6 summarises the *recovery distances* ("**reset**" - *sensu* O'Keeffe *et al.*, 1990), for each of these features, together with TSS, conductivity, pH and alkalinity, in relation to the operating criteria of each dam (Davies *et al.*, 1989; O'Keeffe *et al.*, 1990). The dendrogram in Figure 2.7 visually compares the two rivers, while Table 2.3 compares similarities and differences for ten variables which were measured for all dams on each system, listing qualitative similarities between pairs for each dam. (Note that Laing Dam is excluded from this last analysis because of its grossly polluted inflow - Davies *et al.*, 1989; O'Keeffe *et al.*, 1990).

Looking at the dendrogram illustrated in Figure 2.7 first, this clearly shows that the ***entire*** Palmiet system approximated to the ***upper 20 km*** of the Buffalo, both chemically and physically, with differences rapidly appearing as one progressed beyond this point on the Buffalo, owing to downstream mineralisation and industrial and urban pollution. As far as impacts are concerned, Figure 2.5 clearly shows **major impacts by all dams on each system**

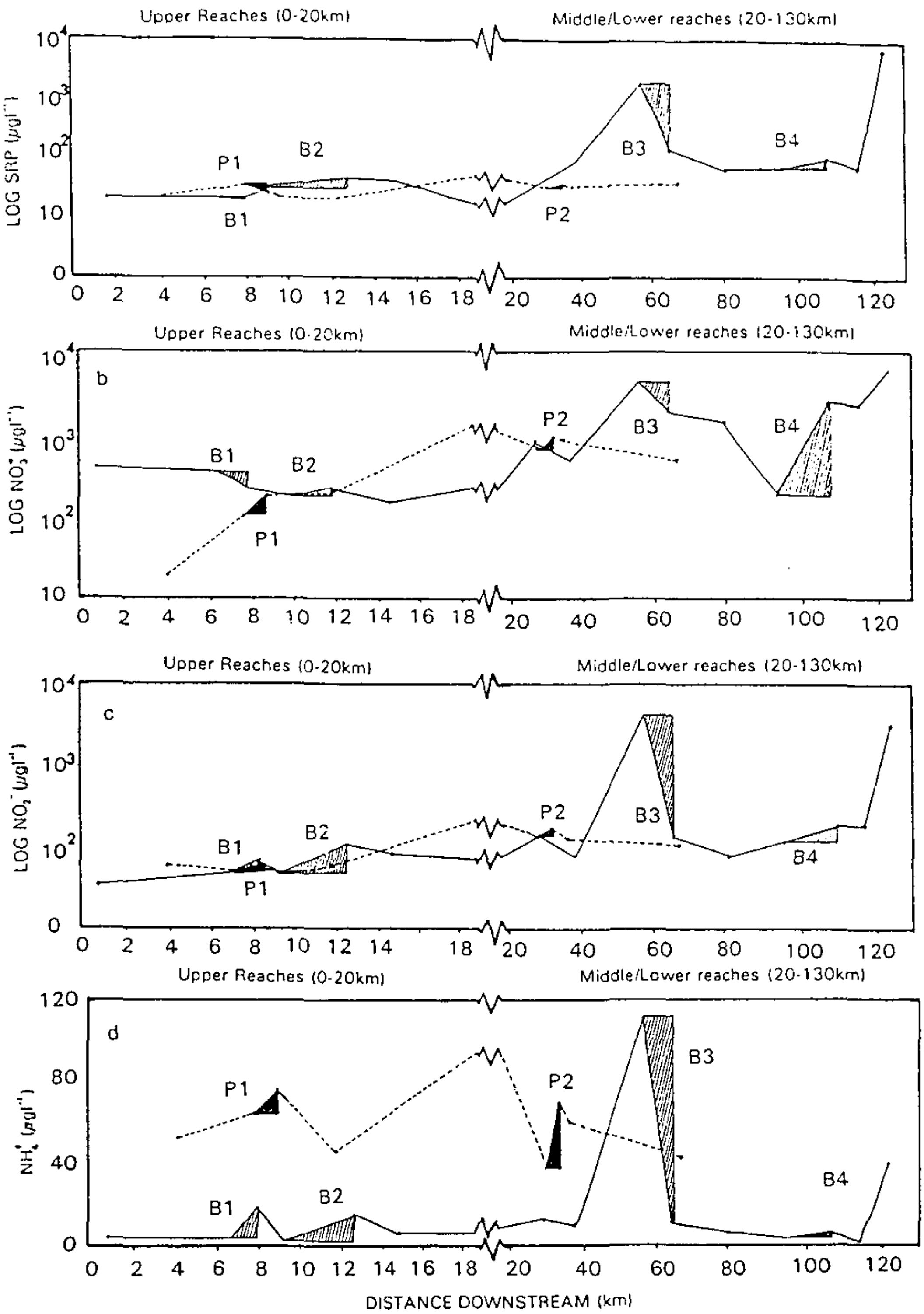



**Figure 2.4:** Spatial changes in the concentrations of (a), soluble reactive phosphate, (b), nitrate, (c), nitrite, and (d), ammonium along the lengths of the Buffalo (continuous line) and Palmiet (broken line) rivers. Note that (a), (b) and (c) have log-scale y-axes, while (d) is linear. Shaded triangles indicate the positions of impoundments, and dam walls on each system are represented by the vertical axes of the triangles. (After O'Keeffe *et al.*, 1990).

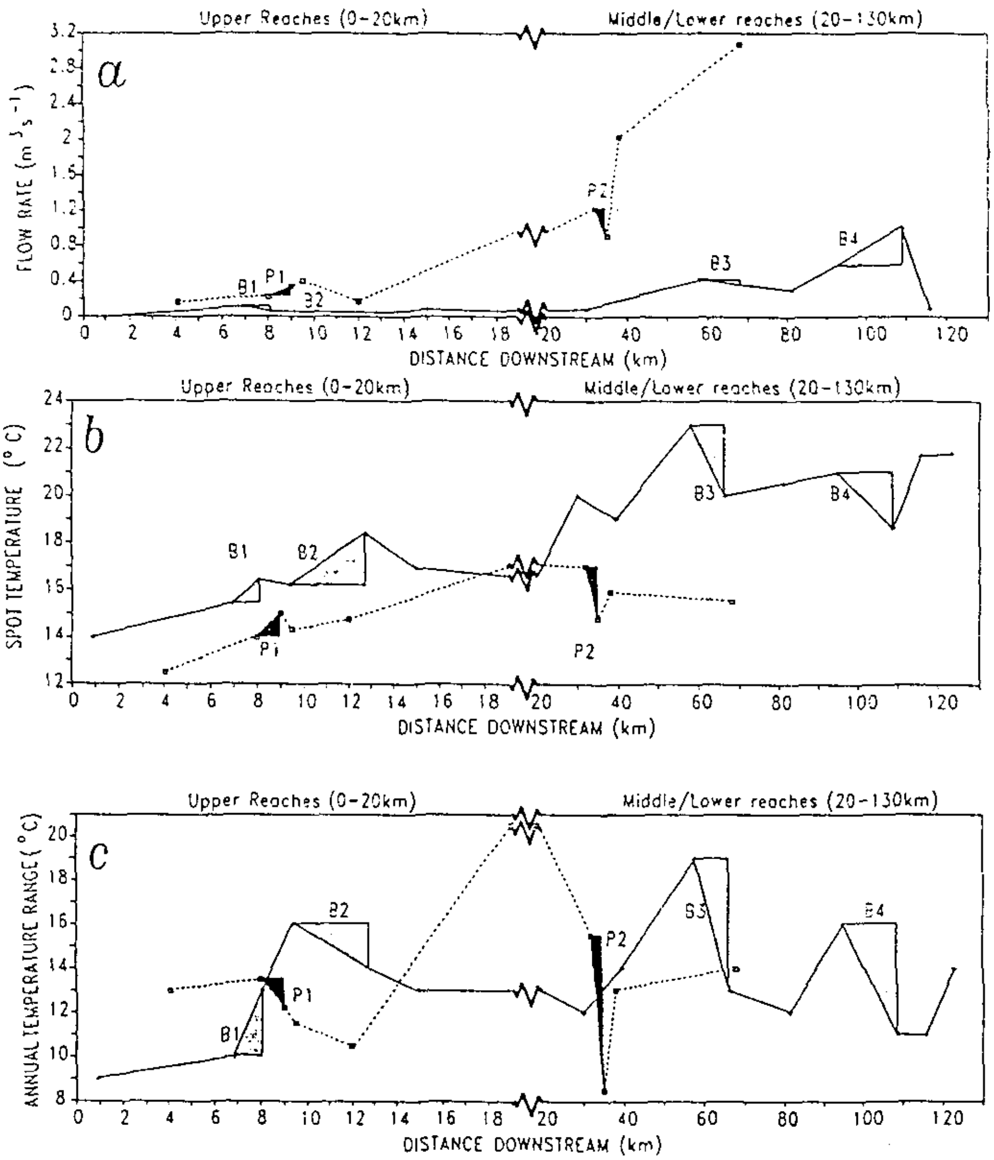



**Figure 2.5:** (a), Median flows ($m^3 s^{-1}$), (b), median spot temperatures, and (c), annual spot temperature ranges along the lengths of the Palmiet (dotted line) and Buffalo (continuous line) rivers. Shaded triangles indicate the positions of the impoundments and the dam walls are represented by the vertical axes of the triangles. (After Davies *et al.*, 1989).

for flow, median spot temperature, and upon the annual temperature range, particularly for dams regulating the upper reaches of both rivers. Interestingly, these upper-river impoundments *behaved similarly despite different release patterns* (Fig. 2.6), and caused only weak chemical effects, most of which recovered rapidly within 3 km (Fig. 2.6). Middle-reach

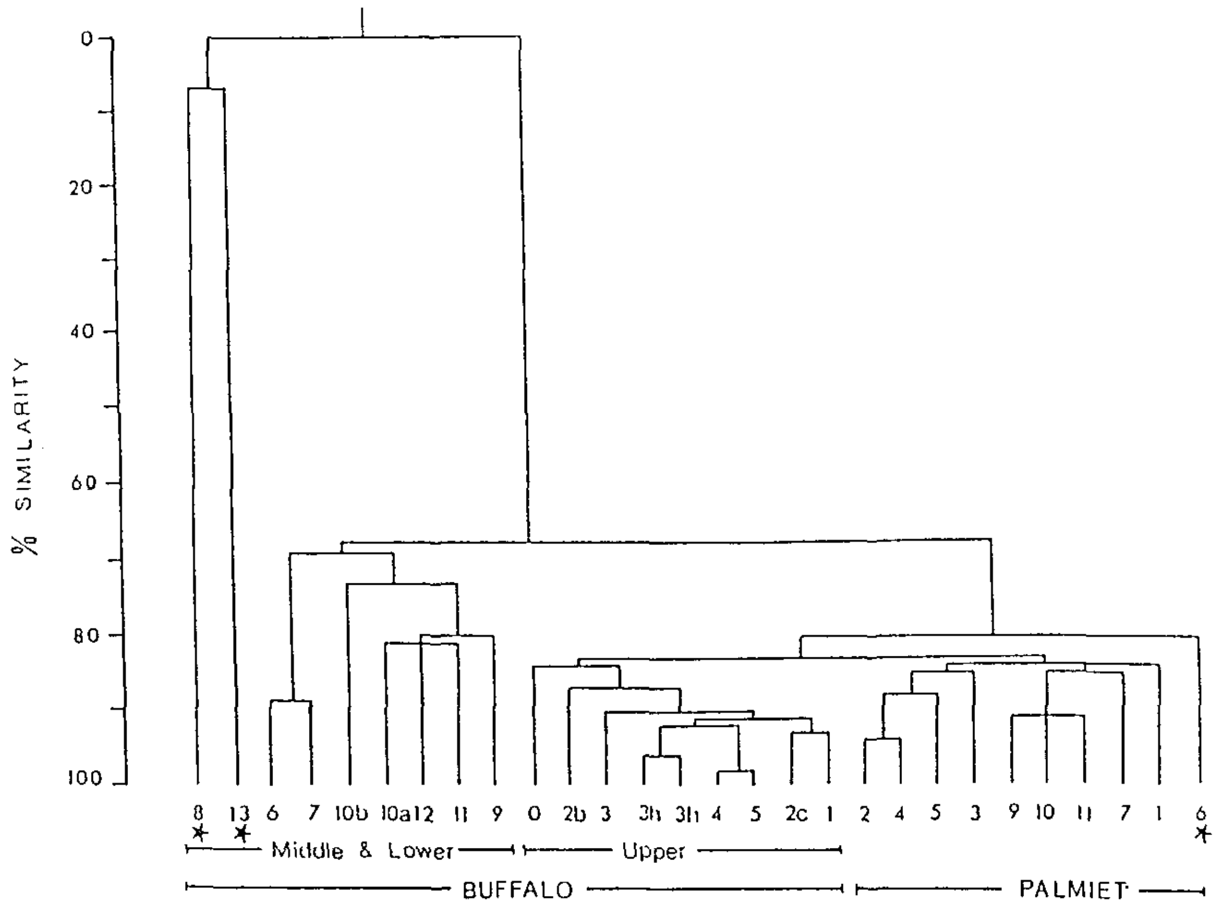



**Figure 2.6:** Similarity dendrogram of the physico-chemical variables measured in the Buffalo River, Eastern Cape, and the Palmiet River, South-Western Cape. Stars indicate polluted sites which are significantly different (particularly in the Buffalo River) from the other sites. Numbers (0-13 for the Buffalo and 1-11 for the Palmiet) refers to sample site numbers (increasing downstream). Positions of the sample sites are detailed in O'Keeffe *et al.*, (1990). (After Davies *et al.*, 1989).

impoundments *also behaved similarly despite different release characteristics* (Fig. 2.6), but they caused more pronounced changes, and recovery distances were longer (up to 30 km). These observations tend to contradict some aspects of the SDC, and other observed *exceptions* to its predictions include alterations to nutrient régimes of the receiving reaches below *all* dams (Fig. 2.6), as well as the already noted changes to annual temperature ranges. In addition, ***all*** impoundments on both systems significantly depressed flow fluctuations (Fig. 2.6).

Although the specific predictions of the SDC model were not generally borne out by this comparative study, the SDC may still be regarded as a useful tool for testing the effects of impoundments on rivers, and the concept of *"recovery, or reset distances"* forms a useful practical framework for the management of releases from impoundments. Ward & Stanford's (1983a) predictions were originally made for **natural rivers** (unperturbed), for which impoundment is the only artificial perturbation. The Buffalo River falls far outside this requirement, for although it is pristine in its upper reaches, it is grossly polluted in the middle reaches. For example, Laing Reservoir (B3), receives polluted water with SRP concentrations of up to a maximum of 9 mg $l^{-1}$, and $NH_4$ levels of up to 14.4 mg $l^{-1}$! Effectively, this reservoir acts as a giant settling tank, radically reducing SRP concentrations to a median concentration of 0.18 mg $l^{-1}$. The dam might therefore be seen as "resetting" the river, in a reversal of Ward & Stanford's (1983a) SDC. Thus, although the regulation of rivers by impoundment has traditionally been viewed by conservationists as a degradation of the river ecosystem, while this is true for unperturbed systems, the presence of Laing Dam on the Buffalo provides protection for the lower reaches from the worst of the upstream eutrophication. Indeed, the purification processes of the dam appear to be far more intense than for a comparable stretch of flowing water (R W Palmer & O'Keeffe, 1990a), and allow for considerable recovery to more acceptable conditions.

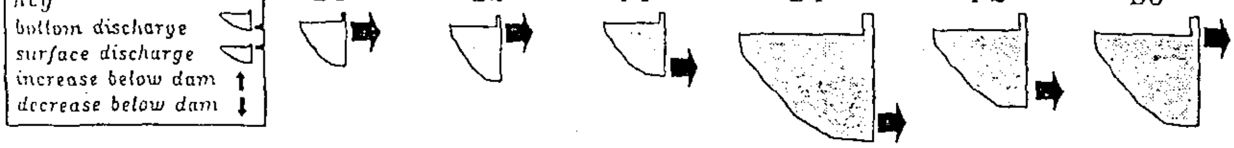
Finally, from this work, the research teams were able to make a number of important conclusions concerning the variables which were most likely to be important in governing the changes that take place downstream of any dam (e.g. Davies *et al.*, 1989; Table 2.3; Fig. 2.7):

1. there were no effects common to all six dams;
2. the position of any dam was of over-riding importance, governing the types of downstream effects, while perhaps surprisingly, the marked differences between the physical and chemical features of the two rivers appeared to have very little influence on the types of effects caused by impoundment;

**Table 2.3**: Similarities and differences in the effects of different dams on the Buffalo and Palmiet rivers. Ten variables were measured for all dams, and qualitative similarities between pairs and groups of dams are listed below; e.g. for dams B1 and B2, seven of the 10 variables showed similar changes above and below the dams. B3 is not included in the analysis, because it received polluted inflow and downstream responses were quiet different to the other dams. (After Davies *et. al.*, 1989).

| Grouping | Number similar (out of 10) | River | Common factors Size | Zone | Release |
|---|---|---|---|---|---|
| B4:P2 | 10 | | | lower | bottom |
| B1:B2 | 7 | Buffalo | small | upper | surface |
| B1:P1 | 6 | | small | upper | |
| B2:P1 | 6 | | small | upper | |
| P1:P2 | 5 | Palmiet | | | bottom |
| B2:P2 | 4 | | | | |
| B4:P1 | 5 | | | | bottom |
| B1:B2:P1 | 5 | | small | upper | |
| B4:P1:P2 | 5 | | | | bottom |
| B2:B4 | 4 | Buffalo | | | |
| B1:P2 | 2 | | | | |
| B1:B2:B4 | 2 | Buffalo | | | |
| B1:B4 | 2 | Buffalo | | | |
| B1:B2:B4:P1:P2 | 2 | | | | |

3. larger impoundments caused more intense downstream impacts, and these impacts took longer to recover;
4. release mechanisms were less important than the position of a dam along the river, but bottom-releases consistently reduced temperature ranges, increased TSS, and increased all nitrogenous compounds measured, and
5. reservoirs were more effective than equivalent lengths of flowing water, at "resetting" grossly polluted systems.




| | B1 | B2 | P1 | B4 | P2 | B3 |
|---|---|---|---|---|---|---|
| SPOT TEMP | ↑ | ↑ 2.2 | ↑ p | ↓ 7 | ↓ 3 | ↓ p |
| ANNUAL TEMP RANGE | ↑ | ↓ | ↓ | ↓ p(14) | ↓ p(3) | ↓ |
| TSS | | | ↑ p(3) | ↑ p(7) | ↑ 3 | ↓ |
| CONDUCTIVITY | | | | ↓ | ↓ 30 | ↓ |
| pH | | | ↑ 0.5 | ↓ p(7)* | ↓ 30 | ↑ |
| ALKALINITY | ↑ 1.3 | ↑ | ↑ 3 | ↓ | ↓ | ↓ |
| SRP | ↓ 1.3 | ↑ 2.2 | ↓ | ↑ p(7) | ↑ p(3) | ↓ r |
| $NO_3$ | ↓ | | ↑ | ↑ | ↑ 30 | ↓ r |
| $NO_2$ | ↑ 1.3 | ↑ | ↑ | ↑ | ↑ 3 | ↓ r |
| $NH_4$ | ↑ 1.3 | ↑ p(2.2) | ↑ 3 | ↑ | ↑ 30 | ↓ r |

**Figure 2.7:** Summary of the effects of six impoundments (B1-B4, Buffalo: and P1-P2, Palmiet) on a variety of physico-chemical features of the receiving reaches downstream of each impoundment. Arrow directions indicate whether or not the variable increased of decreased. Numbers denote measured recovery distances in km, while "p" denotes partial recovery and denotes recovery during low-flow conditions. A blank space indicates no effect, while no number indicates that recovery distances could not be discerned. B3 receives polluted inflow and acts as a "settling pond" in the river (see text) so, although recovery distances are not relevant, the river is "reset" ("r") in terms of the effects of the impoundments upon the major nutrients. (After Davies *et al.*, 1989).

# 2.3 POTENTIAL DAM SITES WITHIN THE SABIE-SAND SYSTEM

## 2.3.1 EXISTING AND POSSIBLE NEW DAMS

There are at present 7 dams on the Sabie-Sand system, although one of them - the Zoeknog Dam, has collapsed and presently forms no barrier to water flow. The Edinburgh, Orinoco, Acornhoek, and Casteel Dams are all small (1.1 to 3.3 x $10^6$ $m^3$) dams in the upper tributaries of the Sand River. The Da Gama Dam is a medium-sized dam (14.3 x $10^6$ $m^3$) on the White Waters tributary of the Sabie River. The Corumana Dam is a very large impoundment (1200 x $10^6$ $m^3$) on the Sabie River in Mozambique, which backs up to the eastern border of the Park.

The upper dams all have the effect of reducing runoff to the KNP, but if we can extrapolate from the previous studies of the effects of dams on rivers in other parts of South Africa, then they are too small and too remote from the Park to have significant effects on the water quality, temperature regime, sediment transport and species composition in the main rivers within the Park boundaries. Any such effects will have recovered within a few kilometres downstream of the dam wall. The Corumana Dam, downstream of the Park, represents a major barrier to upstream migration of fish such as the Tigerfish, and may be the main reason for the scarcity of this species in the Sabie within the Park.

Seven potential new dam sites have been identified on the Sabie and Sand Rivers: Arthur's Seat, Dingleydale, and an enlargement of the Casteel Dam, are all sites situated in the upper reaches of the Sand system, and would be 14, 59, 73, and 39 x $10^6$ $m^3$ respectively. Two potential sites have been identified on the Marite tributary of the Sabie River: the Inyaka site (101 x $10^6$ $m^3$), and the Waterval site (109 x $10^6$ $m^3$). The Madras site is larger (230 x $10^6$ $m^3$), and is situated on the main Sabie River only some 5 km. from where the river joins the western KNP boundary.

## 2.3.2 POTENTIAL EFFECTS OF THE DAMS

### *2.3.2.1 FLOW*

The effects of any of the potential new dams on flow would be crucially dependent on how they are managed. If they are to be built with multi-level outlets, and managed so as to release compensation water to the KNP they could potentially have the beneficial effect of using stored water to augment low flows during droughts. In the worst-case scenario, in which no compensation flow was to be released, any of the proposed dams could at least intercept all the low-flow in their own particular tributary during drought years. The Sand River already stops flowing during most years, and the effect of any of the planned impoundments, although they are not on the main stream, would be to increase the period of no-flow. The Madras site is the only proposal which would dam the main Sabie, and could potentially reduce the flow in the Sabie to less than 20% of its virgin MAR (O'Keeffe and Davies, 1991). This would turn the Sabie into a temporary river, in which low-flows would be completely intercepted for five months of most years. Such a scenario is unlikely, and a Madras Dam, properly managed, holds the greatest potential for augmenting low flows in the Park, since it is the largest of the proposed dams, and the nearest to the Park.

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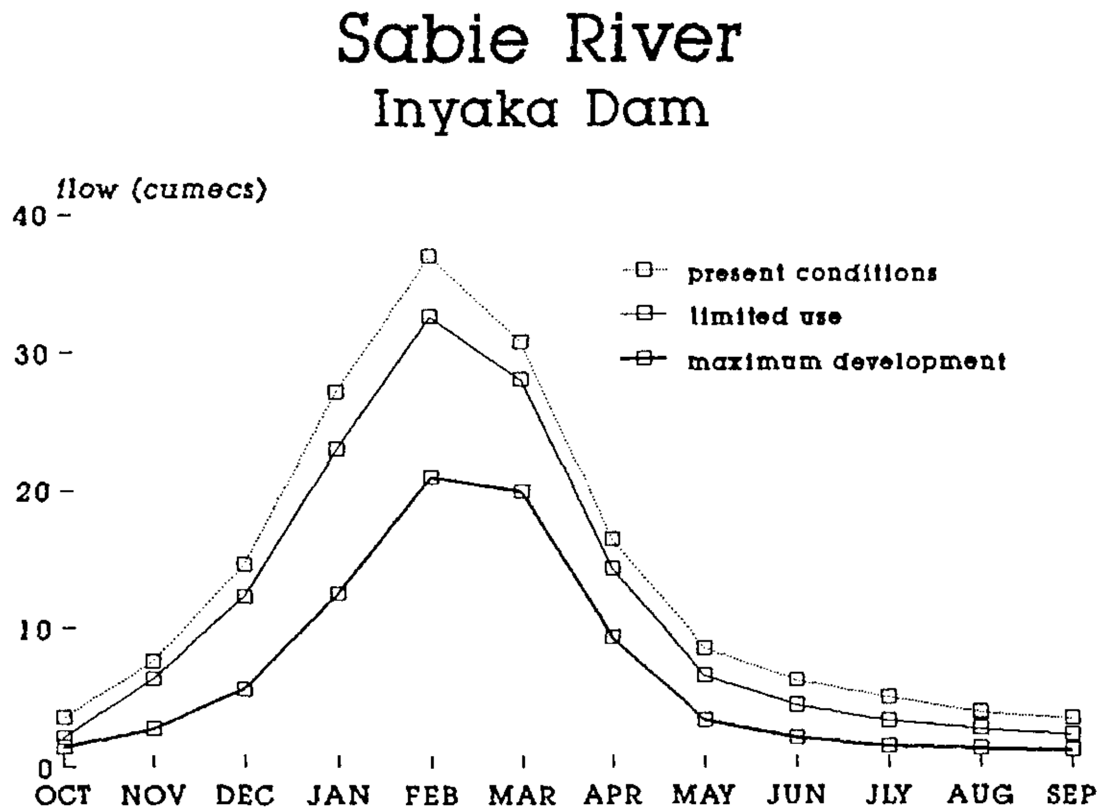


**Figure 2.8:** The effects of the Inyaka Dam on the average mean monthly flow, using Pitman Simulations, for the mid-Sabie River, above the Sand River confluence. With limited use both high and low flows within the Sabie River are affected, low-flows are reduced by almost 50%. Flow reductions within the lower Marite River will be much more marked. Under maximum development, high flows in the Sabie River are markedly reduced while low-flows rely on the upper Sabie alone. The Marite River would be dry for some four months (July-October).

**Developing Inyaka Dam:** The most likely of the dam sites to be developed is the Inyaka site on the Marite tributary, and a detailed examination of the environmental consequences of different management options on this dam was made by the project team in association with Chunnett *et al.*, (O'Keeffe and Davies, 1991). Pitman simulations were run to investigate the effect of the dam on downstream flows. The Inyaka Dam used to its maximum extent would reduce flow in the Sabie in the KNP to less than 40% of its virgin runoff in all years during the dry months (September and October) (Fig. 2.8). During dry years, runoff would be reduced to less than 20% of virgin conditions, and the Sabie River

**Table 2.4:** The effects of the Inyaka and Madras dams on mean monthly peak and base-flows within the Marite and mid-Sabie rivers. Monthly flow data derived from Pitman Simulations.

| DAMS | MANAGEMENT | BASE FLOWS ($m^3/s$) | | PEAK FLOWS ($m^3/s$) | |
|---|---|---|---|---|---|
| | | mid-Sabie | Marite | mid-Sabie | Marite |
| No dams | Present development | 3.5 | 2.1 | 37.1 | 16 |
| Inyaka Dam | Limited use | 2.7 | 1.3 | 31.2 | 10.1 |
| | Maximum use | 1.4 | 0 | 21.1 | 0 |
| Inyaka & Madras dams | Limited use | 2.3 | - | 21.7 | - |
| | Maximum use | 0.05 | - | 18.8 | - |

could stop flowing altogether during droughts. Mid-Sabie River peak flows would on average be reduced by 50%, while base-flows would approximate those seen during the 1990/91 drought (1.4 $m^3 s^{-1}$; Table 2.4). Such conditions would be undesirable from everyone's point of view, and a compromise flow management plan was proposed after a number of simulation scenarios were examined. This plan, known as the "Inyaka Dam - Limited use scenario", would require a compensation flow to be released from the dam which would ensure that the flow in the KNP would never be allowed to fall below un-impounded worst drought conditions. In addition, there would be gradual increases in compensation flow with increases in the inflow to the Dam. As a result, lowest flows would be a rare event, unlikely to occur in consecutive years, and the natural variability of the river flows would be maintained. This scenario, described in detail by O'Keeffe and Davies (1991) (Fig. 2.9), would result in nearly natural flows in wet months during wet years, and flows between 40 - 60% of virgin condition in both wet months during drought years, and dry months during wet years. During the critical dry months during drought years, flows in the Park would be between 20 - 40% of virgin conditions.

The capacity of the Inyaka Dam exceeds the average MAR of the Marite River, potentially holding back both base and peak flows with maximum use. Consequently, the downstream effects of the Inyaka Dam on the Marite River would be extreme compared the those expected for the mid-Sabie River reaches, even with limited use (Table 2.4).

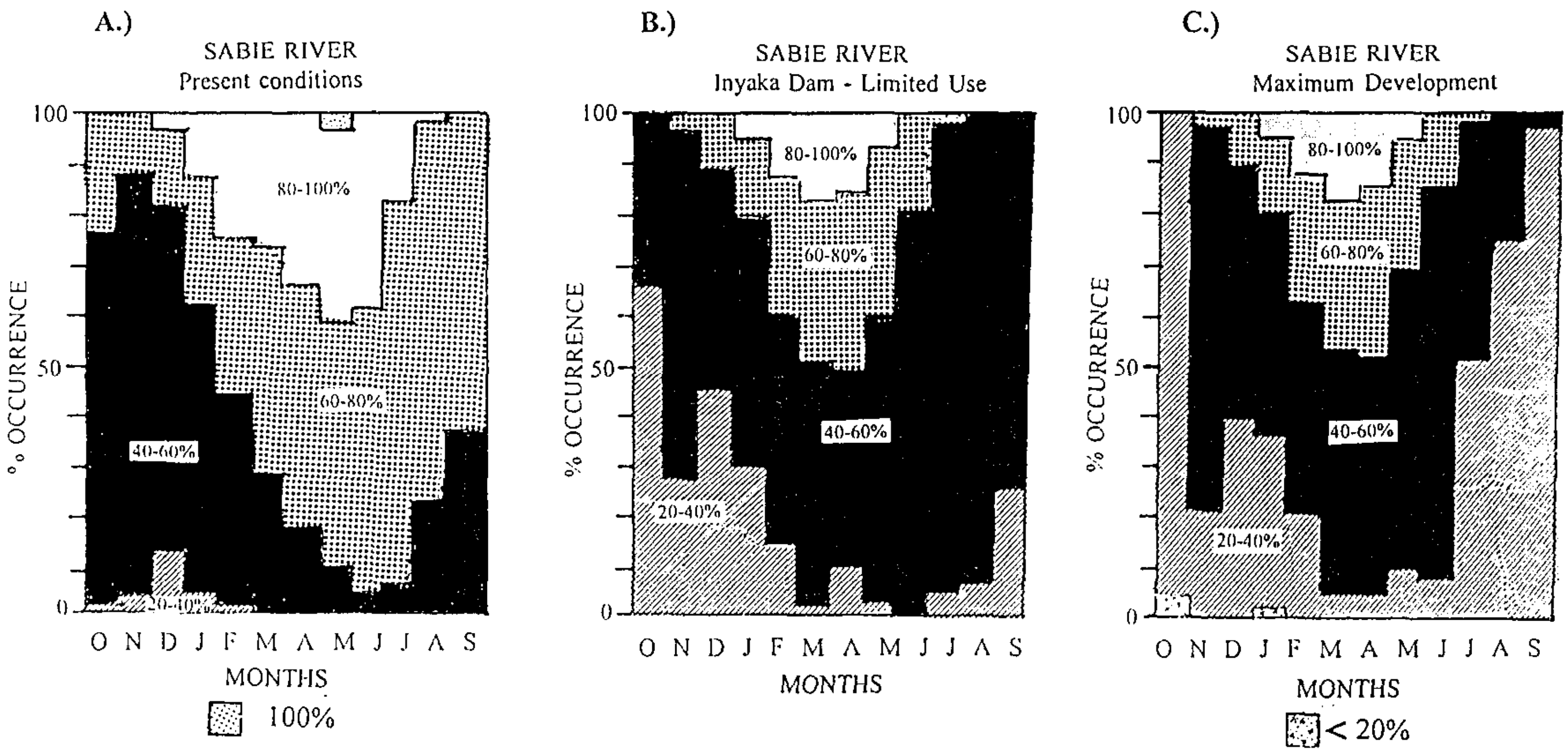


**Figure 2.9:** Monthly discharge patterns in the Sabie River upstream of the Sabie-Sand confluence, under present (a), and regulated by the Inyaka Dam. Conditions under limited (b) and maximum use (c) are given. Discharge patterns are expressed as percentage of natural discharge. (Adapted from O'Keeffe and Davies, 1991).

**Developing the Inyaka and Madras dams:** The Inyaka and Madras Dams together, as a worst case scenario, could potentially regulated the Sabie River completely, reducing peak

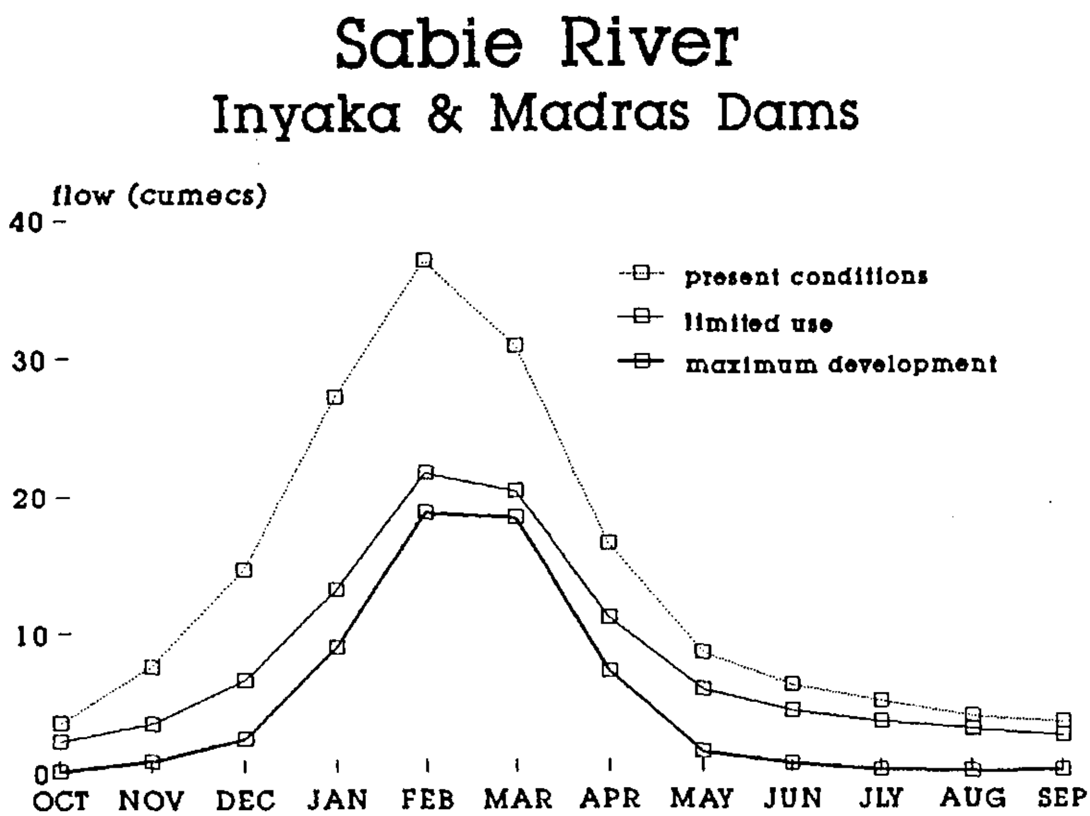


**Figure 2.10:** The effects of the Inyaka and Madras dams on the average mean monthly flow, using Pitman simulations, for the Sabie River immediately above the Sand River confluence. Different management scenarios are shown. The effects on high flows are marked for both limited and maximum use scenarios. Baseflows are healthy in the mid-Sabie River with limited use but they could be stopped for some 4 months with maximum use.

summer flows to similar levels seen with the Inyaka used at maximum capacity (Fig. 2.10). Together they stop flow in the mid-Sabie reaches if no compensatory baseflows were allocated (Table 2.4).

### 2.3.2.2 *THERMAL IMPACTS*

The main effects of impoundments on downstream temperature regimes is to reduce the variability, releasing warmer water in winter and cooler water in summer. The extent of these effects depends on the size of the dam, its position in the river, and whether the water is released from the surface or bottom of the dam. Studies on the Palmiet and Buffalo Rivers (see Section 2.2.1 above), indicated that median temperatures immediately below small dams in the upper reaches of the rivers increased by up to 8°C, but were reduced below larger impoundments in the lower reaches, especially from bottom release outlets. Maximum temperatures were reduced by as much as 16°C by these dams (Palmer and O'Keeffe, 1989). A review of impoundment studies worldwide revealed a log-normal relationship between river discharge and the distance downstream before temperatures recovered (Palmer and O'Keeffe, 1989). This is useful because it allows us to make predictions of the extent of thermal disturbances to be expected from the potential new dams, and the recovery distances. The sites in the upper Sand River and the Marite are likely to cause significant temperature increases downstream, but these should recover within 20 km at the most - well before the water from these dams reaches the Park. The Madras Dam, if it were to be built and operated with a bottom release valve only, would have a major effect of reducing temperatures downstream, possibly by as much as 18 - 20°C, and this effect would extend well into the Park, perhaps for as far as 40 km. Such an effect would have far-reaching consequences for the riverine biota, and would exclude, for example, most of the lowveld fish community.

These effects can be minimised with some planning at the design stage. A dam with a multi-level outlet would allow for water to be released from the surface, or, should this elevate temperatures unacceptably, mixed releases could be arranged from several levels so as to mimic the inflowing temperature.

### 2.3.2.3 *SEDIMENT AND TURBIDITY*

Dams are efficient sediment traps and will intercept almost all of the suspended sediment larger than clay particle size in the river. However, water released from the bottom of a dam wall will re-mobilise sediments and may drastically increase turbidity and suspended sediment downstream. If the sediments at the base of the dam wall are anaerobic, the consequences for the biota downstream may be disastrous. In the Buffalo and Palmiet Rivers the suspended sediment load was increased below bottom-release impoundments from an average of 4.2 to 6 mg $l^{-1}$ below a dam on the Palmiet, and from 31 to 41 mg $l^{-1}$ in the case of the more turbid Buffalo River. Only partial recovery was measured in both cases, at least for the first 7 km downstream. These results imply once again that significant effects would only be felt in the KNP if the Madras Dam were to be built, and that the worst of these effects could be prevented by the incorporation of multi-level outlets in the Dam.

#### *2.3.2.4 BIOLOGICAL IMPACTS*

**Ichthyofauna:** Both the Marite and mid-Sabie Rivers below the proposed dams are highly seasonal in flow (Figs 2.11 & 2.12) and perennial, but their fish assemblages are characteristically different. The Foothill Zone assemblage (FHZ) of the Marite River is aseasonal, and dominated by the catlet *Chiloglanis anoterus* (Fig. 2.11). The Lowveld Zone (LZ) assemblage of the mid-Sabie River is seasonal, dominated by cichlids in the early summer season and by cyprinids soon after the first summer rains, up until the end of the winter dry season (Fig. 2.12). These assemblages are expected to respond differently to impoundment. Differences between the fish typical of both the FHZ and LZ reaches are best explained by evolutionary adaptation to differing water temperature and flow conditions between the more stable mountain source and the drought prone lowland reaches.

Fishes of the Marite River persist in cooler, high energy source waters of the FHZ reaches, and may be expected to be more susceptible to alterations in flow. Of the 19 species recorded (Table 7.3, Volume 1), 6 have been identified as indicative of the FHZ baseline assemblage (Fig. 7.7, Volume 1) which is dominated by the riffle-loving catfish *Chiloglanis anoterus*. Cichlids, which prefer backwaters, are under-represented, while 4 cyprinids making up 15-38% of the catch (59-81% : Fig. 2.11). Throughout the year, the proportions of these groups of fish remain relatively constant (Fig 2.11).

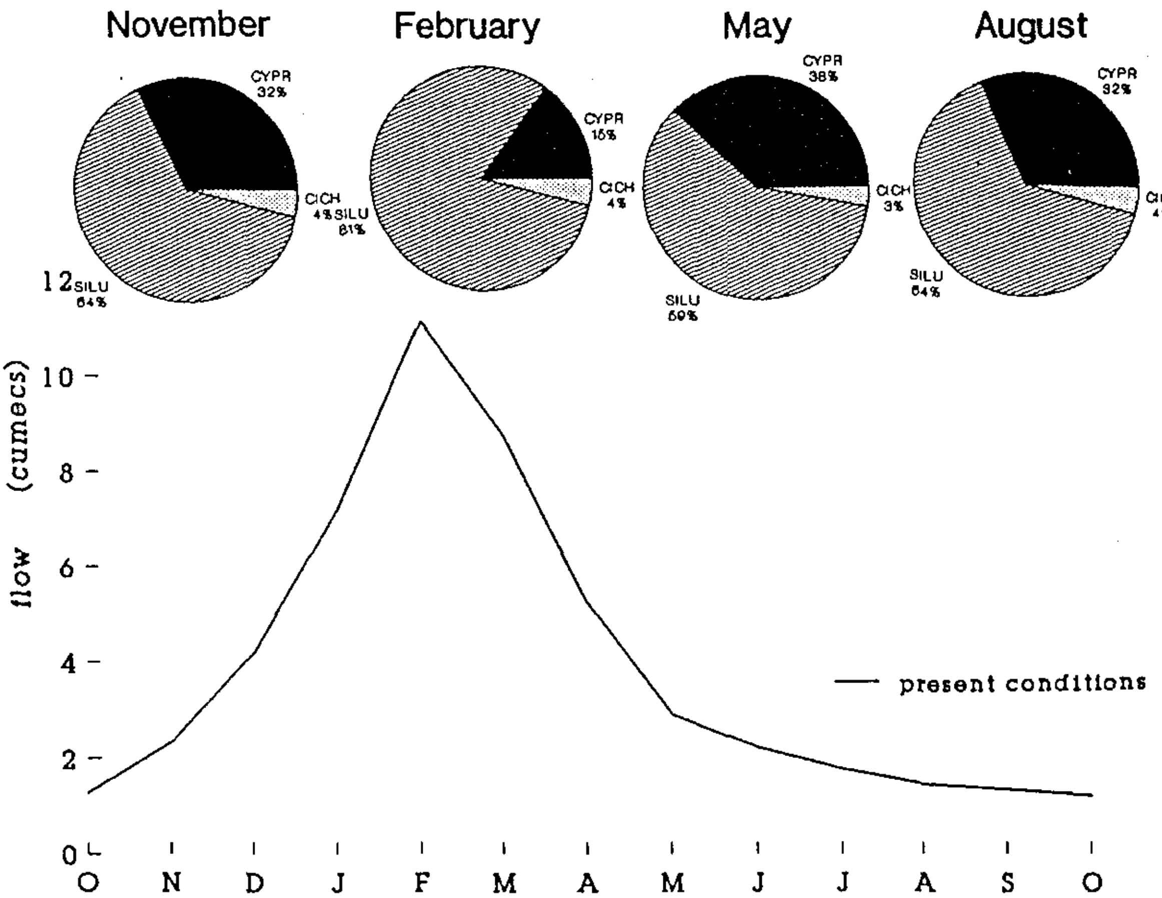


**Figure 2.11:** Changes in the relative abundance in the Foothill Zone (FHZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species makeup and response see Figure 7.7 (Volume 1). Silurids, cichlids and cyprinids do not vary greatly with season, besides an increase in February of *Chiloglanis anoterus* and a shift within the species makeup of the cyprinids. *C.anoterus* dominates the assemblage in all seasons (59-81%). Cichlids are characteristically poorly represented (3-4%) while cyprinids make up 15-32% of the catch.

In contrast, the mid-Sabie River LZ reaches support 30 species (Table 7.2, Volume 1) in warm, more placid waters. Here 11 species are indicative of the baseline assemblage (7.8; Volume 1), with cyprinids dominating the assemblage for roughly 75% of the year and cichlids dominate only in early summer (25%). The dominance of cichlids in November is explained by their early, rain-independent, summer breeding. The highly fecund cyprinids only commence breeding with the onset of the seasonal summer-rains, when their number

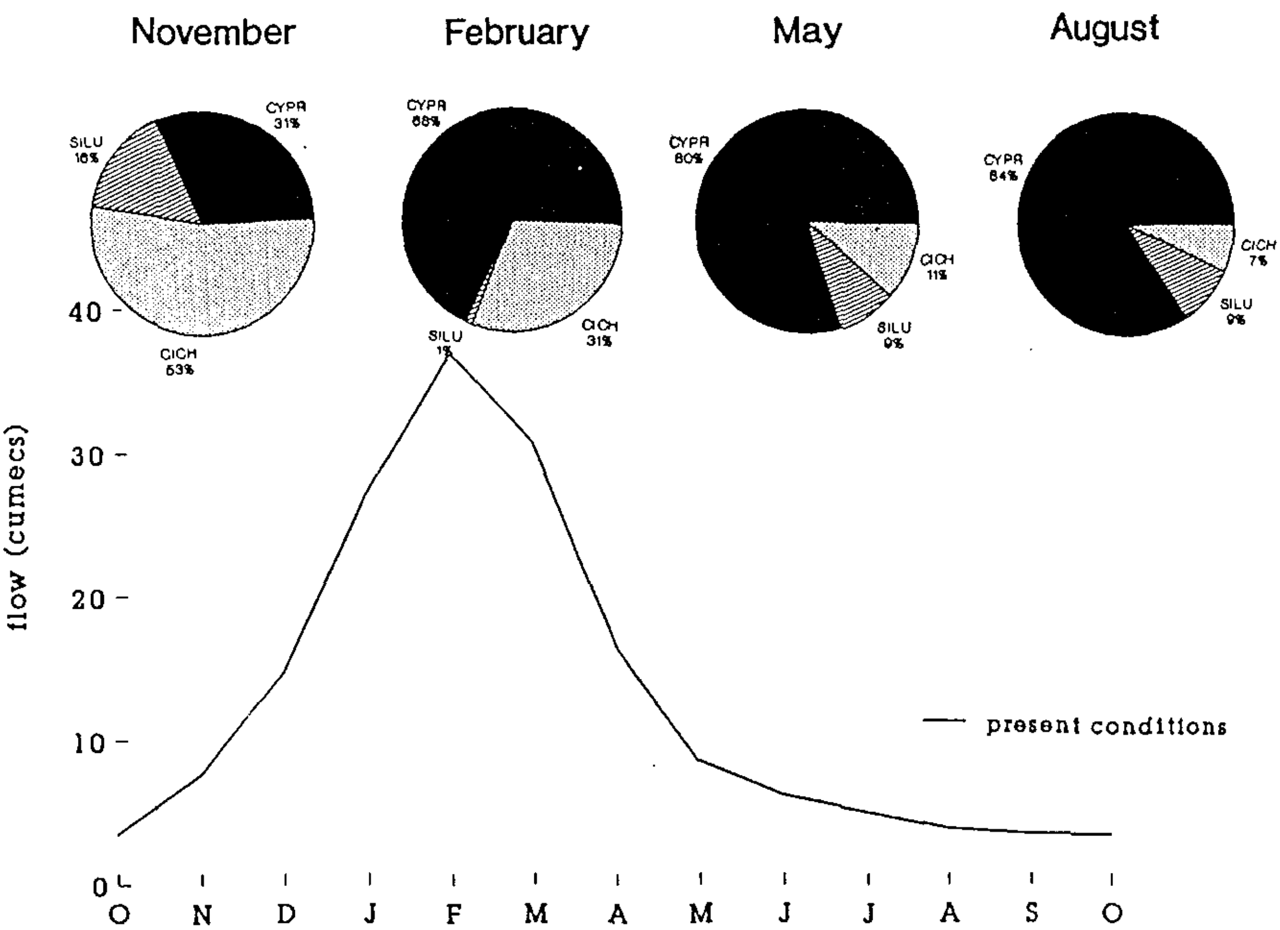


**Figure 2.12:** Changes in the relative abundance in the Lowveld Zone (LZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species see Figure 7.8 (Volume 1). By early summer (November), cichlids have bred independently of the first rains increasing from 7 to 53%. By February and at the height of the seasonal rains, cyprinids have increased from 31 to 58%. During the dry winter season, no breeding takes place while recruitment of the numerous young-of-the-year swell cyprinid numbers (84%).

again increase. During the dry, winter season (May-August), no fish breed, but cyprinid numbers increase further with the recruitment of many young-of-the-year into the population. Should the summer rains fail, (or impoundment drastically reduced summer flows), cichlids alone would breed, effectively locking the LZ assemblage into "November" proportions. This condition will persists through the dry season, presumably until the first summer rains.

**Inyaka Dam:** The 101 $hm^3$ Inyaka Dam could effectively totally regulate the Marite River because its capacity, which is greater than the total annual runoff for the sub-catchment (runoff = 79.6 $hm^3/a$; Chunnett *et al.*, 1990). The Inyaka's effects on the biota, particularly the ichthyofauna, are further complicated by the very different composition of, and response expected between both the FHZ and LZ species.

The Marite remains the premier cool-species river, having never been impacted by early mining pollution and supporting very healthy populations of FHZ species. *Barbus argenteus* and *Amphilius natalensis* were only collected within its reaches during the present survey and the regionally endemic minnow *Barbus brevipinnis* is particularly common here. *Amphilius uranoscopus* is the fourth species with limited range, found occasionally in the lower Marite.

**a) Limited use;** With limited use, as discussed in section 2.3.2.1, the lowveld mid-Sabie River biota would suffer limited effects as the river would remain perennial and the temperature effects associated with the Inyaka Dam, are far enough upstream to have recovered. The seasonal fish assemblages could be expected to mirror those discussed (Fig. 2.12).

The dam's potential effects on the lower Marite and its biota are much more profound. Even with limited use, peak summer flows and baseflows would be markedly reduced while temperature may be elevated. The aseasonal FHZ baseline assemblage (Fig 2.11) may respond as with the passage of the 1991-92 drought in the Sabie River where flows were severely reduced, and temperatures were higher (site 5). Changes in fish abundances within the FHZ with reduced flow were complex and possibly reflect changes in depth, flow microhabitat needs and temperature tolerances. The ultimate effect on the typical species assemblages, should these conditions have persisted, are not known. The rock catlet *C.anoterus,* was greatly reduced (60-19%, Fig. 7.11; Volume 1) possibly because of failing flow microhabitat requirements, while 3 of 4 cyprinids and the only cichlid *Tilapia sparrmanii* increased in proportion. Cool-water *Barbus polylepis* was reduced in number while the eurythermal *Barbus marequensis* increased. It was not known whether increases in *B.marequensis*, which was greatly reduced in LZ reaches, were because of upstream movements.

**b) Maximum use;** Summer peak flows in the mid-Sabie River would be markedly reduced under maximum development and baseflows would be reduced to levels typical of the 1991-92 drought. Although summer flows would not be completely eliminated, the dampening-off of flushing flows typical of rain events would have real effects, possibly reducing the success of many of the summer rain-dependent cyprinids and other species that show event driven local-movements. The seasonal LZ fish assemblage (Fig. 2.12) would be expected to change qualitatively, possibly stabilizing with a higher proportion of cichlids present.

The Marite River under maximum development conditions will be greatly impacted with both drought condition through the year, and flow stoppage through very extended periods. The effects of such extreme regulation within the FHZ reaches, on the fish fauna, would almost certainly be catastrophic. The dominant but flow-sensitive *C.anoterus* would be lost from the downstream reaches as would *A.uranoscopus* and *A.natalensis*. These species are not expected to survive in isolated pools where poor water quality, specifically low oxygen levels, is common. With reduced or no-flow conditions, temperature increases would further exclude FHZ species, effectively moving the FHZ/LZ transition upstream. The drought tolerant *O.mossambicus*, and "weedy species", typical of standing warmwater reaches, may extend their ranges.

**Inyaka & Madras Dams:** This, the most extreme of the possible scenarios would have the most extensive effects on the biota. If the 109 $hm^3$ Madras Dam was built on the Sabie River, it together with the Inyaka Dam, would largely regulate the mid- and lower Sabie reaches.

**a) Limited use;** The Madras Dam, in combination with the Inyaka, would have marked effects of the LZ biota, even with the limited use proposed. Summer peak-flows would be reduced to levels calculated for the Inyaka under maximum development, with similar effects on the fish fauna, while the allocations for the KNP would effectively provide a constant baseflow of some 2.3 $m^3.s^{-1}$. Although the stability of baseflows would prevent the extreme changes monitored over the drought, changes within the LZ reaches are likely because of the reduced summer peak-flows, particularly because the daily flow variations, or flushing flows utilized by many seasonal breeding species, will be attenuated.

As discussed (section 2.3.2.1), the release of baseflow from a dam of this size may well effect the temperature regimes for many kilometres downstream, particularly depending on the level of release. Because the Madras Dam lies close to the natural interface between the distinct fish faunas of the FHZ and LZ, a reduction in temperature will probably alter species distributions convincingly. Although this could arguably extend the range of the FHZ species into the park, this is unlikely because; a) source reaches would be reduced due to the impact of the Inyaka Dam on the lower Marite River, and b) the long-term consistency of such a management option is unrealistic.

**b) Maximum use;** The fish fauna of the mid-Sabie River, under maximum regulation, would be greatly impacted. Although summer peak-flows would only be exploited marginally more, it is the baseflow which would suffer most. The Sabie River could be effectively reduced to a temporary system. The characteristic LZ fish seasonal fish assemblages seen in figure 2.12 would initially resemble those seen in the Sand River during the 1991-2 drought (Fig. 7.12; Volume 1). Cichlids would dominate throughout summer and then through the dry season. Depending on the period that flow in the reach would cease, the drought tolerant LZ fishes would persisted. Volume 2 documents the decline of drought pools in the LZ reach over a five month period. Not all species are able to withstand and no-flow conditions. Both *C.anoterus* and *O.zambezense* would be lost immediately. With extreme drought, even the cichlid *Tilapia rendalli* proves sensitive. Unlike the drought effects monitored in 1991-92, changes due to regulation are more permanent, and under continual maximum use, recovery would not be possible. In this scenario, the fish fauna of the LZ would be radically altered, possibly permanently locked into a drought pattern with cichlids dominant and with species like *Labeo congoro*, *Labeo rosae*, and the mormyrids reduced to remnant populations and many of the minnows reduced in importance (*B.unitaeniatus*, *B.viviparus;* Table 7.7; Volume 1).

**Construction and filling:** The regulatory effects on the biota of dams in operation have been discussed for differing scenarios of flow usage. Recognising the effects of construction on water quality, particularly the release of elevated sediment loads, and the filling of the dam is crucial. During the construction of the Zoeknog Dam, the rock-catlet *C.anoterus* was reduced by 75% within the reach immediately downstream of the construction site (station 25). Here turbidities of 1300 NTU (0.85 g/l suspended sediment) were recorded following a local spate. Although these results are affected by the passage of the 1991-92 drought, they hint at the effects elevated sediments can have on the biota. The Inyaka Dam would, like the Zoeknog, be built in the cool and clear-watered reaches of the Marite River within the FHZ where the largely endemic *C.anoterus* is dominant. The effects of elevated turbidities associated with the construction of the Madras River may be less critical, as natural events within the drylands of the lowveld can produce runoff with exceptionally high turbidities.

The manner in which the dams are filled is also of importance especially when their relative size is taken into account. The Inyaka Dam could intercept all the flow for more than an average year before any overflow would be expected. If the ecological requirements of the riverine biota are to be managed, flow quotas need to be set before the gates are closed!

# 2.4 ZOEKNOG DAM

## 2.4.1 BACKGROUND

The Zoeknog Dam is the smallest of the eight potential impoundments planned for the Sabie-Sand system and is the first of two to be commissioned to date. Construction had started by early 1991 and neared completion by the end of 1992. The dam was 29% full when it failed with the first rains of the 1992-93 wet season in the early hours of Monday, 25 January 1993. Approximately $3x10^6$ $m^3$ of water and an estimated $0,2x10^6$ $m^3$ of earth was discharged into the Mutlumuvi River over a few hours (Plate 1a). The peak flow rate was estimated to equal a 1:10 year flood, with the event still evident two hour later (Erasmus *pers comm.*).

## 2.4.2 STATUS OF THE AQUATIC ENVIRONMENT PRIOR TO CONSTRUCTION

Interpreting the unquestionable effects of the Zoeknog Dam on the Sand River is problematic as the system suffered the worst drought on record during the construction phase.

### *2.4.2.1 PRE-DROUGHT*

Prior to dam construction and the 1991-92 drought, the Mutlumuvi and Sand Rivers below the Zoeknog Dam were in a good condition (Plate 1b). Water quality was unexceptional (Table 2.5) with pH neutral (7.7-8.7), and conductivity (20-120 µs/cm), turbidity (8-23 NTU) and total suspended solids (TSS) (0.025-0.266 g/l) low. Flow had not ceased for some years in the middle Sand River reaches, while the LZ tributaries closer to the escarpment remained perennial, and acted as refuges.

In May 1991, fish were diverse and numerous in the Sand River sub-catchment (Table 2.6). Fishes were abundant both below Zoeknog Dam site in the FHZ (site 25: 11 spp; CPUE of 7.2 fish/min) (Fig. 2.13), and at the LZ sites on the Mutlumuvi (site 19: 19 spp; CPUE of 8 fish/min) (Fig. 2.14 & 2.15) and mid Sand rivers (site 14: 15 spp; CPUE of 6 fish/min).

**Table 2.5:** Selected physico-chemical results for sites relevant to the interpretation of the effects of the Zoeknog Dam burst.

| STATION | DATE | OXYGEN | COND. | pH | TURB. | TSS | FLOW |
|---|---|---|---|---|---|---|---|
| | | % sat | µs/s | | NTU | g/l | $m^3/s$ |
| ZOEKNOG | MAY 91 | 106 | 60 | 7.7 | 23 | 0.146 | 0.407 |
| | 24 AUG 91 | 116 | 60 | 8.7 | 8 | 0.075 | 44.5* |
| | 11 NOV 91 | 105 | 80 | 8.2 | 23 | 0.096 | 27* |
| | 4 FEB 92 | 90 | 80 | 7.5 | 1300 | 8.5 | 31.2* |
| | MAY 92 | 106 | 80 | 7.6 | 150 | 1.136 | 0.0183 |
| | 2 FEB 93 | 112 | 60 | 7.5 | 580 | 5.86 | - |
| (above dam) | 2 FEB 93 | 107 | 50 | 7.7 | 2 | 0.056 | - |
| NEW FOREST | NOV 90 | 118 | - | 8.7 | - | 0.266 | 0.0575 |
| | MAY 91 | 100 | 70 | 7.9 | 10 | 0.025 | 0.1363 |
| | MAY 92 | 109 | 100 | 8.4 | 15 | 0.057 | 0.0097 |
| | NOV 92 | 119 | 220 | 9.2 | 12 | 0.124 | 0.0001 |
| | 2 FEB 93 | 93 | 80 | 7.2 | 261 | 3.867 | - |
| LONDOLOZI | MAY 90 | 106 | - | 8.1 | - | 0.057 | 0.339 |
| | MAY 91 | 114 | 120 | 8 | 9 | 0.024 | 0.329 |
| | MAY 92 | 94 | 180 | 7.9 | 23 | 0.062 | 0.0022 |
| | 11 DEC 92 | 110 | 420 | 7.4 | 28 | 0 | 0.0007 |
| | 27 JAN 93 | - | 90 | 6.9 | 1900 | 2.65 | 4.644 |
| | 29 JAN 93 | 93 | 100 | 6 | 647 | 6.38 | 2.606 |
| | 3 FEB 93 | 100 | 130 | 7.7 | 172 | 0.86 | 1.402 |
| POOL 2B (offstream) | 3 FEB 93 | - | 100 | 8.1 | 738 | 9.136 | ZERO |
| POOL 1A (offstream) | 3 FEB 93 | - | 120 | 8.2 | 272 | 1.975 | ZERO |
| ROOIBOKLAAGTE | MAY 90 | 104 | - | 7.8 | - | 0.002 | 0.2571 |
| | MAY 91 | 95 | 70 | 7.7 | 5 | 0.026 | 0.109 |
| | MAY 92 | 95 | 90 | 7 | 9 | 0.028 | 0.0056 |
| | NOV 92 | 100 | 140 | 7.5 | 13 | 0.068 | 0.1434 |
| SAND RIVER (KNP) | 3 FEB 93 | 105 | 140 | 7.6 | 192 | 1.1 | - |
| (offstream pool) | 3 FEB 93 | 34 | 100 | 7.5 | 1020 | - | ZERO |

* flow reading, cm on gauge plate at weir below Zoeknog dam.

**Table 2.6:** Species number recorded at stations between May 1990 and May 1993.

| | SPECIES NUMBER | | | | | |
|---|---|---|---|---|---|---|
| STATION | MAY 90 | MAY 91 | MAY 92 | NOV 92 | JAN 93 | MAY 93 |
| ZOEKNOG | - | 11 | 8 | - | 6 | 5 |
| NEW FOREST | 12[1] | 19 | 16 | 14 | 5 | 8 |
| LONDOLOZI | 8 | 15 | 18 | 11[2] | 10 | 11 |
| ROOIBOKLAAGTE | 16 | 11 | 15 | 8 | - | 12 |

[1] = Nov 90
[2] = Dec 92

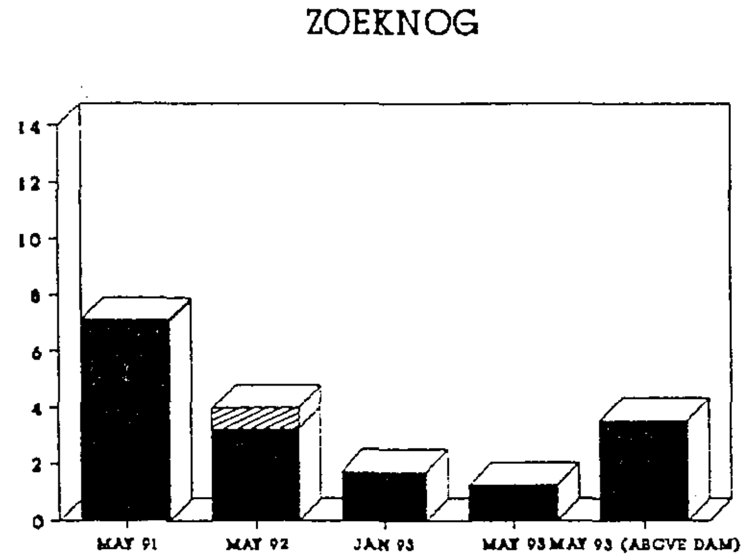


**Figure 2.13:** Catch per unit effort (CPUE) for fish below the Zoeknog dam site between May 1991 and May 1993 and above the dam for May 1993. Fish grouped as lotic (solid bars) or lentic (hatched bars) breeders (see text). Between May 1991 and 1992 and during construction, total CPUEs decreased from approximately 7 to 4 fish per minute. By January 1993, post dam failure, CPUEs were recorded as less than 2 fish per minute while lentic species increased with backwater species absent from the reach. CPUE had not recovered by May 1993, being less than half those recorded immediately above the dam.

The pennant-tailed rock catlet *Chiloglanis anoterus* dominated the FHZ assemblage (Fig. 2.16; CPUE 4.7) immediately below the dam site while the minnows *Barbus eutaenia* and *Barbus brevipinnis* (CPUEs of 0.9 and 0.6 respectively) were also important here. At New Forest 6

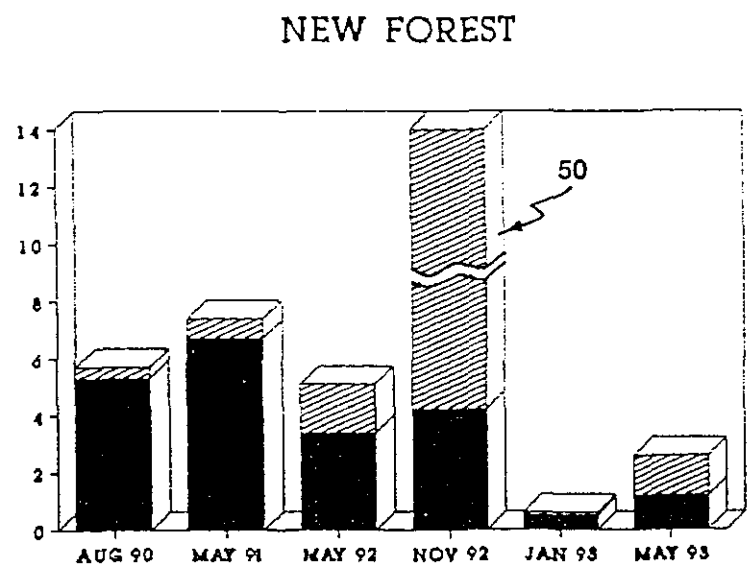


**Figure 2.14:** Catch per unit effort (CPUE) for lotic (solid bars) and lentic fish (hatched bars) between August 1990 and May 1993 at New Forest on the Mutlumuvi River, some 16 km downstream of the Zoeknog Dam. CPUEs between 6 and 7 fish per minute were obtained with a slight decrease over the summer of 1991-92. By the end of the dry season (November 1992) the CPUE had increased considerably. This was attributed to an explosion of the lentic breeder *Oreochromis mossambicus* in drought conditions. The post-dam flush in January 1993 drastically reduced fish in the reach to a remnant particularly the lentic *O.mossambicus*. Three months later CPUE was still very low.

species had CPUEs >0.4, all of them being small, or in the case of *Barbus marequensis*, young-of-the-year (YOY). Both *C.anoterus* and *B.eutaenia* were numerous here and upstream at Zoeknog (Fig. 2.16a & 2.17a). The minnow *Barbus viviparus* was dominant at both Londolozi and New Forest (CPUEs of 2.4 & 2.9 respectively). Both where LZ stations (Fig. 2.17a & 2.18a).

### *2.4.2.2 DROUGHT EFFECTS*

Grouping the species as either lotic or lentic breeders is a useful aid in viewing the shift from high to low flow linked assemblages with the progression of the drought. Lentic breeders were defined as those species which breed in low to zero-flow conditions. They included the cichlids *Oreochromis mossambicus*, *Tilapia rendalli*, *Pseudocrenilabrus philander* and

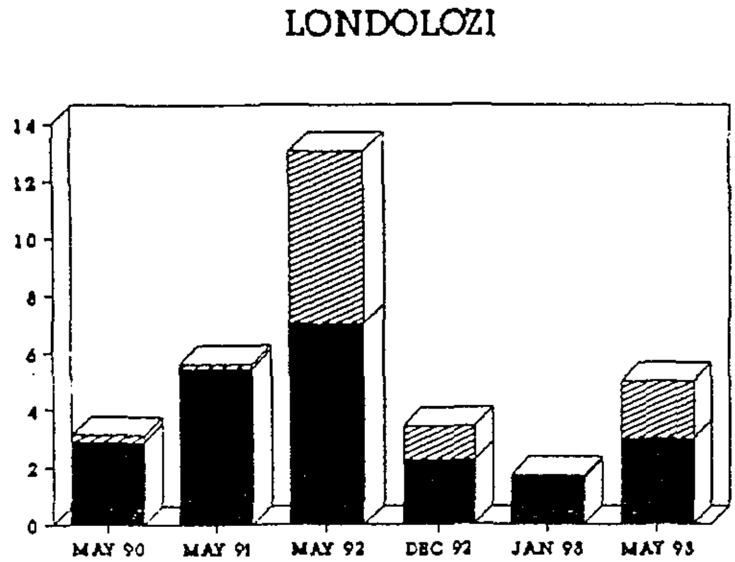


**Figure 2.15:** Catch per unit effort (CPUE) for fish at Londolozi on the mid-Sand river between May 1990 and May 1993. A CPUE of between 3 and 6 fish per minute was recorded before the 1991-92 drought with lentic species (hatched bars) typically making up more than 90% of the assemblage. By May 1992 the Sand river had ceased to flow concentrating the fish in pools and resulting in artificially high CPUEs. Lentic breeders continued to dominate the assemblage. The river was flowing again by December 1992, the November flush having reduced the lentic species noticeably. CPUE after the Zoeknog event, the sixth flushing-flow of the season, measured below 2 fish per minute and were almost exclusively of lotic species 9 (solid bars). Recovery had started by May 1993.

*Serranochromis meridianus*, the gobi *Glossogobius callidus*, and the minnows *Barbus paludinosus* and *Barbus toppini*. Initially, lotic linked species made up more than 90% of the total fish population at all sites (Fig. 2.13, 2.14 & 2.15).

The drought consisted of two components:

a) The failure of the 1991-92 summer wet season.

b) The subsequent extreme dry season that resulted in much of the Sand sub-catchment ceasing to flow in 1992.

During the 1991-92 "wet season" the Sand and Mutlumuvi rivers continued flowing, but at greatly reduced levels. During the 1992 dry season the Sand river progressively stopped

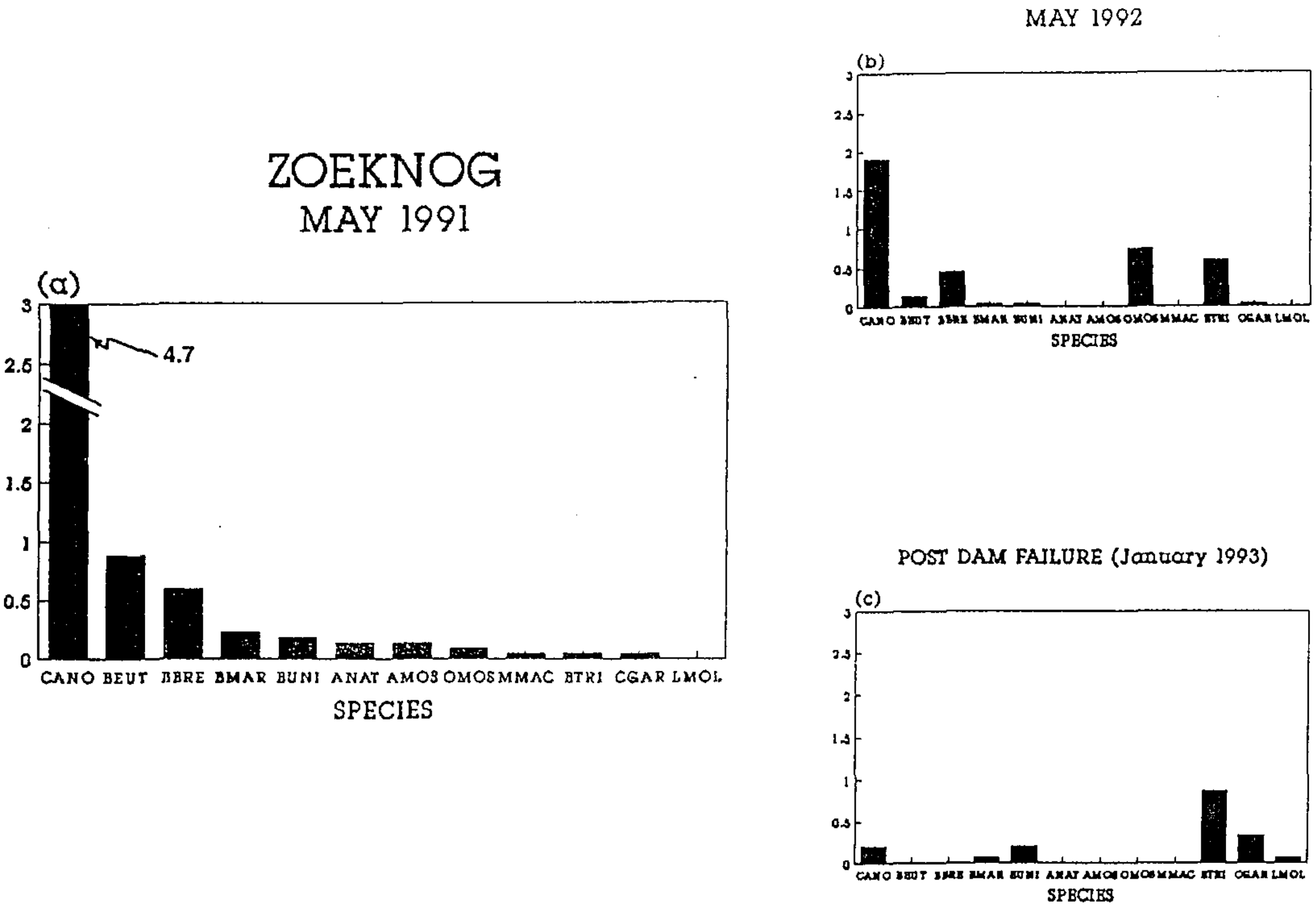


**Figure 2.16:** Catch per unit effort (CPUE) for species below the Zoeknog dam site between May 1991 and January 1993. In May 1991, 11 species were recorded with the rock catlet *Chiloglanis anoterus* particularly numerous (CPUE at 4.7), and the minnows *Barbus eutaenia* and *Barbus brevipinnis* common. As construction proceeded *C.anoterus* and *B.eutaenia* numbers were greatly reduced (May 1992) while numbers of the robust minnow *Barbus trimaculatus* and the blue kurper *Oreochromis mossambicus* increased. Post the dam failure and resultant microhabitat loss, *C.anoterus* was further reduced and the minnows *B.eutaenia B.brevipinnis* and *O.mossambicus* were not recorded.

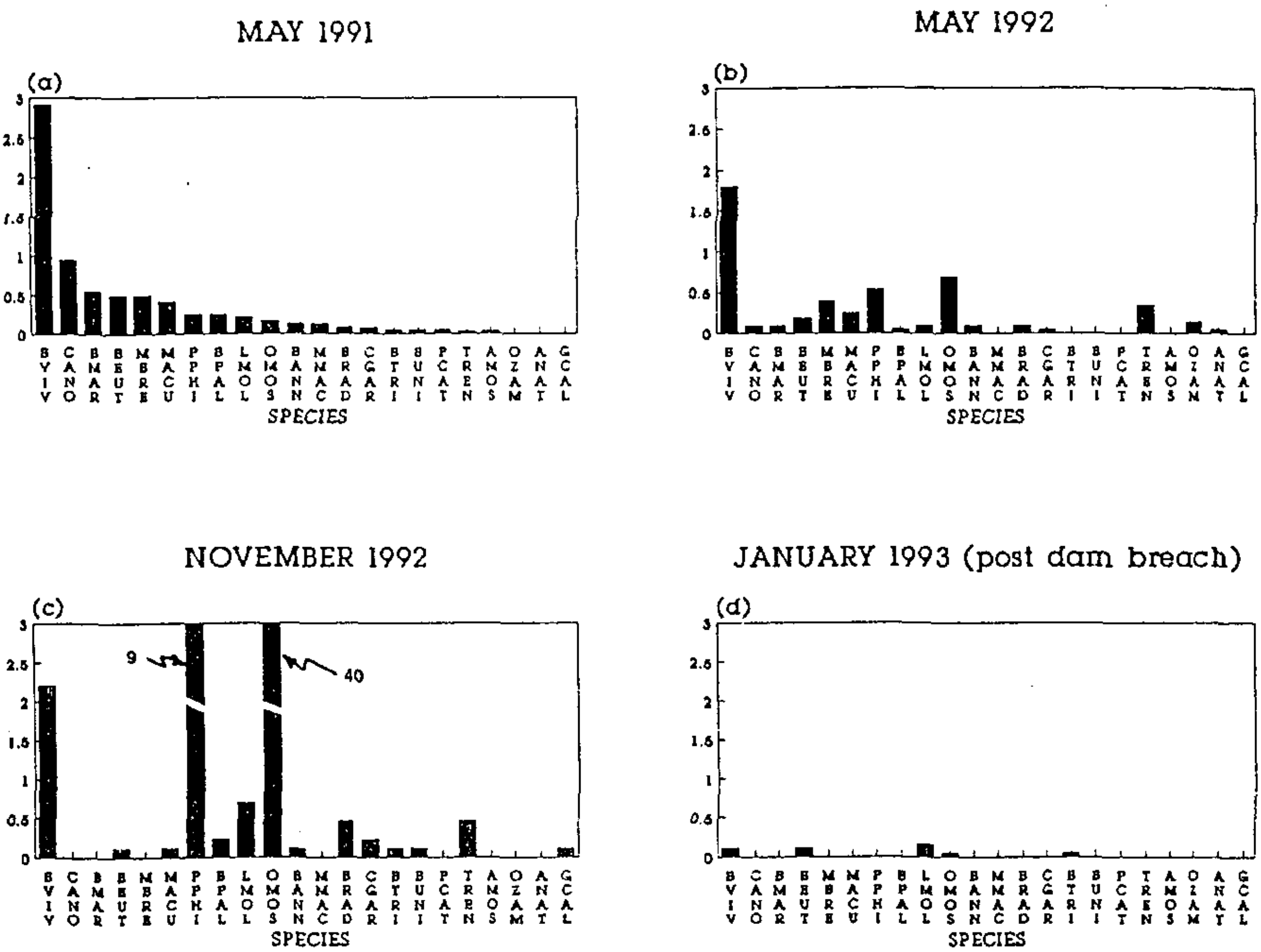


**Figure 2.17:** Catch per unit effort (CPUE) between May 1991 and January 1993 at New Forest on the Mutlumuvi some 16 km below the dam. The diverse and numerous assemblage recorded in May 1991 (19 spp) declines by May 1992 (16 spp). Reductions were marked in the minnows *Barbus viviparus Barbus eutaenia*, the rock catlet *Chiloglanis anoterus*, and the yellow fish *Barbus marequensis*. During this period the cichlids *Oreochromis mossambicus, Pseudocrenilabrus philander* and *Tilapia rendalli* all increased in numbers. By November 1992 *O.mossambicus* and *P.philander* dominated the reach with most species reduced drastically. After the January 1993 Zoeknog flood event, almost the entire cichlid population was removed leaving a remnant of lotic species.

flowing from the east to the west. At Londolozi on the mid-Sand the river had stopped flowing by the end of May, not flowing again until mid-December, 6 month later. At New Forest the flow was very low by May 1992 (0.0097 $m^3.s^{-1}$), and effectively zero by November

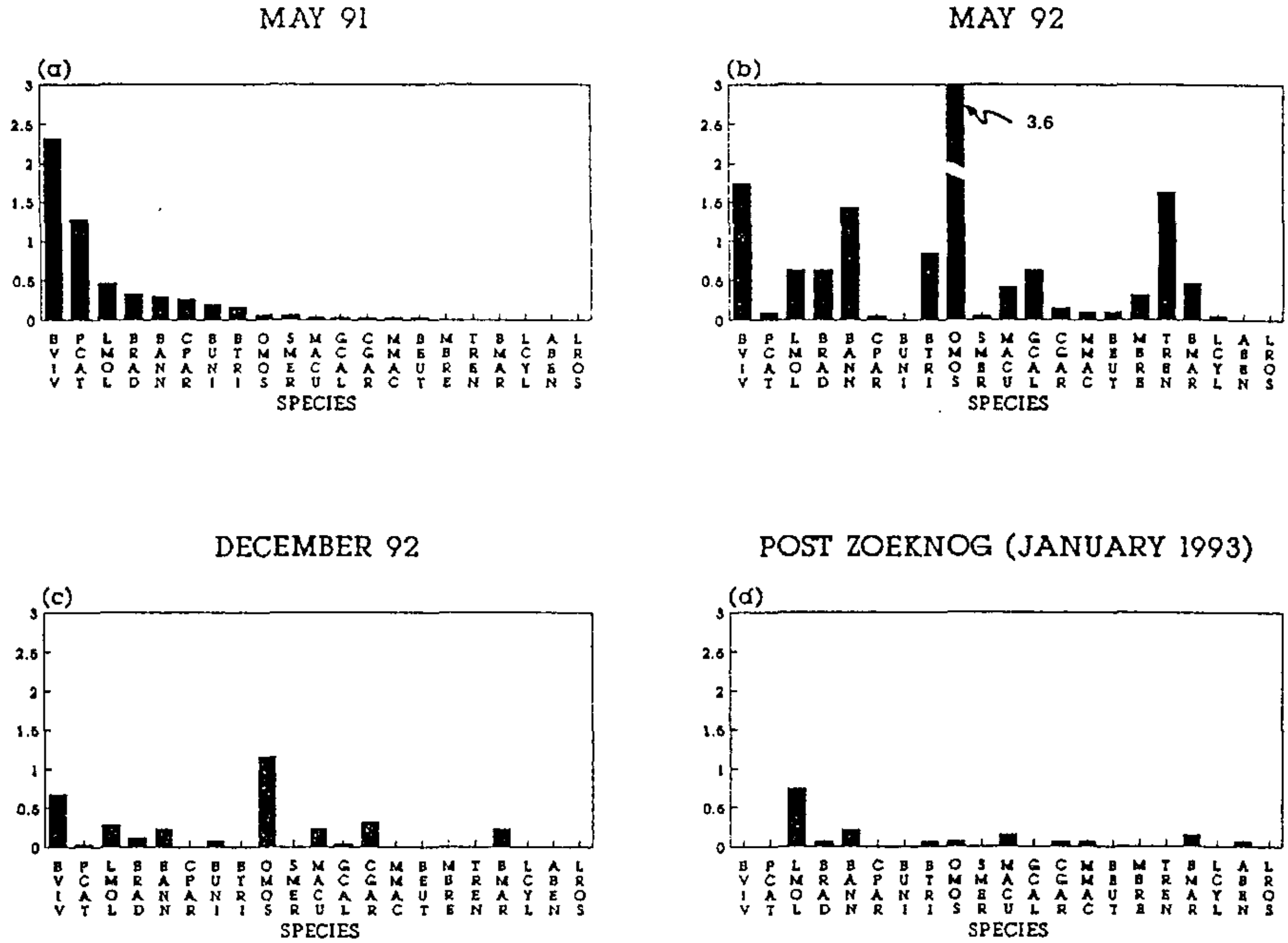


**Figure 2.18:** Catch per unit effort (CPUE) for fish species recorded at Londolozi on the mid-sand river between May 1991 and January 1993. Fifteen species were recorded in May 1991. In May 1992 the river had ceased to flow due to the 1991-92 drought, concentrating the fish into pools. The minnow *Barbus viviparus* and the mormyrid *Petrocephalus catostoma* decreased while the cichlids *Oreochromis mossambicus* (OMOS), *Tilapia rendalli* and the gobi *Glossogobius callidus* all increased in number. By December 1992 the first flushing flood of the season had diluted CPUE, with *O.mossambicus* numbers particularly reduced. *T.rendalli* had reduced prior to the first flood. By the time the Zoeknog failed 5 flushes had reset the system, possibly reducing CPUE further. Numbers of the mudfish *Labeo molybdinus* and the catfish *Clarias gariepinus* increased with both species spawning with the first flush.

at 0.0001 $m^3.s^{-1}$. The flow at Zoeknog was reduced but maintained by its headwaters. The influence of the drought must be considered for each of the following three stations:

1) **Zoeknog (site 25), upper-Mutlumuvi:** The total CPUE in this reach was reduced between May 1991 and May 1992 (Fig. 2.13). *C.anoterus* CPUE was reduced from 4.7 to 1.85 fish per minute on the reach and *B.eutaenia* from 0.84 to 0.16 (Fig. 2.17a & b). Although the discharge was reduced by the drought in May 1992 and the numbers of the lentic *O.mossambicus* increased, these reductions cannot be explained without also considering the effects of dam construction. Due to the proximity of the dam site, turbidity readings were likely to have exceeded measurements recorded on the 4th February 1992 during rain events (1300 NTU and 0.85 g/l TSS) (Table 2.5). *C.anoterus* and *B.eutaenia* are both species most numerous in the clear-watered foothill streams of the catchment.

2) **New Forest (site 19), mid Mutlumuvi:** CPUEs over the 1991-92 failed wet season declined, although there was an increase in the numbers of lentic species (Fig. 2.17a & b) at other stations. Major reductions occurred in *B.viviparus*, *B.eutaenia*, *C.anoterus* and *B.marequensis* numbers. By the end of the 1992 dry season the reach had almost stopped flowing. This condition extended into the 1992 wet season. Lotic species were drastically reduced while the lentic species, *P.philander* and *O.mossambicus*, exploded in numbers (Fig. 2.17c). Construction resulted in high suspensoid loads and turbidity between November 1991 and February 1992 (Table 2.5) and was probably related to local rain events. As the discharge lessened over the drought period, turbidity and TSS effects would have been reduced and drought effects would have become more prominent. The reduction in the numbers of *C.anoterus* and *B.eutaenia* in May 1992 (Fig. 2.17a & b) may be partially explained by increased suspensoid loads.

3) **Londolozi (site 14), mid Sand river:** This reach had effectively stopped flowing by the May 1992 survey, concentrating the resident fish into a large

series of bedrock controlled pools. CPUEs may therefore have been over-estimated because of concentration effects. Between May 1991 and May 1992 there was a major shift in the ratio of lotic to lentic species. The latter increased in proportion from <1% to some 50% of the total catch (Fig. 2.15), with additional increases in three lentic species (Fig. 2.18b). The reach was partially reset by the first rains one month prior to the December 1992 survey. The CPUE on site was greatly reduced particularly for lentic species, due to the dilution of remnant populations and possibly the movement out of the reach.

Because of low summer flows and extended dry season isolation, the changes seen in the fish assemblage at Londolozi are probably related to the drought alone. Monthly surveys were conducted observing the dynamics of isolated populations in series of pools at this site from May 1992 as part of the drought monitoring programme carried out for the KNP (see Vol. 2, Appendix II). Lentic species continued to increase in number although the banded tilapia *T.rendalli* disappeared and the blue kurper *O.mossambicus* dominated. Lentic species were generally in poor condition with low body weights and showed high mortalities. Besides the loss of physical habitat, mortality could also be due to low oxygen levels or predation were probably important.

Rooiboklaagte (site 11) on the upper Sand River, is comparable to New Forest (site 19) in order and zonal position even though baseflows recorded are complicated by significant abstraction (Fig. 2.19). Figures for this site are presented for direct comparison.

ROOIBOKLAAGTE

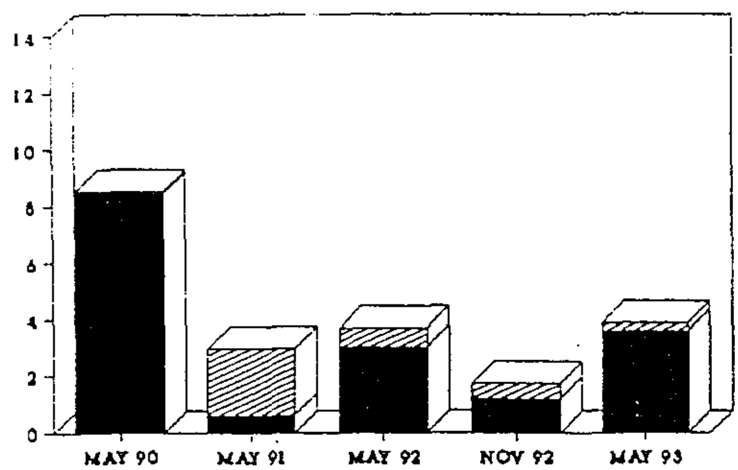


**Figure 2.19:** Catch per unit effort (CPUE) for fish at Rooiboklaagte on the upper Sand River. This site is comparable to New Forest on the Mutlumuvi in position and order. The healthy CPUE of 8 fish per minute recorded in May 1990 was reduced to 3 by May 1991. Lentic species (hatched bars) had increased by May 1991 and had decreased again by May 1992. The river was largely kept flowing through the worst of the drought (May 1992 - November 1992) by re-diverting base flows. In November 1992 although CPUE were low at 2 fish per minute there were many fry in evidence. The reach had recovered to 1992 CPUE levels by May 1993. (Lotic species = solid bars).

## 2.4.3 EFFECTS OF CONSTRUCTION ACTIVITIES ON THE AQUATIC ENVIRONMENT

### *2.4.3.1 ICHTHYOFAUNA*

There were major changes in the occurrence and abundance of species at all stations between May 1991 and the partial completion of the dam in December 1992 over and above the effects of drought already discussed. Construction had dramatic effects on the water quality of the system.

On the 4th February 1992 the turbidity in the Mutlumuvi was some 57 times above previous measurements and was rich in colour. At Zoeknog turbidity measured 1300 NTU and TSS 0.85 $gl^{-1}$ (Table 2.5), while at New Forest the readings were 1400 NTU and 0.886 g/l respectively (Appendix I; Plate 7c). Subsequently, all the turbidity measurements at Zoeknog *were elevated with effects extending downstream according to the discharge.*

### *2.4.3.2 MACRO-INVERTEBRATES*

Unraveling the effect of the Zoeknog's construction on the macro-invertebrate populations is

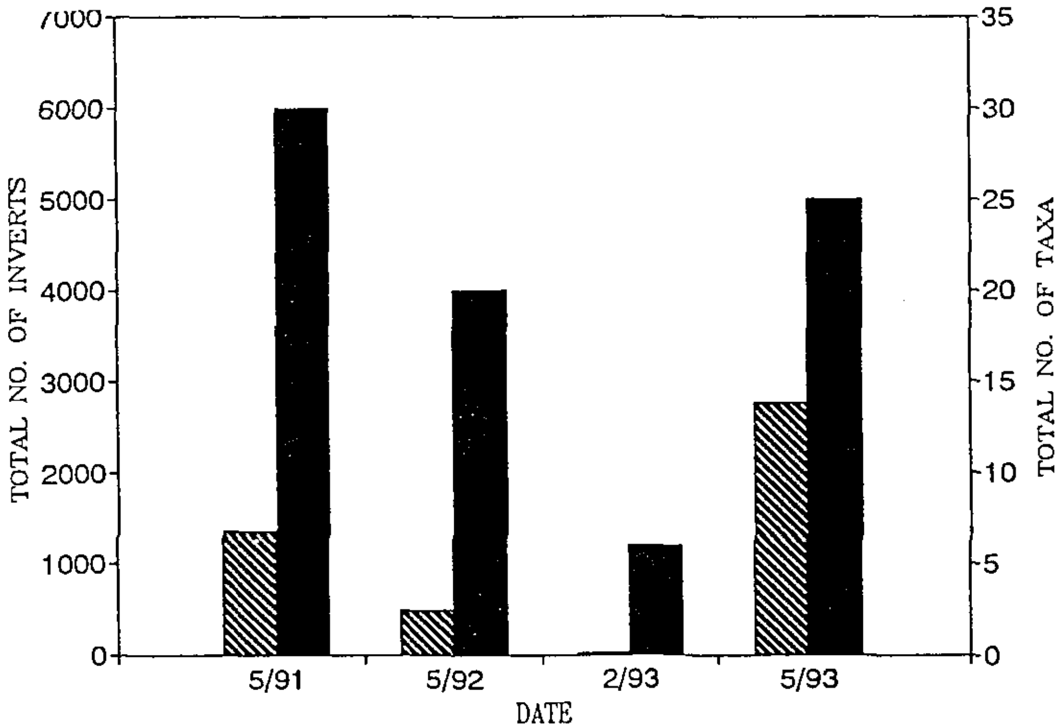


**Figure 2.20:** Total number of taxa and invertebrates at site 19 on the Mutlumuvi River (May 1991 to May 1993).

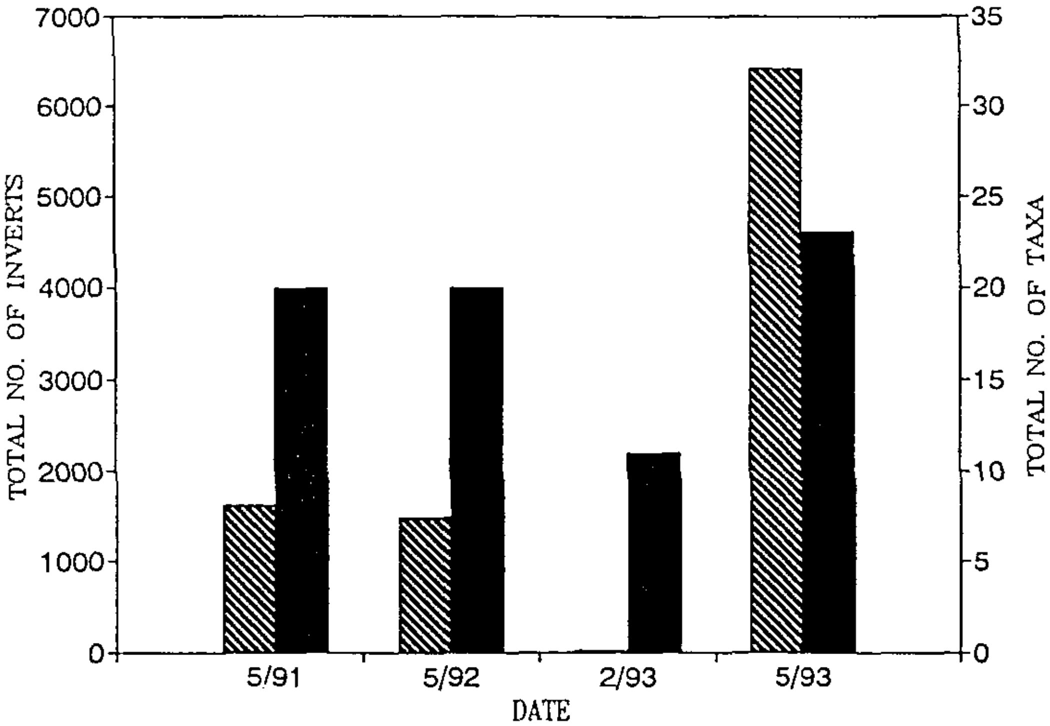


**Figure 2.21:** Total number of taxa and invertebrates at site 25 on the Mutlumuvi River (May 1991 to May 1993).

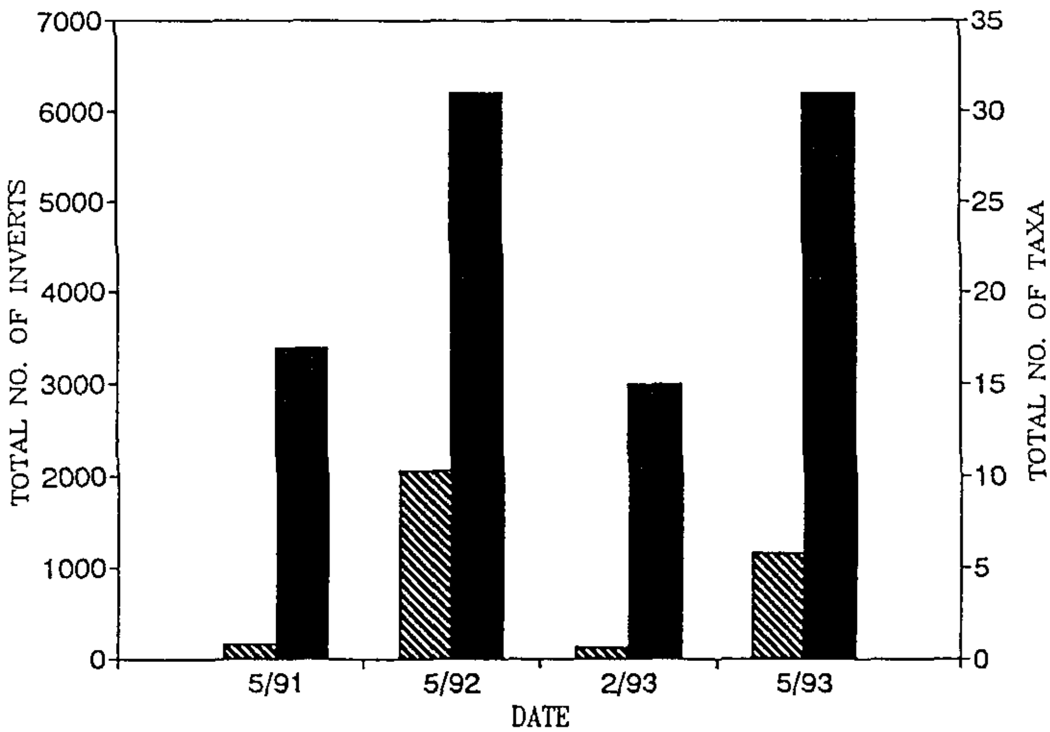


**Figure 2.22:** Total number of taxa and invertebrates at site 14 on the Sand River (May 1991 to May 1993).

difficult. The drought and construction, had reduced macro-invertebrates by May 1992 at site 19 (Fig. 2.20), while their numbers remained unchanged in the perennial reaches (site 25; Fig. 2.21). Although the mid-Sand River (site 14; Fig 2.22) was most severely stressed due to no-flow, macro-invertebrates were seemingly unaffected, possibly an artifact of easier collecting in pools.

## 2.4.4 AQUATIC ENVIRONMENT - IMMEDIATE EFFECTS

There was a gradient of effects on the aquatic environment below the Zoeknog Dam. The breach in the upper Mutlumuvi equaled a 1:10 year flood whereas lower down this volume of flow was not exceptional. The February event gauged only 1.620 m at the exeter weir in the mid Sand River whereas a flow of 2.590 m had been recorded in December (see Fig. 4.7, Vol.1).

Gross microhabitat alteration occurred within the reaches downstream of the dam. At 2 km, over a meter of coarse sand had smothered riffle and run sequences (Plate 1c), reducing the reach to a shallow sandy raceway. The channel showed signs of major disturbance with substrates largely unsorted. At New Forest, some 16 km downstream of the dam, there was evidence of a 2-3 meter flood and a layer of fine sediments deposited in and out of the channel. Fine red silt was evident all the way to the Sabie-Sand confluence.

Turbidity was generally high. Both the Mutlumuvi (Appendix I; Plate 7c) and Sand River downstream of the dam were brick red in colour. Two days after the event the turbidity at Londolozi was still 1900 NTU carrying some 2.652 g/l of silt (Table 2.5). This reduced rapidly over time (Fig. 2.24). The actual sediment load transported during the peak of the event was not recorded but probably did not reach lethal levels judging from Wallen (1951) in Bruton (1985). Wallen showed for a range of species that high turbidity did not cause acute direct effects until suspensoid loads near 20 g/l, and mortalities were only recorded above 50-100 g/l.

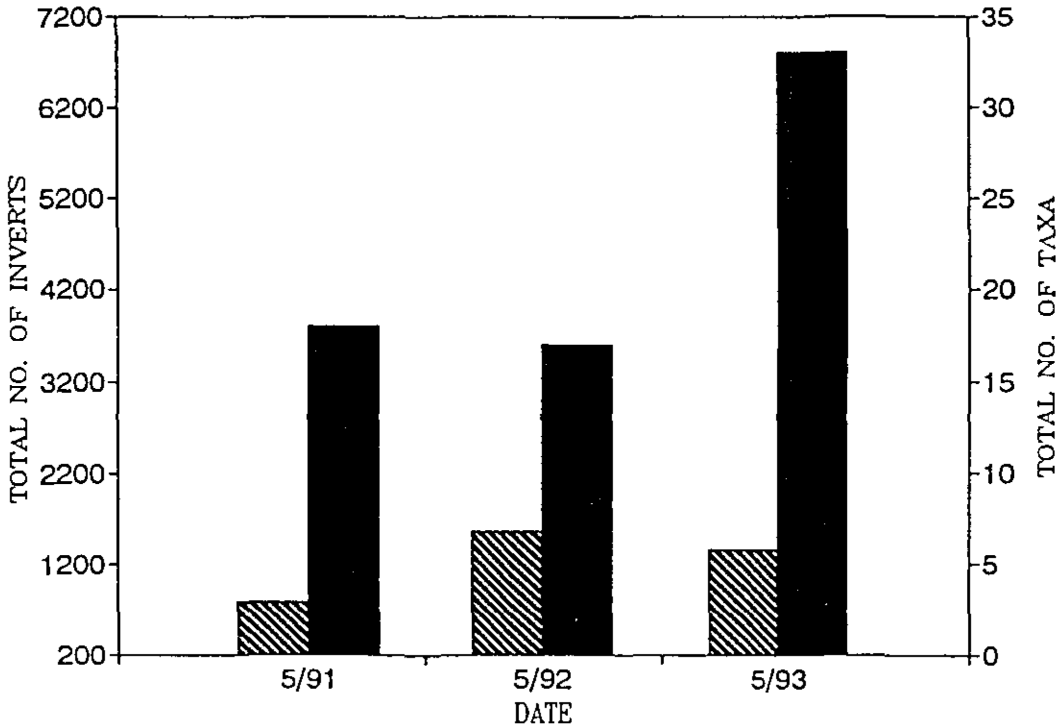


**Figure 2.23:** Total number of taxa and invertebrates at site 11 on the Sand River (May 1991 to May 1993).

Isolated pools recharged during the event showed persistent high turbidity 10 days later, indicating the fine nature of the suspensoids, possibly red clay particles (Fig. 2.24 & Table 2.5). Persistent high turbidity effectively means shading, a factor that may be correlated to low oxygen levels and subsequent mortalities of fish isolated in pools during the drought. A pool on the lower Sand with turbidity of 1020 NTU 10 days after the event had a corresponding oxygen level of 34%!

### *2.4.4.1 ICHTHYOFAUNA*

The lowest CPUEs, over three years, were measured for all stations (Fig. 2.13, 2.14 & 2.15) after dam failure. Fish abundance reflected the gradient of effect identified with increasingly reduced fish CPUE with proximity to the dam site.

1) **At Zoeknog:** CPUE already halved by drought and construction, was halved again by the dam event. The immediate effects of the dam burst were however strongest on the Mutlumuvi above the confluence with the Sand River at Thulamahashi (Fig. 2.13), with species number dropping to just 6 (Table 2.6). The riffle dwelling *C.anoterus* accounted for most of the individual loss, but both FHZ minnows characteristic of the reach were absent. The hardy *B.trimaculatus* remained the most numerous, while an individual juvenile of the flood dispersing *L.molybdinus* was recorded for the first time (Fig. 2.16c). The lentic *O.mossambicus* were further scoured from the reach.

2) **At New Forest:** The lotic fish assemblage was badly effected by the drought. The Zoeknog collapse removed the remaining fish from the reach, reducing the species count from 14 to 5 (Table 2.6). Abundant drought-induced cichlids proved particularly vulnerable to the spate of high flow. The reach was badly impacted, with the lowest CPUE ever recorded (Fig. 2.14) for any site in the catchment over the three years of study measured.

3) **At Londolozi:** The drought impacted, but recovering, fish assemblage appeared to have survived the immediate effects of the dam burst. The mid-Sand River at Londolozi had experienced 5 flushing floods (Fig. 4.7, Vol.1) by the time of the Zoeknog event. The river would therefore have been recovering from the drought. Both *C.gariepinus* and *L.molybdinus* had spawned successfully with the first rains with young appearing in the surveys (Fig. 2.18c). No immediate effect on the lotic fish assemblage could be discerned. The lentic *O.mossambicus*, still numerous following the recent drought, was reduced in the reach.

### 2.4.4.2 *MACRO-INVERTEBRATES*

Following dam failure, low invertebrate numbers were found at all three localities (sites 14,

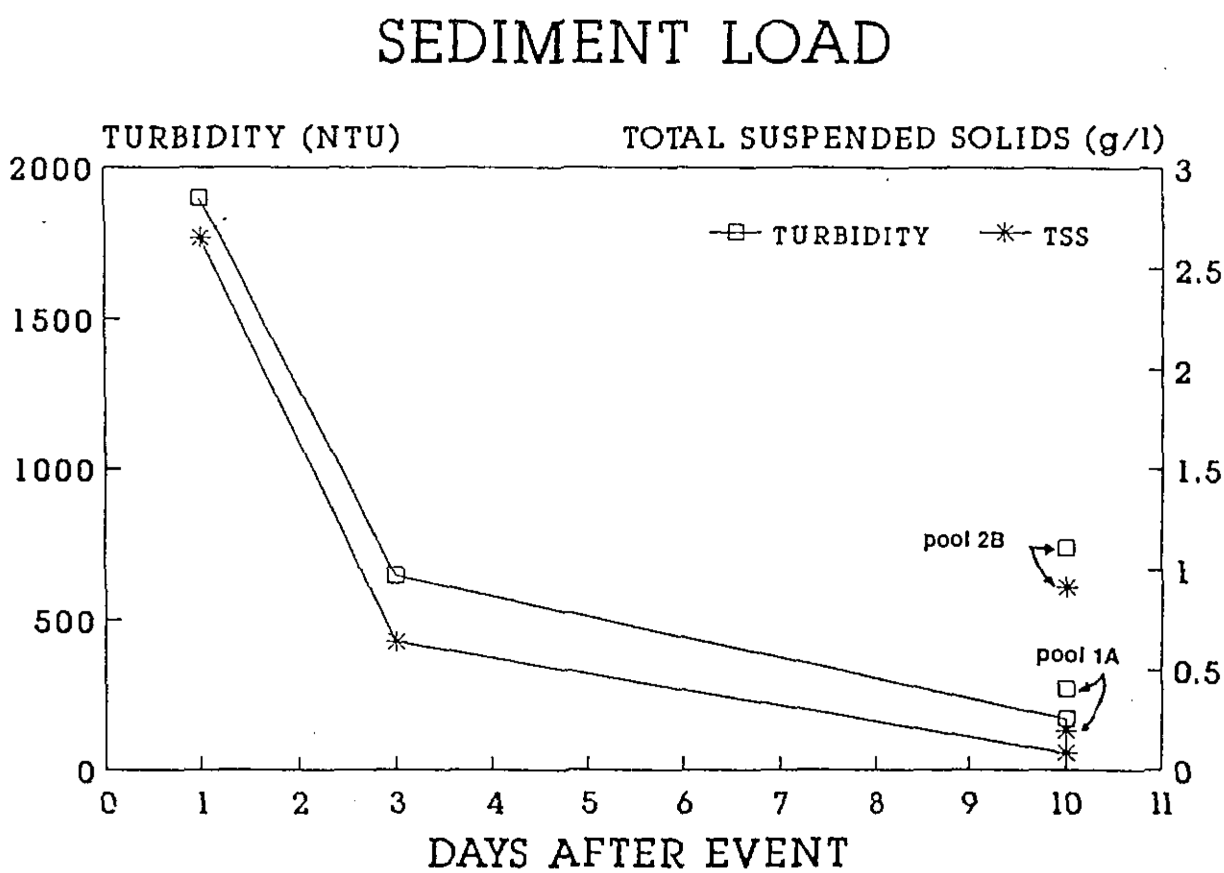


**Figure 2.24:** The sediment load and turbidity following the Zoeknog breach at Londolozi on the Sand River. Both turbidity (1900 NTU) and sediments (2.65 $gl^{-1}$) were high one day after the event and decreased rapidly in the first days. The upper limits at the time of the breach are not know. Ten days after the event, recharged offstream pools 1A and 2B showed higher turbidity and TSS values, possibly indicative of the time of isolation from the main channel.

19 & 25) (Fig. 2.10 to 2.23). Site 14, which was the furthest downstream and the most seriously affected by the drought, now showed the highest number of species and taxa. This supports the hypothesis that a gradient of effects resulted below the dam, with the mid-Sand reaches least impacted.

## 2.4.5 RECOVERY TO DATE

Niemi *et al.*, (1990) concluded that most natural lotic systems are resistant to disturbance, and recover within 3 years. Recovery is ultimately dependent on recolonization. Factors affecting recolonization include time after disturbance, area affected, accessibility of defaunated reach, individual species traits and refuge populations (Niemi *et al.*, 1990), and the nature and quality of the habitat that remains after disturbance.

Stream fish assemblages are not randomly structured units, but rather largely deterministic systems highly predictable from local habitat structure (Meffe and Sheldon, 1990). They show resilience, returning to pre-perturbation states. This recovery is driven by species-specific habitat preferences which have evolved over time with habitat as the template (Southwood, 1977). It was hypothesised that habitat alteration within the Mutlumuvi River would result in slow recovery rates.

**The Mutlumuvi:**

The Mutlumuvi is one of two tributaries that carry the bulk of the Sand River's runoff. Both these streams have perennial headwaters which together provide a valuable perennial refuge area at the western edge of the LZ. The high CPUEs and diversity recorded here and the presence of the flow dependent *C.anoterus* and *O.zambezense,* support this view. The Mutlumuvi was probably the most important refuge tributary for the lowveld fish in the mid-Sabie River. This is significant as the present day mid-Sand River tends toward a seasonal stream resulting in important gaps in the lowveld fish assemblage. Due to the gradient of disturbance seen with the Zoeknog event, the Mutlumuvi River was most impacted. As the Mutlumuvi was itself a refuge for the lower Sand River reaches, its own recovery potential may now be compromised.

Recovery may be further hampered in the Mutlumuvi because it is isolated from the upper Sand River by the mid-Sand River reaches, which are often impacted by drought. Peterson and Bayley (1993) showed that in small areas, the recolonization rate was rapid if neighbouring populations of defaunated species existed. The recovery of species such as *C.anoterus*, *B.eutaenia*, and *O.zambezense*, which are limited in local distribution could, be expected to be slow. This is compounded for the riffle dwelling *C.anoterus* which appears sedentary and has low fecundity, and *O.zambezense* which is exceedingly rare in the nearest refuge in the upper Sand River. Highly mobile species could be expected to recover sooner *e.g.* the silver robber *M.acutidens*, which is present in the lower Sand River

Lowveld species can be expected to be highly resilient as the tropical east coast ecoregion is highly seasonal and the rivers are subject to natural floods and drought. The resilience of the Mutlumuvi and Sand River assemblage is less certain due to the unnatural nature of the conditions relating to the event and the degradation of naturally important refuge areas.

**High turbidity levels effects on the ichthyofauna:**
Although the high turbidities recorded did not appear to result in large scale fish mortality downstream of the dam, the short to long term effects of elevated turbidity must not be under-estimated.

Bruton (1985) reviews the recorded deleterious effects of high turbidity as:

a) Reduced egg and larval survival,
b) altered breeding behaviour,
c) reduced feeding efficiency,
d) reduced growth rates,
e) reduced population size and
f) reduced habitat diversity.

Each discharge event will continue to import fine silt from the dam and coffee plantation site with each flush re-suspending deposits that remain from previous floods. Very high sediment loads and turbidities were recorded in the Sand catchment during the first large rain event in the upper catchment after the breaching of the Zoeknog Dam (Fig. 2.25). Both variables were

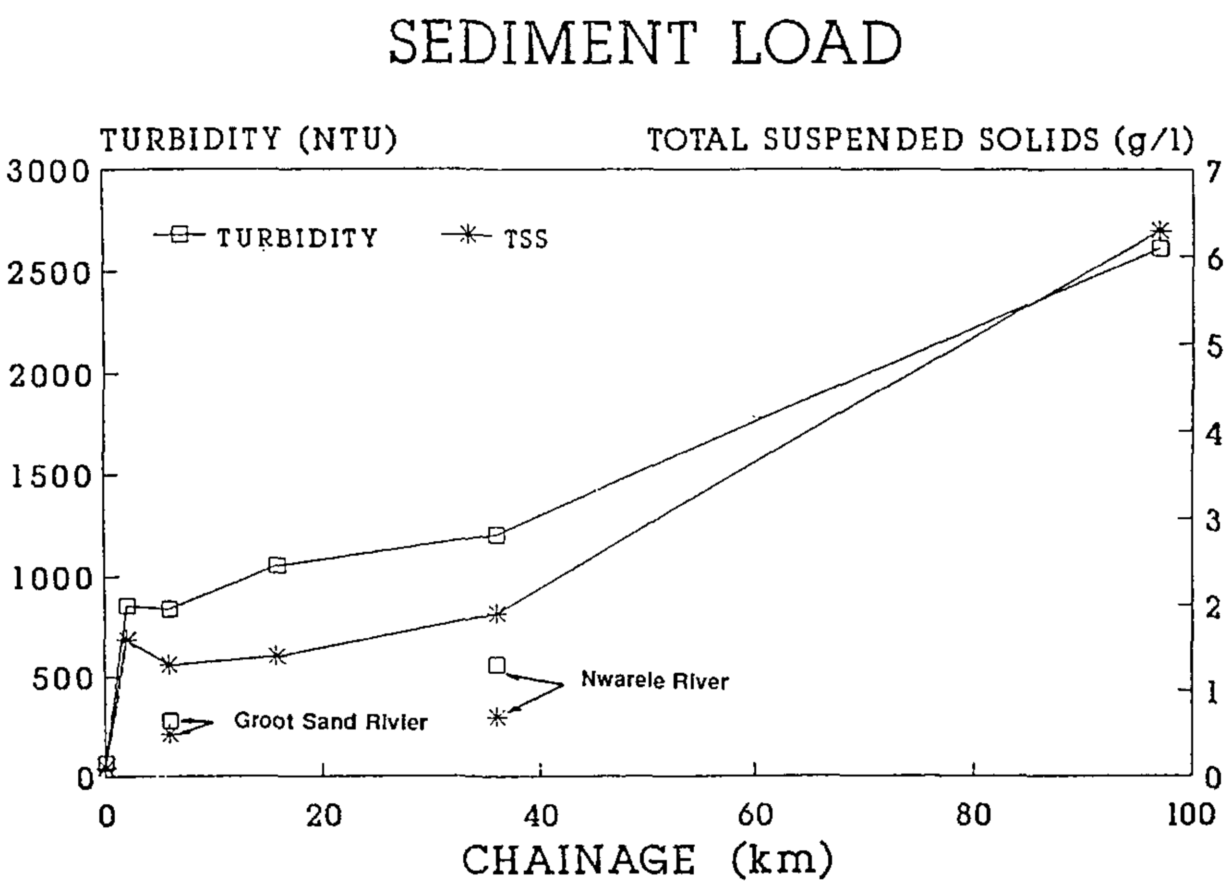


**Figure 2.25:** Sediment load and turbidity measured during the first rain event on 2nd March 1993, following the Zoeknog Dam breach in the Sand sub-catchment. Both variables showed similar trends with values increasing with chainage. A marked increases at the Zoeknog Dam site (2 km) on the Mutlumuvi River is seen with a rise to the highest levels recorded (turbidity 2610 NTU and TSS 6.3 $gl^{-1}$) at the Sabie-Sand confluence. The Groot Sand River and the Nwarele are comparable rivers within the catchment, and support that the Mutlumuvi showed higher turbidity and TSS values than normal.

markedly higher downstream of the dam site towards the Sand-Sabie confluence. It must be remembered that offstream pools are recharged during flush events and fish populations may be at risk due to decreased oxygen levels. Comparable tributaries in the same sub-catchment showed turbidity and TSS values far lower. Turbidity and TSS increased markedly with chainage as sediments were resuspended. In a system struggling to recover from the impact of a drought deteriorated water quality is an added pressure.

### 2.4.5.1 *ICHTHYOFAUNAL RECOVERY TO DATE*

1) **At Zoeknog:** Little meaningful recovery was evident below the dam site after 5 months. Sediments within the highly modified reach had however started being resorted (Plate 1d). CPUEs (Fig. 2.13 & 2.26a, May 1993) and species number (Table 2.6) at Zoeknog were the lowest ever recorded for the site. The previously dominant *C.anoterus*, is still a remnant population and *B.eutaenia*, originally the second most important species, was still absent (Fig. 2.26a).

2) **At New Forest:** Recovery in the Mutlumuvi 16 km downstream, five months after the drought and dam burst, was unimpressive. CPUEs were still very low (Fig. 2.14) with only eight species recorded at roughly half the expected values (Table 2.6). A number of previously numerous species were still absent (*C.anoterus*, *B.marequensis*, *B.eutaenia*, *M.acutidens* & *P.philander*) or under represented (*B.viviparus* & *Mesobola brevianalis*) (Fig. 2.26b).

3) **At Londolozi:** Although there were still some gaps in the species recorded and CPUEs were still low, recovery from the drought was well under way by May 1993 (Fig. 2.15, 2.26c & Table 2.6).

Rooiboklaagte in the upper Sabie-River is directly comparable to site 19, Newforest. Recovery from the drought at site 11 started early and was assisted by baseflows released into the system just before the end of the drought. Many fry of different species were already in evidence during November (Fig. 2.26d).

Assemblage recovery was investigated using Schoener's (1968) Proportional Similarity Index (PSI) (Meffe and Sheldon, 1990);

where $PS_{ij}$ is proportional similarity (from 0.00 = completely different, to 1.00, identical) between two samples $i$ and $j$, $s$ is the number of species, and $p_{in}$ and $p_{jn}$ are species

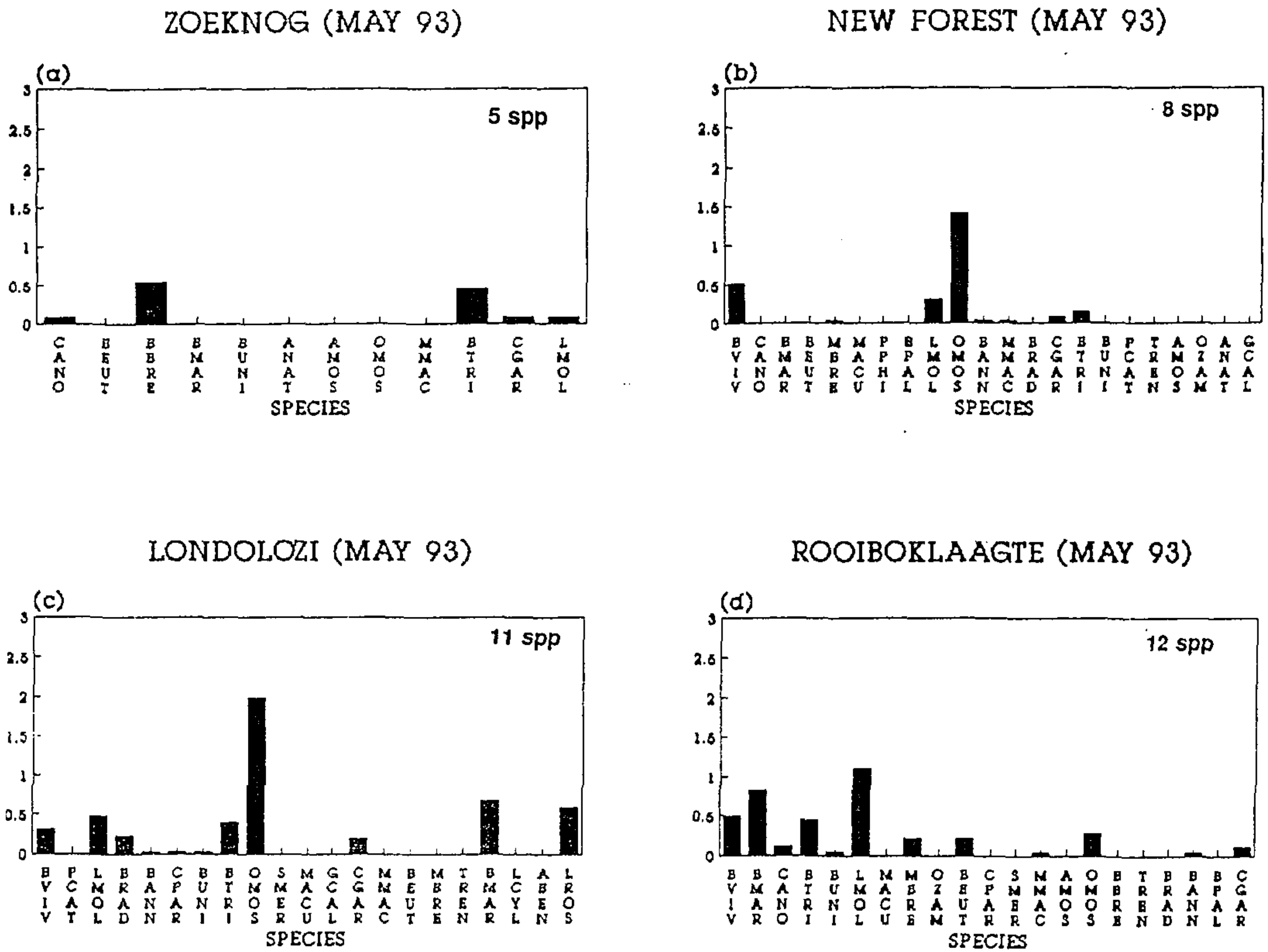


**Figure 2.26:** Recovery five months after the collapse of Zoeknog. On the Mutlumuvi little to no recovery was recorded. Zoeknog (site 25) immediately downstream of the dam recorded the lowest CPUE and species numbers to date (5 spp). *C.anoterus* previously numerous are now a remnant and *B.eutaenia* absent. New Forest showed slight recovery with species recorded roughly 50% of pre-event records (8 spp) and CPUE low. Both *C.anoterus* and *B.eutaenia* markedly absent. *O.mossambicus* again the most numerous. On the Sand River the Londolozi is recovering from the drought with *Labeo rosae*, *C.gariepinus*, *B.marequensis* and *L.molybdinus* juveniles in evidence. Rooiboklaagte (site 11) was recovering well (12 spp). *M.acutidens* was not recorded at any of these sites in May 1993.

proportions of the total numbers of individuals in the $i_{th}$ and $j_{th}$ samples.

$$PS_{ij} = 1 - 0.5 \sum_{n=1}^{s} |p_{in} - p_{jn}|$$

This allows for a quantitative comparison of two samples, and is useful for assessing assemblage similarity/recovery. Index values of greater than 0.7 indicate very similar or stable fish communities (Peterson and Bayley, 1993), but the measure is susceptible to the sampling scale. To avoid very low PSI values for short fishing runs, a baseline assemblage was calculated spanning a full year prior to the drought. Mean PSI values prior to major assemblage changes for the selected sites combined was 0.64 (S.D.= 0.11).

Figure 2.27 shows the results for New Forest (site 19) and Rooiboklaagte, the comparable Sand River tributary site, (site 11). Declining PSI values for site 11 (Nov-Feb 1991-92) and site 19 (May-Aug 1992) both correspond to periods of flow stress within the reach. At New Forest, the Zoeknog collapse keeps the index at its lowest recorded value with the assemblage radically changed in species number and CPUE. There is little recovery at site 19 by May, 5 months after the event.

### *2.4.5.2 MACRO-INVERTEBRATE RECOVERY TO DATE*

By May 1993 following the collapse of the dam, there is some evidence of recovery. This may be misleading as macro-invertebrates were not identified to species. Although total number of invertebrates at site 19 were equivalent to site 25, the severe impact on site 19 was reflected in the low invertebrate diversity. (Fig. 2.20 - 2.22). The species diversity at site 11 (Fig. 2.23) on the upper Sand River is comparable to site 19 on the Mutlumuvi in both stream order and zonal position. Site 11 showed a higher taxa diversity by May 1993 and suggests the recovery potential of an unimpacted reach following drought is higher. Whatever the interpretation, it is apparent that the macro-invertebrates are able to respond more rapidly numerically following both drought and pollution events than the ichthyofauna. What is unclear is the species makeup of the recovered community.

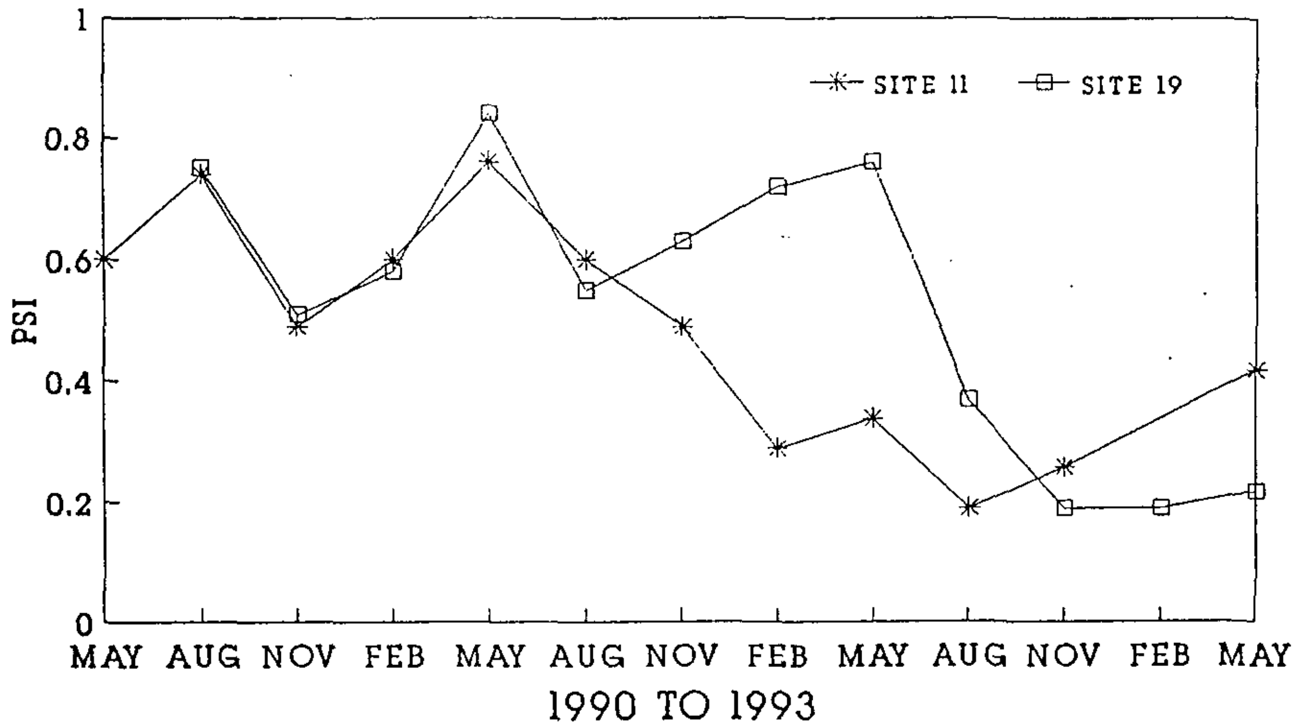


**Figure 2.27:** Similarity and recovery of fish assemblages, measured as proportional similarity index (PSI), at site 11 (Rooiboklaagte) and site 19 (New Forest). Pre-drought quarterly samples for sites spanning Aug 1990 to May 1991 were summed and used as the baseline assemblage. Both sites showed similar PSI values with possible seasonal effects between Aug 1990-91. Both sites 11 (Nov 1991 - Feb 1992) and 19 (May 1992 - Nov 1992) showed rapidly declining PSI values which corresponded to differing periods of low to no-flow in the reaches. Site 11 shows an early start to recovery (0.4 PSI by May). The Zoeknog event keeps the PSI very low at site 19 (Feb 1993), with little recovery by May.

## 2.4.6 CONCLUSIONS

- The collapse of the Zoeknog Dam had clear biotic and abiotic impacts on the Sand River catchment including reductions in CPUEs and local diversity of fish, increases in catchment turbidities and sediment loads, and gross stream bed modifications.
- A west to east gradient of impact is seen.
- An east to west drought gradient complicates interpretation down the reach.
- The Mutlumuvi River was generally heavily impacted, while the lower Sand River impacts are masked by more powerful drought effects.

- The upper reaches at Zoeknog show gross modifications in channel structure with course unsorted substrates smothering typical riffle reaches.
- In the mid-Mutlumuvi at New Forest, the already severely drought stressed fish assemblage was almost totally destroyed.
- At Londolozi, clear impacts of the Zoeknog collapse were masked by drought effects on the mid-Sand River.
- Although difficult to assess, high turbidities impacted off-stream pool fish assemblages in the mid-Sand River floodplain.
- The degradation of the upper lowveld fish refuge reach may reduce the resilience of the lower reaches of the Sand River.
- As the Mutlumuvi was regionally the refuge reach for flow-sensitive fish species, it may prove slow to recover itself as it is isolated from large viable populations of species such as *C.anoterus*, *B.eutaenia* and *O.zambezense.*
- The ichthyofauna of the Mutlumuvi had recovered very little five months after the event.
- Fish species typically numerous in the Mutlumuvi, but which are now drastically reduced or absent, include *C.anoterus, B.eutaenia, B.marequensis, B.viviparus* and *M.acutidens.*

# 3. INSTREAM FLOW REQUIREMENTS OF THE SABIE-SAND RIVERS IN THE KRUGER NATIONAL PARK

## 3.1 WATER USE IN THE SABIE CATCHMENT

At present, commercial forestry using pine and eucalypt is the major water user in the Sabie catchment. However, planned increases in irrigation, and urban water consumption (Table

**Table 3.1:** Present and projected water use in the Sabie catchment. (Modified from Chunnett *et al.*, 1987). Figures in $m^3 \times 10^6 yr^{-1}$.

| | 1987 | 2010 | % increase |
|---|---|---|---|
| Urban | 6.9 | 61.6 | 793 |
| Livestock | 1.8 | 1.8 | 0 |
| Irrigation | 107.7 | 327.9 | 204 |
| Afforestation | 124.9 | 128.8 | 3 |
| **Total** | 241.3 | 520.0 | 115 |

3.1), could cause an increase of 115% in water consumption from the catchment by the year 2010. All of the major users have a fairly steady requirement throughout the year, so that critical low-flow periods are not linked with corresponding low demand. Present water use of $250 \times 10^6 m^3 yr^{-1}$ is equivalent to an average flow of $7.93 m^3 sec^{-1}$. According to hydrological simulations using Pitman's (1973) model, this is higher than the mean flow of the river under natural conditions during July to October (the driest months) (See Fig. 3.1). During the driest months in a 60 year simulation (South African Department of Water Affairs, 1990), flow during all months was below $7 m^3 sec^{-1}$. The present water uses in the upper and middle catchment, if met in full, are therefore sufficient to intercept all surface flow upstream of the Kruger National Park during low-flow months. With the envisaged 115% increase in water use, it is inevitable that the river will be reduced to seasonal flow unless some provision for additional storage can be made.

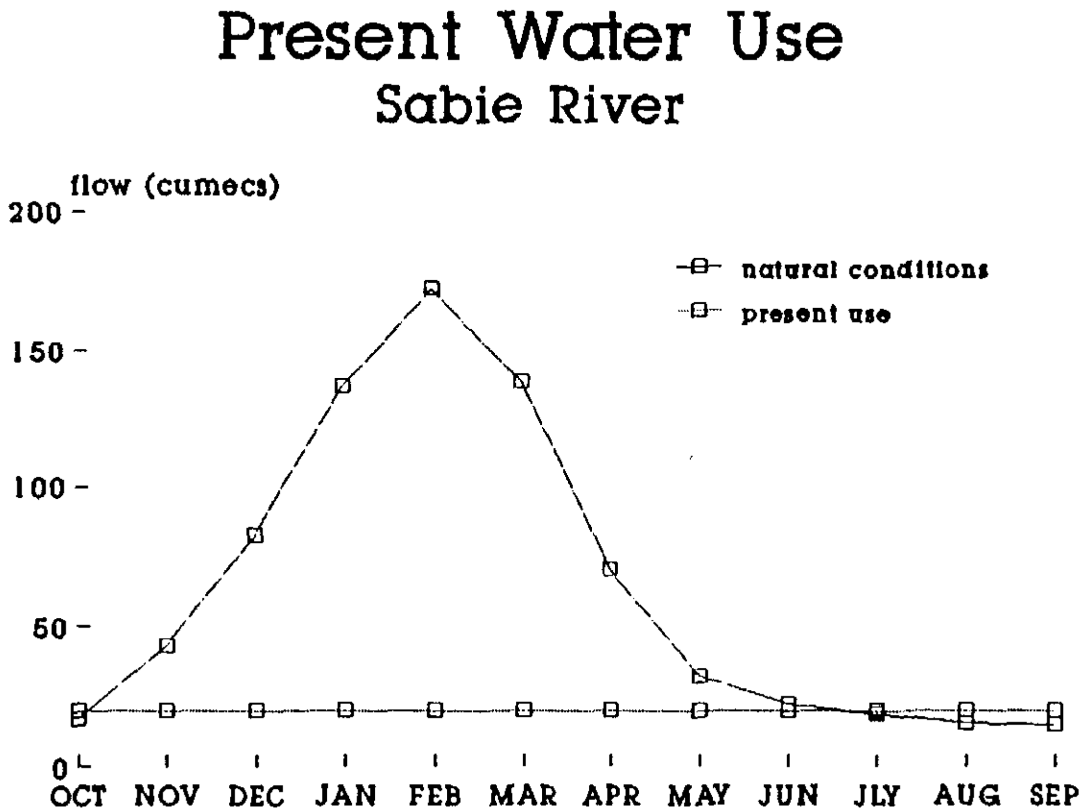


**Figure 3.1:** Mean flow rates in the Sabie River at the Mozambique borber under natural conditions, compared with present water demand, averaged over the year (1985).

# 3.2 PREVIOUS ASSESSMENTS OF THE ENVIRONMENTAL WATER REQUIREMENTS FOR THE SABIE RIVER.

It is within the above framework that the South African Department of Water Affairs initiated research to assess the environmental water requirements of the Sabie River. These requirements are seen as catering primarily for the maintenance of the natural perennial river fauna and flora of the Sabie River in the Kruger National Park. However, it is equally important for the river to remain perennial upstream of the nature conservation areas. The river is extensively used by the people and livestock in the catchment for direct water use - abstraction, laundry and washing. Not only would the reduction of the river to a series of pools cause water shortages, but accumulation of pollutants would lead to health risks, and the availability of standing water as habitat for malarial mosquitoes and bilharzia snails would increase considerably. Fortunately, if the requirements of the conservation areas and Mozambique are met, by definition the upstream reaches of the river will remain perennial.

To date, three independent methods have been used to assess the environmental water requirements of the Sabie River:

a) Davies *et al.*, (1991) used a water budget method in which the consumptive and non-consumptive water uses were estimated, to provide a seasonally-distributed flow requirement. Major consumptive uses were evaporation from the river surface, and evapotranspiration by riparian vegetation, amounting to 30 x $10^6$ $m^3$ $yr^{-1}$ for the Sabie in the KNP. Additional uses for animal drinking and staff/tourist consumption within the Park amounted to 0.5 x $10^6$ $m^3$ $yr^{-1}$. To this consumption was added the limiting non-consumptive requirement, which was assessed as a 0.1m depth of flow over riffles to ensure the maintenance of riffle habitat and passage for fish.

Total baseflow requirements using this method amounted to 136.5 x $10^6$ $m^3$ $yr^{-1}$, distributed as monthly average flows of 0.6 - 5$m^3$ $sec^{-1}$. Additional biannual and longer term flood requirements were also specified.

b) Gore *et al.*, (1992) used the PHABSIM model to provide preliminary estimates of hydraulic habitat requirements for four key species in the Sabie River. They defined *Barbus viviparus*, a small cyprinid fish; *Serranochromis meridianus*, an endemic predatory cichlid fish; *Chiloglanis swierstrai*, a small rheophilic catfish; and the hippo (*Hippopotomas amphibius*), as key species covering the main types of hydraulic habitat requirements. Gore *et al.*, (1992) show habitat preference curves which imply significantly increased habitat loss rates for each species at the discharges indicated

**Table 3.2**: Discharges in the Sabie River below which habitat loss rates for selected species increase rapidly. (Discharges inferred from habitat preference curves in Gore *et al*, 1992).

| Species | Critical Discharge ($m^3sec^{-1}$) |
|---|---|
| *Barbus viviparus* | 3.3 |
| *Serranochromis meridianus* | 3.6 |
| *Chiloglanis swierstrai* | 6.8 |
| *Hippotamus amphibius* | 3.5 |

in Table 3.2. From these measurements, Gore *et al.*, (1992) conclude that the minimum discharge necessary to maintain a "minimum diversity of fish fauna" would be 2 $m^3$ $sec^{-1}$. For three of the four key species, a flow of around 3.5 $m^3$ $sec^{-1}$ would provide acceptable habitat availability (Table 3.2). Gore *et al.*, (1992) found that the relationship between increased species diversity and hydraulic diversity peaked at 6 $m^3$ $sec^{-1}$. Translated into annual water volumes to maintain survival, acceptable and ideal conditions, these flows would require 63, 110, and 189 $m^3$ x $10^6$ respectively.

9c) The third assessment of environmental flow needs used hydrological simulations of natural, present and various future impounded conditions of the Sabie River to predict possible ecological conditions (O'Keeffe and Davies, 1991). Ecological consequences of successive reductions in discharge were then assessed using the River Conservation System (O'Keeffe *et al.*, 1987), an expert-system based model, to determine the conservation status of the river under different management conditions. Recommended flows were presented in the form of a 60 year month by month simulation, relating recommended flows as a percentage of natural flows (O'Keeffe and Davies, 1991). These recommendations, if implemented, would ensure that worst historical drought conditions during the 60 year period of record would not be exceeded, and there would be a very low probability of their being repeated in

**Table 3.3**: Recommendations by O'Keeffe and Davies (1991), (in association with Chunnett Fourie and Partners), for annual flow volumes in the Sabie River at different probabilities of exceedence. (e.g. it is recommended that annual flow should exceed 127 x $10^6$ $m^3$ for at least 19 years in 20).

| % exceedence | Annual volume ($m^3$ x $10^6$) |
|---|---|
| 95 | 127 |
| 75 | 211 |
| 50 | 295 |

consecutive years, or at short intervals. Table 3.3 shows the annual exceedance volumes at various levels of probability.

The worst drought in the 60 year record (1982-83) produced a runoff of 74 x $10^6$ $m^3$, and this was taken as the minimum, or survival, recommendation by O'Keeffe and Davies (1991), although the 1991-92 has now superseded 1982-83 as the worst drought on record. The 95% assured flow, 127 x $10^6$ $m^3$ should ensure acceptable environmental maintenance, while the 75% assured flow - 211 x $10^6$ $m^3$ - should ensure desirable conditions.

Having converted these three assessments to a common currency, that of annual volumes of water at survival, acceptable and desirable levels for environmental maintenance, it is

**Table 3.4**: Base flow recommendations for the Sabie River, from three different methods, aimed at maintaining environmental conditions at a survival, acceptable or desirable level. Recommended volumes are for the Sabie River immediately upstream of the Sabie/Sand confluence. (Flow volumes in $m^3$ x $10^6$ $yr^{-1}$).

| | Survival | Acceptable | Desirable |
|---|---|---|---|
| Consumptive / Non-Consumptive (Davies *et al.*, 1991) | - | 136.5 | - |
| PHABSIM (Gore *et al.*, 1992) | 63 | 110 | 189 |
| Hydrological Simulations (O'Keeffe & Davies, 1991) | 74 | 121 | 211 |
| % of Mean Annual Runoff | 12 | 21 | 35 |

interesting to compare the different recommendations, as in Table 3.4. Bearing in mind that these assessments each used different methods, based on different data, analyzed by different teams, the recommendations are very similar, and give some basis for confidence that they are appropriate base flows for the maintenance of the riverine ecosystem. Seen as a percentage of the present MAR of the Sabie River, they are not unreasonable requirements, and should be accepted as targets for management of the river's water resources.

# 3.3 LESSONS FROM THE 1991-92 DROUGHT.

Since the assessments described above, the Sabie has suffered the worst drought on record (in 1991-92), and this project team was fortunate enough to collect information on the effects on the biota of the river before, during, and after this drought, which provided a natural experiment of the effects of very low (or no) flow (see Vol 2). This volume summarises the lessons which can be inferred from the effects of the drought, in relation to the assessment of environmental flow requirements for the rivers.

If the rivers stop flowing, even for a short time, a number of species will disappear from the static reaches. These will include *Chiloglanis anoterus* and *Opsaridium zambezensis*. In addition to these disappearances, the community structure will change considerably, mainly as a change from dominance by cyprinids to cichlids. These changes do occur naturally during times of seasonal low-flows, but recover during subsequent high flow periods. The natural variability of the flow regime is therefore very important in maintaining the dynamic diversity of species in the river, and both low- and high flows are important in this regard. It is the duration and intensity of these low-flow events which are crucial to the survival of the full mosaic of species in the river. A large number of the fish species stop breeding during low-flows, and the longer that low-flow sequences continue, the longer it will take for the communities to recover. As a general rule, low or no-flow sequences of longer than two months are likely to cause changes to the community from which species will take a year or more to recover. If the river were to be managed to maintain flows at a survival level, species would disappear gradually but permanently due to lack of recruitment. Management of the flow regime should therefore concentrate on the maintenance of natural proportions of all species in the assemblage, rather than on the dangers of the immediate disappearance of species from the system.

The distribution of species in different pools at the Londolozi site in the Sand River during the drought, indicates that at least some of the species position themselves carefully during reducing flows, so as to be able to take advantage of the best possible pool habitat when flow ceases. The rate of flow reduction is therefore very important, and should be as slow as possible. Similarly, high flows (greater than bank-full) are important for replenishing and recolonising off-mainstream pools, which proved to be important refuges during no-flow periods.

Finally, the maintenance of permanently flowing reaches is of the utmost importance to ensure that there are survivors in the system from which recolonisation can take place. The upper reaches of the Sand and Mutlumuvi Rivers are such refuges, as is the main Sabie River. The failure of the Zoeknog Dam in Late 1992 was a compounding disaster for the Mutlumuvi, coming at the end of a two year drought. The fish community was only beginning to recover some five months after the dam failure. The other main stem of this refuge area, the Upper Sand River, had also been affected by the drought, and by the diversion of the entire base flow at the Champagne Castle Citrus Estates (between the Casteel and Dingleydale Dam sites) during 1991. It is likely to be this kind of simultaneous multiple degradation to the system which will eventually cause stresses from which the recovery potential of the rivers will be progressively, negatively impacted.

# 3.4 SUMMARISED FLOW SCENARIOS

## 3.4.1 INTRODUCTION

The purpose of this section is to gather together the detailed information that has been presented in the first two volumes of this report, and summarise it into a form that allows us to predict the consequences of different flows on the habitats, water quality and fauna of the Lowveld Zone of the Sabie River.

Predicting the ecological consequences of changes in the flow regime at this sort of scale (100 km of river) is an inexact science. In detail, the outcome of a drought on the fauna of a river may be different from one year to another, and will depend to a large extent on the following variables:

- The duration and severity of the drought
- The antecedent conditions in the river
- The proportions of different species in the communities before the drought
- Biotic interactions, such as competition, predation, and parasitism/disease during the drought
- Chance events, such as unusually hot weather.

Volume 2 documents the range of different outcomes in a series of pools in the same stretch of the Sand River during the 1992 drought, and demonstrates clearly the likely error of predicting a single set of consequences of a drought even in one part of a river which appears to be subject to the same set of conditions. Predictive accuracy is also reduced by the cumulative inaccuracies and uncertainties of hydrological, geomorphological and water quality simulations, all of which govern the population changes in the communities.

Having emphasised the variability of ecological systems, there are general trends which can be predicted with some confidence, and this section attempts to define those trends in response to different flows of different duration in the LZ of the Sabie River. This zone corresponds with the warm perennially-flowing reaches of the river in the Kruger Park. These predictions would apply equally to the Sand River, stretches of which do stop flowing during dry seasons. The impacts of different flows in the upper reaches of the river have not been dealt with, but would be expected to be more extreme, and would affect different species which are typical of the cooler, steeper gradient upper river.

The consequences of different flows on habitat availability, water quality, and the instream fauna are addressed in Tables 3.5 to 3.7. Predictions are partly quantitative and partly qualitative, because of the uncertainties described above. The tables are designed to provide a structured summary of the effects of a series of flow scenarios of varying duration, during

**Table 3.5:** Predicted effects of different flows for various durations, on the water levels and habitat availability in the Lowveld Zone Sabie River. *This and the following tables are intended to provide a semi-qualitative picture of the effects of different flow regimes on the physical, chemical,* habitat and biological conditions in the Sabie River, based on the measurements and observations made in the Sabie and Sand rivers from 1990-1993.

| Flow Scenario | Dry Season | Wet Season |
|---|---|---|
| no-flow ($0\ m^3s^{-1}$) | ▾ **Occurrence:** The Sabie River has never stopped flowing under present development conditions. ▾ **Habitat:** Runs would dry out with only pools remaining. **(water depth);** Many pools would be shallow. **(flow velocity);** Only standing water available. **(cover);** Depth is the only cover in deeper pools, with time turbidities increase. ***(substrates);*** *The number and type of pools formed relates to the structure and* substrate of the reach concerned. In rocky reaches, series of pools form. In sandy reaches, few pools form while active hippo pools are important. ▾ ***Duration:*** *The length of time pools can survive without the resumption of* flow depends largely on their substrate type but is influenced by initial volume, depth and surface area. Refuge pools formed in unfractured bedrock reaches such as those of the lower Sabie River at Mlondozi (Plate 8A & Vol 2; Plate 4 A-F), hold their water the longest. Pools in sandy reaches (Plate 3A, Vol 2) are dependent on base-flows. **(0-1 month);** Of the initial pools formed, many are shallow. Initial pools of less than 30 cm deep evaporate in the first month while deeper pools in sandy reaches can drain away. **(1-3 months);** By three months roughly half the pools found in bedrock reaches are dry with most of the remainder shallow. **(+3 months);** By six months, a typical bedrock reach may be dry. A detailed discussion is to be found in Vol 2. Because long stretches of the lowveld Sabie River are sandy without bedrock control, we would expect a lot of the river to dry out rapidly with prolonged drought. | ▾ **Occurrence:** As yet never recorded, reducing the Sabie to an ephemeral river. No-flow in summer would most likely occur towards the end of the dry season when the reach is at its lowest. ▾ **Habitat:** Summer habitats would be severely reduced in pools with a stoppage of flow no matter how brief, exactly when the biota is seasonally active. *Evaporation rates would be much higher in summer and the lowveld* Sabie River. Because the dry season is still to follow, most natural pools would dry before the next season. **(water depth);** Runs would dry out. Many shallow *pools would be formed.* ***(flow velocity);*** *Only standing water available.* ***(cover);*** Initially only the cover of pool substrate and depth, as pools become shallower and the biota gets concentrated, turbidity becomes important in some pools. ***(substrates);*** *As discussed (see dry season). Substrate type and channel* structure affect pool persistence. ▾ **Duration:** Prolonged no-flow would further alter the structure of the riparian strip and hence nature and quality of the reaches structure and habitats. **(0-1 month);** More than half the number of refuge pools formed would be lost in the first month due to high temperature. **(1-3 months);** Most pools would dry by the end of three months. **(+3 months);** The reach would be dry. Hippo pools, weirs and dams would be the last important local refuges for some of the biota. |
| extreme drought flows ($0\text{-}1\ m^3s^{-1}$) | ▾ **Occurrence:** For two months in 1992 (the worst drought on record). Extreme drought low-flows extended to over 6 months during the 1992 dry *season (April-October).* ▾ **Habitat:** Some pools isolated within the river bed. These are still connected to base-flows and offer stable refuge as long flow persists (Vol 2; Plate 3A). **(water depth);** Water levels are reduced by up to ±60 cm from typical base-flows (Plate 4A) resulting in very shallow runs. Water depths over riffles are very shallow (<10 cm). Pools are the only deep habitats remaining. **(flow velocity);** Flows in general are very sluggish while in riffles, the available water trickles between the substrate. **(cover);** The rivers reaches are exposed, with little marginal cover available (Vol 1; Fig. 3.7a). **(substrates);** Little sediments are transported. ▾ **Duration:** **(0-1 month);** Extreme low-flows are most likely to be reached in September-October in drought years. **(1-3 months);** In more dry years, extreme low-flows tend to manifest earlier (August-October) **(+3 months);** The total failure of the preceding wet season results in extreme drought flows for the most of the dry season. | ▾ **Occurrence:** As yet never been recorded. ▾ **Habitat:** Habitat area and quality reduced to a minimum as the reach *approaches no-flow. Stranded marginal vegetation at the time of renewed plant* growth, and the lowered water-table can be expected to alter the structure of the riparian strip, impacting reach structure. **(water depth);** Reaches would be *reduced to shallower pools and very shallow runs.* ***(flow velocity);*** *Flows would* be sluggish in runs with flow through, rather than over, riffles. **(cover);** No flooded marginal vegetation and clear shallow waters will expose the biota. **(substrates);** No transport or sorting of sediments would occur. Coarse substrates would remain clogged from the previous dry season. ▾ **Duration: (0-1 month);** Even in the short term, the effects of a summer low-flow of this magnitude would have long felt ecological implications. **(+3 months);** Extended summer low-flows of this magnitude preempt no-flow conditions in the following dry season. |



Table 3.5 cont.

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| drought flows ($1\text{-}3\ m^3s^{-1}$) | ▾ **Occurrence:** The Sabie River system is naturally drought prone, with dry season low-flows of this magnitude occurring every few years. ▾ ***Habitat:*** *The volume of habitat available is greatly reduced.* **(water depth);** Base-flow levels are further reduced by up to ±30 cm. **(flow velocity);** Flows are *generally sluggish.* **(cover);** *Almost no edge vegetation is inundated which* reduces the amount of cover available to the biota (Vol 1; Fig. 3.6c). Relatively more cover remains available in reaches with rocky substrates or where tree roots have stabilized the banks. **(substrates);** Very little sediments are transported. Algal scum develops in sluggish runs while coarse sediments silt up. ▾ **Duration:** Uninterrupted low-flows follow on from the wet season low-flows. **(0-1 month);** Short term drought flows are most likely to originate at the end of the dry season (September-October), **(1-3 months);** with longer term drought low-flows developing earlier (August-October). **(+3 months);** A natural long term drought could extend for up to six months (May-October). | ▾ **Occurrence:** Intense summer drought and the extreme drought low-flows as recorded in the summer of 1991-92, are rare to unnatural. ▾ **Habitat: (water depth);** Water level is reduced by up to ±80 cm from typical wet season base-flows. **(flow velocity);** Flows are sluggish. **(cover);** *Very little cover is available with waters clear, very shallow and isolated from* the marginal vegetation. **(substrates);** Substrates remain silted and commonly covered in algal scum. ▾ **Duration:** As with extreme low-flows, drought flows tend to persist reflecting chronic rain failure. Summer drought flows are of particular concern, as the biota is seasonally active and because the following dry season is still to follow. **(0-1 month);** Flows of this magnitude and duration could be expected with a partially failed wet season or through the delayed onset of summer rains (October-November). **(+3 months);** With persistent summer rain failure these conditions can result in the early onset of the dry season (March-May) as seen in 1991-92. |
| low-flows ($3\text{-}6\ m^3s^{-1}$) | ▾ **Occurrence:** Within the range of expected base-flows for the lowveld Sabie River during winter (Plate 3A & 4B). ▾ **Habitat:** All habitats are available with the low water level restricting the biota to the channel. **(water depth);** Vast areas of these reaches are now shallow. **(flow velocity);** Flow is generally placid. Moderate velocities are only expected at scarce but now shallow riffle habitats. **(cover);** Clear, low-flow waters conditions reduces cover, which is further reduced by limited access to marginal vegetation. Cover loss is greater moving downstream both due to more extreme water level reductions and the dominance of reed versus grass components in edge vegetation (Vol1; Fig. 3.5). **(substrates);** The extensive shallows and sandy runs begin developing an algal scum. ▾ **Duration: (0-1 month) & (1-3 months);** Periods of low-flow interspersed by freshets are usual both at the end of (April-June), and at the onset of the wet season (November-December). **(+3 months);** Four months of uninterrupted base-flow stretch throughout the hight of the dry season (July-October). | ▾ **Occurrence:** Typical of moderate and periodic drought in the system. ▾ **Habitat:** Habitat conditions would be comparable with low-flows experienced in the reach during the dry season during normal years. The summer active marginal vegetation may show zonational changes such as the colonization of exposed sand banks by grasses and herbs. Changes in the structure of the riparian strip are expected. **(water depth);** Wet season water levels of this magnitude would be ±50 cm below levels typical of seasonal low-flows. **(flow velocity);** Flow velocities will remain placid at all but riffle areas where moderate flows are expected. **(cover);** Very little instream cover is available with reduced access to the marginal vegetation fringe. **(substrates);** Silting and algal scum persistence reduces the quality of many substrate types. ▾ **Duration: (0-1 month);** This depends on the nature of the drought. One or two rain events would break the intensity of a developing drought, effectively re-setting the reach. **(1-3 months);** A single rain event would greatly increase the resilience of the reach. **(+3 months);** Complete failure results in profound ecological effect. |
| low-flows to freshets ($6\text{-}20\ m^3s^{-1}$) | ▾ **Occurrence:** During the dry season, discharges of this magnitude are freshets. Freshets above 10 $m^3.s^{-1}$ would be rare, but more likely intermediate between both wet and dry seasons (April-June and July-October). ▾ **Habitat:** All habitats are available, while there is a terrestrial input of food and nutrients into the system. **(water depth);** Water levels rise up to ±80 cm above base-flows (Plate 3 B & C). **(flow velocity);** Moderate flow velocities as the reach is flushed. **(cover);** Cover within the reaches increase, both because of increased turbidities and access to marginal vegetation, restricted during low-flow periods. **(substrates);** Movement of sand in sandy runs evident. Flushing of accumulating fines in quiet waters increases turbidities. ▾ **Duration: (0-1 month);** Freshets during the dry season are by definition short lived. Discharge is elevated for approximately seven days following an event (Vol 1; Fig. 4.7). **(1-3 months);** Elevated flows of this duration are highly improbable for the Sabie River and would alter the character of the system. | ▾ **Occurrence:** Low-flows of this magnitude during the wet season are those most commonly seen in the lowveld Sabie reaches between flow events. ▾ ***Habitat:*** *All habitats are available.* **(water depth);** *Low-flow water levels* are ±50 cm higher than those of dry season low-flows. **(flow velocity);** Moderate flow conditions are available. **(cover);** Marginal vegetation (herbs and grasses) are bounded by their tolerances to the highest flows often experienced in the reach. Wet season high flows define their zonation. A moderate amount of marginal cover is available, providing unique cover otherwise denied to the biota. **(substrates)** Algal scums are stripped and sand transported in runs while fines are moved from some areas, re-sorting substrates. Flows as low as five times that of preceding flows move sediments and sort bed materials. ▾ **Duration: (0-1 month);** Low-flows typical of the wet season are of short duration as rain events continuously flush through the system. The monthly low-flow average gradually rises to a peak in February. **(1-3 months);** Low-flows of this duration may be possible in seasons approaching drought. **(+3 months);** Extended or managed wet season low-flows would be unnatural and remove much of the dynamics that drives this seasonal system. |

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| **Freshets to floods** (>20 $m^3s^{-1}$) | ▾ **Occurrence:** Rare to unnatural to the system under present conditions.<br>▾ **Habitat:** Most habitats would be made available. **(water depth);** Water levels could rise some meters before flooding the banks. **(flow velocity);** Aseasonal high velocities would flush the system with atypical ecological effects. **(cover);** Marginal vegetation would be flooded at the wrong time in its growth cycle. **(substrates);** The sorting and transport of the reaches would proceed aseasonally.<br>▾ **Duration: (0-1 month);** A late or early flood is the most likely of events to occur naturally. Their disruptive effects would probably be measured within a season. **(1-3 months);** Long-term elevated flows would alter the ecology as we understand it considerably. This condition is not possible under present climatic conditions. | ▾ **Occurrence:** Pulses of high-flow or freshets, and large events or floods are typical and unique to this season.<br>▾ **Habitat:** The first freshets of the season are particularly important in re-setting the system. All habitat are made available, including many temporary areas, rich in nutrient input. Flows are highly dynamic and fundamental in the restructuring of the channel. **(water depth);** Water levels can briefly rise some meters, flooding its banks in some areas. **(flow velocity);** High flow velocities are recorded throughout the main channel. **(cover);** Although floodplains are not features of the mid- and lower Sabie River, extensive reedbeds do occur. These are flooded during high flows. (Vol 1; Fig. 3.4). **(substrates);** During high flows the movement of bed-load is important. Channel re-structuring processes take place.<br>▾ **Duration: (0-1 month);** These flows are by definition of short duration. **(1-3 months);** Protracted periods of high flow are not possible under present climatic conditions. |

░ = Flow magnitudes & flow types most commonly associated with the lowveld Sabie River reaches, under present development conditions.

**Table 3.6:** Physico-chemical conditions at different seasonal discharges in the Sabie River lowveld.

| ***Flow Scenario*** | ***Dry Season*** | ***Wet Season*** |
|---|---|---|
| **no-flow**<br>**(0 $m^3s^{-1}$)** | **(at isolation)**<br>▾ **Salinity:** 130-170 µS/cm<br>▾ **pH:** 6.8-7.6<br>▾ **TSS:** 0.0003-0.0007 g/l<br>▾ **Turbidity:** 1-6 NTU<br>▾ **Oxygen:** >60% saturation<br>▾ **Temperature:** 21.5-25.4°C<br><br>**(after 3 months)**<br>▾ **Salinity:** 300-600 µS/cm<br>▾ **pH:** 7.4-9.1<br>▾ **TSS:** 0.0007-0.0018 g/l<br>▾ **Turbidity:** 1-62 NTU<br>▾ **Oxygen:** 7-156% saturation<br>▾ **Temperature:** 18.1-25.3°C<br><br>**(after 5 months)**<br>▾ **Salinity:** 590-900 µS/cm<br>▾ **pH:** 8.5-9.7<br>▾ **TSS:** 0.016-0.053 g/l<br>▾ **Turbidity:** 63-610 NTU<br>▾ **Oxygen:** 7-414% saturation<br>▾ **Temperature:** 28.8-33.6°C<br><br>▾ **Comments:** Only isolated pools remain. The water quality deteriorates over time. Smaller pools can become unacceptably saline (450 µS/cm; DWAF, 1993) or alkaline after 3 months. Shaded pools show low daytime oxygen levels which can result in nighttime fish kills. In exposed pools, dissolved oxygen supersaturates the water due to the presence of algal blooms. After five months isolation, pools are more mineralised (up to 900µS/cm), alkaline (up to pH 10) and much more turbid due to the concentrated action of fish and the development of algal blooms. Much warmer water temperatures are recorded, while dissolved oxygen levels can be even more extreme. | **(at isolation)**<br>▾ **Salinity:** ±130-170 µS/cm<br>▾ **pH:** ±7-8<br>▾ **TSS:** ±0.0003-0.0007 g/l<br>▾ **Turbidity:** ±1-6 NTU<br>▾ **Oxygen:** ±>60% saturation<br>▾ **Temperature:** ±28-35°C<br><br>**(after 3 months)**<br>▾ **Salinity:** ±600-900 µS/cm<br>▾ **pH:** ±9-10<br>▾ **TSS:** ±0.02-0.05 g/l<br>▾ **Turbidity:** ±60-600 NTU<br>▾ **Oxygen:** ±10-410 % saturation<br>▾ **Temperature:** ±28-37°C<br><br>**(after 5 months)**<br>▾ **Salinity:** ±700-1600 µS/cm<br>▾ **pH:** ±9-10<br>▾ **TSS:** ±0.02-0.05 g/l<br>▾ **Turbidity:** ± 60-600 NTU<br>▾ **Oxygen:** ±10-410% saturation<br>▾ **Temperature:** ±28-40°C<br><br>▾ **Comments:** Isolated pools would form. Water quality would deteriorate to extremes more rapidly in the summer months, with pools showing much higher temperatures. After three months, smaller pools would have dried, while the salinities (450 µS/cm; DWAF, 1993) and alkalinities (up to pH 10) of larger pools would have increased to unacceptable levels. Daytime dissolved oxygen in shaded pools would be very low, resulting in nighttime fish-kills. Supersaturated daytime dissolved oxygen levels would occur in exposed pools due to algal blooms. After five months, pools would be more mineralised (>1600µS/cm), alkaline (up to pH 10) and much more turbid. The increase in turbidity is due to the concentrated action of fish and the development of algal blooms. |
| **extreme drought flows**<br>**(0-1 $m^3s^{-1}$)** | ▾ **Salinity:** 150-180 µS/cm<br>▾ **pH:** 7.6-8.2<br>▾ **TSS:** 0.0023-0.0065 g/l<br>▾ **Turbidity:** 2-3 NTU<br>▾ **Oxygen:** >60% saturation<br>▾ **Temperature:** 18.7-27.9°C<br><br>▾ **Comments:** Dry season extreme drought flows may develop poorer oxygen regimes and become moderately warmer than typical low-flows. Very high nutrient concentrations have also been recorded, but in general the water quality is still acceptable. | ▾ **Salinity:** ±150-180 µS/cm<br>▾ **pH:** ±7.5-8<br>▾ **TSS:** ±0.002-0.007 g/l<br>▾ **Turbidity:** ±2-3 NTU<br>▾ **Oxygen:** ±>60% saturation<br>▾ **Temperature:** ±28-35°C<br><br>▾ **Comments:** Extreme drought flow in the summer months could results in very poor oxygen levels and high water temperatures than those typical of "wet season" flows. Nutrient levels may also be elevated, but in general, the water quality is still acceptable. |

Table 3.6 cont.

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| drought flows<br>(1-3 $m^3s^{-1}$) | ▾ **Salinity:** 120-140 μS/cm<br>▾ **pH:** 7.1-7.9<br>▾ **TSS:** 0.0036-0.0064 g/l<br>▾ ***Turbidity:*** *3-5 NTU*<br>▾ **Oxygen:** >80% saturation<br>▾ **Temperature:** 14.2-18.4°C<br><br>▾ **Comments:** The water quality of dry season drought flows are good and similar to those of other flows between 1-6 $m^3s^{-1}$ which are clear, neutral and with moderate dissolved salt levels. Drought flow waters are less oxygenated than typical low-flows. | ▾ **Salinity:** 110-130 μS/cm<br>▾ **pH:** 7.9-8.3<br>▾ **TSS:** 0.003-0.005 g/l<br>▾ ***Turbidity:*** 5-8 NTU<br>▾ **Oxygen:** >80% saturation<br>▾ **Temperature:** 25.5-32.1°C<br><br>▾ **Comments:** The water quality of "wet season" drought flows would remain fair, being similar to other low-flows (1-6 $m^3s^{-1}$). Waters would be clear, neutral and with moderate levels of dissolved salts. Summer flows of this magnitude would nevertheless be less oxygenated and much warmer than dry season drought flows. |
| low-flows<br>(3-6 $m^3s^{-1}$) | ▾ **Salinity:** 90-140 μS/cm<br>▾ **pH:** 7.4-8.1<br>▾ **TSS:** 0.0015-0.0093 g/l<br>▾ **Turbidity:** 2-7 NTU<br>▾ ***Oxygen:*** *>90% saturation*<br>▾ **Temperature:** 15.2-24.5°C<br><br>▾ **Comments:** The water quality of dry season low-flows are good. Low-flows of between 1-6 $m^3s^{-1}$ have waters which are clear, neutral and with moderate dissolved salt levels. Low-flows above 3 $m^3s^{-1}$ are better oxygenated than lower flows while winter low-flows are cooler than wet season low-flows. | ▾ **Salinity:** ±90-140 μS/cm<br>▾ **pH:** ±7-8<br>▾ **TSS:** ±0.002-0.009 g/l<br>▾ **Turbidity:** ±2-7 NTU<br>▾ ***Oxygen:*** *±>90% saturation*<br>▾ **Temperature:** ±25-30°C<br><br>▾ **Comments:** The water quality of wet season low-flows are good and similar to those of other flows between 1-6 $m^3s^{-1}$ which are clear, neutral and with moderate dissolved salt levels. Low-flows above 3 $m^3s^{-1}$ are better oxygenated than lower flows, while summer low-flows are warmer than dry season low-flows. |
| low-flows to freshets<br>(6-20 $m^3s^{-1}$) | ▾ **Salinity:** 80-140 μS/cm<br>▾ **pH:** 7.3-8.2<br>▾ **TSS:** 0.0014-0.228 g/l<br>▾ **Turbidity:** 2-469 NTU<br>▾ **Oxygen:** >90% saturation<br>▾ ***Temperature:*** *16.5-28.3°C*<br><br>▾ **Comments:** Elevated flows in the dry season transport a lot of suspended solids resulting in very high TSS and turbidity measures. These flows may be more turbid than similar wet season low-flows due to less ground cover and riparian vegetation growth. The water quality is good. | ▾ **Salinity:** 80-120 μS/cm<br>▾ **pH:** 7.4-7.5<br>▾ **TSS:** 0.026-0.06 g/l<br>▾ **Turbidity:** 22-52 NTU<br>▾ **Oxygen:** >90% saturation<br>▾ ***Temperature:*** *21.4-27.5°C*<br><br>▾ **Comments:** The water quality is similar to that of wet season low-flows and is good. Summer low-flows are less turbid than corresponding dry season flows due to better developed ground cover and active riparian vegetation growth. |
| freshets to floods<br>(>20 $m^3s^{-1}$) | ▾ **Salinity:** ≤60 μS/cm<br>▾ **pH:** ±7-8<br>▾ **TSS:** ±0.0173-0.228 g/l<br>▾ **Turbidity:** ±90-500 NTU<br>▾ **Oxygen:** >90% saturation<br>▾ **Temperature:** ± 17-25°C<br><br>▾ **Comments:** Winter flood waters would show extremely high TSS and turbidity. Salinities and temperatures would be slightly reduced. | ▾ **Salinity:** ≤60 μS/cm<br>▾ **pH:** 7.4-7.6<br>▾ **TSS:** 0.048-0.052 g/l<br>▾ **Turbidity:** 64-86 NTU<br>▾ **Oxygen:** >90% saturation<br>▾ **Temperature:** 23.5-25.2°C<br><br>▾ ***Comments:*** *Summer floods waters show slightly reduced salinities and* temperatures and increased turbidities. TSS and turbidity are higher, but not as extreme as for similar aseasonal flow events. |

**Table 3.7:** The response of the biota to different seasonal discharges for different durations in the Sabie River lowveld.

| Flow Scenario | Dry Season | Wet Season |
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| no-flow ($0\ m^3s^{-1}$) | ▾ **Lotic Fish:** High mortalities. Surviving fish in stressed condition. No breeding.<br>▾ **Lentic Fish:** Increased mortalities, stressed condition. Very little breeding.<br>▾ **Migratory Fish:** No migration possible as fish are confined to pools.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Absolute numbers reduced but they remain the most abundant group.<br>**Cyprinids:** Reduced to remnants with local extinctions.<br>*Silurids: Reduced or locally extinct.*<br>▾ **Macroinvertebrates:** Flow dependent species disappear.<br>▾ **Indicators:**<br>**(when flow ceases)** *Oreochromis mossambicus* is the most numerous species. Flow dependent species would be most impacted (Table 3.8), while those of shallow water would suffer heavy losses. All species confined to drought pools, concentrated and exposed to rapidly deteriorating water quality conditions. Most Trichoptera and Ephemeroptera are lost with flow cessation as are the oxygen sensitive fishes *Chiloglanis anoterus* and *Opsaridium zambezense*.<br>**(after 1-3 months)** Stunted *O.mossambicus* breed. *Tilapia rendalli* suffers high mortalities. Increased predation by *Clarias gariepinus* and birds.<br>**(after 3-5 months)** Very few pools survive. Most mortalities are the result of the pools drying out. Water quality is poor, remaining fish are emaciated. Only *Labeo molybdinus* and *C.gariepinus* and other deep pool species may attain breeding condition prior to the first summer rains. The LZ is reduced to a handful of hippo pools and man-made weirs. | ▾ **Lotic Fish:** High mortalities. Some local extinctions as most pools dry up. Surviving fish are in poor condition. No breeding.<br>▾ **Lentic Fish:** High mortalities. Most species found in persistent pools remain in a fair condition. Limited or no breeding.<br>▾ **Migratory Fish:** No migration possible as fish are confined to pools.<br>▾ **Fish Assemblage Changes;**<br>**Cichlids:** The most abundant group.<br>***Cyprinids:*** *Reduced to remnant populations. Some local extinctions.*<br>**Silurids:** Reduced to remnant populations. Local extinctions.<br>▾ **Macroinvertebrates:** Flow associated taxa disappear.<br>▾ **Indicators:**<br>**(when flow ceases)** The cichlid *O.mossambicus* is the most abundant fish in pools. Flow dependent species such as *O.zambezense* and *C.anoterus* are lost due to poor oxygen regimes and increased water temperatures.<br>**(1-3 months)** *T.rendalli* losses condition with deteriorating water quality and dies out before pools finally dry. Minnows reduced to remnant population with *Barbus toppini* and *Barbus paludinosus* the most resilient.<br>**(3-5 month)** *C.gariepinus*, *O.mossambicus* can survive to the last because of they have axillary air breathing structures. |
| extreme drought flows ($0\text{-}1\ m^3s^{-1}$) | ▾ **Lotic Fish:** Increased mortalities. Fish in poor condition. No breeding.<br>▾ **Lentic Fish:** Good survival in placid reaches. Most fish remain in good condition. Breeding continues except in more sensitive species as water quality deteriorates.<br>▾ **Migratory Fish:** No migration.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Most abundant population.<br>**Cyprinids:** Reduced to remnant population.<br>**Silurids:** Reduced to remnant population.<br>▾ **Macroinvertebrates:** Most flow dependent species much reduced. Diversity and density reduced.<br>▾ **Indicators:** *O.mossambicus* continues to breed in sluggish reaches, but in stunted form. The gobi *Glossogobius callidus* also breeds. *T.rendalli* copes with deteriorating conditions but ceases to breed. Cyprinids, particularly the flow sensitive species, are very stressed and concentrated with high mortalities (Table 3.8). Many species, particularly the more mobile ones move to the deeper or larger pools or select cover in anticipation of the cessation of flow. Flow sensitive species congregate at or below the last riffle areas in greatly reduced numbers. | ▾ **Lotic Fish:** High mortalities with surviving fish in poor condition. No breeding.<br>▾ **Lentic Fish:** Increased mortalities with fish stressed and in poor condition. Limited breeding.<br>▾ **Migratory Fish:** No migration.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Still the most abundant species following previous dry season.<br>***Cyprinids:*** *Further reduction of dry season numbers.*<br>**Silurids:** Further reductions of dry season low numbers.<br>▾ **Macroinvertebrates:** Flow dependent taxa much reduced.<br>▾ **Indicators:** *O.mossambicus* continues to be the most abundant species but breed in a stunted form. *G.callidus* continues to breed in quiet waters but *T.rendalli* does not breed. Flow sensitive species (*O.zambezense & C.anoterus*) suffer high mortalities due to high temperatures and low oxygen regimes. Shallow water cyprinids suffer because of reduced cover (*Barbus viviparus & Barbus marequensis*). *B.marequensis* move from the runs to riffle area where *Chiloglanis paratus* was previously most abundant. The remaining fish species are concentrated and await improved conditions. Lowveld temporary river minnows *B.paludinosus* and *B.toppini* prosper should these flows become more frequent. |

Table 3.7 cont.

| | | |
|---|---|---|
| **drought flows**<br>**(1-3 $m^3s^{-1}$)** | ▾ **Lotic Fish:** Increased mortalities and poor condition of many species. No breeding.<br>▾ **Lentic Fish:** Good survival and condition. Increased breeding potential at higher temperatures.<br>▾ **Migratory Fish:** No migration.<br>▾ **Fish Assemblage Changes:**<br>*Cichlids: Increase greatly.*<br>**Cyprinids:** Reduced.<br>**Silurids:** Reduced.<br>▾ **Macroinvertebrates:** Reduced dry season community.<br>▾ **Indicators:** Increased breeding success of the cichlids *T.rendalli* and *O.mossambicus*. *O.mossambicus* is particularly prolific in the LZ assemblage by the start of the wet season in November. *B.viviparus* and *B.marequensis*, the most numerous wet season shallow water species, are greatly reduced due to continued cover loss in shallow habitats. All minnow species concentrated and confined to pools. Flow dependent species continue to decline. | ▾ **Lotic Fish:** Increased mortalities. Most species stressed and in poor condition. No breeding.<br>▾ **Lentic Fish:** Good survival rates with fish mostly in good condition and breeding.<br>▾ **Migratory Fish:** Little to no movement expected.<br>▾ **Fish Assemblage Changes:**<br>*Cichlids: Most abundant and increasing in number, following the dry season.*<br>**Cyprinids:** Decrease further from dry season numbers.<br>**Silurids:** Decrease in numbers.<br>▾ **Macroinvertebrates:** Wet season, flow sensitive taxa reduced.<br>▾ **Indicators:** The cichlids *O.mossambicus* and *T.rendalli* breed profusely in sluggish runs and pools, dominating the lowveld assemblage. Sensitive species dependent on flow (*C.anoterus* & *C.anoterus*) in poor condition. Fish are concentrated. Reductions in *B.marequensis* and *B.viviparus*, normally the most abundant shallow-water cyprinids, due to reduced cover and therefore increased mortalities. The minnows *B.toppini* and *B.paludinosus*, typical of lowveld tempory rivers, increase in importance should these low wet-season flows become common. |
| **low-flows**<br>**(3-6 $m^3s^{-1}$)** | ▾ **Lotic Fish:** Good survival and condition. No fish in breeding condition and no breeding.<br>▾ **Lentic Fish:** Excellent survival of fish in good condition. Ideal breeding conditions at higher temperatures results in prolific breeding.<br>▾ **Migratory Fish:** No migration expected.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Increased.<br>**Cyprinids:** No change.<br>**Silurids:** No change.<br>▾ **Macroinvertebrates:** Full range of dry season species.<br>▾ **Indicators:** Reduction of protected shallow habitat leads to the reduction in *B.viviparus* (adults) and *B.marequensis* (juveniles). Flow dependent species (Table 3.8) are stressed while the oxygen sensitive *O.zambezense* and *C.anoterus* are reduced far more than *C.paratus* which seems to tolerate low-flows. | ▾ **Lotic Fish:** Good survival with adequate habitat available. Most species in good condition, most in breeding condition. Little breeding at these low-flows unless preceded by a freshet.<br>▾ **Lentic Fish:** Excellent survival potential with fish in good condition in slower flows. All cichlid species breeding.<br>▾ **Migratory Fish:** Little migration expected but some seasonal/local movements possible.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Marked increase.<br>**Cyprinids:** No change in numbers.<br>**Silurids:** Slight reduction in numbers.<br>▾ **Macroinvertebrates:** Full range of wet season species present.<br>▾ **Indicators:** Cichlids increase rapidly in warm and placid reaches, particularly *O.mossambicus* and *T.rendalli*. After a summer freshet, the minnows attain breeding condition, but little spawning is expected as high flows are few or reduced in magnitude. The water quality of flushing flows is an important spawning cue, and the amount of marginal vegetation flooded is an important factor in breeding success. The larger cyprinids, *B.marequensis* and the Labeos, do not spawn. Lower and hence warmer summer flows stress *C.anoterus* and favour *C.paratus*. |

Table 3.7 cont.

| | | |
|---|---|---|
| low-flows to freshets (6-20 $m^3s^{-1}$) | ▾ **Lotic Fish:** Good survival and improved condition of all species. Early *summer month freshets result in species coming into breeding condition early.* No breeding if these aseasonal flows occur in the cooler months (prior to September).<br>▾ **Lentic Fish:** Good survival and condition. Breeding starts when the waters are warmer, in the dry season summer months (September-November).<br>▾ **Migratory Fish:** Little migration although early summer flushes may result in some recolonization migrations.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Increase in the latter phase of the dry season.<br>**Cyprinids:** No change in abundance.<br>**Silurids:** No change in abundance.<br>▾ ***Macroinvertebrates:*** *Full range of dry season species.*<br>▾ **Indicators:** Cichlids benefit from the improved water quality of dry season freshets. Although higher flows would reduce the amount of habitat available to them *O.mossambicus* and *T.rendalli* would still be most abundant species by the end of the dry season. Cyprinids, particularly those dependent on flow and those needing cover in shallow habitats would thrive with reduced mortalities. Chiloglanids would maintain pre-dry season abundances. The highest attainable dry season diversities and abundances are expected under these flow conditions. | ▾ **Lotic Fish:** Excellent survival potential. All species in good condition. All *species in breeding condition with some serial spawning.*<br>▾ **Lentic Fish:** Good survival potential with fish equally in good condition. Some breeding.<br>▾ **Migratory Fish:** Some migration and local movement takes place. Some recolonization of reaches impacted during the dry season.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Persist at levels attained so far.<br>**Cyprinids:** Increase slightly.<br>**Silurids:** Increase slowly.<br>▾ **Macroinvertebrates:** Full range of wet season species.<br>▾ **Indicators:** Summer low-flows provide good access to most habitats. Young-of-the-year of flow dependent cyprinids, *O.zambezense, B.marequensis* and *L.molybdinus*, increase, especially if higher flow events have occurred. Some flow dependent and marginal to flow species (eg. *B.viviparus*) spawn to a limited degree. *Barbus radiatus* and *Barbus annectens* that prefer quiet pools with cover do well. Cichlids continue breeding if placid flows persist. *C.anoterus* survives normal summer low-flows, although *C.paratus* and *C.swierstrai* are more suited to warmer low-flow conditions. |
| Freshets to floods (>20 $m^3s^{-1}$) | ▾ **Lotic Fish:** Good survival potential. Species maintain condition although not in breeding condition. No breeding unless very close to the onset of the summer season.<br>▾ **Lentic Fish:** Increased mortalities as disrupted early summer breeding and the flushing of young fish from runs. Fishes surviving in backwaters in good condition. If the waters are warm prior to the floods, breeding is disrupted.<br>▾ **Migratory Fish:** No migration of fish is expected in winter. If flood flows occurred during the summer dry season months, early fish movements are expected.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Reduction due to scouring of channel habitats.<br>**Cyprinids:** Remain relatively abundant due to reduced dry season mortalities.<br>**Silurids:** No change.<br>▾ **Macroinvertebrates:** Full range of dry season species but some mortality due to scouring.<br>▾ **Indicators:** The early summer dry season breeding success of cichlids is disrupted by aseasonal flood flow, scouring reaches of breeding nests and young fish. Both *T.rendalli* and *O.mossambicus* affected. Early rains reset the system, bringing cyprinids into early condition which result in early spawning (October-November). The effects of aseasonal flood flows on the natural functioning of the Sabie River lowveld are not known. Dry season floods together with elevated base flows reduce the mortalities of small shallow waters species that require cover (*B.marequensis* and *B.viviparus*). They achieve very high abundances if followed by a good wet season. *C.anoterus* could resist dry season reduction of its winter LZ range. | ▾ **Lotic Fish:** Excellent survival potential. All lotic species in good condition, with all species in breeding condition and breeding. Some flood dependent spawners spawn massively.<br>▾ **Lentic Fish:** Reduced survival potential in flowing reaches. Those that find refuge from flow remain in good condition. Breeding is disrupted.<br>▾ **Migratory Fish:** Potamadromous or migratory fish move extensively within the catchment while the catadromous species migrate from fresh to salt water to breed (Table 3.10). Migrations serve both to recolonize (juveniles and adults) and to provide suitable spawning and nursery sites (adults).<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Decrease.<br>**Cyprinids:** Increase dramatically.<br>**Silurids:** Increase.<br>▾ **Macroinvertebrates:** Full range of flow related species but some mortality due to scouring.<br>▾ **Indicators:** Cichlid breeding is disrupted. Breeding sites scoured and surviving young-of-the-year move into backwaters. Most seasonal lotic species are cued to spawn. Repetitive or high flood flows result in great increases in the larger flood spawning fishes. Labeos (*Labeo rosae, Labeo congoro, L.molybdinus* and *Labeo ruddi*), the yellow fish *B.marequensis* and the larger silurids *C.gariepinus* and *Schilbe intermedius* all spawn freely, as do the characoids *Hydrocynus vittatus* and *Brycinus imberi*. Young-of-the-year of the minnow *Barbus afrohamiltoni* and *L.rosae* may increase to form significant proportions of the fish assemblage. *C.anoterus* extends down into the cooler and strong flowing LZ waters matching the abundance of *C.paratus* at LZ rocky rapids. *C.swierstrai* is common in runs with sand in transit. |

░ = Flow conditions most typical for the Sabie River Lowveld under present developmental conditions.

the wet and dry seasons. We envisage that these tables will be useful to scientists, conservationists, and managers in assessing the effects of modified flows as a result of impoundment and increased water abstraction. We have therefore included the effects of a range of flows which have not normally occurred in the Sabie, and of standing water only, which has never yet occurred, but may do in the future.

## 3.4.2 CHARACTERISTIC FLOWS IN THE SABIE RIVER LOWVELD

Simulated discharges as well as actual mean monthly flows recorded during the course of this study are presented in Figure 4.4a (chapter 4; Vol 1). Flow in the Sabie River fluctuates seasonally but remains perennial in its lowveld section.

The first rains are expected in November whereafter mean monthly discharge increases rapidly to a peak in February. Dry season base-flows are re-established by May, some six months later. Wet season mean monthly flows can be misleading as they are skewed by frequent high flow events.

Tables 3.5-3.7 are structured on the following characteristic flows: Typical **summer low-flows** (6-20 $m^3s^{-1}$), are interspersed by flow peaks called **summer freshets** or **floods** (>20 $m^3s^{-1}$). Single events last several days before base-flow is restored. **Persistent summer low-flows** (3-6 $m^3s^{-1}$) are natural but confined to times of drought. The **summer drought flows** (1-3 $m^3s^{-1}$) of 1992-93 reduced the lowveld Sabie to its lowest recorded level. **Extreme drought flows** (0-1 $m^3s^{-1}$) and **no flow** (0 $m^3s^{-1}$) have yet to be recorded in the Sabie, but do occur in the Sand River. Typical **winter low-flows** (3-6 $m^3s^{-1}$) are normally uninterrupted by higher flows for some months. Winter **freshets** (6-20 $m^3s^{-1}$) do occur in the dry season but **winter floods** (>20 $m^3s^{-1}$) are not natural to the system. Sporadic **winter drought flows** (1-3 $m^3s^{-1}$) are characteristic during very dry winters, while **extreme winter drought flows** (0-1 $m^3s^{-1}$) were only recorded during the 1992-93 drought. **No flow** has never been recorded even during the winter dry season.

### *3.4.2.1 FLOWS AND HABITAT*

The habitat available in the Sabie River lowveld at different discharges is intimately related to the structure of the river, details of which are given in chapter 3 (Vol 1). The lowveld section of the Sabie River is moderately large (5th order) and of gentle gradient (1.7-3.3 $m.km^{-1}$). From edge to edge, the water surface covers approximately 30 m within a single channel, but braided sections do occur. Most reaches are sandy run-pool sequences with limited coarse substrate. Riffle areas are progressively scarce further downstream. Occasional control points of bedrock and boulders occur where geological dykes cut across the channel. The riparian strip spans about 100-400 meters flanked by tall riparian trees and extensive reed-beds (Fig. 3.4; Vol 1). During freshets and especially floods water levels reach the reed-beds and the riparian strip.

Table 3.5 lists the effects of different flows on the availability of habitat:

* **Water depth:** During normal years, low-flow in winter results in shallow runs (±1 m) with only pools offering deep habitats. Summer low-flows in contrast are ±50 cm deeper. Summer floods can temporarily raise the water level some meters, but a rise of some 80 cm would constitute a freshet in the dry season. During drought flows (1-3 $m^3s^{-1}$), water levels are reduced by some 30 cm from normal dry season low-flows. Should the river ever stop flowing, runs would gradually reduce in depth until only pools remain. Initially, many shallow pools would result, and the survival of these pools would depend on the duration of the drought.

* **Flow velocity:** Flow velocities in the lowveld river are governed by its moderate gradient, as well as the water depth and width of the channel. During normal low-flows, scarce riffle areas are the only areas of higher velocity. At the height of winter low-flow and in drought conditions, flows in runs become sluggish, resulting in algal mat development and very little sediment transport. Freshets increase the rate of transport, and wet season freshets and floods can increase flows in general to high levels effectively scouring the channel,

sorting and transporting sediments. In early summer, these increased flows are important in resetting the water quality and habitats in the river.

* **Cover:** Marginal vegetation has an important role in providing cover to the biota. The lowest limits colonised by terrestrial plants is largely governed by the water level of summer low-flows (6-10 $m^3s^{-1}$). During winter low-flow (3-6 $m^3s^{-1}$) little marginal vegetation cover is available for the fauna. Coarse substrates too provide excellent cover. This type of cover is more important towards west where loose-substrate riffles occur. Similar reduced flows in summer have marked effects on spawning sites and the survival of young-of-the-year of most seasonal breeding fishes. At very low flows turbidity is very low and only deep pools provide cover. Isolated pools can become turbid due to concentrated fish activity, or by algal blooms.

### *3.4.2.2 FLOWS AND PHYSICO-CHEMISTRY*

Like the physico-chemistry of the catchment in general (chapter 5: Vol 1), the water quality of the lowveld Sabie River is good. The effects of different flows are tabled in Table 3.6. In normal years, the waters are neutral (pH 7-8.2), with moderate dissolved solids (0.001-0.228 g/l) and well oxygenated (>90%). Turbidities vary according to the season with low low-flow turbidities (2-7 NTUs) and higher turbidities recorded after rain (up to 470 NTUs). Events during the normal dry season are particularly turbid.

Under extreme drought (0-1 $m^3s^{-1}$), waters tend to become warmer, less oxygenated and slightly eutrophic. Temperature increases are particularly high (up to 35°C) in the hotter summer months with drought flows. If flow stops, the potential for water quality changes over time are very great. No flow during the hotter summer season results in increased evaporation and therefor more rapid deterioration of the water quality. Extremes in salinity (1600 µS/cm), pH (9-10), oxygen (<15% saturation), temperature (up to 40°C), as well as increased nutrient levels are expected (Table 3.6).

### 3.4.2.3 *FLOW AND THE ICHTHYOFAUNA*

Of the 49 species of fish found in the Sabie-Sand catchment (see chapter 7; Vol 1), populations of 36 species are resident in the lowveld reaches of the Sabie River, and define the Lowveld Zone. Differences in flow effects microhabitat available, breeding potential, and movement of the biota (Table 3.7).

* **Flow microhabitat needs:** Flow microhabitat requirements of both juveniles and

**Table 3.8:** Flow micro-habitat needs of the lowveld target species.

| Taxonomic Group | Species | Flow Microhabitat | | | | | |
|---|---|---|---|---|---|---|---|
| | | out of flow | | next to flow | | in flow | |
| | | J | A | J | A | J | A |
| Characins | *Micralestes acutidens* | | | * | | | * |
| Cichlids | *Oreochromis mossambicus* | * | * | | | | |
| | *Pseudocrenilabrus philander* | * | * | | | | |
| | *Serranochromis meridianus* | * | * | | | | |
| | *Tilapia rendalli* | * | * | | | | |
| Cyprinids | *Barbus annectens* | * | * | | | | |
| | *Barbus marequensis* | | | | * | * | |
| | *Barbus radiatus* | * | * | | | | |
| | *Barbus trimaculatus* | | | * | * | | |
| | *Barbus unitaeniatus* | | | * | * | | |
| | *Barbus viviparus* | | | * | * | | |
| | *Labeo molybdinus* | | | | | * | * |
| | *Opsaridium zambezense* | | | | | * | * |
| Silurids | *Chiloglanis anoterus* | | | | | * | * |

adults for target species are summarized in Table 3.8. Target species were either abundant (accounting for 6% of the catch on any field trip), or of special interest (*Serranochromis meridianus* is endemic). All the cichlids and two deep pool minnows preferred quiet waters away from flow while a suite of minnows enjoyed quiet waters close to flowing water. Five species required faster current at either juvenile or adult stages.

* **Flow requirement for breeding:** All the lowveld species are seasonal breeders coming into condition in the warmer summer months, with the possible exception of *C. anoterus*. Species can be divided into lotic or lentic breeders depending on whether flowing

**Table 3.9:** Flow requirements of lowveld target species for seasonal breeding.

| Taxonomic Group | Species | Lentic Breeders | Lotic Breeders | |
|---|---|---|---|---|
| | | out of current | | in current |
| Characins | *Micralestes acutidens* | | | * |
| Cichlids | *Oreochromis mossambicus* | * | | |
| | *Pseudocrenilabrus philander* | * | | |
| | *Serranochromis meridianus* | * | | |
| | *Tilapia rendalli* | * | | |
| Cyprinids | *Barbus annectens* | | * | |
| | *Barbus marequensis* | | | * |
| | *Barbus radiatus* | | * | |
| | *Barbus trimaculatus* | | * | |
| | *Barbus unitaeniatus* | | * | |
| | *Barbus viviparus* | | * | |
| | *Labeo molybdinus* | | | * |
| | *Opsaridium zambezense* | | | * |
| Silurids | *Chiloglanis anoterus* | | | * |

water is required for successful breeding (Table 3.9). Of the target species, only the cichlids breed independent of flow. Many of the minnow species do breed in quiet waters but only after a flow event following physico-chemical cues or access to flooded marginal vegetation. While some species are able to attain breeding condition during extreme drought and breed during the first rain event (*C. gariepinus* and *L. molybdinus*), the first freshet/flood of the summer season is needed to restore the water quality and make habitat available for the majority of seasonal species. Seasonal spawning minnows attain breeding condition within the first month following rains. Extensive spawning can be expected with each subsequent flow event.

* **Movement:** Flow, particularly summer flow events are important for fish movements. Table 3.10 categorises movements for all LZ species. Most lowveld species have been shown to move at some stage during their lifespan. These movements are important in breeding (two catadromous & 24 potamadromous species) and dispersal (juveniles of 7 potamadromous species). Labeos are particularly geared to seasonal flow-induced migrations. Species that show both juvenile and adult migrations are often the first fish to recolonise defaunated reaches following droughts.

* **Seasonal discharge and patterns in fish abundance:** During normal rain year, the LZ assemblage shows very distinct seasonal shifts in abundance in the two most abundant taxa (Fig. 2.12). Lentic breeding cichlids successfully breed as waters warm but prior to and irrespective of the first summer rains. They dominate the lowveld assemblage by the end of the dry season (October-November). The high flows of the wet season disrupt the breeding of the cichlids while allowing the cyprinids and other seasonal species to breed successfully. By the end of the wet season, cyprinids normally re-dominate the lowveld assemblage.

Summer drought effectively locks the lowveld assemblage into the pattern typical of the late dry season, where cichlids dominate. Summer drought is followed by an extreme dry season which further reduces most fish numbers. Predation is much higher for some shallow water/marginal vegetation species while mortalities are higher for many lotic species due to

**Table 3.9:** Flow requirements of lowveld target species for seasonal breeding.

| Taxonomic Group | Species | Movement Type | | | | |
|---|---|---|---|---|---|---|
| | | Non-migratory | Potamodromous | | Catadromous | |
| | | J & A | Juveniles | Adults | Juveniles | Adults |
| Anguillids | *Anguilla mossambicus* | | | | * | * |
| | *Anguilla bengalensis* | | | | * | * |
| Characins | *Brycinus imberi* | | | * | | |
| | *Hydrocynus vittatus* | | * | * | | |
| | *Micralestes acutidens* | | | * | | |
| Cichlids | *Oreochromis mossambicus* | | * | * | | |
| | *Pseudocrenilabrus philander* | * | | | | |
| | *Serranochromis meridianus* | * | | | | |
| | *Tilapia rendalli* | | * | | | |
| Cyprinids | *Barbus afrohamiltoni* | * | | | | |
| | *Barbus annectens* | * | | | | |
| | *Barbus eutaenia* | | | * | | |
| | *Barbus marequensis* | | | * | | |
| | *Barbus paludinosus* | | | * | | |
| | *Barbus radiatus* | * | | | | |
| | *Barbus toppini* | | | * | | |
| | *Barbus trimaculatus* | | | * | | |
| | *Barbus unitaeniatus* | | | * | | |
| | *Barbus viviparus* | | | * | | |
| | *Labeo congoro* | | | * | | |
| | *Labeo cylindricus* | | * | * | | |
| | *Labeo molybdinus* | | * | * | | |
| | *Labeo rosae* | | * | * | | |
| | *Labeo ruddi* | | | * | | |
| | *Mesobola brevianalis* | * | | | | |
| | *Opsaridium zambezense* | | | *1 | | |
| Gobies | *Glossogobius callidus* | | | *2 | | |
| | *Glossogobius giuris* | * | | | | |
| Mormyrids | *Marcusenius macrolepidotus* | | | * | | |
| | *Petrocephalus catostoma* | | | * | | |
| Silurids | *Chiloglanis anoterus* | * | | | | |
| | *Chiloglanis paratus* | | | * | | |
| | *Chiloglanis swierstrai* | | | *3 | | |
| | *Clarias gariepinus* | | * | * | | |
| | *Schilbe intermedius* | * | | | | |
| | *Synodontis zambezensis* | | | *3 | | |

The movements catergories are modified from Deacon (1995) excepting; 1 = Bok and Cambray (1995), 2 = Skelton, 1994 & 3 = Weeks, this report).

stress and disease. Besides a few notable exceptions discussed, lowveld species are resilient to drought which refelcts a pre-adaptation to drought. This must be explained by their region of origin. Never-the-less under no-flow conditions, duration of isolation is important due to deteriorating refuge conditions where even the cichlids are affected. *T.rendalli* eventually declines, while *O.mossambicus* classically dominates under extreme drought conditions, but is stunted in size.

With unusually wet years, cyprinid dominance is still expected, but the species makeup will reflect higher flows with the relative increase of some species, such as the Labeo, *L. rosae* and the minnow *B. afrohamiltoni*.

# 4. FUTURE MONITORING REQUIREMENTS

## 4.1 OBJECTIVES OF A MONITORING PROGRAMME FOR THE SABIE-SAND RIVER SYSTEM

It is impossible to manage any system effectively without the necessary information, and therefore an effective monitoring programme is the cornerstone of any management plan for the Sabie-Sand rivers. The monitoring programme must ensure that the right kinds of information are collected, in enough of the right places, at the right frequency, and are then analyzed and presented in a manner that will initially help managers to take informed decisions, and subsequently allow them to evaluate the consequences of those decisions objectively.

Four kinds of cost considerations dictate how comprehensively the above aims can be achieved: the money available to get the necessary monitoring equipment, to set it up and maintain it; the manpower to visit the sites and take the measurements/samples; the available expertise to design the system, operate the equipment, and analyze and present the results; and the environmental costs associated with equipment and structures in the field or destructive sampling of biota.

To be useful, a monitoring system has to operate efficiently for the long term, so that the funding, manpower and expertise must be assured, and any monitoring equipment must be durable or easily replaceable. Durability and environmental costs are particularly important considerations in the KNP, where natural vandals ranging from elephants to baboons abound, and where unsightly structures or barriers in the rivers are especially undesirable. For example, a continuous flow-gauging weir is expensive to set up, and is an unsightly and environmentally costly barrier, but is durable, with low maintenance costs, requires little manpower to operate, but some specialist input to analyze and present. Water chemistry samples, unless automatically collected, entail few environmental or capital costs (if an analytical laboratory is available), but require frequent collecting trips, and are expensive to analyze, requiring considerable specialist input.

The obvious agency to carry out monitoring of the Sabie-Sand rivers within the KNP is the National Parks Board, since they have jurisdiction, permanent personnel with much of the required expertise, and much of the required equipment. It must be acknowledged that their resources are already stretched, and that some of the specialist expertise (eg water chemistry, hydrology, aquatic invertebrates) would need to be imported, so that any additional monitoring activities would have to be carefully designed for minimum extra work and cost. Outside the Park the responsibilities are more diffuse, but the Mpumalanga Department of Nature Conservation may be the most appropriate organisation to oversee the monitoring programme. The DWAF at present operates the hydrological gauging weirs and collects and analyses water samples for chemical analysis, within the framework of a national monitoring programme. There would be no need to change this arrangement since the DWAF is well equipped and makes the data freely available to any interested party.

Since this report deals only with some of the environmental components of the Sabie-Sand rivers, the proposed monitoring system will also be confined to those aspects of the rivers, and the processes which help to maintain them. The purpose of the monitoring system would therefore be to provide information on the status of the biota of the rivers, and on the status of the physical and chemical processes that affect the biota. Aspects of the rivers such as the riparian vegetation, the large animals associated with the rivers, groundwater relationships, and human use of the rivers are being addressed by separate projects, and will not be discussed here in detail, although their importance is stressed. Specifically, the objectives of the monitoring programme would be as follows:

- To measure the relative density and diversity of the fish and invertebrate communities of the rivers, so as to document changes at different spatial and temporal scales. So that, for example, there would be baseline data before, during, and after on the abundance of different fish species in a drought, and also so that long-term trends in changing fish communities can be recognised.
- To document the size and shape of the river channels and the variety of habitats within them, so that long term changes in channel morphology and the availability of suitable habitat in response to changing flow patterns can be quantified.
- To measure the changes in important physico-chemical attributes of the rivers, so as to recognise seasonal and long term changes in the water quality of the rivers.
- To gauge the flow of the rivers so that the natural patterns of seasonal, drought/flood, and wet/dry sequences can be recognised, and the effects of impoundment and increased abstraction can be followed.

The level of detail of the proposed monitoring activities should be governed by the necessity for an early warning system, rather than for a comprehensive explanation of processes in the river. Monitoring activities should provide a "red flag" to signal undesirable changes in the river, without necessarily identifying the cause of the problem. Once a problem is identified, more detailed studies will be required to examine the causes and scope of the problem.

## 4.2 PRESENT MONITORING ACTIVITIES

The present long term monitoring activities on the Sabie-Sand can be summarised as follows:

- Continuous flow gauging at 12 gauging weirs, with record lengths varying from 47 to 5 years. The gauges are distributed from the upper reaches to the Mozambique border, with 10 outside the KNP and 2 inside. Four of the gauges are on the Main Sabie, one is on the Sand and 7 are on other tributaries.

- At these gauging weirs and 3 other sites within the KNP, water samples are collected on average every 2 to 3 weeks, and are analyzed for a suite of major ions, salinity, phosphates, nitrates + nitrites, and ammonium. These samples have been collected since the mid-1960's at some sites, but only since 1983 at others. More recently, metal concentrations in the sediments have also been measured every 6 months at the sites within the Park.
- Irregular fish surveys have been carried out on all parts of the Sabie-Sand since 1963 (Gaigher, 1969). The surveys within the KNP are now more regular, but information on fish distributions upstream of the Park is still sporadic.
- Benthic invertebrates have similarly been sampled sporadically since the early 1960's, but at present there is no regular programme to update previous surveys.
- Aerial photography coverage of the Sabie-Sand catchment has been updated every 10 years since 1940, at a scale of 1:30 000 - 1: 75 000. False colour infra-red photographic surveys have been flown annually since 1981 over selected sections of the river within the KNP.
- Fixed point photography sites on the Sabie and Sand Rivers within the KNP have been recorded in since 1985, but there are no sites on the rivers outside the Park.

## 4.3 ADDITIONAL MONITORING REQUIREMENTS

Within the KNP, the Sabie and Sand Rivers are being adequately monitored with respect to hydrology, water chemistry, and fish communities. Some aspects of water quality, particularly water temperature and suspended sediments, have only recently begun to be monitored. Building up a long-term database on water temperatures is extremely important, since temperature is a key determinant of biotic performance. The Sabie River has been described as a cold finger of water flowing into the Kruger Park, (due to its high gradient from the escarpment to the lowveld), and any impoundment on the mainstream will fundamentally alter the temperature regime (see section 2.3.2). The collection of data on sediment transport is fundamental to an understanding of the erosion and deposition processes which govern the dynamics of channel formation, and these will also change fundamentally if a dam is built on the mainstream. Sediment transport information during floods is particularly valuable.

Outside the Park, little or no information on temperatures and sediments has been collected, and in addition, there are at present no established sites for fixed point photography, apart from those which have been photographed quarterly at 9 sites established during this project. Fixed point photography, apart from monitoring the changes in vegetation and channel form over time, also builds up an invaluable library of flows at different stages. If this can be linked to discharge measurements at a nearby gauge, such photographs provide a visual document of the effects of different flows in the river, which is often more valuable than more rigorous information. Fixed point photography is an ideal example of a monitoring method which is cost-effective in every way, being cheap, requiring little skill to operate or to interpret, and causing no environmental effects. Fixed point photographs were taken during this study at all quarterly monitoring sites throughout the study period, including many sites outside of the KNP. Examples of which can be seen in Appendix I.

## 4.4 CONCLUSIONS AND RECOMMENDATIONS

For a comprehensive monitoring exercise, which would provide information on the major environmental aspects of the rivers and riparian zones, the following metrics, samples and records need to be collected:

Hydrology
Water chemistry
Geomorphology
Ecological or habitat integrity
Riparian vegetation
Social use of the river

Fish

Invertebrates

These do not include aspects such as catchment land-use, health-related microbiological sampling, or the use of water for domestic, farming or industrial purposes. These are all beyond the scope of this report. The social use of the river is also beyond the scope of this project, but a monitoring exercise would aim to evaluate the direct use of the river by people, and their requirements for the state of the river, the riparian zone, and its resources. Any environmental monitoring programme should be centred around the natural resource needs of the population in the catchment, and the social use is therefore an essential prerequisite for further planning.

Of the list above, only hydrology and water chemistry are adequately measured throughout the catchment for environmental purposes. Within the Kruger Park, fish are regularly sampled, and fixed point photographs provide some idea of habitat and channel changes over time. Depending on the resources available, some or all of the following activities should be undertaken throughout the catchment, to ensure an adequate database from which to assess long-term changes in the rivers, and to act as warning systems should particular problems arise:

- Regular invertebrate sampling, using the SASS4 rapid biomonitoring system. At least once per year, and preferably twice a year in the wet and dry seasons.
- Resurveys of existing rated transects to check on channel changes, approximately every 10 years.
- Initial surveys to measure the ecological integrity of the rivers, using the methods of Kleynhans (in press), followed by resurveys every 10 years.
- Transect surveys through the riparian vegetation, to check on species changes over time, regeneration, and mortality amongst mature trees. (Details to be provided by the researchers at the Centre for Water in the Environment, Wits University).

In addition, the following activities should be extended from the Park to be carried out throughout the catchment:

- Regularly fish sampling, at least once a year, using the Index of Biotic Integrity approach presently being developed by Dr Andrew Deacon of the National Parks Board. Samples should be collected at the same time each year, to allow for seasonal changes in fish communities (described in Volume 1 of this report). A May survey would best reflect the success of the preceding wet season prior to dry season reductions, while the rivers are easily fishable.
- Regular fixed point photographs, once a year at the same time of year (preferably in winter during low-flow conditions).

The more sites that can be regularly monitored, the more accurate will be the picture of changes in the rivers, and the more likely it will be that problems will be identified at an early stage. However, a realistic minimum number of sites that would provide information on the different parts of the system (inside and outside the Kruger Park, would be eight, at the following locations (Site numbers are those used during this project, and are referenced in Volume 1):

- Upper Sabie, site 3, downstream of Sabie town.
- Sabie River at Mkhuhlu, site 6.
- Sabie River below the confluence of the Sand, site 9.
- Sabie River at Mlondozi, near the Mozambique border, site 20.
- Upper Sand River at Rooiboklaagte, site 11.
- Sand River at Londolozi, site 14.
- Mutlumuvi River at New Forest, site 19.
- Marite River downstream of the proposed Inyaka dam, site 21.

Before any decisions are taken to finalise a monitoring design, it would be useful to take account of two new initiatives that are being planned at present:

- The national biomonitoring programme: This is an initiative of DWAF, and a site selection and sampling protocol is being planned. The Sabie River is being considered as a pilot test catchment for the programme. The recommended sampling procedure will include the use of SASS4, IBI, an index of riparian vegetation, and a habitat diversity assessment. Any monitoring programme for the Sabie River should obviously be compatible with the planned national biomonitoring programme.

- A research project to link biotic responses to abiotic factors in the Sabie River: This is an initiative of the Kruger National Park Rivers Research Programme, and will be undertaken during 1996. A major aim of the project will be to develop a model to predict the effects of changing flow regimes on the geomorphology, and therefore habitat diversity, and therefore fish communities of the Sabie. A fish sampling programme designed to verify the predictions of the resulting model would considerably improve the accuracy of predictions, and therefore any fish monitoring programme should take account of the data requirements of the model.

# 5. CONCLUSIONS AND MANAGEMENT OPTIONS TO MAINTAIN THE CONDITION AND ASSEMBLAGES OF THE SABIE-SAND SYSTEM

## 5.1 INTRODUCTION AND SCOPE

This project concentrated on the instream fauna and water quality of the Sabie-Sand rivers, and the conclusions and recommendations in this section are therefore largely confined to these aspects of the river. The findings of the project are related to the effects of planned impoundments on the rivers, and to the consequences of reduced flows. The solutions to the problem of maintaining the ecological integrity of the Sabie-Sand system lie largely outside the river itself: they revolve around the management of the catchment as a whole. Land-use patterns, increasing population, increasing irrigation, and associated sources of pollution are at the root of the problems in the rivers, and managing the rivers themselves is akin to treating the symptoms rather than the causes.

Recommendations for the management of the catchments, while essential for the maintenance of the rivers, are beyond the scope of this report, and are only mentioned in passing. This section draws conclusions about the effects of impoundment (both positive and negative) and the consequences of long-term flow reductions on the instream fauna and water quality of the rivers. Even these conclusions will need to be examined in the light of geomorphological changes (erosion and sediment deposition) resulting from changes in the flow regime. Such changes will inevitably effect the availability of different habitats which, together with local hydraulic conditions and water quality, govern the distribution and abundance of the biota in the river.

The final two sections suggest some general and specific management policies and aims which will help to mitigate the effects of impoundments and flow reduction, and further work which will improve our ability to predict future changes in the biota as a result of these changes.

## 5.2 THE SABIE RIVER

The results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the River, and that the riverine fauna of the Sabie still appears to be as diverse as ever. Some of the larger species, such as the tiger fish and *Labeo rubropunctatus*, may be present in only low numbers, and this is a result of the lack of extensive deep habitat in the river. This survey was conducted mainly during times of very low flow, and may therefore have given a biased picture in this regard. For similar reasons, the floodplain spawners, such as *Labeo rosae*, are also scarce in the system, since they rely on over-bankfull flows to provide breeding habitat. The assemblages had yet to recover from the drought when sampling stopped in May 1993, so it is difficult to say how long full recovery may take. It is certain that, if low-flow conditions become the norm, the assemblages in the Sabie will change considerably.

Water quality in the Sabie is still excellent, and in some aspects is considerably better than the drinking water supplied in much of South Africa. It is important to remember that we are not dealing with an original state of the river, since mine dump pollution virtually wiped out the natural fauna in the middle reaches earlier in the century. The recovery of the fauna has been remarkable, and has only been possible because of the presence of refuge tributaries in the system. One cannot help wondering if the same level of recolonisation would be possible if similar pollution were to reach the Sabie now. There are still species (such as *Barbus brevipinnis, Barbus argenteus, Amphilius natalensis* and *Amphilius uranoscopus*) which are missing from the reaches between Sabie town and Hazeyview. This is a result of the historic mining pollution, and the presence of cascades and waterfalls which prevent these weak swimmers from recolonising these reaches.

# 5.3 THE SAND RIVER

The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the assemblages are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation. The drought, the construction and subsequent collapse of the Zoeknog Dam on the Mutlumuvi, and the diversion of the upper Sand by the Champagne Castle Citrus Estates during 1991, all combined to degrade conditions in these upper reaches. If such multiple events and conditions were to become more frequent, the survival of natural assemblages in the upper and middle portions of the Sand River would be put at risk.

# 5.4 THE EFFECTS OF DAMS

At present, with no significant impoundments on the Sabie-Sand system, the options for managing the flow regime for the environment are extremely limited. Normally, dams are seen as having a detrimental effect on the natural ecology of a river, but in the case of rivers that are already impacted, dams can provide opportunities for rehabilitation. In the case of the Sabie-Sand, low-flows in particular are seriously affected in the Park by upstream abstractions. Impoundments provide the chance to augment irrigation water, and to provide compensation flows to the Park.

Most of the proposed dams are probably too small and too remote from the Park to provide effective low-flow augmentation. However, the Madras Dam, on the Sabie mainstream and very close to the Park's western boundary, would have severe effects on the water quality, temperature and sediment transport within the Park, and is also large enough to intercept all but the largest floods. The option of choice, from an environmental point of view, would be the Inyaka Dam in the Marite tributary. This would have consequences for the Marite, but is far enough from the Park for conditions downstream in the Sabie to recover. It is large enough to provide compensation flows to the Park, and would not intercept high flows, since the site is in a tributary of the system. Compensation flows should be linked to the dam inflows, as suggested by O'Keeffe and Davies (1991). The conclusions of O'Keeffe and Davies (1991) should be seen as part of an ongoing assessment of the flow requirements for the rivers. There is an IFR workshop planned for the Sabie River in 1996, and further work emerging from the Kruger National Park Rivers Research Programme will also increase the resolution and confidence of these estimates.

The confluence of the Marite and the main Sabie River is about 20 km downstream of the Inyaka dam site. Changes to the hydraulic habitats, water temperature and water chemistry will be severe throughout this stretch of the tributary, unless great care is taken to provide adequate base-flows, and periodic floods through the dam.

Existing and proposed impoundments on the Sand River are all remote from the Kruger Park and associated private reserves, but affect the important perennial upper tributaries of the Sand, which act as refugia during droughts. The construction phase of the Zoeknog Dam, during which flow downstream ceased, and large areas of catchment were cleared, caused considerable reduction in riverine fauna downstream, as did the subsequent collapse of the central section of the dam.

# 5.5 THE EFFECTS OF CONSISTENTLY REDUCED FLOWS

Whether dams are built or not, it seems most probable that the flows in all the rivers of the Sabie-Sand catchment will continue to be reduced as demand increases, particularly for domestic and irrigation supplies. This reduction will have the greatest impact on low-flows, and during droughts, when supplies are at their lowest and demand remains stable or increases. Irrigation pumping on the main Sabie River can already reduce the flow in the Kruger park to a trickle during the dry season. This section therefore summarises the effects of long-term reductions in flow on the instream fauna, and on water quality.

## 5.5.1 FISH ASSEMBLAGES

The effects of flow reductions on the fish assemblages of the Sabie-Sand have to be seen in the framework of the different zones of the rivers, and during the wet and dry seasons. In the Foothill Zone (FHZ), there are less seasonal effects, and the consequences of reduced or no-flow would be the reduction or disappearance of flow-sensitive species (such as *Chiloglanis anoterus*). Pool and marginal species will continue to survive and will dominate the fish assemblages. In the Lowveld Zone (LZ), where seasonal changes are marked, a permanent reduction in flow will result in the continued dominance of the dry season assemblage, dominated by cichlids, and the permanent reduction of cyprinids and other flow-dependent species. Lower flows in the dry winter season will result in stressed assemblages, no breeding and the disappearance of flow-dependent species, especially in rivers which cease to flow.

Generally, mean water temperatures will increase as flow is reduced, and there will be a shift of some of the more flow- and temperature- sensitive elements of the LZ assemblages further upstream. Depending on water releases from the Inyaka Dam, the Sabie River immediately below the Marite confluence could become a refuge for flow-dependent LZ species. This depends on the assumption that the main water abstractions for irrigation and domestic supply would be at and downstream of Mkhuhlu.

## 5.5.2 INVERTEBRATE COMMUNITIES

Many invertebrate species are extremely sensitive to flow conditions. During drought conditions in 1992 the average number of taxa was half that during the wetter conditions in 1990, and densities were reduced by an order of magnitude. Riffle species, which require flowing water between and over cobbles, are particularly vulnerable to reduced or no-flow, but species of the marginal habitats are also affected as the water's edge recedes from the vegetated river margins.

A permanent reduction in flow, with probable periods of no-flow during droughts, would result in the disappearance of many species, particularly mayflies, caddisflies, and simuliid flies. The resulting communities would resemble those typically found in temporary rivers, such as the middle reaches of the Sand River. The loss of biodiversity in these circumstances is not confined to invertebrate species, since they form a crucial part of the food base for other organisms, particularly fish and amphibians, and make significant contributions to the processing of organic matter.

The change from flowing water to static conditions will also provide opportunities for the increase of those species which favour stagnant water. These unfortunately include mosquitoes and Bilharzia host snails. The Sand River is already a centre for bilharzia transmission, but it is unlikely that the Sabie is at present.

## 5.5.3 WATER QUALITY

Water quality throughout the Sabie-Sand system is generally good, with the exception of some of the temporary reaches of the Sand and its tributaries in areas of high population density. Up to the present, reduced flows have not resulted in water quality deterioration beyond acceptable limits, except in isolated pools during drought conditions. Reduced flows will however result in less dilution of the effluents and irrigation return flows that reach the river. The Marite, in particular, has not historically suffered from the mining and urban developments that have affected the Sabie, and the building of Inyaka Dam will considerably reduce the high quality water which at present helps to dilute the additives to the Sabie River. Increased farming, and the introduction of more water borne sewerage will mean that the salt and nutrient concentrations in the Sabie-Sand will inevitably rise in the future. However, concentrations at present are remarkably low, and should not reach critical levels for many years. The presence of dams also provides the option of making releases to dilute effluents during critical periods.

The effects of the Inyaka dam on temperature, sediments and water quality in the Marite have already been mentioned. These effects are unlikely to extend into the main Sabie, but the Marite is perhaps the most important refuge for cold water species, because it has never been polluted, and it is inhabited by the only viable populations of *Barbus brevipinnis*, a regional endemic, and by populations of three restricted cold-water species, the minnow *Barbus argenteus*, and two catfish species - *Amphilius natalensis* and *Amphilius uranoscopus*.

## 5.5.4 PERENNIAL REFUGES

The Sabie-Sand has suffered extreme droughts and chemical pollution from mining during its history, and yet all the fish species which have ever been recorded are still present in the rivers. There is therefore a considerable resilience in the system, and this is a consequence of refuge areas in which populations can survive during critical periods, followed by recolonisation during favourable conditions. The maintenance of these refuge areas is therefore crucial to the continued ecological integrity of the system.

From the point of view of perennial flow, the most important remaining refuge reaches in the LZ are:

- The main Sabie River, which has always been perennial throughout its length.

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# APPENDIX

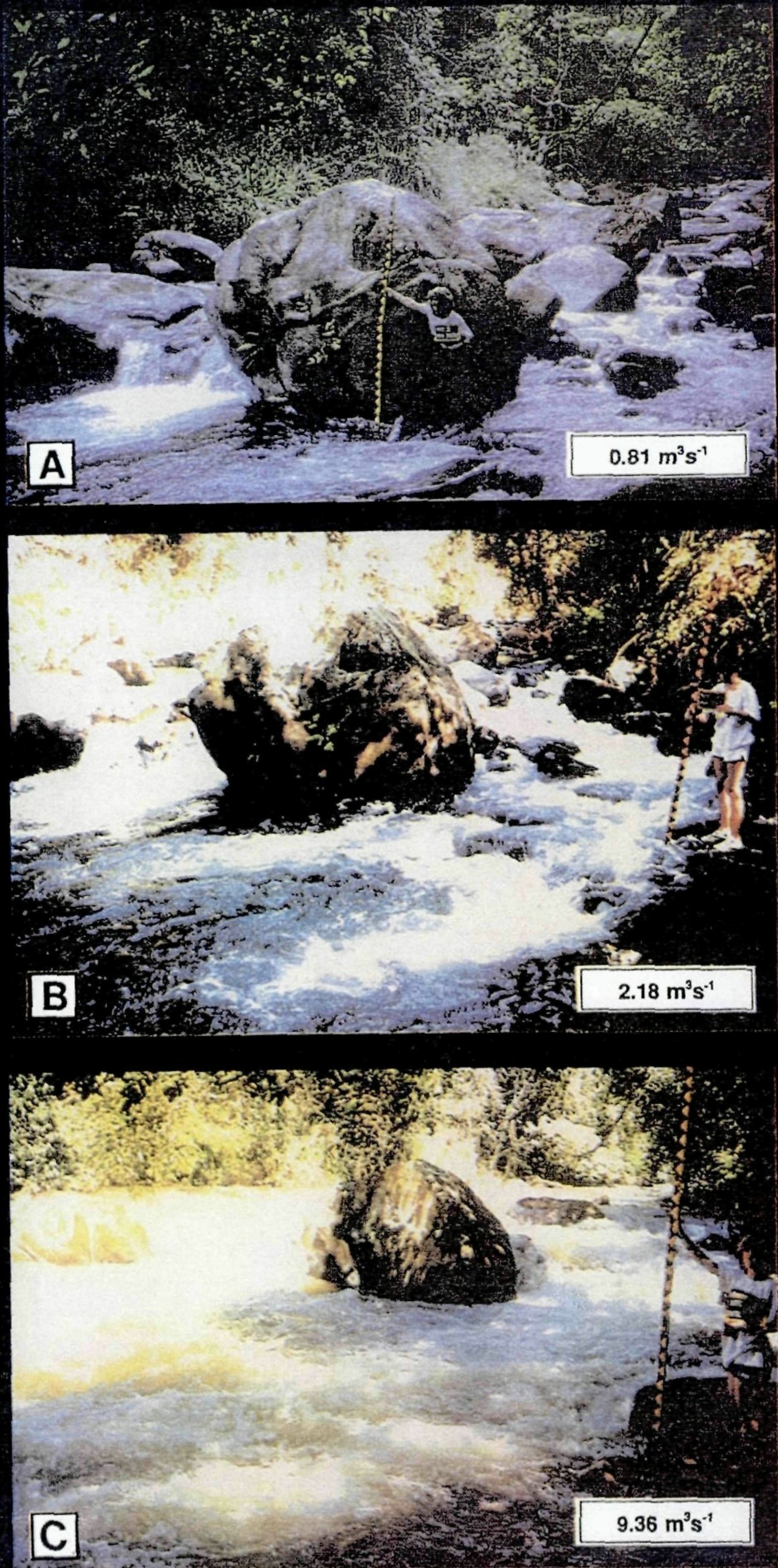


**Plate 1:** Station 3 (Rocky boulder) on the upper Sabie River at different discharges. A = $0.81\ m^3s^{-1}$, November 1990; B = $2.18\ m^3s^{-1}$, August 1991 & C = $9.36\ m^3s^{-1}$, February 1991.


**Plate 2:** Station 5 (Hazyview) on the upper Sabie River at different discharges. A = 0.91 $m^3s^{-1}$, August 1992; B = 1.82 $m^3s^{-1}$, February 1992; C = 3.57 $m^3s^{-1}$, May 1990 & D = 17.10 $m^3s^{-1}$, February 1991.

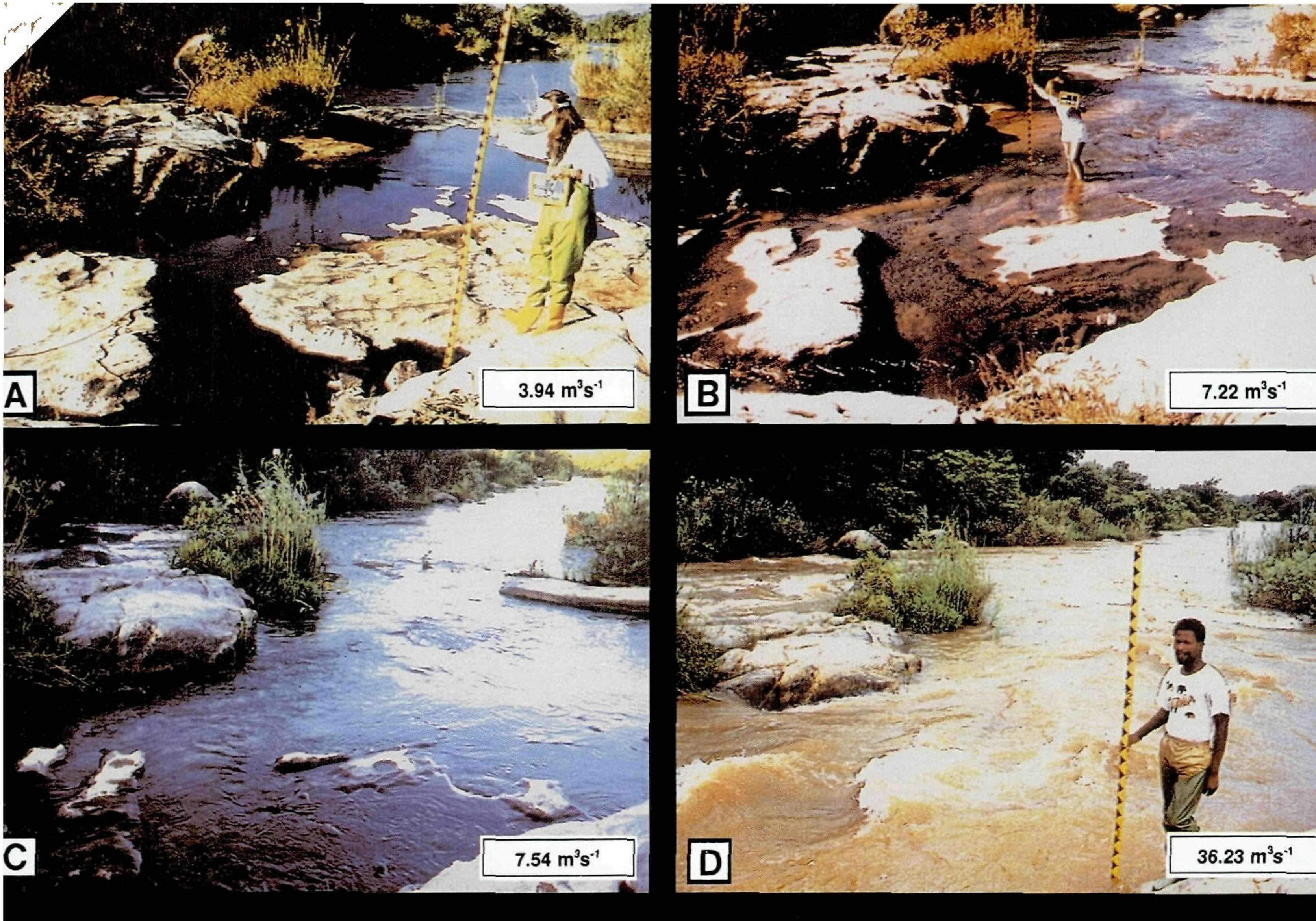


**Plate 3:** Station 7 (Three lions) on the mid-Sabie River at different discharges. A = 3.94 $m^3s^{-1}$, August 1990; B = 7.22 $m^3s^{-1}$ May 1990; C = 7.54 $m^3s^{-1}$, May 1991 & D = 36.23 $m^3s^{-1}$, February 1991.

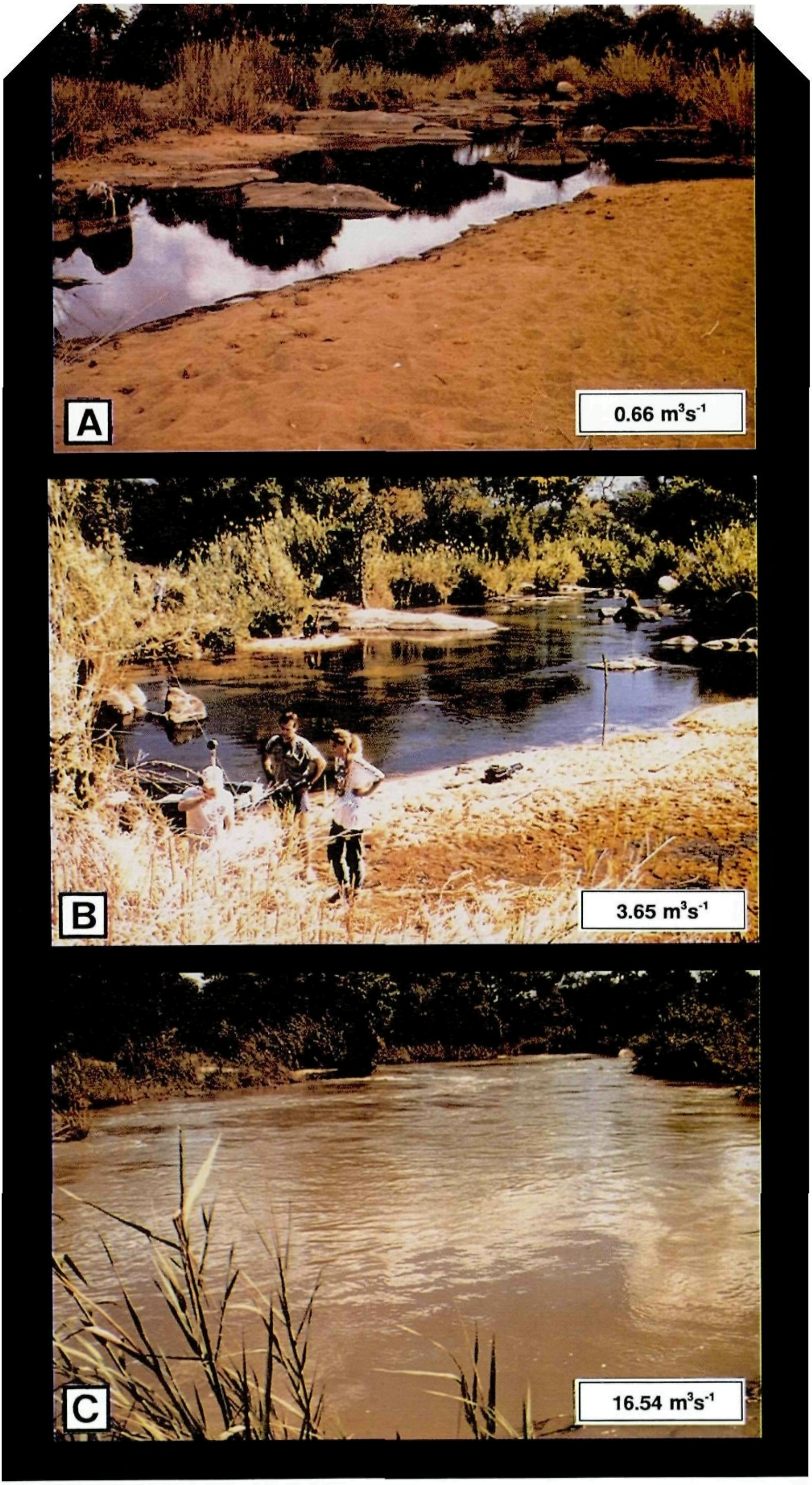


**Plate 4:** Station 9 (Confluence) on the lower Sabie River at different discharges. A = 0.66 $m^3s^{-1}$, September 1992; B = 3.65 $m^3s^{-1}$, July 1991 & C = 16.54 $m^3s^{-1}$, February 1993.

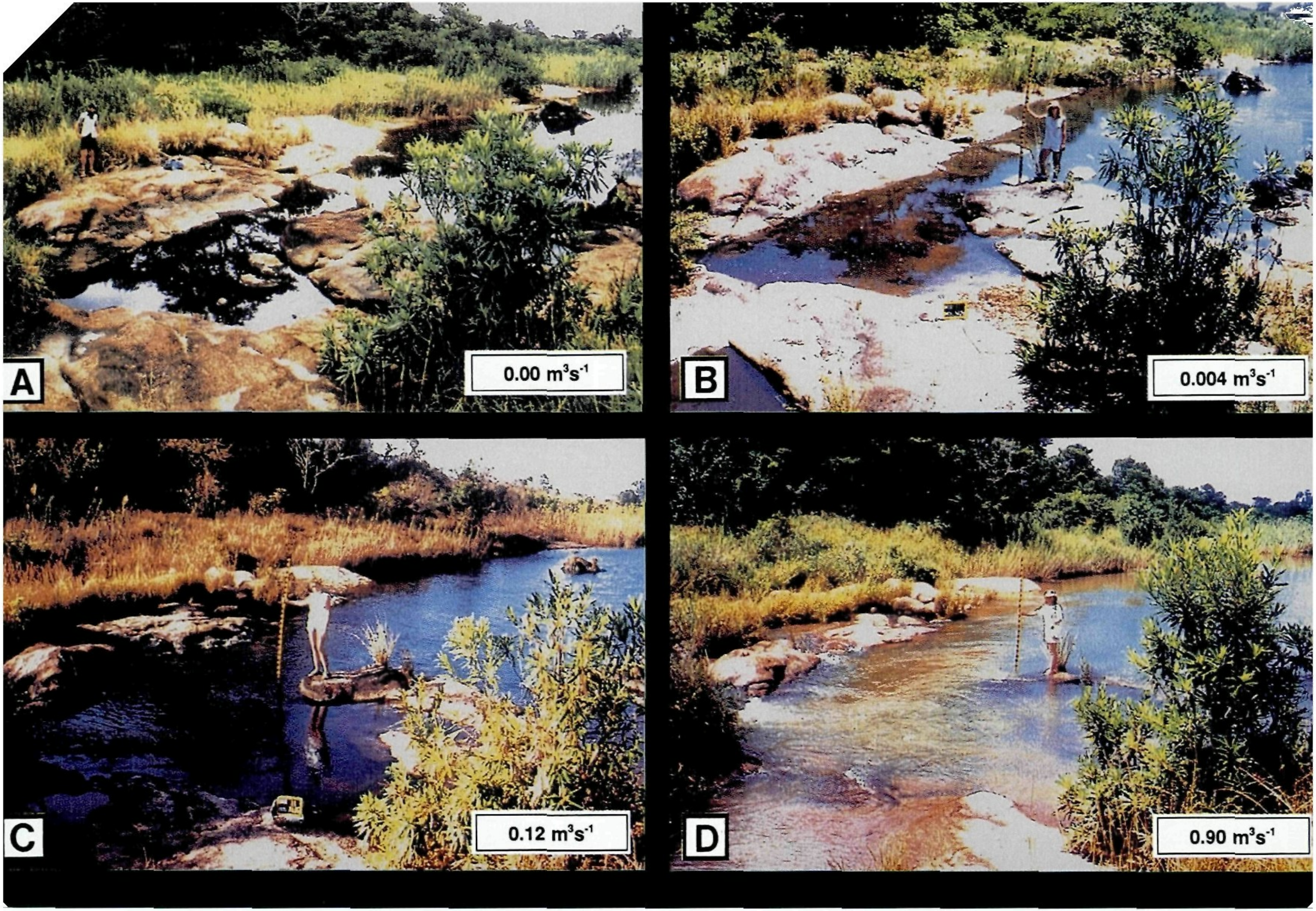


**Plate 5:** Station 11 (Rooiboklaagte) on the upper Sand River at different discharges. A = 0.00 $m^3s^{-1}$, February 1991; B = 0.004 $m^3s^{-1}$, November 1990; C = 0.12 $m^3s^{-1}$, August 1991 & D = 0.90 $m^3s^{-1}$, February 1991.

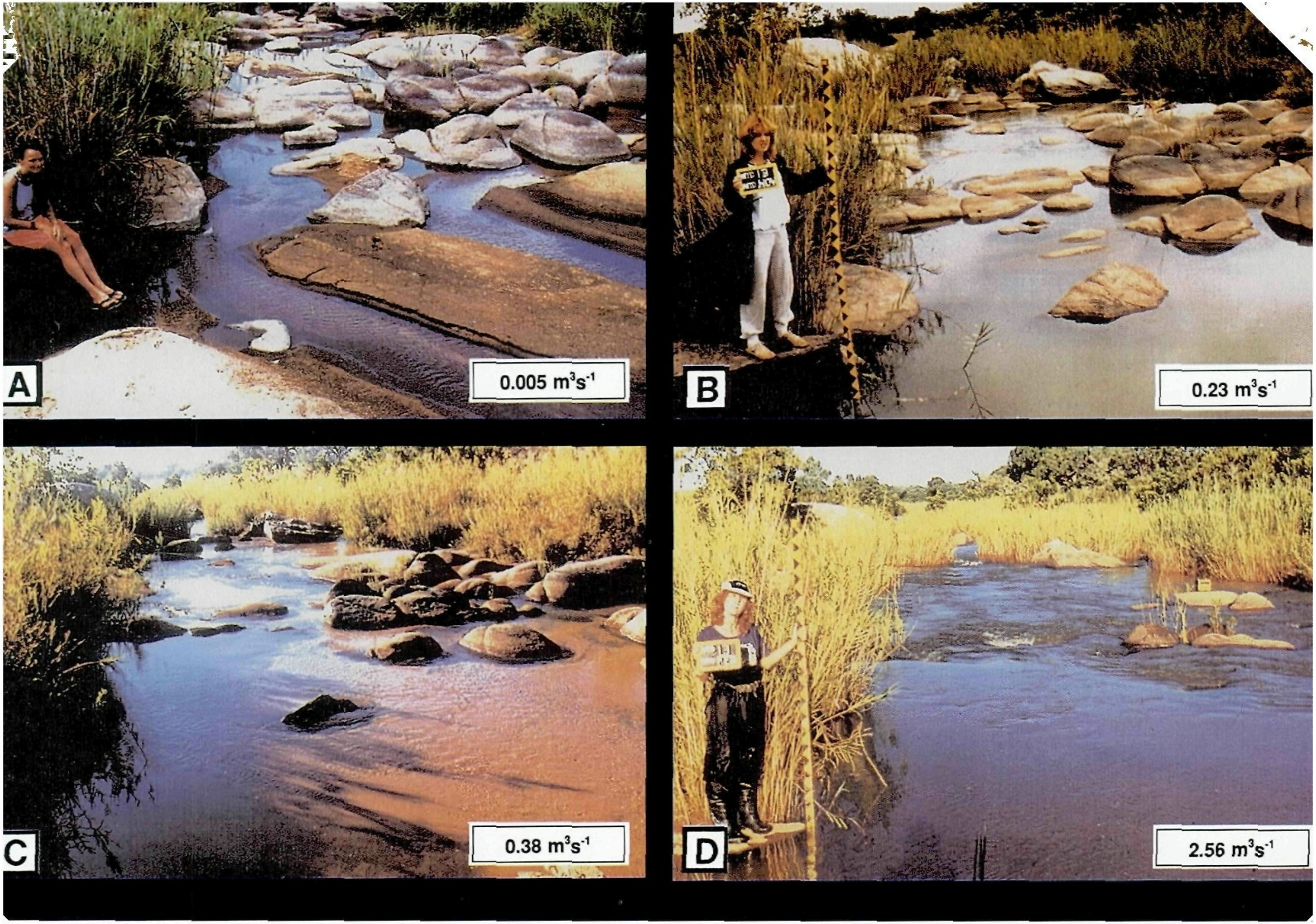


**Plate 6:** Station 13 (Exeter) on the mid-Sand River at different discharges. A = 0.005 $m^3s^{-1}$, February 1992; B = 0.23 $m^3s^{-1}$, November 1990; C = 0.38 $m^3s^{-1}$, May 1991 & D = 2.56 $m^3s^{-1}$, February 1991.

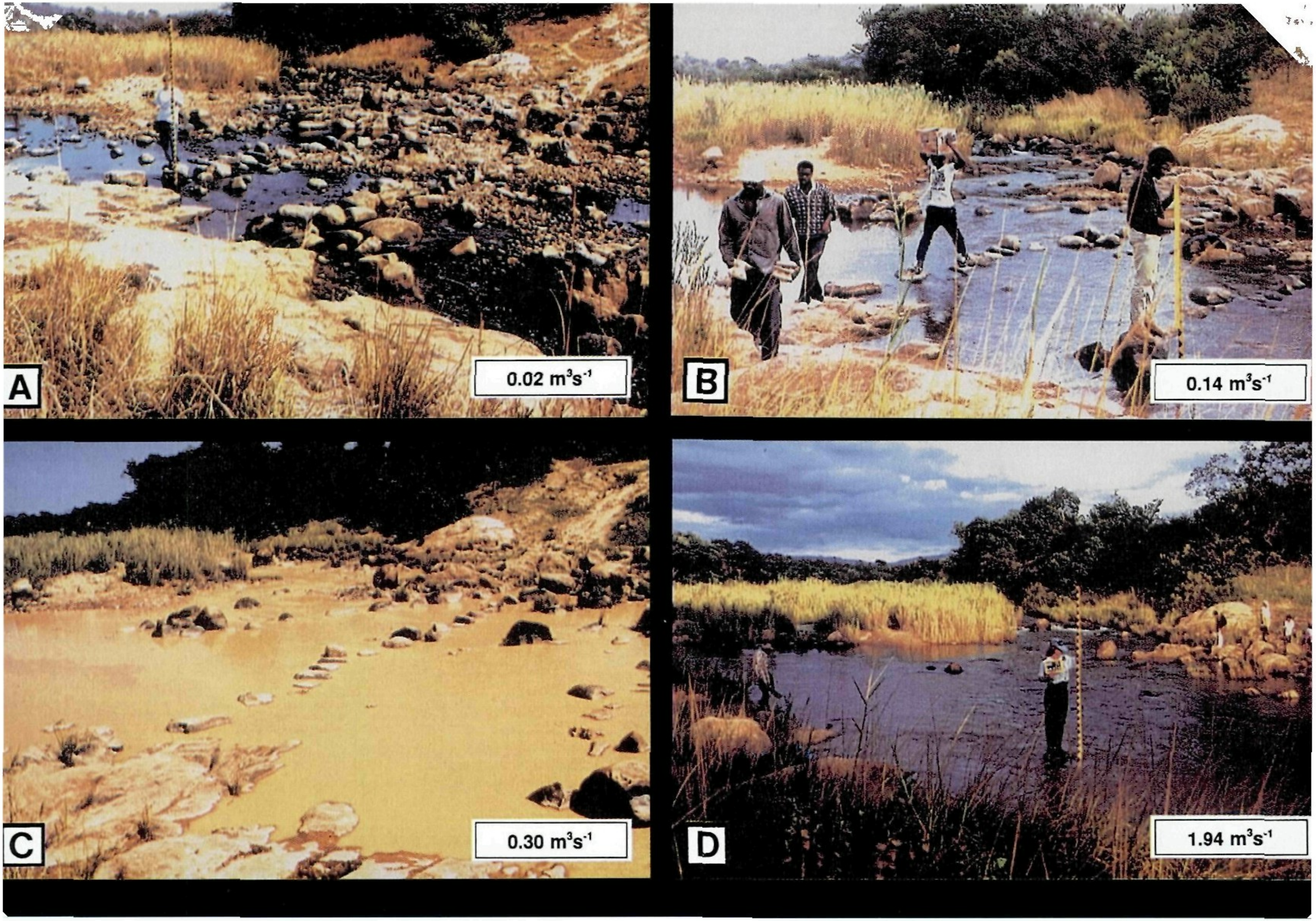


**Plate 7:** Station 19 (New Forest) on the Mutlumuvi River at different discharges. A = 0.02 $m^3s^{-1}$ August 1991; B = 0.14 $m^3s^{-1}$ May 1991; C = 0.30 $m^3s^{-1}$, February 1992 & D = 1.94 $m^3s^{-1}$, February 1991.

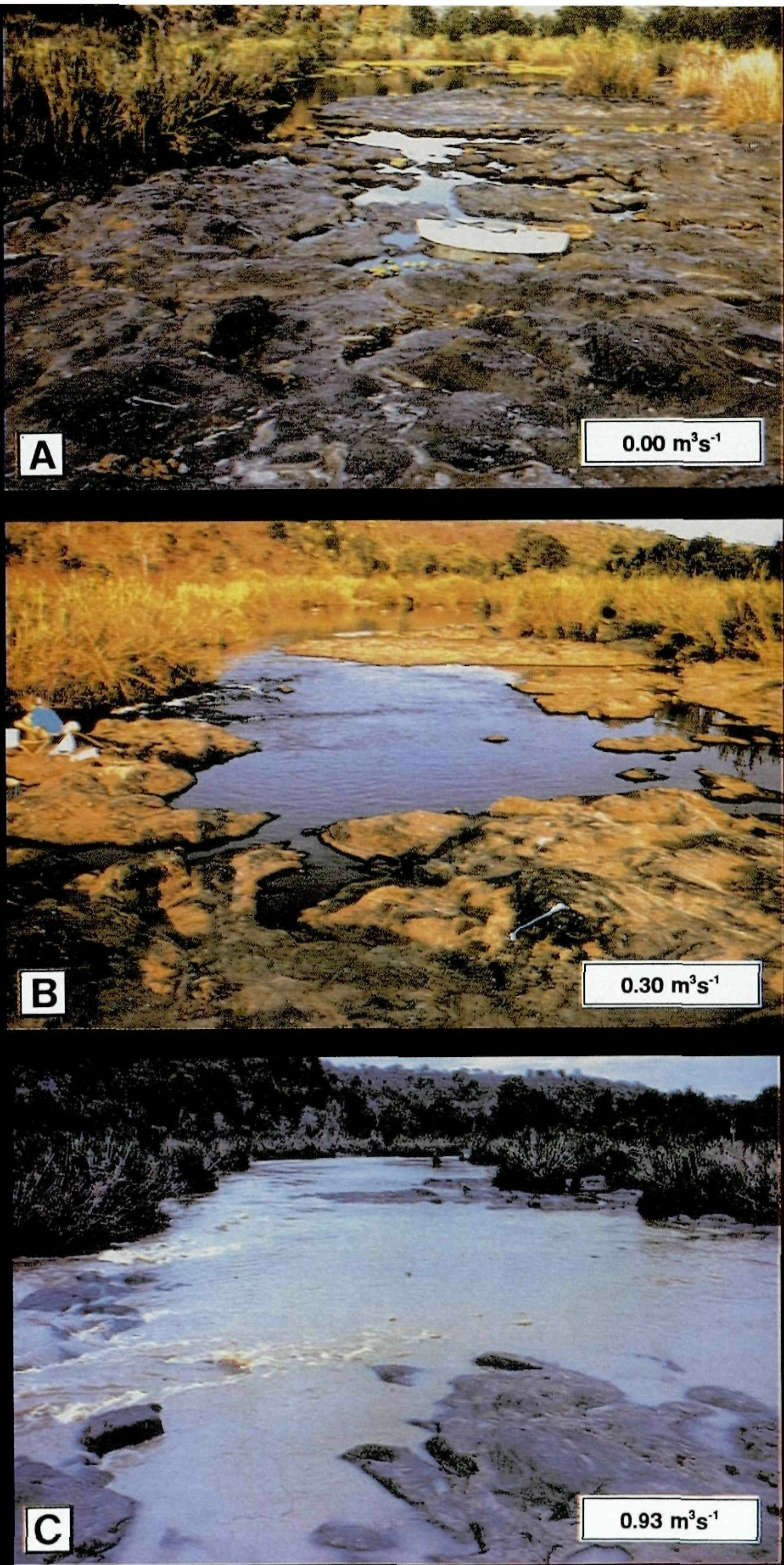


**Plate 8:** Station 20 (Mlondozi) on the lower Sabie River at different discharges. A = 0.00 m$^3$s$^{-1}$, May 1992; B = 0.30 m$^3$s$^{-1}$, August 1991 & C = 0.93 m$^3$s$^{-1}$, November 1991.


**Plate 9:** Station 21 (The Gums) on the Marite River at different discharges. A = 0.09 $m^3s^{-1}$, May 1992; B = 0.60 $m^3s^{-1}$ November 1990; C = 2.75 $m^3s^{-1}$, February 1991 & D = 4.86 $m^3s^{-1}$, February 1993.

# A PRE-IMPOUNDMENT STUDY OF THE SABIE-SAND RIVER SYSTEM, MPUMALANGA WITH SPECIAL REFERENCE TO PREDICTED IMPACTS ON THE KRUGER NATIONAL PARK

## VOLUME THREE

## THE EFFECTS OF PROPOSED IMPOUNDMENTS AND MANAGEMENT RECOMMENDATIONS

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The name of the region where this work was done was changed from
EASTERN TRANSVAAL
to
MPUMALANGA
during the publication of this report.
Where the name Eastern Transvaal appears in the text, please read
Mpumalanga

# EXECUTIVE SUMMARY

Section numbers in the executive summary relate to the chapter headings and subsections in the main report.

## 1. INTRODUCTION

This project was begun in January 1990 in response to a need to characterise the fauna of the Sabie-Sand River system for which plans were already advanced to build impoundments. During the cource of the project, the region was subjected to the worst drought on record. As a result the scope and duration of the project was extended. This volume is the first of three which describe the results.

Volume 1 describes the ecological status of the Sabie, the Sand and other major tributaries of the system, including the diversity and distribution of the fish and macro-invertebrate faunas, and their habitat requirements. The second volume describes the results of a drought monitoring programme in which three reaches of the Sabie and one in the Sand River were intensively sampled throughout the worst drought on record, from 1991 to 1992.

The purpose of this volume is to assess the probable effects of proposed impoundments in the Sabie-Sand River (both positive and negative) on the ecology of the downstream reaches, and to draw on the information from volumes one and two to make recommendations for the management and monitoring of the flows in the river.

## 2. EFFECTS OF PROPOSED DAMS

Chapter 2 begins with an extensive review of the effects of dams on the downstream reaches of rivers, including reduction of water temperature ranges; delayed seasonality; changes in water quality; and in the type of organic material. The concept of recovery distance, the distance downstream necessary for the effects of impoundments to dissipate, is explained. Studies on the effects of dams on the Buffalo River (eastern Cape), and the Palmiet River (western Cape), are also reviewed, and summarised as follows:

1. there were no effects common to all six dams;
2. the position of any dam was of over-riding importance, governing the types of downstream effects, while perhaps surprisingly, the marked differences between the physical and chemical features of the two rivers appeared to have very little influence on the types of effects caused by impoundment;
3. larger impoundments caused more intense downstream impacts, and these impacts took longer to recover;
4. release mechanisms were less important than the position of a dam along the river, but bottom-releases consistently reduced temperature ranges, increased TSS, and increased all nitrogenous compounds measured, and
5. reservoirs were more effective than equivalent lengths of flowing water, at "*resetting*" grossly polluted systems.

2.3 Existing and potential dam sites within the Sabie-Sand system

There are at present 7 dams on the Sabie-Sand system, although one of them - the Zoeknog Dam, has collapsed and presently forms no barrier to water flow. The Edinburgh, Orinoco, Acornhoek, and Casteel Dams are all small (1.1 to 3.3 x $10^6$ $m^3$) dams in the upper tributaries of the Sand River. The Da Gama Dam is a medium-sized dam (14.3 x $10^6$ $m^3$) on the White Waters tributary of the Sabie River. The Corumana Dam is a very large impoundment (1200 x $10^6$ $m^3$) on the Sabie River in Mozambique, which backs up to the eastern border of the Park.

The upper dams all have the effect of reducing runoff to the KNP, but if we can extrapolate from the previous studies of the effects of dams on rivers in other parts of South Africa, then they are too small and too remote from the Park to have significant effects on the water quality, temperature regime, sediment transport and species composition in the main rivers within the Park boundaries. Any such effects will have recovered within a few kilometres downstream of the dam wall. The Corumana Dam, downstream of the Park, represents a major barrier to upstream migration of fish such as the Tigerfish, and may be the main reason for the scarcity of this species in the Sabie within the Park.

Seven potential new dam sites have been identified on the Sabie and Sand Rivers: Arthur's Seat, Dingleydale, and an enlargement of the Casteel Dam, are all sites situated in the upper reaches of the Sand system, and would be 14, 59, 73, and 39 x $10^6$ $m^3$ respectively. Two potential sites have been identified on the Marite tributary of the Sabie River: the Inyaka site (101 x $10^6$ $m^3$), and the Waterval site (109 x $10^6$ $m^3$). The Madras site is the largest (230 x $10^6$ $m^3$), and is situated on the main Sabie River only some 5 km from where the river joins the western KNP boundary.

2.3.2 Potential effects of the dams

The Madras site is the only proposal which would dam the main Sabie, and could potentially reduce the flow in the Sabie to less than 20% of its virgin MAR (O'Keeffe and Davies, 1991). This would turn the Sabie into a temporary river, in which low-flows would be completely intercepted for five months of most years. The most likely of the dam sites to be developed is the Inyaka site on the Marite tributary. If the dam were exploited to its maximum potential for water supply, runoff would be reduced to less than 20% of virgin conditions during dry years, and the Sabie River could stop flowing altogether during droughts. Mid-Sabie River peak flows would on average be reduced by 50%, while base-flows would approximate those seen during the 1990/91 drought (1.4 $m^3$ $s^{-1}$; Table 2.4). A compromise proposal: "Inyaka Dam - Limited use scenario", would require a compensation flow to be released from the dam which would ensure that the flow in the KNP would never be allowed to fall below un-impounded worst drought conditions. In addition, there would be gradual increases in compensation flow with increases in the inflow to the Dam. As a result, lowest flows would be a rare event, unlikely to occur in consecutive years. This scenario would result in nearly natural flows in wet months during wet years, and flows between 40 - 60% of virgin condition in both wet months during drought years, and dry months during wet years. During the critical dry months during drought years, flows in the Park would be between 20 - 40% of virgin conditions.

Dam sites in the upper Sand River and the Marite are likely to cause significant temperature increases downstream, but these should recover within 20 km at the most - well before the water from these dams reaches the Park. The Madras Dam, if it were to be built and operated with a bottom release valve only, would have a major effect of reducing temperatures downstream, possibly by as much as 18 - 20°C, and this effect would extend well into the Park, perhaps for as far as 40 km. Such an effect would have far-reaching consequences for the riverine biota, and could exclude, for example, most of the lowveld fish community.

Dams are sediment traps, and it can be expected that any of the planned impoundments would have local effects in intercepting sediments, leading to clear "sediment-hungry" water downstream. Only the Madras Dam would affect the rivers in the Park.

As the dam are situated in the middleveld close to the FHZ and LZ transition, the potential for complex range extension/reduction of species is great. A further consideration is that the characteristic FHZ and LZ fish assemblages would respond differently to impoundment.

Downstream of the Marite Dam, FHZ species sensitive to water temperature would decreases. The dominant FHZ species *Chiloglanis anoterus* is unable to survive any period of no-flow and would suffer local extinction as would other less numerous and localised Amphilius catfishes and *Opsaridium zambezense*. In the LZ, the more resilient assemblage would show less species composition shifts, but rather proportional shift in the importance of species. The alternating seasonal dominance of cyprinid to cichlids could be offset with impoundment reduced or no-flow, as seen during drought. Cichlids and other drought species would dominate the assemblage, with *Oreochromis mossambicus* replacing *Barbus viviparus* as the most abundant in the LZ. Decreased water temperature in the LZ such as predicted with the building of the Madras dam, would significantly alter distributions of LZ fish in the KNP.

The biotic effects of both the Inyaka and Madras dams at limited and maximum use are discussed.

## 2.4 Zoeknog dam

Zoeknog dam, on the Mutlumuvi River, was 29% full when it failed with the first rains of the 1992-93 wet season. Approximately $3x10^6$ $m^3$ of water and an estimated $0,2x10^6$ $m^3$ of earth was discharged into the Mutlumuvi River over a few hours (Plate 1a).

During the construction phase of the dam there had already been major changes in the occurrence and abundance of species. The turbidity in the Mutlumuvi was some 57 times above previous measurements (1300 NTU, TSS 0.85 $gl^{-1}$) (Table 2.5).

The effects of construction on the biota were masked by the 1992-93 drought, and progressively downstream in the mid Sand River reaches, but cannot alone explain the drastic reduction of the biota recorded. Immediately downstream of the dam, the most abundant fish species *Chiloglanis anoterus* and *Barbus eutaenia* were reduced by 60 and 80% even though the Mutlumuvi remained perennial at this elevation. Both these species are most numerous in the clear-watered foothill streams of the catchment and may have been affected by high turbidity.

The collapse of the dam resulted in a flow equivalent to a 1:10 year flood in the Mutlumuvi, but flows attenuated downstream. Gross microhabitat alteration occurred within the reaches downstream of the dam. At 2 km, over a meter of coarse sand had smothered riffle and run sequences (Plate 1c). At New Forest, some 16 km downstream of the dam, there was evidence of a 2-3 meter flood and a layer of fine sediments deposited in and out of the channel. Fine red silt was evident all the way to the Sabie-Sand confluence. Two days after the event the turbidity at Londolozi was still 1900 NTU (2.652 g/l of silt) (Table 2.5).

The lowest fish densities during the project were measured for all stations after dam failure. Effects were greatest in the Mutlumuvi with CPUE immediately below the dam reduced halved from post drought/construction catches. Following the dam burst CPUE was recorded at its lowest for any site during the entire study period, catchment-wide, in the mid-Mutlumuvi (site 19)! Cichlids which had come to dominate the catches in the stressed Mutlumuvi River were themselves scoured during the high flow event, contributing to the low CPUE seen.

Following dam failure, low invertebrate numbers were found as far downstream as site 14, the furthest downstream site in the Sand River. Invertebrates appeared to recover from the effects of the drought and the collapse of the dam more quickly than did the fish.

In the Mutlumuvi, recovery may have been hampered because it is isolated from the upper Sand River by the mid-Sand River reaches, which are often impacted by drought. Little meaningful recovery was evident below the dam site after 5 months. Sediments within the highly modified reach had however started being resorted (Plate 1d).

Fish density and diversity was still very low at the New Forest site 5 months after the collapse of the dam, but recovery was well under way at Londolozi (site 14).

Three months after the dam failure, both diversity and total numbers of invertebrates showed an apparent recovery. All four sites showed recovery to pre-drought and pre-dam failure conditions (Fig. 2.20 - 2.23).

In summary, the collapse of the Zoeknog dam had the following effects:

- A severe reduction in the density and diversity of the instream fauna
- Modification of the instream habitats

- The Mutlumuvi River was generally heavily impacted, while the lower Sand River impacts are masked by more powerful drought effects.
- The upper reaches at Zoeknog show gross modifications in channel structure with course unsorted substrates smothering typical riffle reaches.
- In the mid-Mutlumuvi at New Forest, the already severely drought stressed fish assemblage was almost totally destroyed.
- At Londolozi, clear impacts of the Zoeknog event were masked by drought effects on the mid-Sand River.
- Although difficult to assess, high turbidities impacted off-stream pool fish assemblages in the mid-Sand River floodplain.
- The degradation of the upper lowveld fish refuge reach may reduce the resilience of the lower reaches of the Sand River.
- The ichthyofauna of the Mutlumuvi had recovered very little five months after the event.

## 3. INSTREAM FLOW REQUIREMENTS OF THE SABIE-SAND RIVERS IN THE KRUGER NATIONAL PARK

3.2 Previous assessments of the environmental water requirements for the Sabie river.
To date, three independent methods have been used to assess the environmental water requirements of the Sabie River:

a) Davies *et al.*, (1991) used a water budget method in which the consumptive and non-consumptive water uses were estimated, to provide a seasonally-distributed flow requirement.
b) Gore *et al.*, (1992) used the PHABSIM model to provide preliminary estimates of hydraulic habitat requirements for four key species in the Sabie River.
c) The third assessment of environmental flow needs used hydrological simulations of natural, present and various future impounded conditions of the Sabie River to predict

possible ecological conditions (O'Keeffe and Davies, 1991). Ecological consequences of successive reductions in discharge were then assessed using the River Conservation System (O'Keeffe *et al.*, 1987), an expert-system based model, to determine the *conservation status* of the river under different management conditions.

Table 3.4 compares the recommendations of the three methods. Bearing in mind that these assessments each used different methods, based on different data, analyzed by different teams, the recommendations are very similar, and give some basis for confidence that they are appropriate base flows for the maintenance of the riverine ecosystem. Seen as a percentage of the present MAR of the Sabie River, they are not unreasonable requirements, and should be accepted as targets for management of the river's water resources.

3.3 Lessons from the 1991-92 drought.

If the LZ rivers stop flowing, even for a short time, a number of species will disappear from the static reaches. These will include *Chiloglanis anoterus* and *Opsaridium zambezensis*. In addition to these disappearances, the community structure will change considerably, mainly as a change from dominance by cyprinids to cichlids.

As a general rule, low or no-flow sequences of longer than two months are likely to cause changes to the community from which species will take a year or more to recover. If the river were to be managed to maintain flows at a survival level, species would disappear gradually but permanently due to lack of recruitment. Management of the flow regime should therefore concentrate on the maintenance of natural proportions of all species in the assemblage, rather than on the dangers of the immediate disappearance of species from the system.

The rate of flow reduction is very important, and should be as slow as possible. High flows (greater than bank-full) are important for replenishing and recolonising off-mainstream pools, which proved to be important refuges during no-flow periods.

Finally, the maintenance of permanently flowing reaches is of the utmost importance to ensure that there are survivors in the system from which recolonisation can take place. The upper reaches of the Sand and Mutlumuvi Rivers are such refuges, as is the main Sabie River.

### 3.4 Summarised flow scenarios

The consequences of different flows on habitat availability, water quality, and the instream fauna are addressed in Tables 3.5 to 3.7. Predictions are partly quantitative and partly qualitative. The tables are designed to provide a structured summary of the effects of a series of flow scenarios of varying duration, during the wet and dry seasons. We envisage that these tables will be useful to scientists, conservationists, and managers in assessing the effects of modified flows as a result of impoundment and increased water abstraction.

## 4. FUTURE MONITORING REQUIREMENTS

The objectives of a monitoring programme for the Sabie-Sand would be as follows:

- To measure the relative density and diversity of the fish and invertebrate communities of the rivers, so as to document changes at different spatial and temporal scales.
- To document the size and shape of the river channels and the variety of habitats within them, so that long term changes in channel morphology and the availability of suitable habitat in response to changing flow patterns can be quantified.
- To measure the changes in important physico-chemical attributes of the rivers, so as to recognise seasonal and long term changes in the water quality of the rivers.
- To gauge the flow of the rivers so that the natural patterns of seasonal, drought/flood, and wet/dry sequences can be recognised, and the effects of impoundment and increased abstraction can be followed.

### 4.2 Present monitoring activities

The present long term monitoring activities on the Sabie-Sand can be summarised as follows:

- Continuous flow gauging at 12 gauging weirs, with record lengths varying from 47 to 5 years.

- At these gauging weirs and 3 other sites within the KNP, water samples are collected on average every 2 to 3 weeks, and are analysed for a suite of major ions, salinity, phosphates, nitrates + nitrites, and ammonium.
- Irregular fish surveys have been carried out on all parts of the Sabie-Sand since 1963 (Gaigher, 1969).
- Benthic invertebrates have similarly been sampled sporadically since the early 1960's, but at present there is no regular programme to update previous surveys.
- Aerial photography coverage of the Sabie-Sand catchment has been updated every 10 years since 1940. Within the KNP colour aerial photography surveys have been flown over the river at a scale of 1:5k - 1:10k.
- Fixed point photography sites on the Sabie and Sand Rivers within the KNP have been recorded in recent years, but there are no sites on the rivers outside the Park.

4.3 Additional monitoring requirements

To ensure an adequate database from which to assess long-term changes in the rivers, and to act as warning systems should particular problems arise:

- Regular invertebrate sampling, using the SASS4 rapid biomonitoring system. At least once per year, and preferably twice a year in the wet and dry seasons.
- Resurveys of existing rated transects to check on channel changes, approximately every 10 years.
- Initial surveys to measure the ecological integrity of the rivers, using the methods of Kleynhans (in press), followed by resurveys every 10 years.
- Transect surveys through the riparian vegetation, to check on species changes over time, regeneration, and mortality amongst mature trees. (Details to be provided by the researchers at the Centre for Water in the Environment, Wits University).

In addition, the following activities should be extended from the Park to be carried out throughout the catchment:

- Regularly fish sampling, at least once a year, using the Index of Biotic Integrity approach presently being developed by Dr Andrew Deacon of the National Parks

Board. Samples should be collected at the same time each year, to allow for seasonal changes in fish communities (described in Volume one of this report).

- Regular fixed point photographs, once a year at the same time of year (preferably in winter during low-flow conditions).

Eight sites have been identified as the realistic minimum number of monitoring sites through which to characterise the Sabie-Sand system:

- Upper Sabie, site 3, downstream of Sabie town.
- Sabie River at Mkhuhlu, site 6.
- Sabie River below the confluence of the Sand, site 9.
- Sabie River at Mlondozi, near the Mozambique border, site 20.
- Upper Sand River at Rooiboklaagte, site 11.
- Mutlumuvi River at New Forest, site 19
- Sand River at Londolozi, site 14.
- Marite River downstream of the proposed Inyaka dam, site 21.

## 5. CONCLUSIONS, AND MANAGEMENT OPTIONS TO MAINTAIN THE CONDITION AND COMMUNITIES OF THE SABIE-SAND SYSTEM

The results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the Sabie River. If low-flow conditions become the norm, the communities in the Sabie will change considerably. Water quality in the Sabie is still excellent.

The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the communities are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation.

## 5.4 The effects of dams

Most of the proposed dams are probably too small and too remote from the Park to provide effective low-flow augmentation. However, the Madras Dam, on the Sabie mainstream and very close to the Park's western boundary, would have severe effects on the water quality, temperature and sediment transport within the Park, and is also large enough to intercept all but the largest floods. The option of choice, from an environmental point of view, would be the Inyaka Dam in the Marite tributary. This would have consequences for the Marite, but is far enough from the Park for conditions downstream in the Sabie to recover. It is large enough to provide compensation flows to the Park, and would not intercept high flows, since the site is in a tributary of the system. Compensation flows be linked to the dam inflows, as suggested by O'Keeffe and Davies (1991). The conclusions of O'Keeffe and Davies (1991) should be seen as part of an ongoing assessment of the flow requirements for the rivers.

Existing and proposed impoundments on the Sand River are all remote from the Kruger Park and associated private reserves, but affect the important perennial upper tributaries of the Sand, which act as refugia during droughts.

## 5.5 The effects of consistently reduced flows

The effects of flow reductions on the fish communities of the Sabie-Sand have to be seen in the framework of the different zones of the rivers, and during the wet and dry seasons. In the Foothill Zone (FHZ), there are less seasonal effects, and the consequences of reduced or no-flow would be the reduction or disappearance of flow-sensitive species (such as *Chiloglanis anoterus*). Pool and marginal species will continue to survive and will dominate the fish assemblages. In the Lowveld Zone (LZ), where seasonal changes are marked, a permanent reduction in flow will result in the continued dominance of the dry season assemblage, dominated by cichlids, and the permanent reduction of cyprinids and other flow-dependent species. Lower flows in the dry winter season will result in stressed communities, no breeding and the disappearance of flow-dependent species, especially in rivers which cease to flow.

Generally, mean water temperatures will increase as flow is reduced, and there will be a shift of some of the more flow- and temperature- sensitive elements of the LZ communities further upstream.

Many invertebrate species are extremely sensitive to flow conditions. During drought conditions in 1992 the average number of taxa was half that during the wetter conditions in 1990, and densities were reduced by an order of magnitude. The loss of biodiversity in these circumstances is not confined to invertebrate species, since they form a crucial part of the food base for other organisms, particularly fish and amphibians, and make significant contributions to the processing of organic matter.

The change from flowing water to static conditions will also provide opportunities for the increase of those species which favour stagnant water. These unfortunately include mosquitoes and Bilharzia host snails. The Sand River is already a centre for bilharzia transmission, but it is unlikely that the Sabie is at present.

Up to the present, reduced flows have not resulted in water quality deterioration beyond acceptable limits, except in isolated pools during drought conditions. Reduced flows will however result in less dilution of the effluents and irrigation return flows that reach the river. The presence of dams provides the option of making releases to dilute effluents during critical periods.

The maintenance of refuge areas is crucial to the continued ecological integrity of the system. From the point of view of perennial flow, the most important remaining refuge reaches in the LZ are:

- The main Sabie River, which has always been perennial throughout its length.
- The upper reaches of the Sand and Mutlumuvi tributaries

In the FHZ, the most important refuge is the Marite River.

## 5.6 Recommendations

- The overriding priority for the Main Sabie River is to maintain a perennial flow to the Mozambique border.
- Throughout the system, the maintenance of perennial flows in refuge areas is crucial to the ability of the fauna to survive critical low-flow periods.
- Flow management policy should attempt to build in as much of the natural between and within season variability as possible.
- Education and information: There is an urgent need to inform people in all parts of the catchment about the values of maintaining the resources of the rivers in the long term.
- Following the development of the national biomonitoring programme, a coherent monitoring programme
- As a matter of general policy, all new dams should incorporate multiple release ports at different levels, to provide options for water quality and temperature mixing.
- The adoption of the "Inyaka Dam, Limited Use" policy (see section 2.3.2) will cause only minor ecological disruption to the Sabie River ecosystem, and will provide new options for low-flow augmentation.
- The Inyaka Dam will, however, have significant effects on the unique fauna of the Marite River, unless care is taken during construction, perennial flows are maintained, and the temperature of water releases is controlled within natural limits.
- Madras Dam, if it is built, would have very severe effects on the downstream riverine ecosystem, through flow reduction and changed water quality, unless a strict water release policy was ensured. In the latter case, it could provide the best options for environmental flow releases into the Kruger Park.
- To provide for augmentation of low-flows in the Sand River, the building of the New Forest Dam on the Mutlumuvi, and a transfer facility to the Dam from Inyaka, could be considered. In addition, the repair, or at least stabilisation of the broken Zoegnog

Dam should be a priority, since further high flows will tranport more sediments from the wall down river.

- Strict control of any fish stocking in Inyaka dam will be necessary, especially to prevent the introduction of cool-water-tolerant bass species, which would have a catastrophic effect on the smaller indigenous species in the upper rivers.
- It would be possible to reintroduce the fish species that are missing from the upper middle reaches of the Sabie River (upstream of site 3) due to historic mining effluent.
- Even in temporary rivers during the dry season, it is necessary to ensure some base flow from time to time, to top-up pools and improve water quality.

5.6.3 Further information required

- Model development to predict the effects of changes in abiotic driving forces (such as flow) on the riverine biota.
- Breeding requirements of fish.
- Migration and local movement patterns of fish, and their importance to the life-cycles of different species.
- A socio-economic analysis of the long-term values of the natural resources of the rivers.

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dominates the assemblage in all seasons (59-81%). Cichlids are characteristically poorly represented (3-4%) while cyprinids make up 15-32% of the catch.

**Figure 2.12:** Changes in the relative abundance in the Lowveld Zone (LZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species see Figure 7.8 (Volume 1). By early summer (November), cichlids have bred independently of the first rains increasing from 7 to 53%. By February and at the height of the seasonal rains, cyprinids have increased from 31 to 58%. During the dry winter season, no breeding takes place while recruitment of the numerous young-of-the-year swell cyprinid numbers (84%).

**Figure 2.13:** Catch per unit effort (CPUE) for fish below the Zoeknog dam site between May 1991 and May 1993 and above the dam for May 1993. Fish grouped as lotic (solid bars) or lentic (hatched bars) breeders (see text). Between May 1991 and 1992 and during construction, total CPUEs decreased from approximately 7 to 4 fish per minute. By January 1993, post dam failure, CPUEs were recorded as less than 2 fish per minute while lentic species increased with backwater species absent from the reach. CPUE had not recovered by May 1993, being less than half those recorded immediately above the dam.

**Figure 2.14:** Catch per unit effort (CPUE) for lotic (solid bars) and lentic fish (hatched bars) between August 1990 and May 1993 at New Forest on the Mutlumuvi River, some 16 km downstream of the Zoeknog Dam. CPUEs between 6 and 7 fish per minute were obtained with a slight decrease over the summer of 1991-92. By the end of the dry season (November 1992) the CPUE had increased considerably. This was attributed to an explosion of the lentic breeder *Oreochromis mossambicus* in drought conditions. The post-dam flush in January 1993 drastically reduced fish in the reach to a remnant particularly the lentic *O.mossambicus*. Three months later CPUE was still very low.

**Figure 2.15:** Catch per unit effort (CPUE) for fish at Londolozi on the mid-Sand river between May 1990 and May 1993. A CPUE of between 3 and 6 fish per minute was recorded before the 1991-92 drought with lentic species (hatched bars) typically making up more than 90% of the assemblage. By May 1992 the Sand river had ceased to flow concentrating the fish in pools and resulting in artificially high CPUEs. Lentic breeders continued to dominate the assemblage. The river was flowing again by December 1992, the November flush having reduced the lentic species noticeably. CPUE after the Zoeknog collapse, the sixth flushing-flow of the season, measured below 2 fish per minute and were almost exclusively of lotic species 9 (solid bars). Recovery had started by May 1993.

**Figure 2.16:** Catch per unit effort (CPUE) for species below the Zoeknog dam site between May 1991 and January 1993. In May 1991, 11 species were recorded with the rock catlet *Chiloglanis anoterus* particularly numerous (CPUE at 4.7), and the

minnows *Barbus eutaenia* and *Barbus brevipinnis* common. As construction proceeded *C.anoterus* and *B.eutaenia* numbers were greatly reduced (May 1992) while numbers of the robust minnow *Barbus trimaculatus* and the blue kurper *Oreochromis mossambicus* increased. Post the dam failure and resultant microhabitat loss, *C.anoterus* was further reduced and the minnows *B.eutaenia B.brevipinnis* and *O.mossambicus* were not recorded.

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| | |
|---|---|
| CPUE: | Catch Per Unit Effort |
| DO: | Dissolved Oxygen |
| DWAF: | Department of Water Affairs and Forestry |
| FHZ: | Foothill Zone |
| GIS: | Geographical Information System |
| IBT: | Inter Basin Transfer |
| IFR: | Instream Flow Requirement |
| mASL: | Meters Above Sea Level |
| KNP: | Kruger National Park |
| KNPRRP: | Kruger National Park Rivers Research Programme |
| LZ: | Lowveld Zone |
| MLA: | Maximum Level of Acceptability |
| NOEL: | No Observed Effect Level |
| NT: | Number of Taxa |
| NTU: | Nephelometric Turbidity Unit |
| PSI: | Proportional Similarity Index |
| SL: | Standard Length |
| SRP: | Soluble Reactive Phosphorous |
| TMS: | Table Mountain Sandstone |
| TDS: | Total Dissolved Solids |
| TNI: | Total Number of Invertebrates |
| TSS: | Total Suspended Solids |
| YOY: | Young of the Year |

# 1. INTRODUCTION

This is the third of three volumes of a report which contributes to the ecological knowledge base for the Sabie-Sand River system in the eastern Transvaal. Volume one described the present ecological status of the main rivers of the system, reporting on the results of a three year field study of the fish and invertebrate communities and the water quality, from the headwaters on the escarpment to the eastern boundary of the Kruger National Park at the Mozambique border (Fig. 1.1).

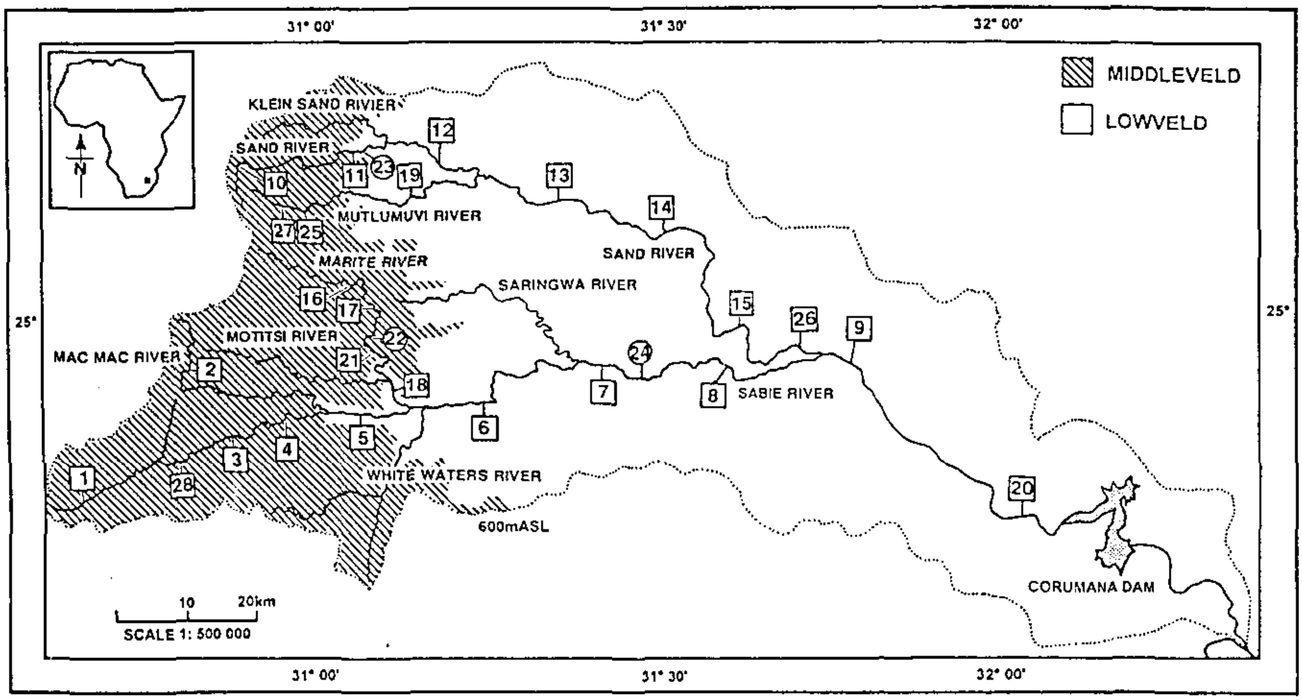



**Figure 1.1:** Station locality map for all sites sampled over the study period, including annual survey, quarterly monitoring and once-off sites. Gill-net stations shown as circles.

During the course of the field study, the catchment experienced the worst drought on record, with the failure of the 1992 wet season. Flows in the main Sabie within the KNP were reduced to 0.5 $m^3s^{-1}$, and the middle reaches of the Sand River ceased to flow for more than

5 months. The effects of the drought were magnified by the abstraction of water upstream of the KNP, mainly for irrigation. Ecologically and socially disruptive as this drought was, it provided a unique natural experiment through which to investigate the effects of low flows on the biota of the system.

The second volume of this report describes the results of a drought monitoring programme in which three reaches of the Sabie and one in the Sand River were intensively sampled throughout the drought. Because the fieldwork was started in 1990, a year of average rainfall, and ended in May 1993, 7 months after the drought was broken by good rains, the effects on the biota could be followed from a year of good conditions, through the drought, and back into the beginnings of a recovery period. The first two volumes of this report document these changes, and draw conclusions as to the short-and long-term effects of very low (or no) flow on the biota of the rivers. Separate studies, by researchers from the KNP and the University of the Witwatersrand, investigated the effects of the drought on the riparian vegetation, and the large terrestrial and aquatic animals associated with the river. A further separate study during the same period investigated the biota of the Letaba River (Chutter and Heath, 1993), and volume 1 of this report also contains a comparison of the biota and conditions of the Sabie and Letaba Rivers.

At present, the Sabie River has no major impoundments on its mainstream, and only one (the Da Gama dam on the White Waters River) on its major tributaries other than the Sand. The Sand River has four small dams on the upper reaches of its tributaries, of which only the Edinburgh had a significant effect on low flows during the drought. Within the next few years, the Inyaka Dam will be built on the Marite tributary of the Sabie, and it is likely that further dams will also be necessary for the supply of water to the increasing number of people in the catchment, and to ensure that sufficient water reaches the Kruger Park to maintain the ecological functioning of the Sabie-Sand River system - biologically the most diverse in the country.

The purpose of this volume is to assess the probable effects of the proposed impoundments in the Sabie-Sand River (both positive and negative) on the ecology of the downstream reaches, and to draw on the information from volumes one and two to make recommendations for the management and monitoring of the flows in the river. Since there are at present no major dams in the system, it has been necessary to infer the probable effects from our knowledge of impoundments on other rivers. The volume begins with a review of the present ecological knowledge of the effects of dams, and relates this to the size and position along the river of the proposed dams on the Sabie, and characteristics of the river compared to those of the rivers in which the effects of dams have been investigated.

The Zoegnog dam, recently built on the Mutlumuvi tributary of the Sand River, was the object of monitoring during the project, but the central section collapsed in January 1993, sending a pulse of sediment-laden water down the Sand River and into the Sabie. The monitoring report therefore covers the effects of the construction of the dam and its subsequent collapse, rather than assessing the effects of the operation of the dam on the downstream reaches.

In the past 12 years, the idea that water flowing to the sea is wasted has been superceded by the realisation that it is necessary to leave some water in rivers to maintain them as functioning natural resources. This idea was adopted by the Department of Water Affairs and Forestry (DWAF) in the form of the environment as a separate water user, competing with other users (agriculture, industry etc.) for water allocations. This policy is now being challenged by the view of the river as the resource, from which users should motivate their needs (O'Keeffe, 1994). The DWAF White Paper on "Water Supply and Sanitation" has accepted this concept, expressed in the following extract: "The environment should not therefore be regarded as a 'user' of water in competition with other users, but as the base from which the resource is derived and without which no development is sustainable".

Section 3.4 discusses the instream flow requirements (also known as ecological flow requirements, or environmental water allocations, King and Tharme, 1993) for the Sabie-Sand River. The instream flow requirement (IFR) of a river is the volume of water needed in the river channel to maintain the biota and ecological processes in the river in a "desired state", which may be its natural state, or some modified state required by the users of the river. This volume of water should be quantified in terms of the magnitude, timing, duration and frequency of different flows (King and Tharme, 1993). Basically, this comes down to answering the question: "How much water of what quality should be left in the river to maintain it in a condition required by the users of the river?".

The question may be a simple one, but the answers are extremely complex to come to, as researchers and managers have discovered over the past 12 years. The details and philosophy of the IFR process, and methods by which it may be assessed have been extensively discussed by King and Tharme (1993), and are also covered in appendix 1 of volume one of this report. Section 3.4 does not attempt to prescribe an IFR for the Sabie-Sand, since this is to be addressed extensively at several levels by the Kruger National Park Rivers Research Programme (KNPRRP), but presents a matrix of the consequences for the instream biota of different flows for different periods of time. The predictions are restricted to the fish, invertebrates and water quality of the river, since these were the components of the system addressed in this project.

It is envisaged that this information will be combined with that on the riparian vegetation, the hydrology, hydraulics, channel morphology and sediment dynamics, currently being assembled by researchers in the KNPRRP. This will provide a comprehensive picture of the modified flow regime following impoundment, the changed sediment regime and channel morphology, the availability of different types of hydraulic habitat, and the consequences for the riverine biota, including the riparian vegetation and associated large mammals. How far this can be achieved, and at what resolution, has yet to be discovered.

The last two chapters of this volume address the management of the rivers from an environmental point of view, including the need for an integrated monitoring system for the Sabie-Sand catchment. The information collected during the project is interpreted into a form that will hopefully be useful to those who have to manage the rivers for the benefit of all the different users of the many resources which the rivers provide, and will continue to provide, if we can manage them sensibly.

# 2. EFFECTS OF PROPOSED DAMS

## 2.1 RIVER REGULATION BY DAMS: A REVIEW OF ECOLOGICAL RESEARCH

The complexities of the impacts of river regulation on receiving reaches of rivers are adequately summarised in Figure 2.1; but to analyze them all would take another Monograph, and we intend to concentrate on only a few aspects, with special reference to the arid/semi-arid nature of our subcontinent. In a dryland region like southern Africa, the effects of flow regulation are ecologically catastrophic at every level, simply because the biota of dryland rivers is **adapted to an unregulated régime** (see e.g. Fig. 2.2). Indeed, our rivers inherit much of their character from the climate, and their flow behaviour especially mirrors the erratic patterns of rainfall, with variable periods of drought punctuated by flooding that may be equally variable in timing, duration, and in magnitude. The significance of a single *flood pulse* (Junk *et al.*, 1989) must be judged against the history of inundation at one place, and the flood régime, describing variations in both space and time (Puckridge *et al.*, 1993). Hydrological variability strongly influences the evolutionary character of the biota - for example, many resident species are highly tolerant of environmental extremes and are **reproductively opportunistic**; where flooding is modified, as for irrigation, the character of the ecosystem is likely to change. Moreover, the high degree of spatial and temporal variability suggests that the times for dryland river ecosystems **to respond to and recover from environmental changes will be prolonged** - the *raison d'être* for this section.

The hydrological character of a number of arid regions has been studied by McMahon (1979) and Finlayson & McMahon (1988). These studies, based upon annual flow records and peak discharge series, concluded that:

1. arid zone rivers *are* more *variable* than those in humid regions (Table 2.1);

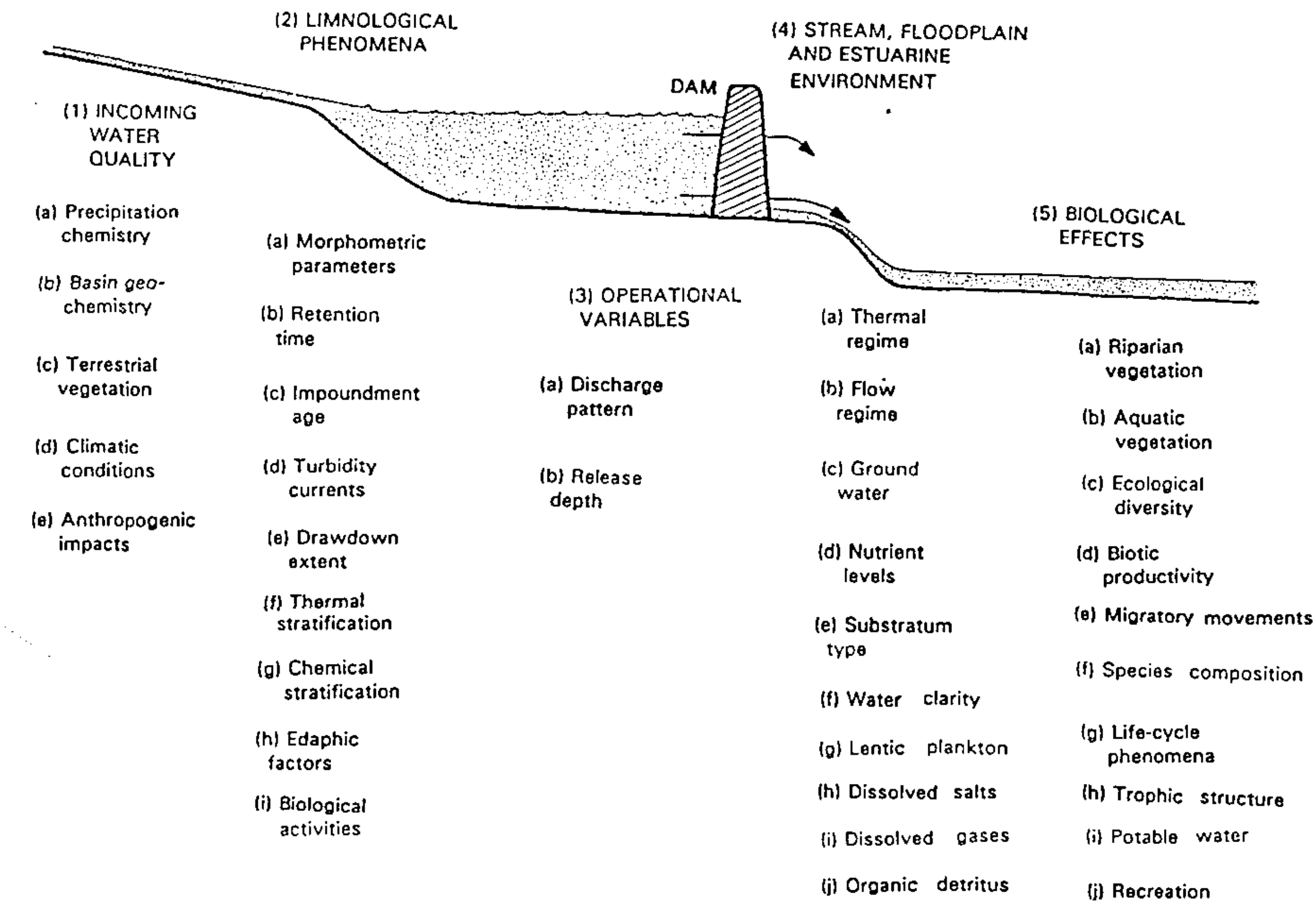



**Figure 2.1:** Major factors and phenomena influencing the receiving reaches of rivers below impoundments, and resultant effects on the biota. (Modified from Ward *et al.*, 1984).

2. hydrological characteristics based upon humid-region data *cannot be extrapolated to arid regions*, and;
3. the maximum potential flow regulation in arid regions is generally 10% of the mean annual flow, except in North America, where up to 40% regulation is possible.

The Coefficient of Variation ($C_v$) expressed as a percentage, is a useful measure of hydrological variability (Table 2.1). Arid regions have a mean $C_v$ of 99 for annual flows, in

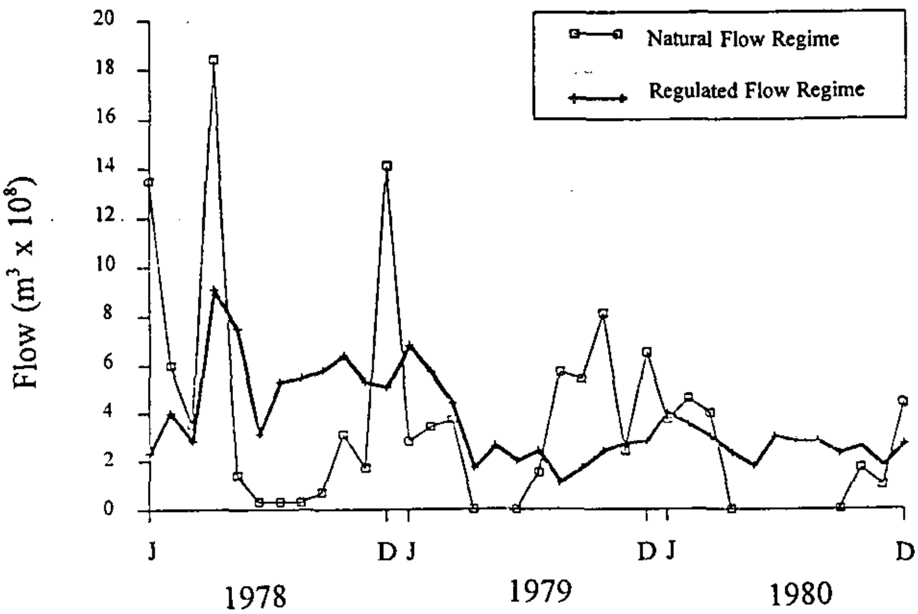



**Figure 2.2:** Natural (thin line) and regulated (thick line) flow regimes of the Orange River. (After Cambrey *et al.*, 1986).

comparison to humid regions in North America (30), Europe (20) and Asia (20). Maximum $C_v$'s for individual arid regions are in Australia (127), southern Africa (114) and the Mediterranean (125) (although see Table 2.1 from Van Biljon & Visser, in manuscript). Finlayson & McMahon (1988) state that, generally, areas of low precipitation (hence low runoff) exhibit high flow variability, with $C_v$'s being twice those of humid regions, irrespective of drainage basin size.

Flood flows in arid regions are also more highly variable than those in other climatic regions. For example, the widely used measure of flood variability, the ratio $O_{100}/O$ (the 100 year recurrence flood interval divided by the mean annual flood), is on average >1.5 times higher in arid regions than elsewhere (Finlayson & McMahon, 1988). Flood flows in both arid Australia and southern Africa exhibit the *greatest degree of variability* with values **>12** (Davies *et al.*, 1993).

**Table 2.1:** (a): Characteristics of representative South African rivers arranged by Province (from north, through central, to the coast, working west to east).
(b): Mean variability for rivers in other parts of the world as a comparison, using the coefficient of Variation ($C_v$) of MAR. (Modified from Van Biljon & Visser, in manuscript). Data for the last 4 rows of section (b) generated by C. Stewart.

(a).

| RIVER | LOCALITY | Catchment area (km²) | Mean precipitation (mm) | Runoff MAR ($m^3 x 10^6 a^{-1}$) | $C_v$ (%) |
|---|---|---|---|---|---|
| Crocodile | Hartbeespoort | 4 112 | 688 | 154 | 78 |
| Hennops | Zwartkops | 808 | 709 | 13 | 148 |
| Great Marico | Marico-Bosveld | 1 219 | 613 | 32 | 118 |
| Luvuvhu | Albasini | 509 | 706 | 24 | 108 |
| Olifants | Kromdraai | 3 989 | 693 | 139 | 99 |
| Vaal | Standerton | 8 193 | 726 | 550 | 82 |
| Harts | Taung | 10 990 | 546 | 52 | 158 |
| Orange | Aliwal North | 37 075 | 725 | 5 131 | 56 |
| Dorpspruit | Victoria West | 280 | 216 | 1 | 162 |
| Olifants | Clanwilliam | 2 033 | 396 | 394 | 53 |
| Doring | Melkboom | 24 044 | 214 | 1 | 73 |
| Berg | Wellington | 713 | 1 034 | 547 | 64 |
| Steenbras | Steenbras | 67 | 1 076 | 45 | 33 |
| Hermitage | Swellendam | 9 | 773 | 8 | 35 |
| Brak | Bellair | 558 | 288 | 2 | 107 |
| Kammanassie | Kammanassie | 1 505 | 637 | 39 | 110 |
| Sundays | Vanryneveids Pass | 3 681 | 337 | 35 | 154 |
| Kubusi | Thornhill | 491 | 786 | 54 | 79 |
| Mzimkulu | F.P. 160 | 545 | 1 050 | 225 | 30 |
| Tugela | Colenso | 4 176 | 889 | 944 | 47 |
| Slang | Vlakdrift | 676 | 786 | 131 | 53 |
| Pongolo | Intulembi | 7 081 | 787 | 1 059 | 59 |
| Bonnie Brook | Broadholms | 119 | 844 | 13 | 39 |
| Komati | Hooggenoeg | 5 499 | 670 | 528 | 62 |
| Noordkaap | Bellevue | 126 | 1 123 | 43 | 42 |
| Sabie | Sabie | 174 | 1 268 | 67 | 41 |

*Mean coefficient of variation in discharge for 83 South African rivers (including those listed above): 89%.*

(b).

| COUNTRY / REGION | Number of rivers *in the analysis* | Coefficient of variation (%) |
|---|---|---|
| USA | 72 | 38 |
| Canada | 13 | 20 |
| Europe | 37 | 22 |
| Victoria State (Australia) | 10 | 53 |
| Australia and New Zealand | - | 50 |
| Africa | - | 23 |
| Asia | - | 27 |
| South Africa | >83 | 117 |

In terms of physical responses to flow regulation, the transfer of energy and mass is a governing influence in all rivers. Depending upon local geomorphology, these transfers may affect all parts of the physical environment of a fluvial system (Walker & Thoms, 1992). Their significance, in terms of physical and ecological functioning, is accentuated in semi-arid rivers because of their enhanced variability and unpredictable nature. Thus, increasing human control over semi-arid rivers is extremely serious in that the regulated flow régime is so **different** from the natural régime that *the environmental impact on these systems is probably very much greater than for rivers elsewhere.* The consequences of flow regulation on the transfer of energy and mass, and the related morphological adjustments are well documented (e.g. Petts, 1984). Most of these examples are, however, from humid regions and recent work by Thoms & Walker (1992) and Walker & Thoms (1992), for instance, indicates that the environmental response to flow regulation in arid regions may differ from responses recorded elsewhere, and may be catastrophic.

The concept of *dominant discharge*, defined as the increment of discharge that transports the largest fraction of the annual sediment load over some years, has been used by Thoms & Walker (1992) to illustrate the impact of flow regulation on semi-arid rivers. It is calculated as the product of the frequency of occurrence and the sediment transport rate. Wolman & Miller (1960) have argued that in the long-term it is the relatively frequent *intermediate* flows that transport the greatest volume of sediment and that, therefore, such flows govern the morphology of the channel. This magnitude-frequency concept is, however, climatically dependent (Graf, 1985), and semi-arid rivers have high dominant discharges in comparison to humid and temperate systems. Ecologically, this implies that the disturbance régime is characterised by *high magnitude-low frequency* events. Flow regulation *reduces* the dominant discharge of semi-arid rivers (e.g. Fig. 2.2), thereby *decreasing the variability* of hydrological, sediment transport, and disturbance régimes (e.g *sensu* Reice, 1984, 1987; Resh *et al.*, 1988). This decrease in variability, or *increase in predictability*, has implications for both the physical and the ecological functioning of these systems.

Figure 2.3 highlights the impact of flow regulation on flow and sediment transport in semi-arid rivers (Thoms & Walker, 1992). The impacts of flow regulation, and hence the model (Fig. 2.3), depend on at least three factors:

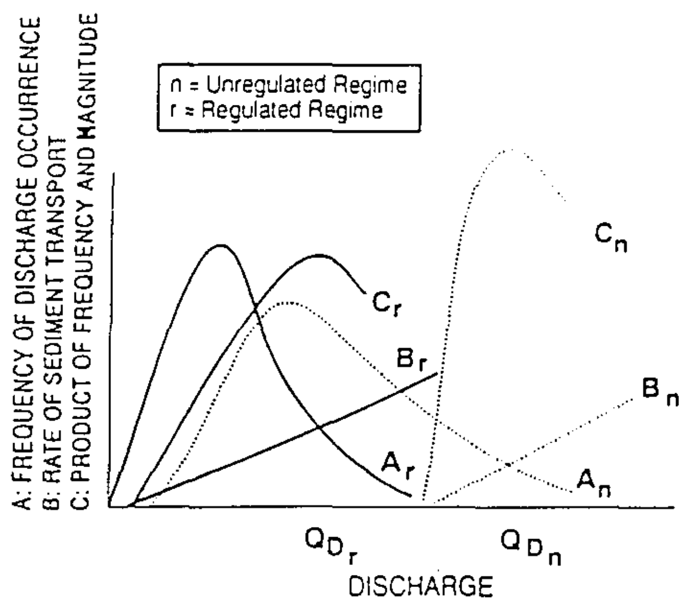



**Figure 2.3:** A conceptual model of the impact of flow regulation on water and sediment transport. (Courtesy of M Thoms, University of Sydney and K Walker, University of Adelaide).

## 2.1.1 CHANGES IN THE FLOW RÉGIME

Curves $A_n$ and $A_r$ represent discharge frequencies for particular periods. The subscript $_n$ denotes the unregulated or semi-arid condition, and $_r$, the regulated condition. Reservoir operations generally decrease the magnitude and increase the frequency and duration of downstream flows. Thus, the regulated discharge-frequency curve has a pronounced peak which is displaced to the left of the pre-regulation curve (Fig. 2.3).

## 2.1.2 THE SEDIMENT TRANSPORT RATE

The curves $B_n$ and $B_r$ (Fig. 2.3) represent transport rates derived for the same periods. The position and slope of the curves depend on the competence and capacity of flows and the availability of sediment. A reduction in flow decreases the ability of a river to transport large quantities of sediment, particularly coarser sediment (*cf* Petts & Thoms, 1986). Reservoirs isolate upstream source areas, restricting sediment availability to downstream reaches. Furthermore, a reduction in the size and frequency of flood events restricts sediment entrainment from floodplain sources.

### 2.1.3. INTERACTIONS BETWEEN THE FLOW AND SEDIMENT RÉGIMES

The product of the two preceding factors is represented by the curves $C_n$ and $C_r$ (Fig. 2.3). Each curve is peaked, with the apex denoting the magnitude of the dominant discharge. The post-regulation curve ($C_r$) is located left of the pre-regulation curve ($C_n$). Thus, discharges which occur relatively more frequently now dominate the sediment transport régime.

This model is incomplete, as it deals only with suspended sediment, but in its current form it does describe the impact of flow regulation on semi-arid rivers in terms both of a reduction in the magnitude of dominant discharge events and the overall variability of the sediment transport régime, or disturbance régime. As such, it may provide a useful framework for investigating the physical impact of catchment disturbances on semi-arid fluvial systems. (**Note:** we are indebted to Martin Thoms - Sydney - and to Keith Walker - Adelaide - for permission to incorporate the model and their discussion of it in this Monograph).

## 2.2 BRIEF REVIEW OF REGULATED RIVERS RESEARCH IN SOUTH AFRICA

Early evidence on the effects of impoundment on South African rivers was collected by Chutter (1967), who investigated the benthos below the Vaal-Hartz Diversion Weir in order to understand the reasons for plague outbreaks of the mammalophilic simuliid, *Simulium* *chutteri*. This work provided an excellent background for later efforts at control. *Concentrating on the stones-in-current fauna*, Chutter noted that the densities of *S. chutteri* peaked when flow fluctuations were greatest (the weir operated on a *weekly flow variation*, supplying irrigation water). The larvae were better able to invade newly flooded habitat than their predators and competitors (predation mainly from hydropsychid Trichoptera - competition from other simuliids). Large populations persisted for up to 50 km below the weir, and Chutter ascribed this last observation to the *seasonal reversal* of the flow rate. Later, Chutter (1969), reported that the benthic invertebrate community below the Vaal Barrage had **recovered** some 8 km downstream, from the effects of the reservoir.

It was Pitchford & Visser (1975) who provided one of the rare pre- and post-impoundment studies of a southern african river. They compared water temperatures downstream of the Verwoerd Dam on the Orange River, with a view to predicting the possible spread of schistosomiasis vector snails in the system. They found that the range was reduced from 19.6°C (before), to 12.8°C (after), and that seasonal effects were delayed by the thermal inertia of the reservoir water mass, such that winter temperatures were elevated, and summer temperatures decreased. They concluded that in this system, at least, the disease vectors, *Biomphalaria pfeifferi* and *Bulinus* (*Physopsis*) sp., could find conditions more favourable for them than hitherto, and that there was the possibility of the summer transmission of bilharzia. However, and fortunately, this finding has not been borne out; no incidence of the disease has yet been reported in the system.

Only two other studies of "pre-impoundment" conditions have been carried out on southern african rivers: Cahora Bassa, built on the Middle Zambezi, and the Epupa Scheme on the Cunene River in Namibia. However, even these studies have come **AFTER** the construction of other impoundments, upstream on the same system: Kariba, on the Middle Zambezi, some 200 km above Cahora Bassa, and the Ruacana Diversion scheme on the Cunene in Namibia, as well as the Caluéque and Govê dams (amongst others) upstream in Angola - this makes interpretation of any results somewhat difficult!

Recent studies on South African rivers have concentrated on the effects of existing dams, comparing conditions upstream of the impoundments with those downstream. Transported material as well as other physico-chemical variables were examined in relation to the Elandsdrift Dam on the Great Fish River in the eastern Cape (R W Palmer & O'Keeffe, 1990b). Physico-chemical variables and riffle-dwelling benthic invertebrates were sampled above and below the reservoir over one year, and differed markedly. Typical taxa above the impoundment included Ephemeroptera, hydropsychid Trichoptera, Chironomidae, Nematoda and the pest blackfly *Simulium chutteri*, while immediately below, the numbers of benthic invertebrates were reduced, and typical taxa included Chironomidae, *Hydra* sp., Oligochaeta, and non-pest species of Simuliidae. Surface-released water contained high levels of chlorophyll-*a*, and low concentrations of suspended material compared to in-flowing water, while bottom-releases contained low levels of chlorophyll-*a*, but high concentrations of $NH_4$, illustrating the impact of different release régimes. Conditions took between 25-86 km to *recover* to "above impoundment" levels. Draining of the reservoir produced water with high concentrations of suspended material (2829 $mgl^{-1}$), caused fish kills for 3.5 km downstream, and depleted benthic invertebrate population densities for over 200 km, the latter recovering within two months.

## 2.2.1 THE BUFFALO AND PALMIET STUDIES: A COMPARISON OF CONTRASTING SYSTEMS

On a much larger scale than those studies cited above, a very detailed collaborative study of the downstream effects of six impoundments on two contrasting rivers commenced in 1986, between the Freshwater Research Unit, University of Cape Town - Palmiet River - and the then Institute for Freshwater Studies, at Rhodes University - Buffalo River. The systems were carefully chosen to contrast in almost every aspect, other than that both were multiply regulated by dams. Every effort was made to ensure compatibility of approach, and techniques were standardised as far as possible. The results of this study, together with separate reports on each system are variously covered by Byren & Davies (1989), Davies *et* *al.*, (1989), O'Keeffe *et al.*, (1990), C G Palmer (1991), C G Palmer *et al.*, (1991, 1993a,b), R W Palmer & O'Keeffe (1990a,c), R W Palmer (1991), and Gale (1992). The objectives of the programme were the development of a predictive capability for the effects of impoundments on southern african rivers, the measurement of the intensity of those effects, and the estimation of associated "*recovery distances*" (**discontinuities**) for a wide variety of variables, based on the ideas of Ward & Stanford (1983a,b) - respectively, the *Serial Discontinuity Concept* (SDC), and the *Intermediate Disturbance Hypothesis* (IDH).

Table 2.2 lists the major attributes of each river, together with the physical attributes of the six study dams - two on the Palmiet and four on the Buffalo (Davies *et al.*, 1989; O'Keeffe *et al.*, 1990).

The Palmiet River rises in the Hottentots-Holland mountains within the Nuweburg State Forest Reserve. The headwaters are surrounded by the typical open canopy of the Mountain Fynbos of the region. The middle reaches flow through intensive fruit-farming areas and, before widening into its estuary, the lower reaches flow through a second reserve, the Kogelberg State Forest, which is under threat from a highly complex and controversial group of proposals to impound the lower reaches and elsewhere in the valley (see Rothmann, 1992).

The system is short (74 km), steep, clear, cool and acid, and the underlying geology consists almost exclusively of Table Mountain Sandstone (TMS) (Byren & Davies, 1989; Gale, 1992). The river is impounded five times within the first 40 km, mostly irrigation storages, but including a pumped-storage hydro-power scheme. Loosely controlled water abstractions include private irrigation and domestic water supply to the local towns. Of the five existing dams, two were extensively studied by Byren & Davies (1989), Davies *et al.*, (1989), and O'Keeffe *et al.*, (1990), in the context of their impacts, namely: the upper-reach Nuweburg Dam (P1), and Arieskraal Dam (P2) built on the mid/lower reaches. Both are bottom-release dams (Table 2.2). Eleven study sites above and below the two dams, and one on a pristine

**Table 2.2:** Physical attributes of the Palmiet and Buffalo river systems, and the six impoundments studied by the collaborative regulated rivers research programme of the Freshwater Research Unit (UCT), and the Institute for Freshwater Studies (Rhodes University) (After Davies *et. al.*, 1989)

| | BUFFALO | PALMIET |
|---|---|---|
| Catchment Size (km$^2$) | 1 230 | 500 |
| Length (km) | 140 | 74 |
| Stream order | 4 | 4 |
| MAR (10$^6$m$^2$) | 85 | 228 |
| Source altitude (m) | 1 300 | 1 133 |
| Number of dams | 4 | 5 |
| Rainfall | summer | winter |
| Turbidity | turbid | clear |
| pH | alkaline | acid |
| Temperatue | warm | cool |
| Pollution | severe (mid-reach) | mild (mid-reach) |

| | BUFFALO | | | | PALMIET | |
|---|---|---|---|---|---|---|
| | Maden B1 | Rooikrans B2 | Laing B3 | Bridle Drift B4 | Nuweburg P1 | Arieskraal P2 |
| Distance from source (km) | 8 | 12 | 66 | 109 | 8 | 35 |
| Capacity (10$^6$m$^3$) | 0.3 | 5.4 | 22.1 | 75.5 | 3.9 | 5.9 |
| Catchment area (km$^2$) | 31 | 48 | 913 | 1 176 | ? | ? |
| Altitude (m) | 525 | 518 | 310 | 109 | 500 | 200 |
| Release type (surface/bottom) | S | S | S | S/B | B | S/B |
| Compensation flow (yes/no) | N | Y | N | Y | Y | Y |

tributary of the Palmiet, were sampled between April 1986 and September 1987 in order to assess recovery distances for a variety of physico-chemical variables. In addition, between February 1987 and April 1988, the benthic communities at seven of these sites were sampled (Gale, 1992).

On the other side of the Cape, the Buffalo rises in virtually pristine, indigenous forest, and then flows through intensive agricultural land, before entering the urban/industrial complex of King Williams Town/Zwelitsha, and is impounded four times (dams B1-B4). Laing Reservoir (B3), immediately below Zwelitsha, receives very poor quality water, which is purified and returned to the towns. The lower reaches of the river are impounded at Bridle Drift (B4), and this reservoir supplies Mdantsane and East London. Sewage effluent from Mdantsane enters the river below the Bridle Drift Dam (B4), considerably reducing water quality. The system supplies 80% of the water requirements for a population of *ca* 730 000 - present demand is 53x106 $m^3$ $yr^{-1}$, while the four impoundments provide a firm yield of 57.7x106 $m^3$ $yr^{-1}$ (South African Department of Water Affairs, 1986). The river is therefore being exploited near to its sustainable limit, although an IBT from the neighbouring Great Kei River will augment the dependable yield by 36.1x106 $m^3$ $yr^{-1}$ (South African Department of Water Affairs, 1986).

These studies are unique for the continent from two angles. Firstly, they comprise *entire rivers*, from headwaters to estuary, and secondly, they were designed to allow for direct comparison. In terms of the impacts of regulation on the physico-chemistry of the two rivers, the major spatial findings are summarised for selected variables in Figure 2.4 (SRP, $NO_3$, $NO_2$, and $NH_4$), and Figure 2.5 (flow rate, spot temperatures, and annual temperature ranges), while Figure 2.6 summarises the *recovery distances* ("**reset**" - *sensu* O'Keeffe *et al.*, 1990), for each of these features, together with TSS, conductivity, pH and alkalinity, in relation to the operating criteria of each dam (Davies *et al.*, 1989; O'Keeffe *et al.*, 1990). The dendrogram in Figure 2.7 visually compares the two rivers, while Table 2.3 compares similarities and differences for ten variables which were measured for all dams on each system, listing qualitative similarities between pairs for each dam. (Note that Laing Dam is excluded from this last analysis because of its grossly polluted inflow - Davies *et al.*, 1989; O'Keeffe *et al.*, 1990).

Looking at the dendrogram illustrated in Figure 2.7 first, this clearly shows that the ***entire*** Palmiet system approximated to the ***upper 20 km*** of the Buffalo, both chemically and physically, with differences rapidly appearing as one progressed beyond this point on the Buffalo, owing to downstream mineralisation and industrial and urban pollution. As far as impacts are concerned, Figure 2.5 clearly shows **major impacts by all dams on each system**

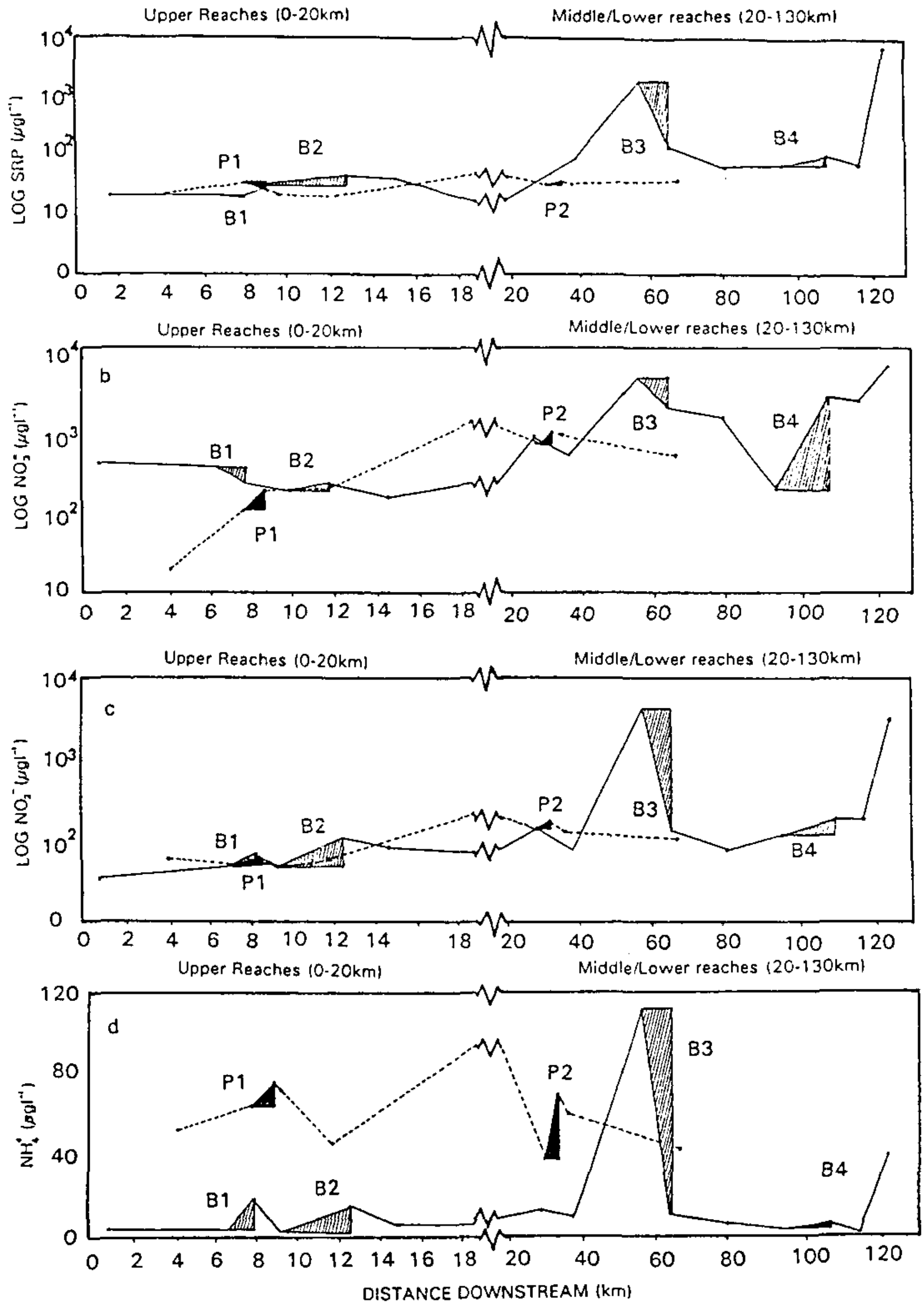



**Figure 2.4:** Spatial changes in the concentrations of (a), soluble reactive phosphate, (b), nitrate, (c), nitrite, and (d), ammonium along the lengths of the Buffalo (continuous line) and Palmiet (broken line) rivers. Note that (a), (b) and (c) have log-scale y-axes, while (d) is linear. Shaded triangles indicate the positions of impoundments, and dam walls on each system are represented by the vertical axes of the triangles. (After O'Keeffe *et al.*, 1990).

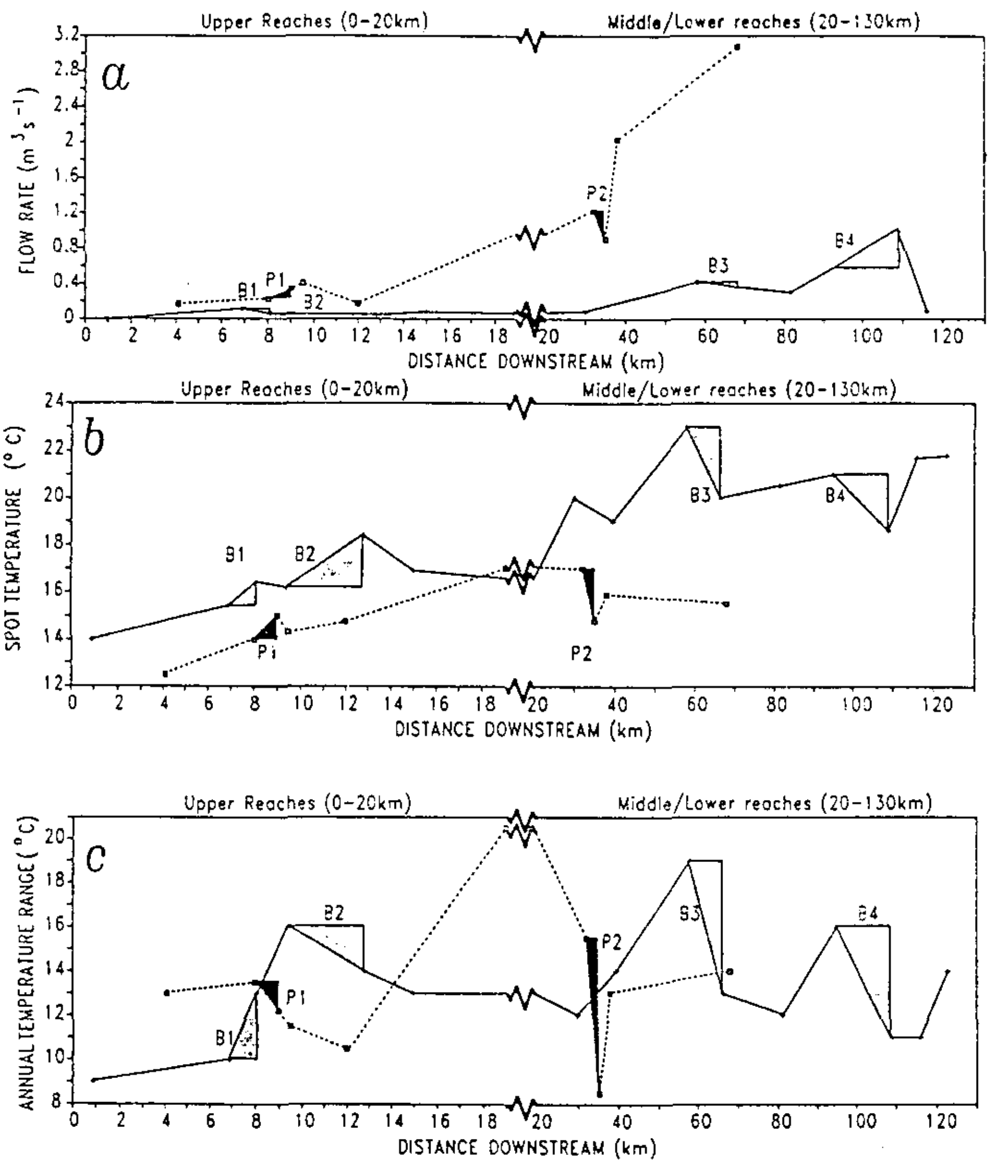



**Figure 2.5:** (a), Median flows ($m^3.s^{-1}$), (b), median spot temperatures, and (c), annual spot temperature ranges along the lengths of the Palmiet (dotted line) and Buffalo (continuous line) rivers. Shaded triangles indicate the positions of the impoundments and the dam walls are represented by the vertical axes of the triangles. (After Davies *et al.*, 1989).

for flow, median spot temperature, and upon the annual temperature range, particularly for dams regulating the upper reaches of both rivers. Interestingly, these upper-river impoundments *behaved similarly despite different release patterns* (Fig. 2.6), and caused only weak chemical effects, most of which recovered rapidly within 3 km (Fig. 2.6). Middle-reach

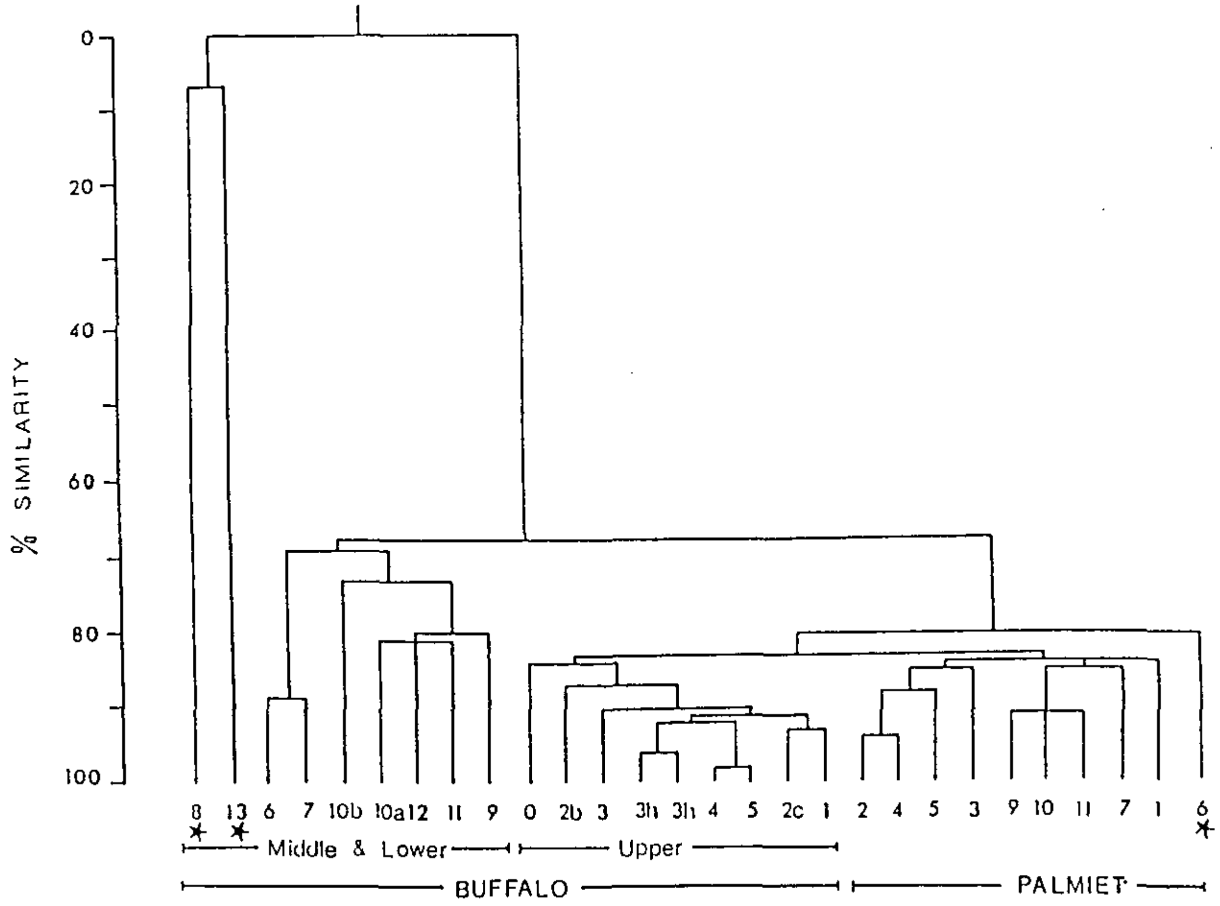



**Figure 2.6:** Similarity dendrogram of the physico-chemical variables measured in the Buffalo River, Eastern Cape, and the Palmiet River, South-Western Cape. Stars indicate polluted sites which are significantly different (particularly in the Buffalo River) from the other sites. Numbers (0-13 for the Buffalo and 1-11 for the Palmiet) refers to sample site numbers (increasing downstream). Positions of the sample sites are detailed in O'Keeffe *et al.*, (1990). (After Davies *et al.*, 1989).

impoundments *also behaved similarly despite different release characteristics* (Fig. 2.6), but they caused more pronounced changes, and recovery distances were longer (up to 30 km). These observations tend to contradict some aspects of the SDC, and other observed *exceptions* to its predictions include alterations to nutrient régimes of the receiving reaches below *all* dams (Fig. 2.6), as well as the already noted changes to annual temperature ranges. In addition, *all* impoundments on both systems significantly depressed flow fluctuations (Fig. 2.6).

Although the specific predictions of the SDC model were not generally borne out by this comparative study, the SDC may still be regarded as a useful tool for testing the effects of impoundments on rivers, and the concept of *"recovery, or reset distances"* forms a useful practical framework for the management of releases from impoundments. Ward & Stanford's (1983a) predictions were originally made for **natural rivers** (unperturbed), for which impoundment is the only artificial perturbation. The Buffalo River falls far outside this requirement, for although it is pristine in its upper reaches, it is grossly polluted in the middle reaches. For example, Laing Reservoir (B3), receives polluted water with SRP concentrations of up to a maximum of 9 mg $l^{-1}$, and $NH_4$ levels of up to 14.4 mg $l^{-1}$! Effectively, this reservoir acts as a giant settling tank, radically reducing SRP concentrations to a median concentration of 0.18 mg $l^{-1}$. The dam might therefore be seen as "resetting" the river, in a reversal of Ward & Stanford's (1983a) SDC. Thus, although the regulation of rivers by impoundment has traditionally been viewed by conservationists as a degradation of the river ecosystem, while this is true for unperturbed systems, the presence of Laing Dam on the Buffalo provides protection for the lower reaches from the worst of the upstream eutrophication. Indeed, the purification processes of the dam appear to be far more intense than for a comparable stretch of flowing water (R W Palmer & O'Keeffe, 1990a), and allow for considerable recovery to more acceptable conditions.

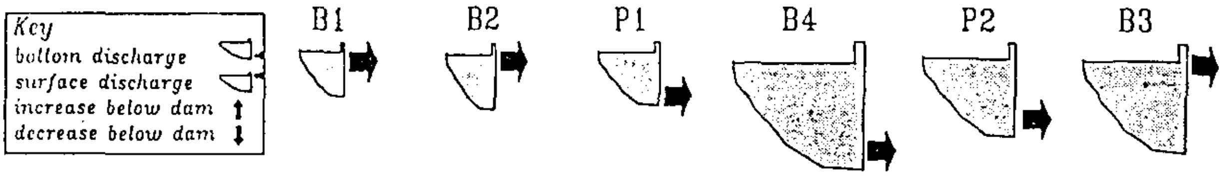
Finally, from this work, the research teams were able to make a number of important conclusions concerning the variables which were most likely to be important in governing the changes that take place downstream of any dam (e.g. Davies *et al.*, 1989; Table 2.3; Fig. 2.7):

1. there were no effects common to all six dams;
2. the position of any dam was of over-riding importance, governing the types of downstream effects, while perhaps surprisingly, the marked differences between the physical and chemical features of the two rivers appeared to have very little influence on the types of effects caused by impoundment;

**Table 2.3**: Similarities and differences in the effects of different dams on the Buffalo and Palmiet rivers. Ten variables were measured for all dams, and qualitative similarities between pairs and groups of dams are listed below; e.g. for dams B1 and B2, seven of the 10 variables showed similar changes above and below the dams. B3 is not included in the analysis, because it received polluted inflow and downstream responses were quiet different to the other dams. (After Davies *et. al.*, 1989).

| Grouping | Number similar (out of 10) | River | Common factors Size | Zone | Release |
|---|---|---|---|---|---|
| B4:P2 | 10 | | | lower | bottom |
| B1:B2 | 7 | Buffalo | small | upper | surface |
| B1:P1 | 6 | | small | upper | |
| B2:P1 | 6 | | small | upper | |
| P1:P2 | 5 | Palmiet | | | bottom |
| B2:P2 | 4 | | | | |
| B4:P1 | 5 | | | | bottom |
| B1:B2:P1 | 5 | | small | upper | |
| B4:P1:P2 | 5 | | | | bottom |
| B2:B4 | 4 | Buffalo | | | |
| B1:P2 | 2 | | | | |
| B1:B2:B4 | 2 | Buffalo | | | |
| B1:B4 | 2 | Buffalo | | | |
| B1:B2:B4:P1:P2 | 2 | | | | |

3. larger impoundments caused more intense downstream impacts, and these impacts took longer to recover;
4. release mechanisms were less important than the position of a dam along the river, but bottom-releases consistently reduced temperature ranges, increased TSS, and increased all nitrogenous compounds measured, and
5. reservoirs were more effective than equivalent lengths of flowing water, at "resetting" grossly polluted systems.




| | B1 | B2 | P1 | B4 | P2 | B3 |
|---|---|---|---|---|---|---|
| SPOT TEMP | ↑ | ↑ *2.2* | ↑ *p* | ↓ *7* | ↓ *3* | ↓ *p* |
| ANNUAL TEMP RANGE | ↑ | ↓ | ↓ | ↓ *p(14)* | ↓ *p(3)* | ↓ |
| TSS | | | ↑ *p(3)* | ↑ *p(7)* | ↑ *3* | ↓ |
| CONDUCTIVITY | | | | ↓ | ↓ *30* | ↓ |
| pH | | | ↑ *0.5* | ↓ *p(7)** | ↓ *30* | ↑ |
| ALKALINITY | ↑ *1.3* | ↑ | ↑ *3* | ↓ | ↓ | ↓ |
| SRP | ↓ *1.3* | ↑ *2.2* | ↓ | ↑ *p(7)* | ↑ *p(3)* | ↓ *r* |
| $NO_3$ | ↓ | | ↑ | ↑ | ↑ *30* | ↓ *r* |
| $NO_2$ | ↑ *1.3* | ↑ | ↑ | ↑ | ↑ *3* | ↓ *r* |
| $NH_4$ | ↑ *1.3* | ↑ *p(2.2)* | ↑ *3* | ↑ | ↑ *30* | ↓ *r* |

**Figure 2.7:** Summary of the effects of six impoundments (B1-B4, Buffalo: and P1-P2, Palmiet) on a variety of physico-chemical features of the receiving reaches downstream of each impoundment. Arrow directions indicate whether or not the variable increased of decreased. Numbers denote measured recovery distances in km, while "p" denotes partial recovery and denotes recovery during low-flow conditions. A blank space indicates no effect, while no number indicates that recovery distances could not be discerned. B3 receives polluted inflow and acts as a "settling pond" in the river (see text) so, although recovery distances are not relevant, the river is "reset" ("r") *in terms of the effects of the impoundments* upon the major nutrients. (After Davies *et al.*, 1989).

# 2.3 POTENTIAL DAM SITES WITHIN THE SABIE-SAND SYSTEM

## 2.3.1 EXISTING AND POSSIBLE NEW DAMS

There are at present 7 dams on the Sabie-Sand system, although one of them - the Zoeknog Dam, has collapsed and presently forms no barrier to water flow. The Edinburgh, Orinoco, Acornhoek, and Casteel Dams are all small (1.1 to 3.3 x $10^6$ $m^3$) dams in the upper tributaries of the Sand River. The Da Gama Dam is a medium-sized dam (14.3 x $10^6$ $m^3$) on the White Waters tributary of the Sabie River. The Corumana Dam is a very large impoundment (1200 x $10^6$ $m^3$) on the Sabie River in Mozambique, which backs up to the eastern border of the Park.

The upper dams all have the effect of reducing runoff to the KNP, but if we can extrapolate from the previous studies of the effects of dams on rivers in other parts of South Africa, then they are too small and too remote from the Park to have significant effects on the water quality, temperature regime, sediment transport and species composition in the main rivers within the Park boundaries. Any such effects will have recovered within a few kilometres downstream of the dam wall. The Corumana Dam, downstream of the Park, represents a major barrier to upstream migration of fish such as the Tigerfish, and may be the main reason for the scarcity of this species in the Sabie within the Park.

Seven potential new dam sites have been identified on the Sabie and Sand Rivers: Arthur's Seat, Dingleydale, and an enlargement of the Casteel Dam, are all sites situated in the upper reaches of the Sand system, and would be 14, 59, 73, and 39 x $10^6$ $m^3$ respectively. Two potential sites have been identified on the Marite tributary of the Sabie River: the Inyaka site (101 x $10^6$ $m^3$), and the Waterval site (109 x $10^6$ $m^3$). The Madras site is larger (230 x $10^6$ $m^3$), and is situated on the main Sabie River only some 5 km. from where the river joins the western KNP boundary.

## 2.3.2 POTENTIAL EFFECTS OF THE DAMS

### *2.3.2.1 FLOW*

The effects of any of the potential new dams on flow would be crucially dependent on how they are managed. If they are to be built with multi-level outlets, and managed so as to release compensation water to the KNP they could potentially have the beneficial effect of using stored water to augment low flows during droughts. In the worst-case scenario, in which no compensation flow was to be released, any of the proposed dams could at least intercept all the low-flow in their own particular tributary during drought years. The Sand River already stops flowing during most years, and the effect of any of the planned impoundments, although they are not on the main stream, would be to increase the period of no-flow. The Madras site is the only proposal which would dam the main Sabie, and could potentially reduce the flow in the Sabie to less than 20% of its virgin MAR (O'Keeffe and Davies, 1991). This would turn the Sabie into a temporary river, in which low-flows would be completely intercepted for five months of most years. Such a scenario is unlikely, and a Madras Dam, properly managed, holds the greatest potential for augmenting low flows in the Park, since it is the largest of the proposed dams, and the nearest to the Park.

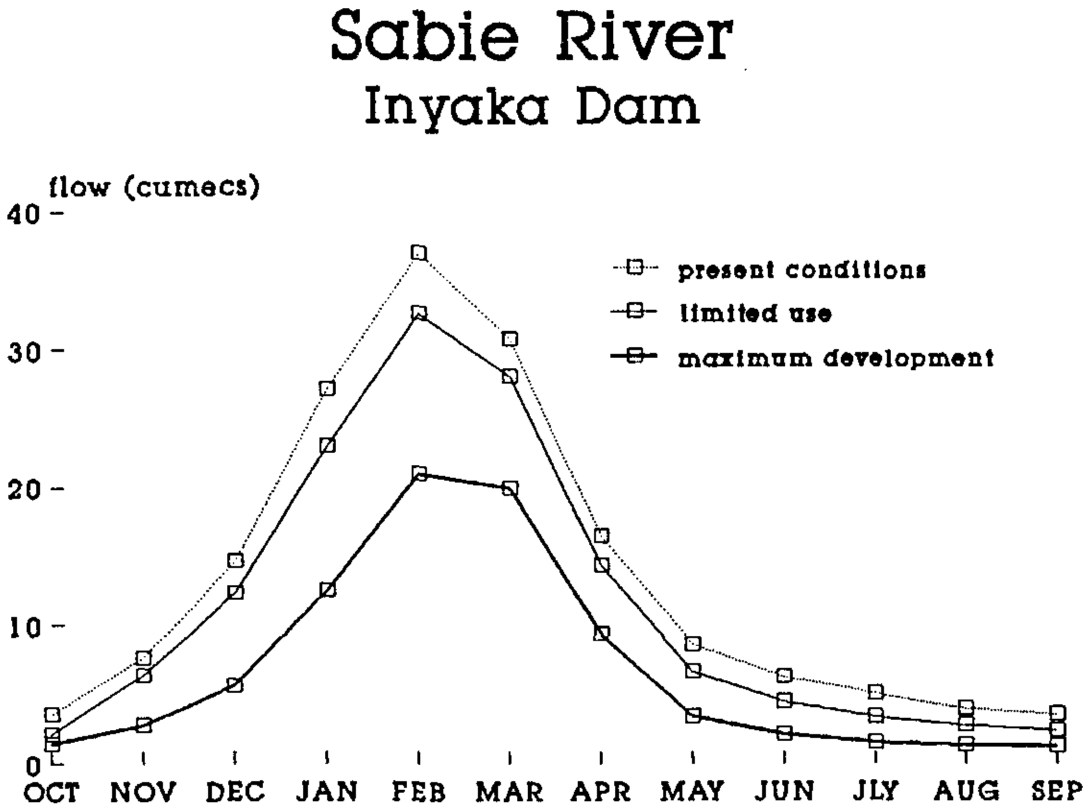



**Figure 2.8:** The effects of the Inyaka Dam on the average mean monthly flow, using Pitman Simulations, for the mid-Sabie River, above the Sand River confluence. With limited use both high and low flows within the Sabie River are affected, low-flows are reduced by almost 50%. Flow reductions within the lower Marite River will be much more marked. Under maximum development, high flows in the Sabie River are markedly reduced while low-flows rely on the upper Sabie alone. The Marite River would be dry for some four months (July-October).

**Developing Inyaka Dam:** The most likely of the dam sites to be developed is the Inyaka site on the Marite tributary, and a detailed examination of the environmental consequences of different management options on this dam was made by the project team in association with Chunnett *et al.*, (O'Keeffe and Davies, 1991). Pitman simulations were run to investigate the effect of the dam on downstream flows. The Inyaka Dam used to its maximum extent would reduce flow in the Sabie in the KNP to less than 40% of its virgin runoff in all years during the dry months (September and October) (Fig. 2.8). During dry years, runoff would be reduced to less than 20% of virgin conditions, and the Sabie River

**Table 2.4:** The effects of the Inyaka and Madras dams on mean monthly peak and base-flows within the Marite and mid-Sabie rivers. Monthly flow data derived from Pitman Simulations.

| DAMS | MANAGEMENT | BASE FLOWS ($m^3/s$) | | PEAK FLOWS ($m^3/s$) | |
|---|---|---|---|---|---|
| | | mid-Sabie | Marite | mid-Sabie | Marite |
| No dams | Present development | 3.5 | 2.1 | 37.1 | 16 |
| Inyaka Dam | Limited use | 2.7 | 1.3 | 31.2 | 10.1 |
| | Maximum use | 1.4 | 0 | 21.1 | 0 |
| Inyaka & Madras dams | Limited use | 2.3 | - | 21.7 | - |
| | Maximum use | 0.05 | - | 18.8 | - |

could stop flowing altogether during droughts. Mid-Sabie River peak flows would on average be reduced by 50%, while base-flows would approximate those seen during the 1990/91 drought (1.4 $m^3$ $s^{-1}$; Table 2.4). Such conditions would be undesirable from everyone's point of view, and a compromise flow management plan was proposed after a number of simulation scenarios were examined. This plan, known as the "Inyaka Dam - Limited use scenario", would require a compensation flow to be released from the dam which would ensure that the flow in the KNP would never be allowed to fall below un-impounded worst drought conditions. In addition, there would be gradual increases in compensation flow with increases in the inflow to the Dam. As a result, lowest flows would be a rare event, unlikely to occur in consecutive years, and the natural variability of the river flows would be maintained. This scenario, described in detail by O'Keeffe and Davies (1991) (Fig. 2.9), would result in nearly natural flows in wet months during wet years, and flows between 40 - 60% of virgin condition in both wet months during drought years, and dry months during wet years. During the critical dry months during drought years, flows in the Park would be between 20 - 40% of virgin conditions.

The capacity of the Inyaka Dam exceeds the average MAR of the Marite River, potentially holding back both base and peak flows with maximum use. Consequently, the downstream effects of the Inyaka Dam on the Marite River would be extreme compared the those expected for the mid-Sabie River reaches, even with limited use (Table 2.4).

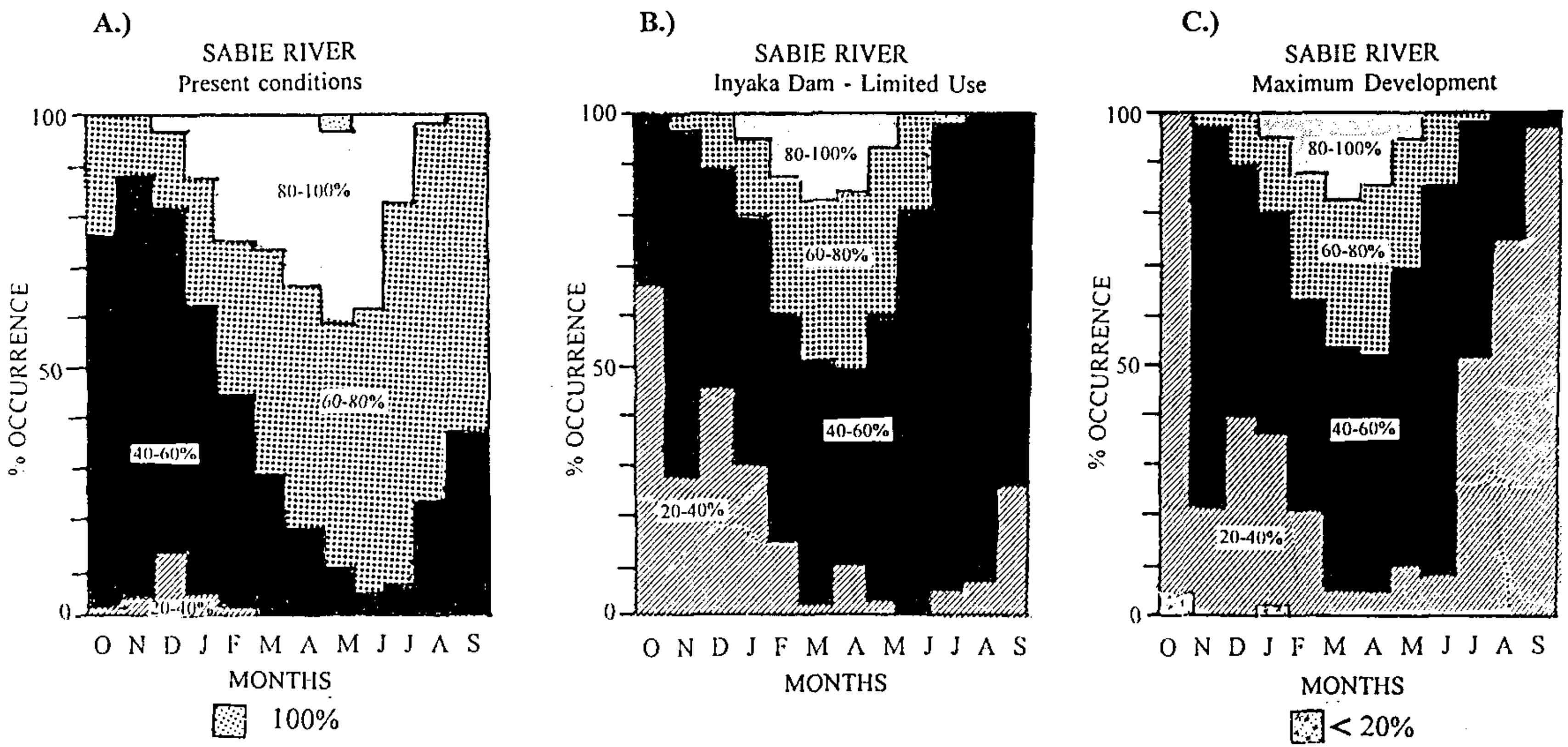



**Figure 2.9:** Monthly discharge patterns in the Sabie River upstream of the Sabie-Sand confluence, under present (a), and regulated by the Inyaka Dam. Conditions under limited (b) and maximum use (c) are given. Discharge patterns are expressed as percentage of natural discharge. (Adapted from O'Keeffe and Davies, 1991).

**Developing the Inyaka and Madras dams:** The Inyaka and Madras Dams together, as a worst case scenario, could potentially regulated the Sabie River completely, reducing peak

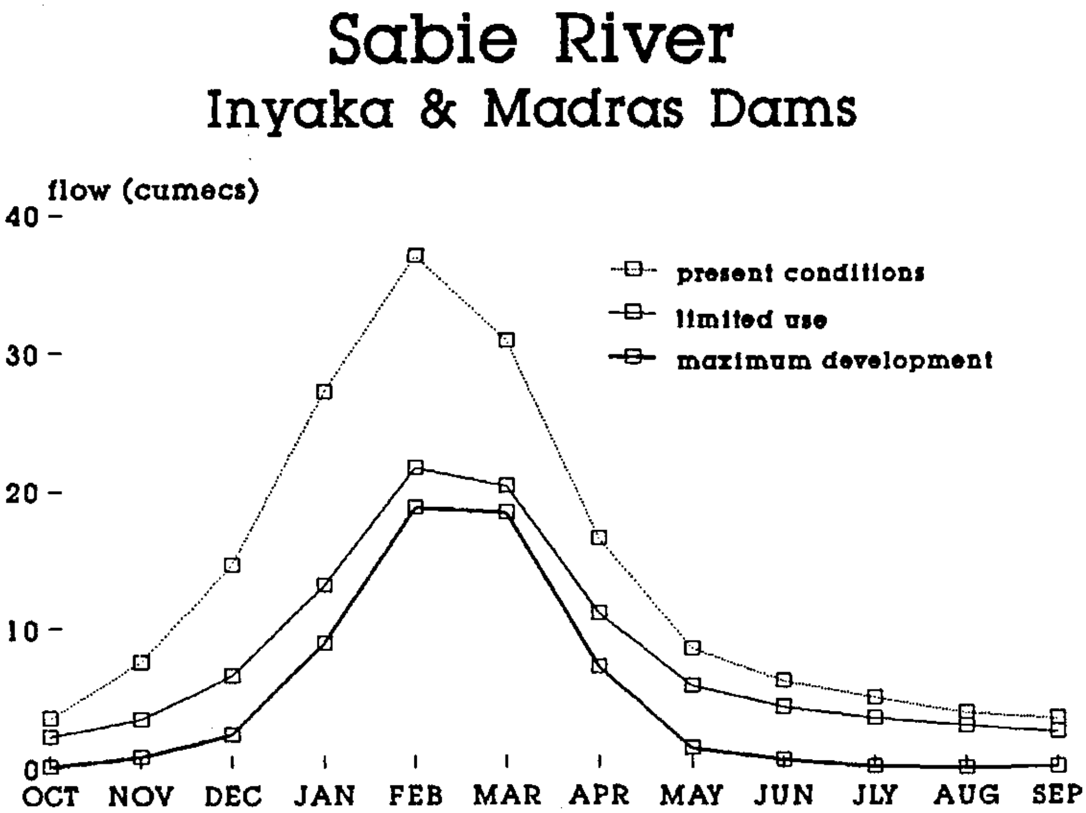



**Figure 2.10:** The effects of the Inyaka and Madras dams on the average mean monthly flow, using Pitman simulations, for the Sabie River immediately above the Sand River confluence. Different management scenarios are shown. The effects on high flows are marked for both limited and maximum use scenarios. Baseflows are healthy in the mid-Sabie River with limited use but they could be stopped for some 4 months with maximum use.

summer flows to similar levels seen with the Inyaka used at maximum capacity (Fig. 2.10). Together they stop flow in the mid-Sabie reaches if no compensatory baseflows were allocated (Table 2.4).

### 2.3.2.2 *THERMAL IMPACTS*

The main effects of impoundments on downstream temperature regimes is to reduce the variability, releasing warmer water in winter and cooler water in summer. The extent of these effects depends on the size of the dam, its position in the river, and whether the water is released from the surface or bottom of the dam. Studies on the Palmiet and Buffalo Rivers (see Section 2.2.1 above), indicated that median temperatures immediately below small dams in the upper reaches of the rivers increased by up to 8°C, but were reduced below larger impoundments in the lower reaches, especially from bottom release outlets. Maximum temperatures were reduced by as much as 16°C by these dams (Palmer and O'Keeffe, 1989). A review of impoundment studies worldwide revealed a log-normal relationship between river discharge and the distance downstream before temperatures recovered (Palmer and O'Keeffe, 1989). This is useful because it allows us to make predictions of the extent of thermal disturbances to be expected from the potential new dams, and the recovery distances. The sites in the upper Sand River and the Marite are likely to cause significant temperature increases downstream, but these should recover within 20 km at the most - well before the water from these dams reaches the Park. The Madras Dam, if it were to be built and operated with a bottom release valve only, would have a major effect of reducing temperatures downstream, possibly by as much as 18 - 20°C, and this effect would extend well into the Park, perhaps for as far as 40 km. Such an effect would have far-reaching consequences for the riverine biota, and would exclude, for example, most of the lowveld fish community.

These effects can be minimised with some planning at the design stage. A dam with a multi-level outlet would allow for water to be released from the surface, or, should this elevate temperatures unacceptably, mixed releases could be arranged from several levels so as to mimic the inflowing temperature.

### 2.3.2.3 *SEDIMENT AND TURBIDITY*

Dams are efficient sediment traps and will intercept almost all of the suspended sediment larger than clay particle size in the river. However, water released from the bottom of a dam wall will re-mobilise sediments and may drastically increase turbidity and suspended sediment downstream. If the sediments at the base of the dam wall are anaerobic, the consequences for the biota downstream may be disastrous. In the Buffalo and Palmiet Rivers the suspended sediment load was increased below bottom-release impoundments from an average of 4.2 to 6 mg $l^{-1}$ below a dam on the Palmiet, and from 31 to 41 mg $l^{-1}$ in the case of the more turbid Buffalo River. Only partial recovery was measured in both cases, at least for the first 7 km downstream. These results imply once again that significant effects would only be felt in the KNP if the Madras Dam were to be built, and that the worst of these effects could be prevented by the incorporation of multi-level outlets in the Dam.

### *2.3.2.4 BIOLOGICAL IMPACTS*

**Ichthyofauna:** Both the Marite and mid-Sabie Rivers below the proposed dams are highly seasonal in flow (Figs 2.11 & 2.12) and perennial, but their fish assemblages are characteristically different. The Foothill Zone assemblage (FHZ) of the Marite River is aseasonal, and dominated by the catlet *Chiloglanis anoterus* (Fig. 2.11). The Lowveld Zone (LZ) assemblage of the mid-Sabie River is seasonal, dominated by cichlids in the early summer season and by cyprinids soon after the first summer rains, up until the end of the winter dry season (Fig. 2.12). These assemblages are expected to respond differently to impoundment. Differences between the fish typical of both the FHZ and LZ reaches are best explained by evolutionary adaptation to differing water temperature and flow conditions between the more stable mountain source and the drought prone lowland reaches.

Fishes of the Marite River persist in cooler, high energy source waters of the FHZ reaches, and may be expected to be more susceptible to alterations in flow. Of the 19 species recorded (Table 7.3, Volume 1), 6 have been identified as indicative of the FHZ baseline assemblage (Fig. 7.7, Volume 1) which is dominated by the riffle-loving catfish *Chiloglanis anoterus*. Cichlids, which prefer backwaters, are under-represented, while 4 cyprinids making up 15-38% of the catch (59-81% : Fig. 2.11). Throughout the year, the proportions of these groups of fish remain relatively constant (Fig 2.11).

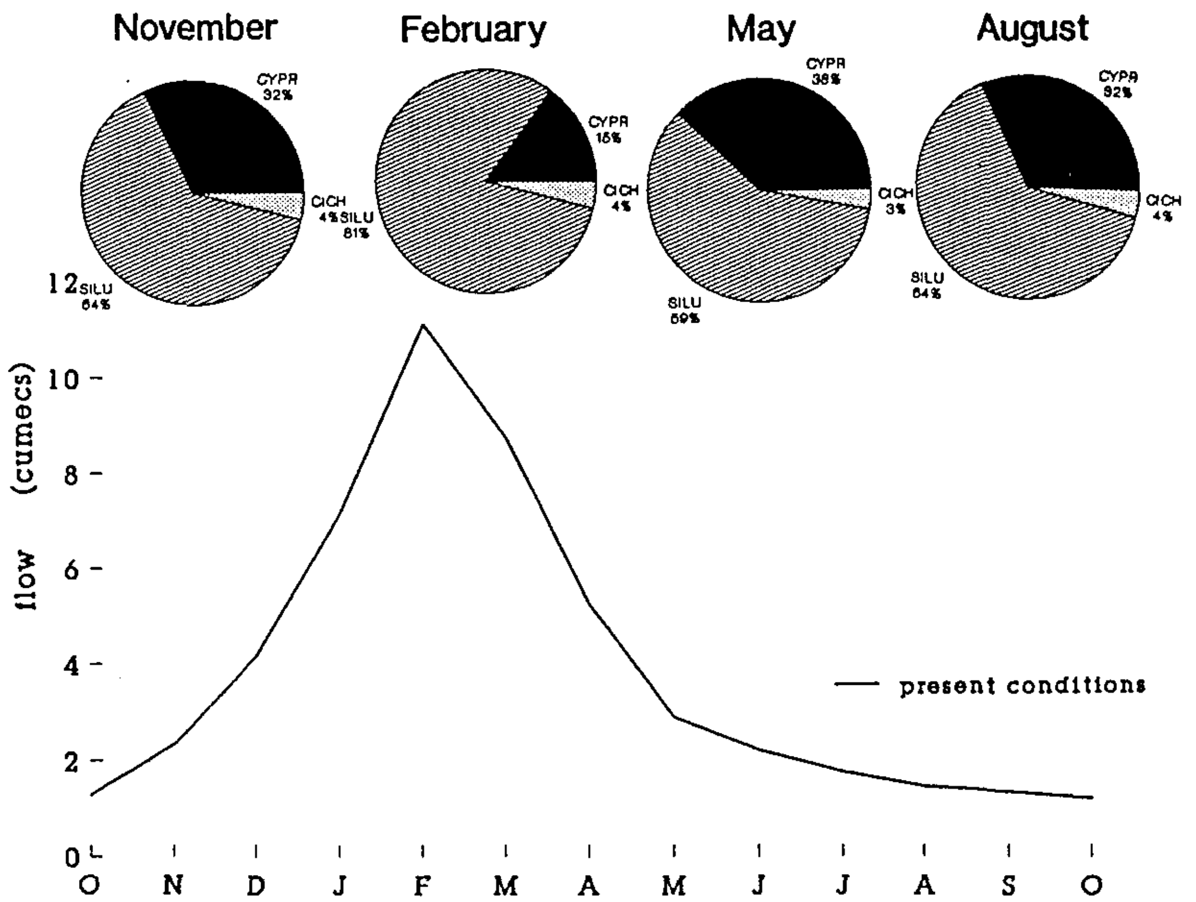



**Figure 2.11:** Changes in the relative abundance in the Foothill Zone (FHZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species makeup and response see Figure 7.7 (Volume 1). Silurids, cichlids and cyprinids do not vary greatly with season, besides an increase in February of *Chiloglanis anoterus* and a shift within the species makeup of the cyprinids. *C.anoterus* dominates the assemblage in all seasons (59-81%). Cichlids are characteristically poorly represented (3-4%) while cyprinids make up 15-32% of the catch.

In contrast, the mid-Sabie River LZ reaches support 30 species (Table 7.2, Volume 1) in warm, more placid waters. Here 11 species are indicative of the baseline assemblage (7.8; Volume 1), with cyprinids dominating the assemblage for roughly 75% of the year and cichlids dominate only in early summer (25%). The dominance of cichlids in November is explained by their early, rain-independent, summer breeding. The highly fecund cyprinids only commence breeding with the onset of the seasonal summer-rains, when their number

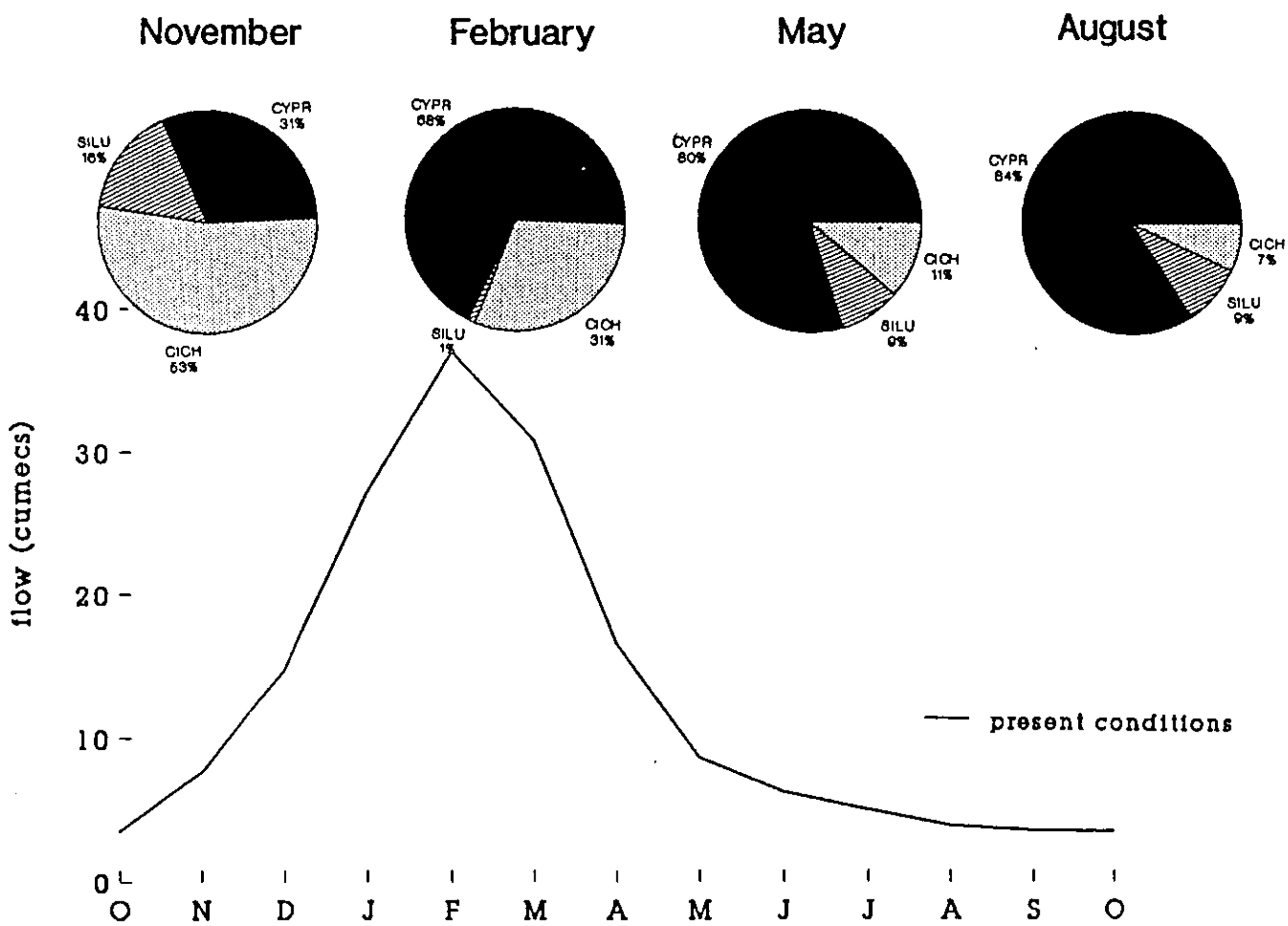



**Figure 2.12:** Changes in the relative abundance in the Lowveld Zone (LZ) of major fish groups; cichlids, silurids and cyprinids throughout a year of average flow, under present conditions. For details of individual species see Figure 7.8 (Volume 1). By early summer (November), cichlids have bred independently of the first rains increasing from 7 to 53%. By February and at the height of the seasonal rains, cyprinids have increased from 31 to 58%. During the dry winter season, no breeding takes place while recruitment of the numerous young-of-the-year swell cyprinid numbers (84%).

again increase. During the dry, winter season (May-August), no fish breed, but cyprinid numbers increase further with the recruitment of many young-of-the-year into the population. Should the summer rains fail, (or impoundment drastically reduced summer flows), cichlids alone would breed, effectively locking the LZ assemblage into "November" proportions. This condition will persists through the dry season, presumably until the first summer rains.

**Inyaka Dam:** The 101 $hm^3$ Inyaka Dam could effectively totally regulate the Marite River because its capacity, which is greater than the total annual runoff for the sub-catchment (runoff = 79.6 $hm^3/a$; Chunnett *et al.*, 1990). The Inyaka's effects on the biota, particularly the ichthyofauna, are further complicated by the very different composition of, and response expected between both the FHZ and LZ species.

The Marite remains the premier cool-species river, having never been impacted by early mining pollution and supporting very healthy populations of FHZ species. *Barbus argenteus* and *Amphilius natalensis* were only collected within its reaches during the present survey and the regionally endemic minnow *Barbus brevipinnis* is particularly common here. *Amphilius uranoscopus* is the fourth species with limited range, found occasionally in the lower Marite.

**a) Limited use;** With limited use, as discussed in section 2.3.2.1, the lowveld mid-Sabie River biota would suffer limited effects as the river would remain perennial and the temperature effects associated with the Inyaka Dam, are far enough upstream to have recovered. The seasonal fish assemblages could be expected to mirror those discussed (Fig. 2.12).

The dam's potential effects on the lower Marite and its biota are much more profound. Even with limited use, peak summer flows and baseflows would be markedly reduced while temperature may be elevated. The aseasonal FHZ baseline assemblage (Fig 2.11) may respond as with the passage of the 1991-92 drought in the Sabie River where flows were severely reduced, and temperatures were higher (site 5). Changes in fish abundances within the FHZ with reduced flow were complex and possibly reflect changes in depth, flow microhabitat needs and temperature tolerances. The ultimate effect on the typical species assemblages, should these conditions have persisted, are not known. The rock catlet *C.anoterus*, was greatly reduced (60-19%, Fig. 7.11; Volume 1) possibly because of failing flow microhabitat requirements, while 3 of 4 cyprinids and the only cichlid *Tilapia sparrmanii* increased in proportion. Cool-water *Barbus polylepis* was reduced in number while the eurythermal *Barbus marequensis* increased. It was not known whether increases in *B.marequensis*, which was greatly reduced in LZ reaches, were because of upstream movements.

**b) Maximum use;** Summer peak flows in the mid-Sabie River would be markedly reduced under maximum development and baseflows would be reduced to levels typical of the 1991-92 drought. Although summer flows would not be completely eliminated, the dampening-off of flushing flows typical of rain events would have real effects, possibly reducing the success of many of the summer rain-dependent cyprinids and other species that show event driven local-movements. The seasonal LZ fish assemblage (Fig. 2.12) would be expected to change qualitatively, possibly stabilizing with a higher proportion of cichlids present.

The Marite River under maximum development conditions will be greatly impacted with both drought condition through the year, and flow stoppage through very extended periods. The effects of such extreme regulation within the FHZ reaches, on the fish fauna, would almost certainly be catastrophic. The dominant but flow-sensitive *C.anoterus* would be lost from the downstream reaches as would *A.uranoscopus* and *A.natalensis*. These species are not expected to survive in isolated pools where poor water quality, specifically low oxygen levels, is common. With reduced or no-flow conditions, temperature increases would further exclude FHZ species, effectively moving the FHZ/LZ transition upstream. The drought tolerant *O.mossambicus*, and "weedy species", typical of standing warmwater reaches, may extend their ranges.

**Inyaka & Madras Dams:** This, the most extreme of the possible scenarios would have the most extensive effects on the biota. If the 109 $hm^3$ Madras Dam was built on the Sabie River, it together with the Inyaka Dam, would largely regulate the mid- and lower Sabie reaches.

**a) Limited use;** The Madras Dam, in combination with the Inyaka, would have marked effects of the LZ biota, even with the limited use proposed. Summer peak-flows would be reduced to levels calculated for the Inyaka under maximum development, with similar effects on the fish fauna, while the allocations for the KNP would effectively provide a constant baseflow of some 2.3 $m^3.s^{-1}$. Although the stability of baseflows would prevent the extreme changes monitored over the drought, changes within the LZ reaches are likely because of the reduced summer peak-flows, particularly because the daily flow variations, or flushing flows utilized by many seasonal breeding species, will be attenuated.

As discussed (section 2.3.2.1), the release of baseflow from a dam of this size may well effect the temperature regimes for many kilometres downstream, particularly depending on the level of release. Because the Madras Dam lies close to the natural interface between the distinct fish faunas of the FHZ and LZ, a reduction in temperature will probably alter species distributions convincingly. Although this could arguably extend the range of the FHZ species into the park, this is unlikely because; a) source reaches would be reduced due to the impact of the Inyaka Dam on the lower Marite River, and b) the long-term consistency of such a management option is unrealistic.

**b) Maximum use;** The fish fauna of the mid-Sabie River, under maximum regulation, would be greatly impacted. Although summer peak-flows would only be exploited marginally more, it is the baseflow which would suffer most. The Sabie River could be effectively reduced to a temporary system. The characteristic LZ fish seasonal fish assemblages seen in figure 2.12 would initially resemble those seen in the Sand River during the 1991-2 drought (Fig. 7.12; Volume 1). Cichlids would dominate throughout summer and then through the dry season. Depending on the period that flow in the reach would cease, the drought tolerant LZ fishes would persisted. Volume 2 documents the decline of drought pools in the LZ reach over a five month period. Not all species are able to withstand and no-flow conditions. Both *C.anoterus* and *O.zambezense* would be lost immediately. With extreme drought, even the cichlid *Tilapia rendalli* proves sensitive. Unlike the drought effects monitored in 1991-92, changes due to regulation are more permanent, and under continual maximum use, recovery would not be possible. In this scenario, the fish fauna of the LZ would be radically altered, possibly permanently locked into a drought pattern with cichlids dominant and with species like *Labeo congoro*, *Labeo rosae*, and the mormyrids reduced to remnant populations and many of the minnows reduced in importance (*B.unitaeniatus*, *B.viviparus;* Table 7.7; Volume 1).

**Construction and filling:** The regulatory effects on the biota of dams in operation have been discussed for differing scenarios of flow usage. Recognising the effects of construction on water quality, particularly the release of elevated sediment loads, and the filling of the dam is crucial. During the construction of the Zoeknog Dam, the rock-catlet *C.anoterus* was reduced by 75% within the reach immediately downstream of the construction site (station 25). Here turbidities of 1300 NTU (0.85 g/l suspended sediment) were recorded following a local spate. Although these results are affected by the passage of the 1991-92 drought, they hint at the effects elevated sediments can have on the biota. The Inyaka Dam would, like the Zoeknog, be built in the cool and clear-watered reaches of the Marite River within the FHZ where the largely endemic *C.anoterus* is dominant. The effects of elevated turbidities associated with the construction of the Madras River may be less critical, as natural events within the drylands of the lowveld can produce runoff with exceptionally high turbidities.

The manner in which the dams are filled is also of importance especially when their relative size is taken into account. The Inyaka Dam could intercept all the flow for more than an average year before any overflow would be expected. If the ecological requirements of the riverine biota are to be managed, flow quotas need to be set before the gates are closed!

# 2.4 ZOEKNOG DAM

## 2.4.1 BACKGROUND

The Zoeknog Dam is the smallest of the eight potential impoundments planned for the Sabie-Sand system and is the first of two to be commissioned to date. Construction had started by early 1991 and neared completion by the end of 1992. The dam was 29% full when it failed with the first rains of the 1992-93 wet season in the early hours of Monday, 25 January 1993. Approximately $3x10^6$ $m^3$ of water and an estimated $0{,}2x10^6$ $m^3$ of earth was discharged into the Mutlumuvi River over a few hours (Plate 1a). The peak flow rate was estimated to equal a 1:10 year flood, with the event still evident two hour later (Erasmus *pers comm.*).

## 2.4.2 STATUS OF THE AQUATIC ENVIRONMENT PRIOR TO CONSTRUCTION

Interpreting the unquestionable effects of the Zoeknog Dam on the Sand River is problematic as the system suffered the worst drought on record during the construction phase.

### *2.4.2.1 PRE-DROUGHT*

Prior to dam construction and the 1991-92 drought, the Mutlumuvi and Sand Rivers below the Zoeknog Dam were in a good condition (Plate 1b). Water quality was unexceptional (Table 2.5) with pH neutral (7.7-8.7), and conductivity (20-120 µs/cm), turbidity (8-23 NTU) and total suspended solids (TSS) (0.025-0.266 g/l) low. Flow had not ceased for some years in the middle Sand River reaches, while the LZ tributaries closer to the escarpment remained perennial, and acted as refuges.

In May 1991, fish were diverse and numerous in the Sand River sub-catchment (Table 2.6). Fishes were abundant both below Zoeknog Dam site in the FHZ (site 25: 11 spp; CPUE of 7.2 fish/min) (Fig. 2.13), and at the LZ sites on the Mutlumuvi (site 19: 19 spp; CPUE of 8 fish/min) (Fig. 2.14 & 2.15) and mid Sand rivers (site 14: 15 spp; CPUE of 6 fish/min).

**Table 2.5:** Selected physico-chemical results for sites relevant to the interpretation of the effects of the Zoeknog Dam burst.

| STATION | DATE | OXYGEN % sat | COND. µs/s | pH | TURB. NTU | TSS g/l | FLOW m³/s |
|---|---|---|---|---|---|---|---|
| ZOEKNOG | MAY 91 | 106 | 60 | 7.7 | 23 | 0.146 | 0.407 |
| | 24 AUG 91 | 116 | 60 | 8.7 | 8 | 0.075 | 44.5* |
| | 11 NOV 91 | 105 | 80 | 8.2 | 23 | 0.096 | 27* |
| | 4 FEB 92 | 90 | 80 | 7.5 | 1300 | 8.5 | 31.2* |
| | MAY 92 | 106 | 80 | 7.6 | 150 | 1.136 | 0.0183 |
| | 2 FEB 93 | 112 | 60 | 7.5 | 580 | 5.86 | - |
| (above dam) | 2 FEB 93 | 107 | 50 | 7.7 | 2 | 0.056 | - |
| NEW FOREST | NOV 90 | 118 | - | 8.7 | - | 0.266 | 0.0575 |
| | MAY 91 | 100 | 70 | 7.9 | 10 | 0.025 | 0.1363 |
| | MAY 92 | 109 | 100 | 8.4 | 15 | 0.057 | 0.0097 |
| | NOV 92 | 119 | 220 | 9.2 | 12 | 0.124 | 0.0001 |
| | 2 FEB 93 | 93 | 80 | 7.2 | 261 | 3.867 | - |
| LONDOLOZI | MAY 90 | 106 | - | 8.1 | - | 0.057 | 0.339 |
| | MAY 91 | 114 | 120 | 8 | 9 | 0.024 | 0.329 |
| | MAY 92 | 94 | 180 | 7.9 | 23 | 0.062 | 0.0022 |
| | 11 DEC 92 | 110 | 420 | 7.4 | 28 | 0 | 0.0007 |
| | 27 JAN 93 | - | 90 | 6.9 | 1900 | 2.65 | 4.644 |
| | 29 JAN 93 | 93 | 100 | 6 | 647 | 6.38 | 2.606 |
| | 3 FEB 93 | 100 | 130 | 7.7 | 172 | 0.86 | 1.402 |
| POOL 2B (offstream) | 3 FEB 93 | - | 100 | 8.1 | 738 | 9.136 | ZERO |
| POOL 1A (offstream) | 3 FEB 93 | - | 120 | 8.2 | 272 | 1.975 | ZERO |
| ROOIBOKLAAGTE | MAY 90 | 104 | - | 7.8 | - | 0.002 | 0.2571 |
| | MAY 91 | 95 | 70 | 7.7 | 5 | 0.026 | 0.109 |
| | MAY 92 | 95 | 90 | 7 | 9 | 0.028 | 0.0056 |
| | NOV 92 | 100 | 140 | 7.5 | 13 | 0.068 | 0.1434 |
| SAND RIVER (KNP) | 3 FEB 93 | 105 | 140 | 7.6 | 192 | 1.1 | - |
| (offstream pool) | 3 FEB 93 | 34 | 100 | 7.5 | 1020 | - | ZERO |

* *flow reading, cm on gauge plate at weir below Zoeknog dam.*

**Table 2.6:** Species number recorded at stations between May 1990 and May 1993.

| | SPECIES NUMBER | | | | | |
|---|---|---|---|---|---|---|
| STATION | MAY 90 | MAY 91 | MAY 92 | NOV 92 | JAN 93 | MAY 93 |
| ZOEKNOG | - | 11 | 8 | - | 6 | 5 |
| NEW FOREST | 12[1] | 19 | 16 | 14 | 5 | 8 |
| LONDOLOZI | 8 | 15 | 18 | 11[2] | 10 | 11 |
| ROOIBOKLAAGTE | 16 | 11 | 15 | 8 | - | 12 |

[1] = Nov 90
[2] = Dec 92

ZOEKNOG

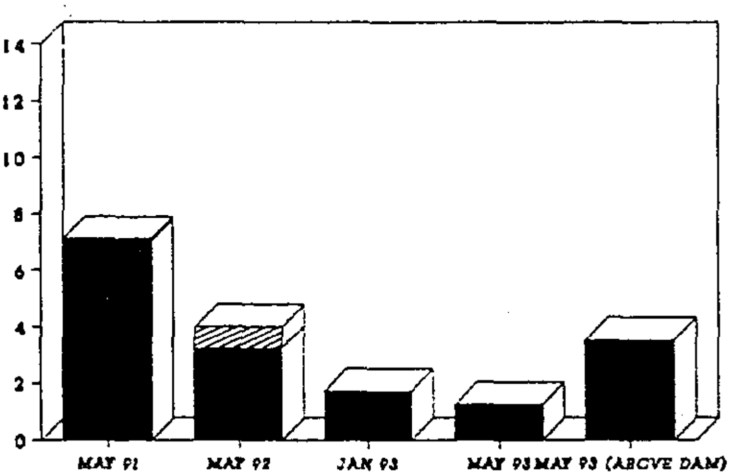



**Figure 2.13:** Catch per unit effort (CPUE) for fish below the Zoeknog dam site between May 1991 and May 1993 and above the dam for May 1993. Fish grouped as lotic (solid bars) or lentic (hatched bars) breeders (see text). Between May 1991 and 1992 and during construction, total CPUEs decreased from approximately 7 to 4 fish per minute. By January 1993, post dam failure, CPUEs were recorded as less than 2 fish per minute while lentic species increased with backwater species absent from the reach. CPUE had not recovered by May 1993, being less than half those recorded immediately above the dam.

The pennant-tailed rock catlet *Chiloglanis anoterus* dominated the FHZ assemblage (Fig. 2.16; CPUE 4.7) immediately below the dam site while the minnows *Barbus eutaenia* and *Barbus brevipinnis* (CPUEs of 0.9 and 0.6 respectively) were also important here. At New Forest 6

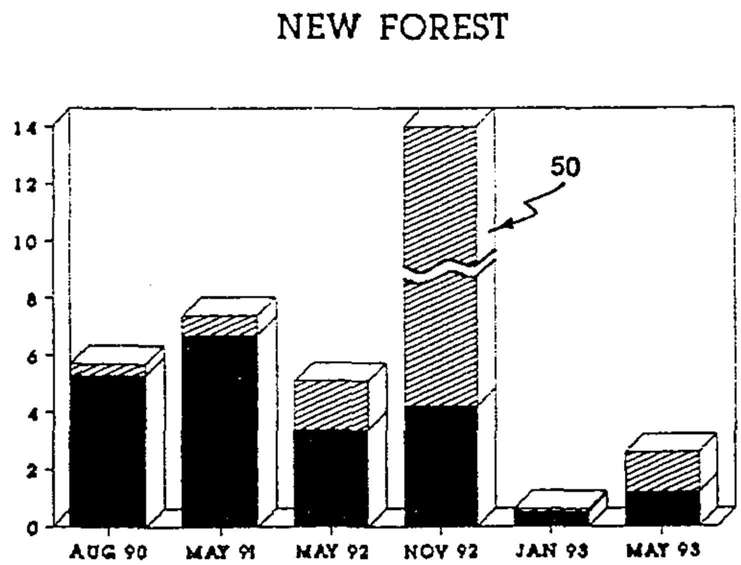



**Figure 2.14:** Catch per unit effort (CPUE) for lotic (solid bars) and lentic fish (hatched bars) between August 1990 and May 1993 at New Forest on the Mutlumuvi River, some 16 km downstream of the Zoeknog Dam. CPUEs between 6 and 7 fish per minute were obtained with a slight decrease over the summer of 1991-92. By the end of the dry season (November 1992) the CPUE had increased considerably. This was attributed to an explosion of the lentic breeder *Oreochromis mossambicus* in drought conditions. The post-dam flush in January 1993 drastically reduced fish in the reach to a remnant particularly the lentic *O.mossambicus*. Three months later CPUE was still very low.

species had CPUEs >0.4, all of them being small, or in the case of *Barbus marequensis*, young-of-the-year (YOY). Both *C.anoterus* and *B.eutaenia* were numerous here and upstream at Zoeknog (Fig. 2.16a & 2.17a). The minnow *Barbus viviparus* was dominant at both Londolozi and New Forest (CPUEs of 2.4 & 2.9 respectively). Both where LZ stations (Fig. 2.17a & 2.18a).

### *2.4.2.2 DROUGHT EFFECTS*

Grouping the species as either lotic or lentic breeders is a useful aid in viewing the shift from high to low flow linked assemblages with the progression of the drought. Lentic breeders were defined as those species which breed in low to zero-flow conditions. They included the cichlids *Oreochromis mossambicus*, *Tilapia rendalli*, *Pseudocrenilabrus philander* and

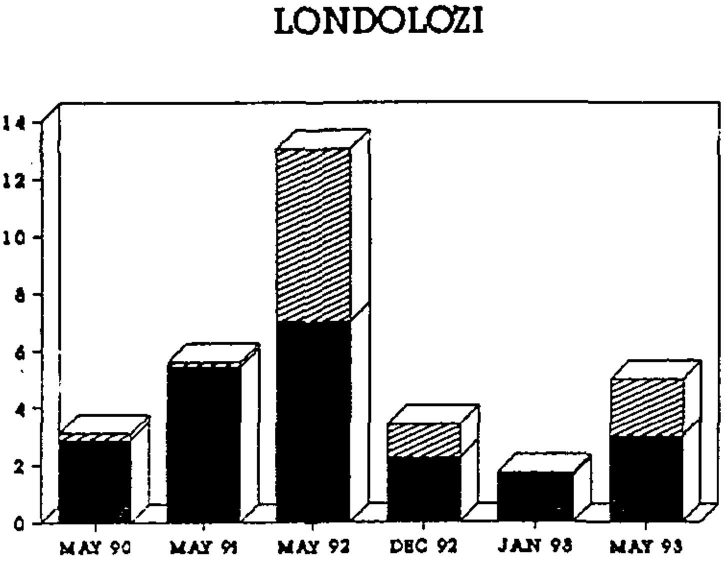



**Figure 2.15:** Catch per unit effort (CPUE) for fish at Londolozi on the mid-Sand river between May 1990 and May 1993. A CPUE of between 3 and 6 fish per minute was recorded before the 1991-92 drought with lentic species (hatched bars) typically making up more than 90% of the assemblage. By May 1992 the Sand river had ceased to flow concentrating the fish in pools and resulting in artificially high CPUEs. Lentic breeders continued to dominate the assemblage. The river was flowing again by December 1992, the November flush having reduced the lentic species noticeably. CPUE after the Zoeknog event, the sixth flushing-flow of the season, measured below 2 fish per minute and were almost exclusively of lotic species 9 (solid bars). Recovery had started by May 1993.

*Serranochromis meridianus*, the gobi *Glossogobius callidus*, and the minnows *Barbus paludinosus* and *Barbus toppini*. Initially, lotic linked species made up more than 90% of the total fish population at all sites (Fig. 2.13, 2.14 & 2.15).

The drought consisted of two components:

a) The failure of the 1991-92 summer wet season.

b) The subsequent extreme dry season that resulted in much of the Sand sub-catchment ceasing to flow in 1992.

During the 1991-92 "wet season" the Sand and Mutlumuvi rivers continued flowing, but at greatly reduced levels. During the 1992 dry season the Sand river progressively stopped

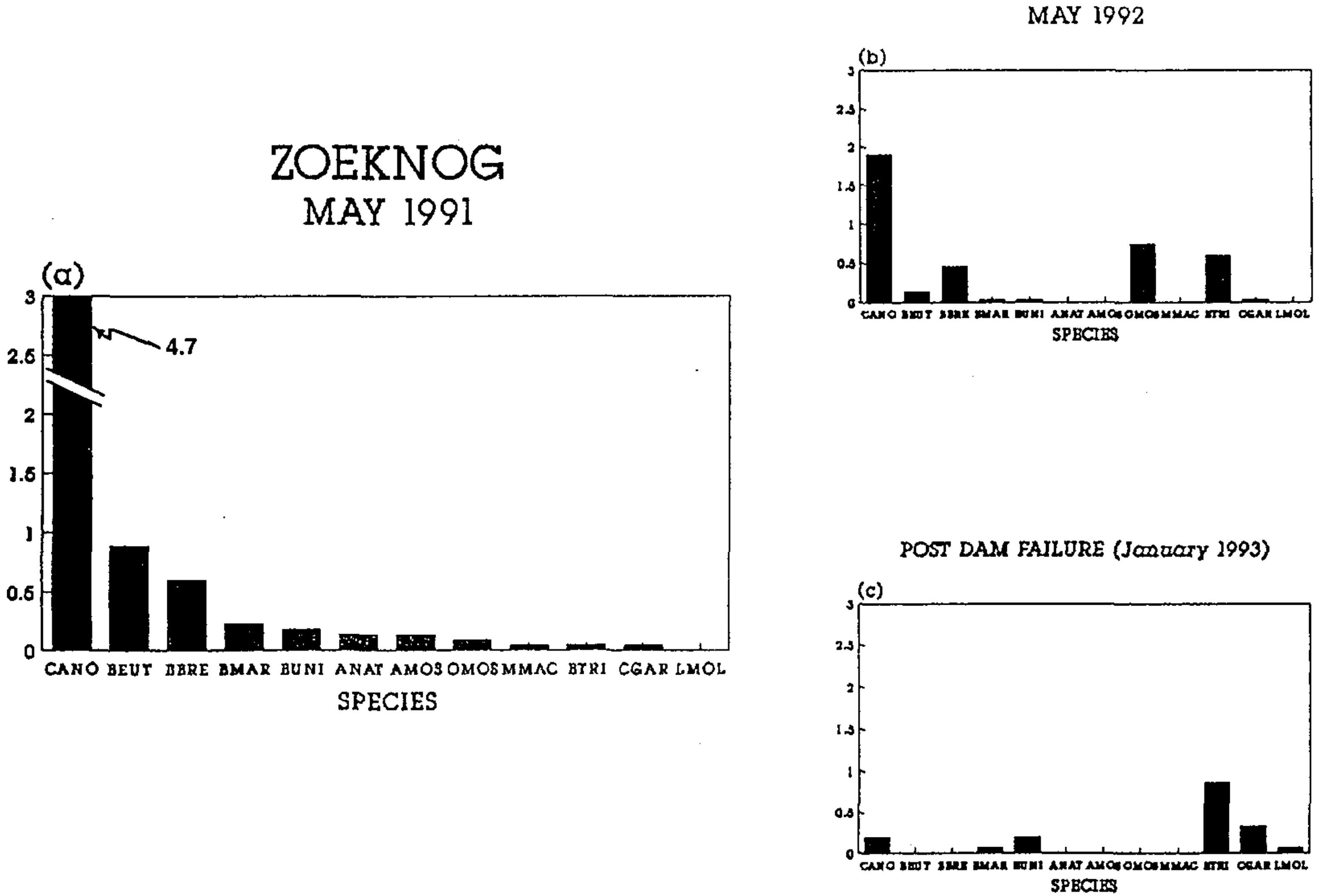



**Figure 2.16:** Catch per unit effort (CPUE) for species below the Zoeknog dam site between May 1991 and January 1993. In May 1991, 11 species were recorded with the rock catlet *Chiloglanis anoterus* particularly numerous (CPUE at 4.7), and the minnows *Barbus eutaenia* and *Barbus brevipinnis* common. As construction proceeded *C.anoterus* and *B.eutaenia* numbers were greatly reduced (May 1992) while numbers of the robust minnow *Barbus trimaculatus* and the blue kurper *Oreochromis mossambicus* increased. Post the dam failure and resultant microhabitat loss, *C.anoterus* was further reduced and the minnows *B.eutaenia B.brevipinnis* and *O.mossambicus* were not recorded.

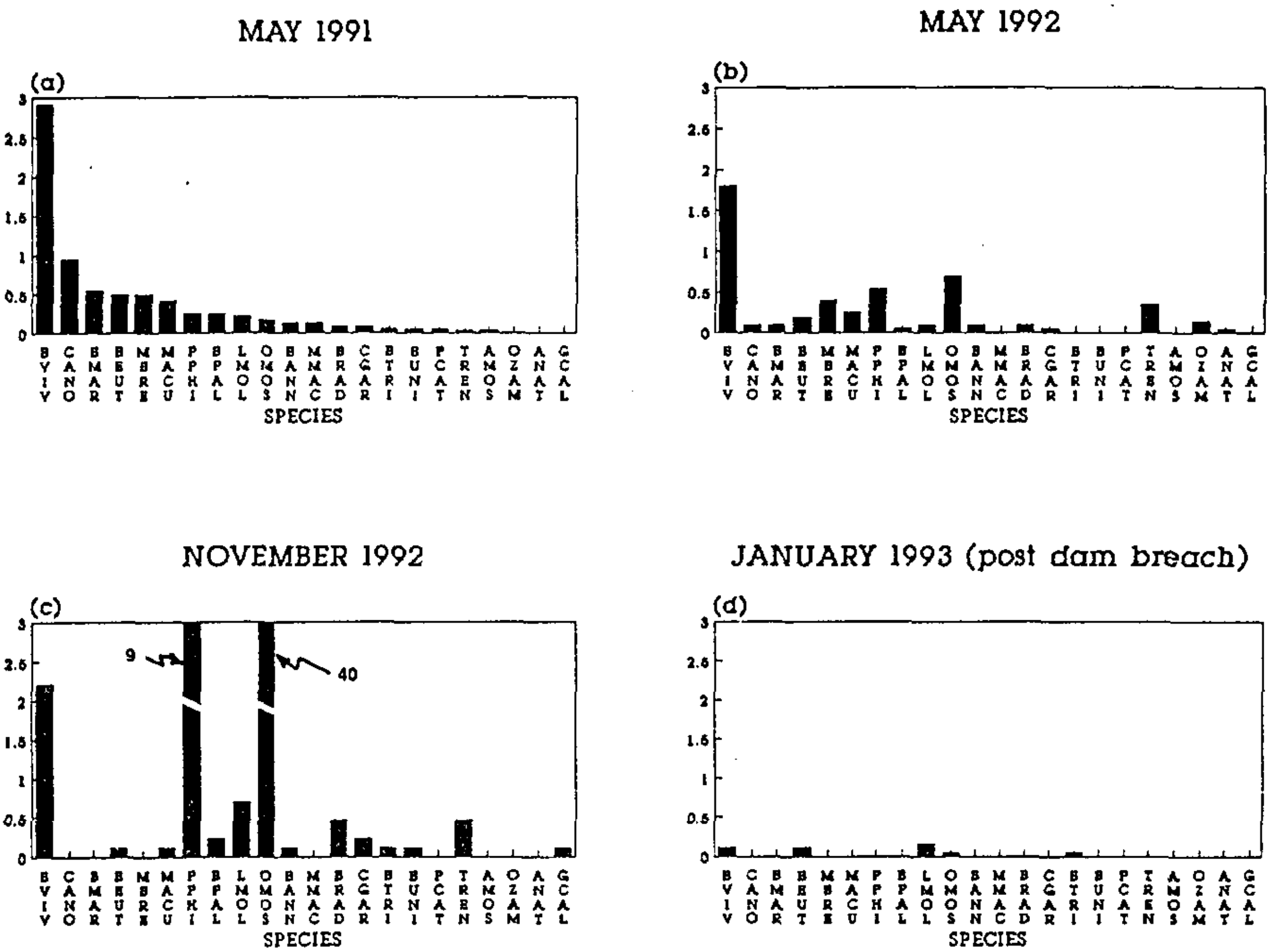



**Figure 2.17:** Catch per unit effort (CPUE) between May 1991 and January 1993 at New Forest on the Mutlumuvi some 16 km below the dam. The diverse and numerous assemblage recorded in May 1991 (19 spp) declines by May 1992 (16 spp). Reductions were marked in the minnows *Barbus viviparus Barbus eutaenia*, the rock catlet *Chiloglanis anoterus*, and the yellow fish *Barbus marequensis*. During this period the cichlids *Oreochromis mossambicus*, *Pseudocrenilabrus philander* and *Tilapia rendalli* all increased in numbers. By November 1992 *O.mossambicus* and *P.philander* dominated the reach with most species reduced drastically. After the January 1993 Zoeknog flood event, almost the entire cichlid population was removed leaving a remnant of lotic species.

flowing from the east to the west. At Londolozi on the mid-Sand the river had stopped flowing by the end of May, not flowing again until mid-December, 6 month later. At New Forest the flow was very low by May 1992 (0.0097 $m^3.s^{-1}$), and effectively zero by November

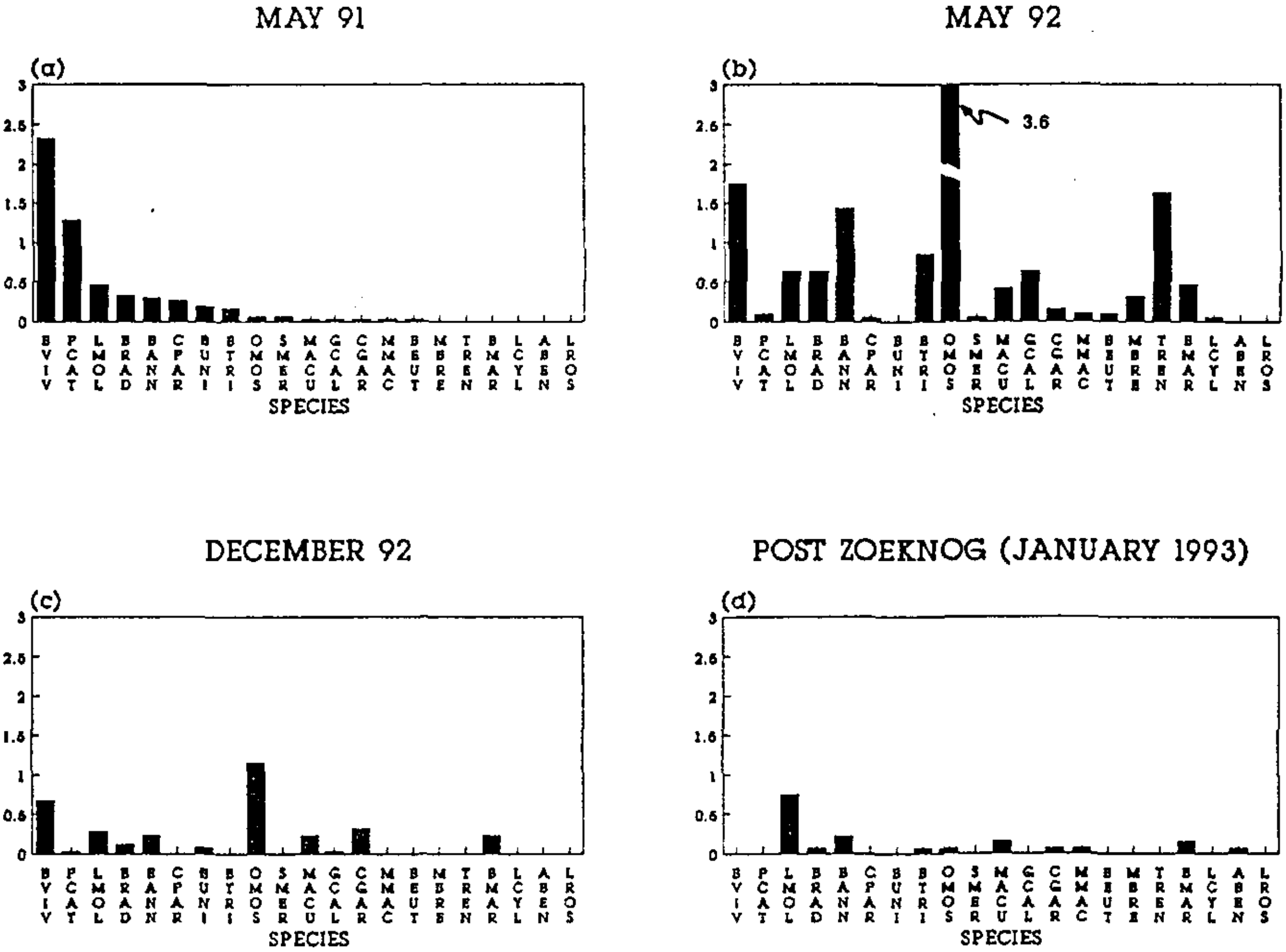



**Figure 2.18:** Catch per unit effort (CPUE) for fish species recorded at Londolozi on the mid-sand river between May 1991 and January 1993. Fifteen species were recorded in May 1991. In May 1992 the river had ceased to flow due to the 1991-92 drought, concentrating the fish into pools. The minnow *Barbus viviparus* and the mormyrid *Petrocephalus catostoma* decreased while the cichlids *Oreochromis mossambicus* (OMOS), *Tilapia rendalli* and the gobi *Glossogobius callidus* all increased in number. By December 1992 the first flushing flood of the season had diluted CPUE, with *O.mossambicus* numbers particularly reduced. *T.rendalli* had reduced prior to the first flood. By the time the Zoeknog failed 5 flushes had reset the system, possibly reducing CPUE further. Numbers of the mudfish *Labeo molybdinus* and the catfish *Clarias gariepinus* increased with both species spawning with the first flush.

at 0.0001 $m^3.s^{-1}$. The flow at Zoeknog was reduced but maintained by its headwaters. The influence of the drought must be considered for each of the following three stations:

1) **Zoeknog (site 25), upper-Mutlumuvi:** The total CPUE in this reach was reduced between May 1991 and May 1992 (Fig. 2.13). *C.anoterus* CPUE was reduced from 4.7 to 1.85 fish per minute on the reach and *B.eutaenia* from 0.84 to 0.16 (Fig. 2.17a & b). Although the discharge was reduced by the drought in May 1992 and the numbers of the lentic *O.mossambicus* increased, these reductions cannot be explained without also considering the effects of dam construction. Due to the proximity of the dam site, turbidity readings were likely to have exceeded measurements recorded on the 4th February 1992 during rain events (1300 NTU and 0.85 g/l TSS) (Table 2.5). *C.anoterus* and *B.eutaenia* are both species most numerous in the clear-watered foothill streams of the catchment.

2) **New Forest (site 19), mid Mutlumuvi:** CPUEs over the 1991-92 failed wet season declined, although there was an increase in the numbers of lentic species (Fig. 2.17a & b) at other stations. Major reductions occurred in *B.viviparus*, *B.eutaenia*, *C.anoterus* and *B.marequensis* numbers. By the end of the 1992 dry season the reach had almost stopped flowing. This condition extended into the 1992 wet season. Lotic species were drastically reduced while the lentic species, *P.philander* and *O.mossambicus*, exploded in numbers (Fig. 2.17c). Construction resulted in high suspensoid loads and turbidity between November 1991 and February 1992 (Table 2.5) and was probably related to local rain events. As the discharge lessened over the drought period, turbidity and TSS effects would have been reduced and drought effects would have become more prominent. The reduction in the numbers of *C.anoterus* and *B.eutaenia* in May 1992 (Fig. 2.17a & b) may be partially explained by increased suspensoid loads.

3) **Londolozi (site 14), mid Sand river:** This reach had effectively stopped flowing by the May 1992 survey, concentrating the resident fish into a large

series of bedrock controlled pools. CPUEs may therefore have been over-estimated because of concentration effects. Between May 1991 and May 1992 there was a major shift in the ratio of lotic to lentic species. The latter increased in proportion from <1% to some 50% of the total catch (Fig. 2.15), with additional increases in three lentic species (Fig. 2.18b). The reach was partially reset by the first rains one month prior to the December 1992 survey. The CPUE on site was greatly reduced particularly for lentic species, due to the dilution of remnant populations and possibly the movement out of the reach.

Because of low summer flows and extended dry season isolation, the changes seen in the fish assemblage at Londolozi are probably related to the drought alone. Monthly surveys were conducted observing the dynamics of isolated populations in series of pools at this site from May 1992 as part of the drought monitoring programme carried out for the KNP (see Vol. 2, Appendix II). Lentic species continued to increase in number although the banded tilapia *T.rendalli* disappeared and the blue kurper *O.mossambicus* dominated. Lentic species were generally in poor condition with low body weights and showed high mortalities. Besides the loss of physical habitat, mortality could also be due to low oxygen levels or predation were probably important.

Rooiboklaagte (site 11) on the upper Sand River, is comparable to New Forest (site 19) in order and zonal position even though baseflows recorded are complicated by significant abstraction (Fig. 2.19). Figures for this site are presented for direct comparison.

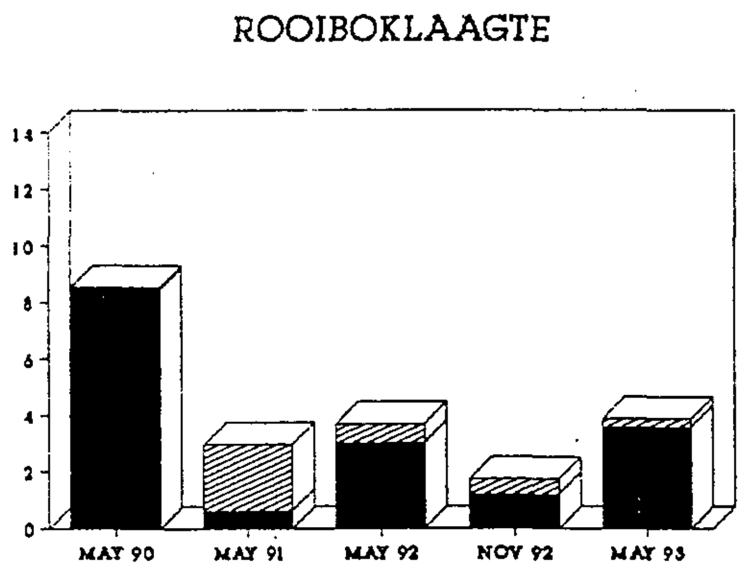



**Figure 2.19:** Catch per unit effort (CPUE) for fish at Rooiboklaagte on the upper Sand River. This site is comparable to New Forest on the Mutlumuvi in position and order. The healthy CPUE of 8 fish per minute recorded in May 1990 was reduced to 3 by May 1991. Lentic species (hatched bars) had increased by May 1991 and had decreased again by May 1992. The river was largely kept flowing through the worst of the drought (May 1992 - November 1992) by re-diverting base flows. In November 1992 although CPUE were low at 2 fish per minute there were many fry in evidence. The reach had recovered to 1992 CPUE levels by May 1993. (Lotic species = solid bars).

## 2.4.3 EFFECTS OF CONSTRUCTION ACTIVITIES ON THE AQUATIC ENVIRONMENT

### *2.4.3.1 ICHTHYOFAUNA*

There were major changes in the occurrence and abundance of species at all stations between May 1991 and the partial completion of the dam in December 1992 over and above the effects of drought already discussed. Construction had dramatic effects on the water quality of the system.

On the 4th February 1992 the turbidity in the Mutlumuvi was some 57 times above previous measurements and was rich in colour. At Zoeknog turbidity measured 1300 NTU and TSS 0.85 $gl^{-1}$ (Table 2.5), while at New Forest the readings were 1400 NTU and 0.886 g/l respectively (Appendix I; Plate 7c). Subsequently, all the turbidity measurements at Zoeknog were elevated with effects extending downstream according to the discharge.

### *2.4.3.2 MACRO-INVERTEBRATES*

Unraveling the effect of the Zoeknog's construction on the macro-invertebrate populations is

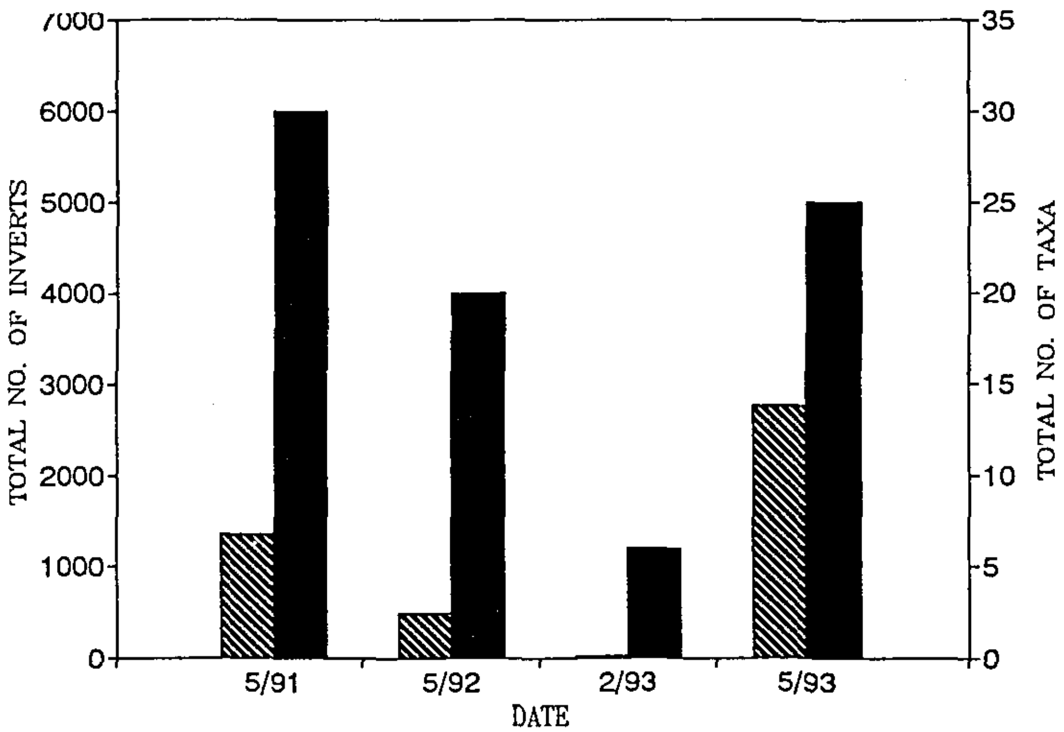



**Figure 2.20:** Total number of taxa and invertebrates at site 19 on the Mutlumuvi River (May 1991 to May 1993).

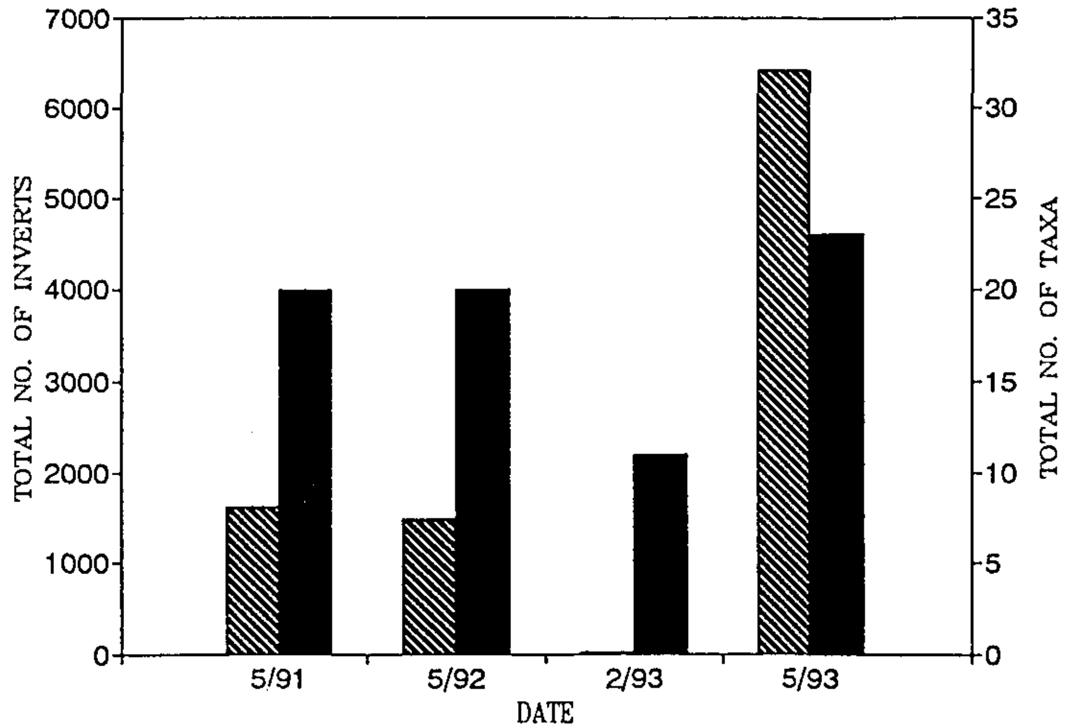



**Figure 2.21:** Total number of taxa and invertebrates at site 25 on the Mutlumuvi River (May 1991 to May 1993).

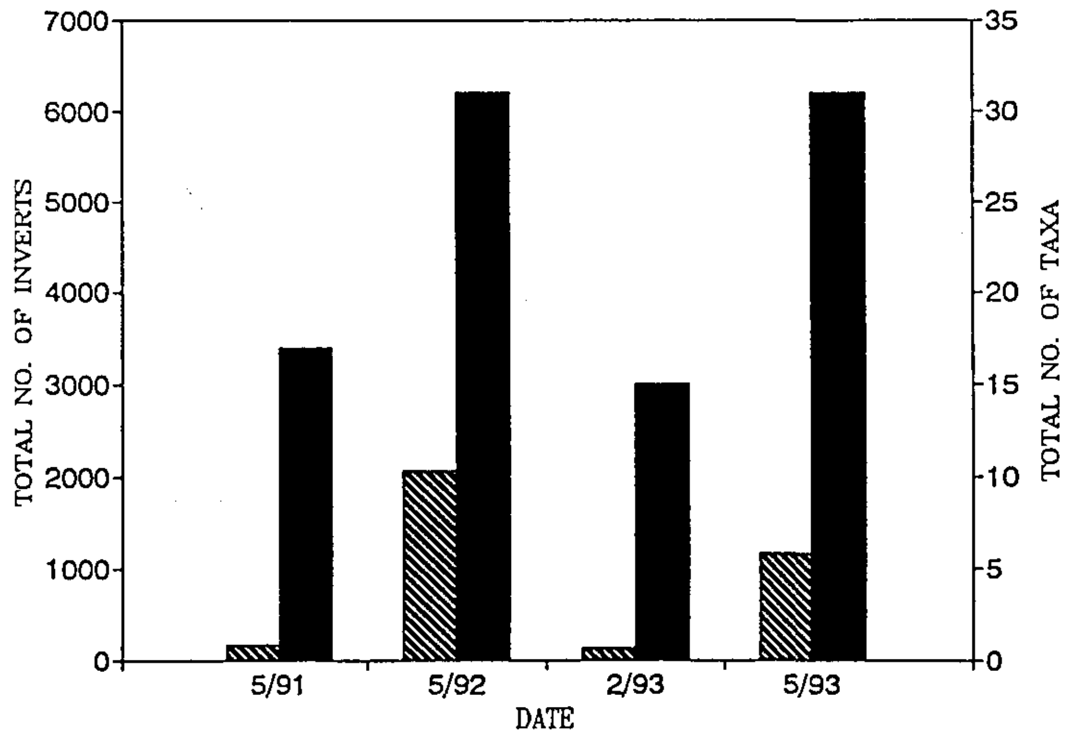



**Figure 2.22:** Total number of taxa and invertebrates at site 14 on the Sand River (May 1991 to May 1993).

difficult. The drought and construction, had reduced macro-invertebrates by May 1992 at site 19 (Fig. 2.20), while their numbers remained unchanged in the perennial reaches (site 25; Fig. 2.21). Although the mid-Sand River (site 14; Fig 2.22) was most severely stressed due to no-flow, macro-invertebrates were seemingly unaffected, possibly an artifact of easier collecting in pools.

## 2.4.4 AQUATIC ENVIRONMENT - IMMEDIATE EFFECTS

There was a gradient of effects on the aquatic environment below the Zoeknog Dam. The breach in the upper Mutlumuvi equaled a 1:10 year flood whereas lower down this volume of flow was not exceptional. The February event gauged only 1.620 m at the exeter weir in the mid Sand River whereas a flow of 2.590 m had been recorded in December (see Fig. 4.7, Vol.1).

Gross microhabitat alteration occurred within the reaches downstream of the dam. At 2 km, over a meter of coarse sand had smothered riffle and run sequences (Plate 1c), reducing the reach to a shallow sandy raceway. The channel showed signs of major disturbance with substrates largely unsorted. At New Forest, some 16 km downstream of the dam, there was evidence of a 2-3 meter flood and a layer of fine sediments deposited in and out of the channel. Fine red silt was evident all the way to the Sabie-Sand confluence.

Turbidity was generally high. Both the Mutlumuvi (Appendix I; Plate 7c) and Sand River downstream of the dam were brick red in colour. Two days after the event the turbidity at Londolozi was still 1900 NTU carrying some 2.652 g/l of silt (Table 2.5). This reduced rapidly over time (Fig. 2.24). The actual sediment load transported during the peak of the event was not recorded but probably did not reach lethal levels judging from Wallen (1951) in Bruton (1985). Wallen showed for a range of species that high turbidity did not cause acute direct effects until suspensoid loads near 20 g/l, and mortalities were only recorded above 50-100 g/l.

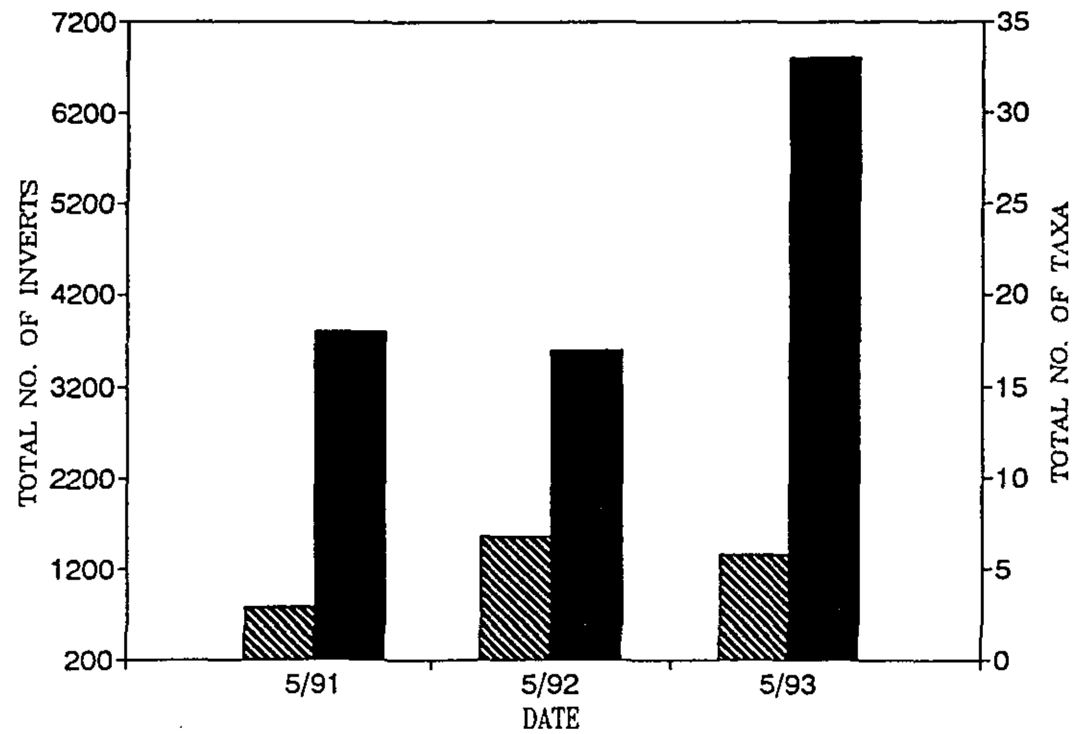



**Figure 2.23:** Total number of taxa and invertebrates at site 11 on the Sand River (May 1991 to May 1993).

Isolated pools recharged during the event showed persistent high turbidity 10 days later, indicating the fine nature of the suspensoids, possibly red clay particles (Fig. 2.24 & Table 2.5). Persistent high turbidity effectively means shading, a factor that may be correlated to low oxygen levels and subsequent mortalities of fish isolated in pools during the drought. A pool on the lower Sand with turbidity of 1020 NTU 10 days after the event had a corresponding oxygen level of 34%!

### *2.4.4.1 ICHTHYOFAUNA*

The lowest CPUEs, over three years, were measured for all stations (Fig. 2.13, 2.14 & 2.15) after dam failure. Fish abundance reflected the gradient of effect identified with increasingly reduced fish CPUE with proximity to the dam site.

1) **At Zoeknog:** CPUE already halved by drought and construction, was halved again by the dam event. The immediate effects of the dam burst were however strongest on the Mutlumuvi above the confluence with the Sand River at Thulamahashi (Fig. 2.13), with species number dropping to just 6 (Table 2.6). The riffle dwelling *C.anoterus* accounted for most of the individual loss, but both FHZ minnows characteristic of the reach were absent. The hardy *B.trimaculatus* remained the most numerous, while an individual juvenile of the flood dispersing *L.molybdinus* was recorded for the first time (Fig. 2.16c). The lentic *O.mossambicus* were further scoured from the reach.

2) **At New Forest:** The lotic fish assemblage was badly effected by the drought. The Zoeknog collapse removed the remaining fish from the reach, reducing the species count from 14 to 5 (Table 2.6). Abundant drought-induced cichlids proved particularly vulnerable to the spate of high flow. The reach was badly impacted, with the lowest CPUE ever recorded (Fig. 2.14) for any site in the catchment over the three years of study measured.

3) **At Londolozi:** The drought impacted, but recovering, fish assemblage appeared to have survived the immediate effects of the dam burst. The mid-Sand River at Londolozi had experienced 5 flushing floods (Fig. 4.7, Vol.1) by the time of the Zoeknog event. The river would therefore have been recovering from the drought. Both *C.gariepinus* and *L.molybdinus* had spawned successfully with the first rains with young appearing in the surveys (Fig. 2.18c). No immediate effect on the lotic fish assemblage could be discerned. The lentic *O.mossambicus*, still numerous following the recent drought, was reduced in the reach.

### 2.4.4.2 *MACRO-INVERTEBRATES*

Following dam failure, low invertebrate numbers were found at all three localities (sites 14,

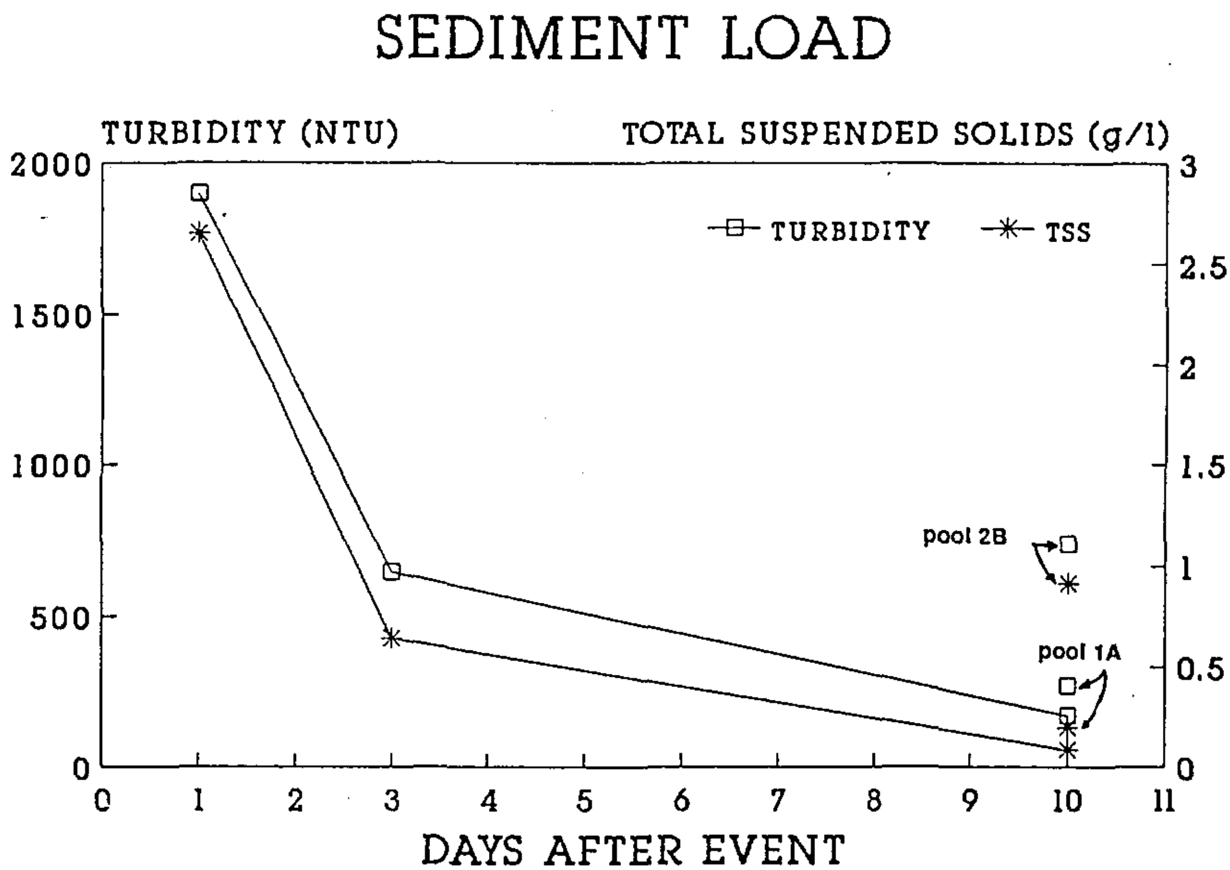



**Figure 2.24:** The sediment load and turbidity following the Zoeknog breach at Londolozi on the Sand River. Both turbidity (1900 NTU) and sediments (2.65 $gl^{-1}$) were high one day after the event and decreased rapidly in the first days. The upper limits at the time of the breach are not know. Ten days after the event, recharged offstream pools 1A and 2B showed higher turbidity and TSS values, possibly indicative of the time of isolation from the main channel.

19 & 25) (Fig. 2.10 to 2.23). Site 14, which was the furthest downstream and the most seriously affected by the drought, now showed the highest number of species and taxa. This supports the hypothesis that a gradient of effects resulted below the dam, with the mid-Sand reaches least impacted.

## 2.4.5 RECOVERY TO DATE

Niemi *et al.*, (1990) concluded that most natural lotic systems are resistant to disturbance, and recover within 3 years. Recovery is ultimately dependent on recolonization. Factors affecting recolonization include time after disturbance, area affected, accessibility of defaunated reach, individual species traits and refuge populations (Niemi *et al.*, 1990), and the nature and quality of the habitat that remains after disturbance.

Stream fish assemblages are not randomly structured units, but rather largely deterministic systems highly predictable from local habitat structure (Meffe and Sheldon, 1990). They show resilience, returning to pre-perturbation states. This recovery is driven by species-specific habitat preferences which have evolved over time with habitat as the template (Southwood, 1977). It was hypothesised that habitat alteration within the Mutlumuvi River would result in slow recovery rates.

**The Mutlumuvi:**

The Mutlumuvi is one of two tributaries that carry the bulk of the Sand River's runoff. Both these streams have perennial headwaters which together provide a valuable perennial refuge area at the western edge of the LZ. The high CPUEs and diversity recorded here and the presence of the flow dependent *C.anoterus* and *O.zambezense,* support this view. The Mutlumuvi was probably the most important refuge tributary for the lowveld fish in the mid-Sabie River. This is significant as the present day mid-Sand River tends toward a seasonal stream resulting in important gaps in the lowveld fish assemblage. Due to the gradient of disturbance seen with the Zoeknog event, the Mutlumuvi River was most impacted. As the Mutlumuvi was itself a refuge for the lower Sand River reaches, its own recovery potential may now be compromised.

Recovery may be further hampered in the Mutlumuvi because it is isolated from the upper Sand River by the mid-Sand River reaches, which are often impacted by drought. Peterson and Bayley (1993) showed that in small areas, the recolonization rate was rapid if neighbouring populations of defaunated species existed. The recovery of species such as *C.anoterus*, *B.eutaenia*, and *O.zambezense*, which are limited in local distribution could, be expected to be slow. This is compounded for the riffle dwelling *C.anoterus* which appears sedentary and has low fecundity, and *O.zambezense* which is exceedingly rare in the nearest refuge in the upper Sand River. Highly mobile species could be expected to recover sooner *e.g.* the silver robber *M.acutidens*, which is present in the lower Sand River

Lowveld species can be expected to be highly resilient as the tropical east coast ecoregion is highly seasonal and the rivers are subject to natural floods and drought. The resilience of the Mutlumuvi and Sand River assemblage is less certain due to the unnatural nature of the conditions relating to the event and the degradation of naturally important refuge areas.

**High turbidity levels effects on the ichthyofauna:**

Although the high turbidities recorded did not appear to result in large scale fish mortality downstream of the dam, the short to long term effects of elevated turbidity must not be under-estimated.

Bruton (1985) reviews the recorded deleterious effects of high turbidity as:

a) Reduced egg and larval survival,
b) altered breeding behaviour,
c) reduced feeding efficiency,
d) reduced growth rates,
e) reduced population size and
f) reduced habitat diversity.

Each discharge event will continue to import fine silt from the dam and coffee plantation site with each flush re-suspending deposits that remain from previous floods. Very high sediment loads and turbidities were recorded in the Sand catchment during the first large rain event in the upper catchment after the breaching of the Zoeknog Dam (Fig. 2.25). Both variables were

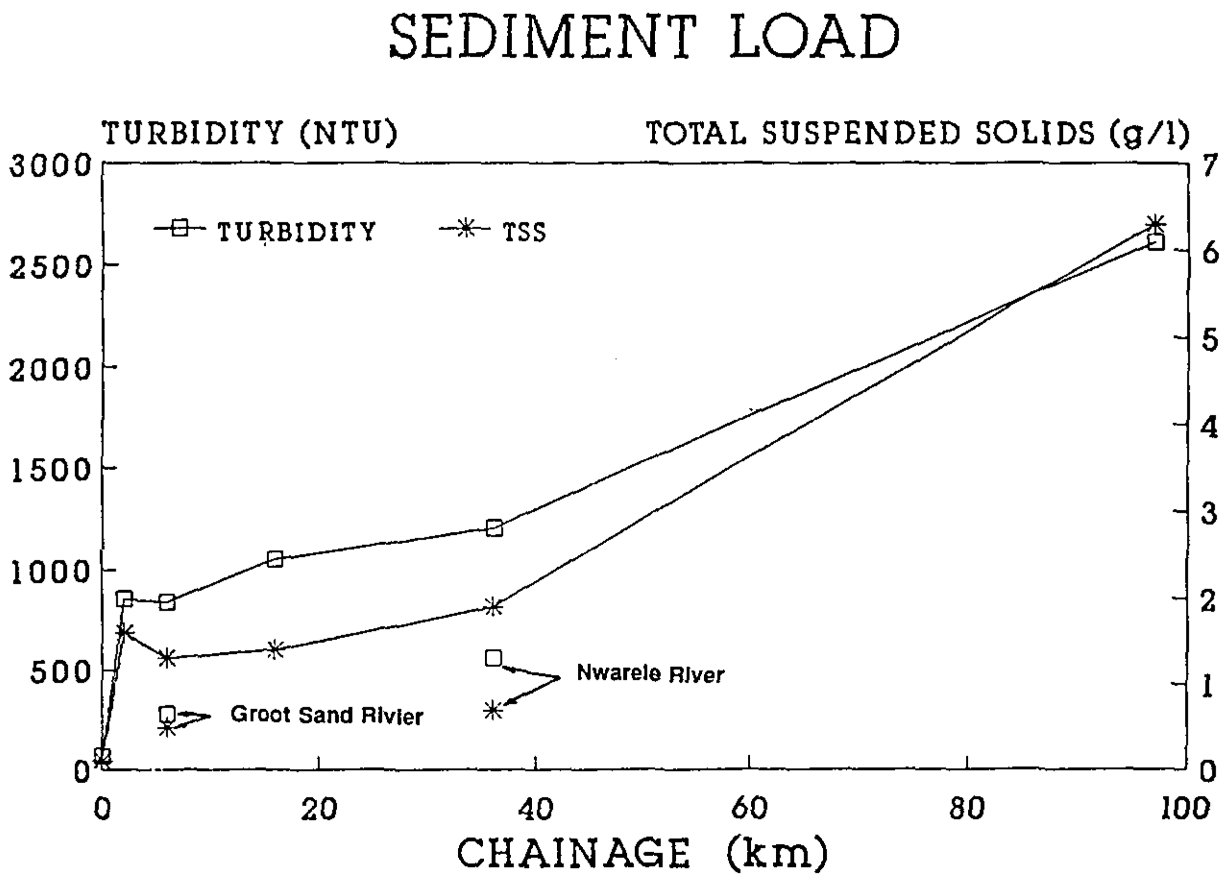



**Figure 2.25:** Sediment load and turbidity measured during the first rain event on 2nd March 1993, following the Zoeknog Dam breach in the Sand sub-catchment. Both variables showed similar trends with values increasing with chainage. A marked increases at the Zoeknog Dam site (2 km) on the Mutlumuvi River is seen with a rise to the highest levels recorded (turbidity 2610 NTU and TSS 6.3 $gl^{-1}$) at the Sabie-Sand confluence. The Groot Sand River and the Nwarele are comparable rivers within the catchment, and support that the Mutlumuvi showed higher turbidity and TSS values than normal.

markedly higher downstream of the dam site towards the Sand-Sabie confluence. It must be remembered that offstream pools are recharged during flush events and fish populations may be at risk due to decreased oxygen levels. Comparable tributaries in the same sub-catchment showed turbidity and TSS values far lower. Turbidity and TSS increased markedly with chainage as sediments were resuspended. In a system struggling to recover from the impact of a drought deteriorated water quality is an added pressure.

### 2.4.5.1 *ICHTHYOFAUNAL RECOVERY TO DATE*

1) **At Zoeknog:** Little meaningful recovery was evident below the dam site after 5 months. Sediments within the highly modified reach had however started being resorted (Plate 1d). CPUEs (Fig. 2.13 & 2.26a, May 1993) and species number (Table 2.6) at Zoeknog were the lowest ever recorded for the site. The previously dominant *C.anoterus*, is still a remnant population and *B.eutaenia*, originally the second most important species, was still absent (Fig. 2.26a).

2) **At New Forest:** Recovery in the Mutlumuvi 16 km downstream, five months after the drought and dam burst, was unimpressive. CPUEs were still very low (Fig. 2.14) with only eight species recorded at roughly half the expected values (Table 2.6). A number of previously numerous species were still absent (*C.anoterus*, *B.marequensis*, *B.eutaenia*, *M.acutidens* & *P.philander*) or under represented (*B.viviparus* & *Mesobola brevianalis*) (Fig. 2.26b).

3) **At Londolozi:** Although there were still some gaps in the species recorded and CPUEs were still low, recovery from the drought was well under way by May 1993 (Fig. 2.15, 2.26c & Table 2.6).

Rooiboklaagte in the upper Sabie-River is directly comparable to site 19, Newforest. Recovery from the drought at site 11 started early and was assisted by baseflows released into the system just before the end of the drought. Many fry of different species were already in evidence during November (Fig. 2.26d).

Assemblage recovery was investigated using Schoener's (1968) Proportional Similarity Index (PSI) (Meffe and Sheldon, 1990);

where $PS_{ij}$ is proportional similarity (from 0.00 = completely different, to 1.00, identical) between two samples $i$ and $j$, $s$ is the number of species, and $p_{in}$ and $p_{jn}$ are species

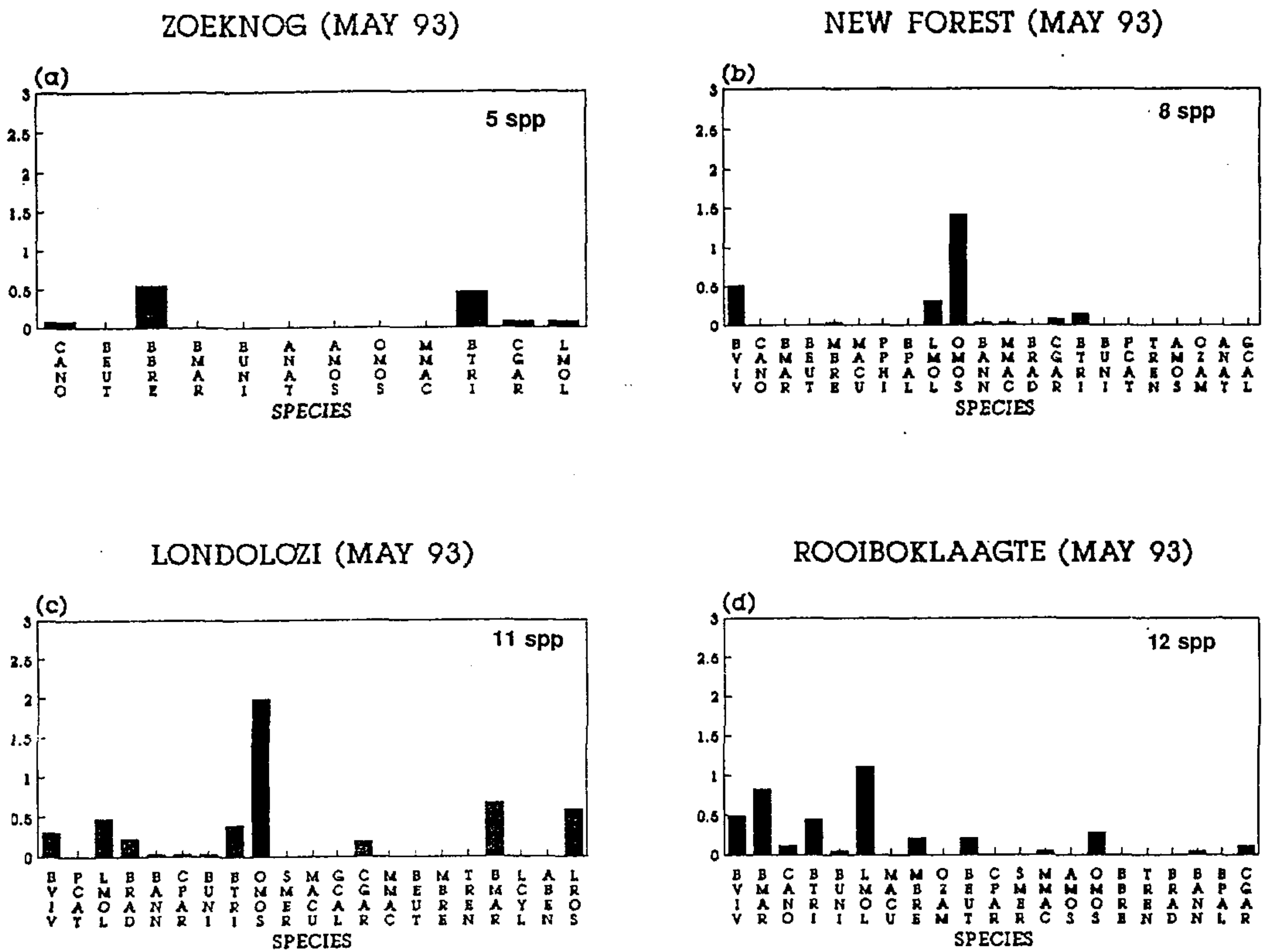



**Figure 2.26:** Recovery five months after the collapse of Zoeknog. On the Mutlumuvi little to no recovery was recorded. Zoeknog (site 25) immediately downstream of the dam recorded the lowest CPUE and species numbers to date (5 spp). *C.anoterus* previously numerous are now a remnant and *B.eutaenia* absent. New Forest showed slight recovery with species recorded roughly 50% of pre-event records (8 spp) and CPUE low. Both *C.anoterus* and *B.eutaenia* markedly absent. *O.mossambicus* again the most numerous. On the Sand River the Londolozi is recovering from the drought with *Labeo rosae*, *C.gariepinus*, *B.marequensis* and *L.molybdinus* juveniles in evidence. Rooiboklaagte (site 11) was recovering well (12 spp). *M.acutidens* was not recorded at any of these sites in May 1993.

proportions of the total numbers of individuals in the $i_{th}$ and $j_{th}$ samples.

$$PS_{ij}=1-0.5\sum_{n=1}^{s}|p_{in}-p_{jn}|$$

This allows for a quantitative comparison of two samples, and is useful for assessing assemblage similarity/recovery. Index values of greater than 0.7 indicate very similar or stable fish communities (Peterson and Bayley, 1993), but the measure is susceptible to the sampling scale. To avoid very low PSI values for short fishing runs, a baseline assemblage was calculated spanning a full year prior to the drought. Mean PSI values prior to major assemblage changes for the selected sites combined was 0.64 (S.D.= 0.11).

Figure 2.27 shows the results for New Forest (site 19) and Rooiboklaagte, the comparable Sand River tributary site, (site 11). Declining PSI values for site 11 (Nov-Feb 1991-92) and site 19 (May-Aug 1992) both correspond to periods of flow stress within the reach. At New Forest, the Zoeknog collapse keeps the index at its lowest recorded value with the assemblage radically changed in species number and CPUE. There is little recovery at site 19 by May, 5 months after the event.

### *2.4.5.2 MACRO-INVERTEBRATE RECOVERY TO DATE*

By May 1993 following the collapse of the dam, there is some evidence of recovery. This may be misleading as macro-invertebrates were not identified to species. Although total number of invertebrates at site 19 were equivalent to site 25, the severe impact on site 19 was reflected in the low invertebrate diversity. (Fig. 2.20 - 2.22). The species diversity at site 11 (Fig. 2.23) on the upper Sand River is comparable to site 19 on the Mutlumuvi in both stream order and zonal position. Site 11 showed a higher taxa diversity by May 1993 and suggests the recovery potential of an unimpacted reach following drought is higher. Whatever the interpretation, it is apparent that the macro-invertebrates are able to respond more rapidly numerically following both drought and pollution events than the ichthyofauna. What is unclear is the species makeup of the recovered community.

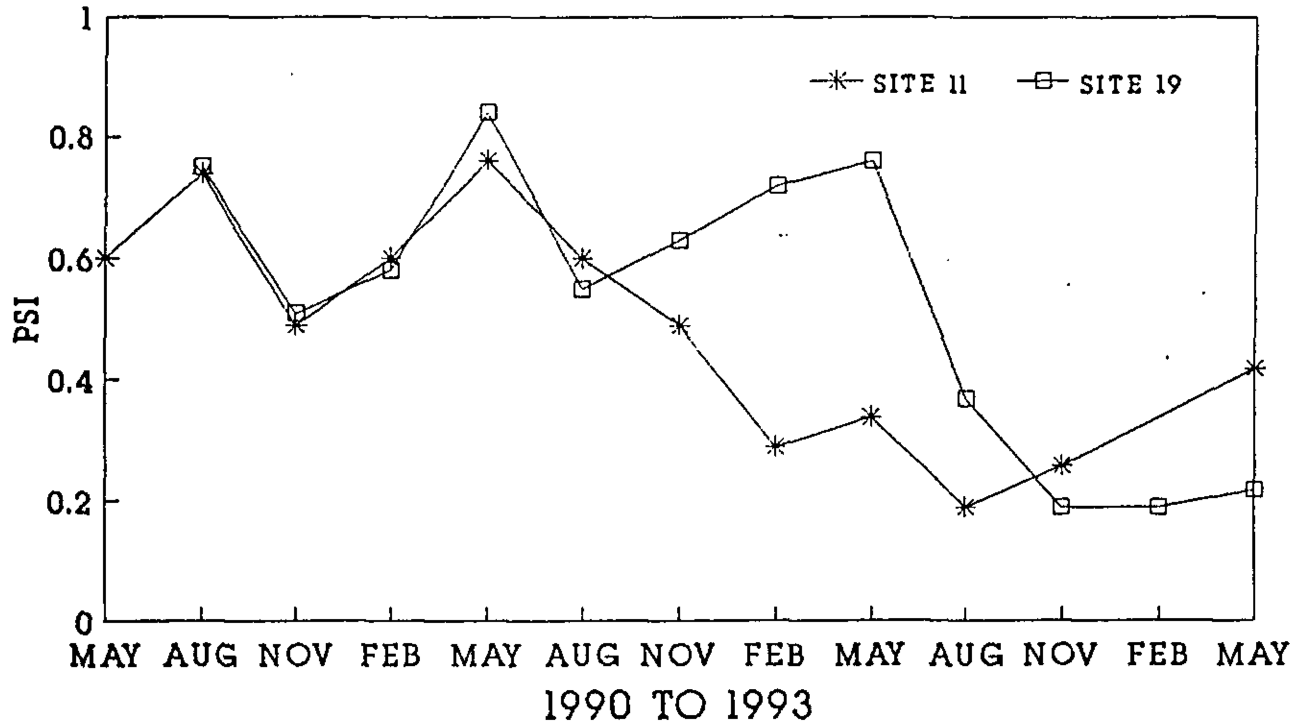



**Figure 2.27:** Similarity and recovery of fish assemblages, measured as proportional similarity index (PSI), at site 11 (Rooiboklaagte) and site 19 (New Forest). Pre-drought quarterly samples for sites spanning Aug 1990 to May 1991 were summed and used as the baseline assemblage. Both sites showed similar PSI values with possible seasonal effects between Aug 1990-91. Both sites 11 (Nov 1991 - Feb 1992) and 19 (May 1992 - Nov 1992) showed rapidly declining PSI values which corresponded to differing periods of low to no-flow in the reaches. Site 11 shows an early start to recovery (0.4 PSI by May). The Zoeknog event keeps the PSI very low at site 19 (Feb 1993), with little recovery by May.

## 2.4.6 CONCLUSIONS

- The collapse of the Zoeknog Dam had clear biotic and abiotic impacts on the Sand River catchment including reductions in CPUEs and local diversity of fish, increases in catchment turbidities and sediment loads, and gross stream bed modifications.
- A west to east gradient of impact is seen.
- An east to west drought gradient complicates interpretation down the reach.
- The Mutlumuvi River was generally heavily impacted, while the lower Sand River impacts are masked by more powerful drought effects.

- The upper reaches at Zoeknog show gross modifications in channel structure with course unsorted substrates smothering typical riffle reaches.
- In the mid-Mutlumuvi at New Forest, the already severely drought stressed fish assemblage was almost totally destroyed.
- At Londolozi, clear impacts of the Zoeknog collapse were masked by drought effects on the mid-Sand River.
- Although difficult to assess, high turbidities impacted off-stream pool fish assemblages in the mid-Sand River floodplain.
- The degradation of the upper lowveld fish refuge reach may reduce the resilience of the lower reaches of the Sand River.
- As the Mutlumuvi was regionally the refuge reach for flow-sensitive fish species, it may prove slow to recover itself as it is isolated from large viable populations of species such as *C.anoterus*, *B.eutaenia* and *O.zambezense*.
- The ichthyofauna of the Mutlumuvi had recovered very little five months after the event.
- Fish species typically numerous in the Mutlumuvi, but which are now drastically reduced or absent, include *C.anoterus*, *B.eutaenia*, *B.marequensis*, *B.viviparus* and *M.acutidens*.

# 3. INSTREAM FLOW REQUIREMENTS OF THE SABIE-SAND RIVERS IN THE KRUGER NATIONAL PARK

## 3.1 WATER USE IN THE SABIE CATCHMENT

At present, commercial forestry using pine and eucalypt is the major water user in the Sabie catchment. However, planned increases in irrigation, and urban water consumption (Table

**Table 3.1:** Present and projected water use in the Sabie catchment. (Modified from Chunnett *et al.*, 1987). Figures in $m^3 \times 10^6\ yr^{-1}$.

| | 1987 | 2010 | % increase |
|---|---|---|---|
| Urban | 6.9 | 61.6 | 793 |
| Livestock | 1.8 | 1.8 | 0 |
| Irrigation | 107.7 | 327.9 | 204 |
| Afforestation | 124.9 | 128.8 | 3 |
| **Total** | 241.3 | 520.0 | 115 |

3.1), could cause an increase of 115% in water consumption from the catchment by the year 2010. All of the major users have a fairly steady requirement throughout the year, so that critical low-flow periods are not linked with corresponding low demand. Present water use of $250 \times 10^6\ m^3\ yr^{-1}$ is equivalent to an average flow of $7.93\ m^3\ sec^{-1}$. According to hydrological simulations using Pitman's (1973) model, this is higher than the mean flow of the river under natural conditions during July to October (the driest months) (See Fig. 3.1). During the driest months in a 60 year simulation (South African Department of Water Affairs, 1990), flow during all months was below $7\ m^3\ sec^{-1}$. The present water uses in the upper and middle catchment, if met in full, are therefore sufficient to intercept all surface flow upstream of the Kruger National Park during low-flow months. With the envisaged 115% increase in water use, it is inevitable that the river will be reduced to seasonal flow unless some provision for additional storage can be made.

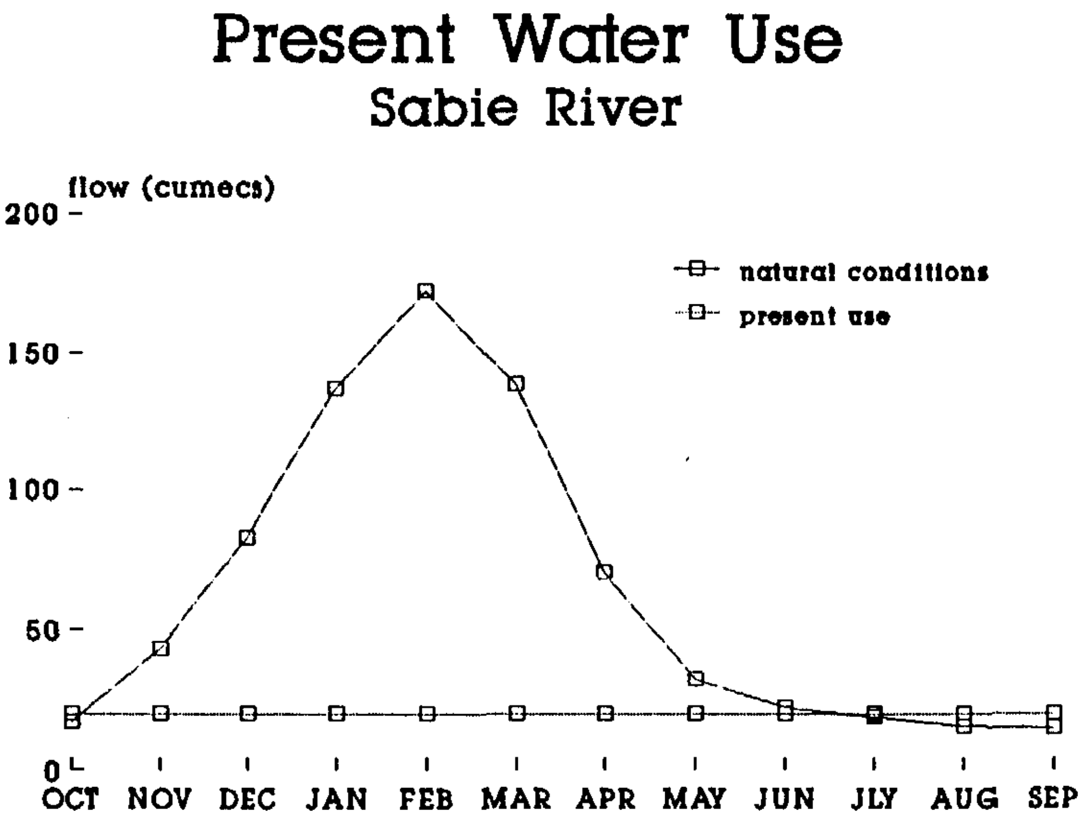



**Figure 3.1:** Mean flow rates in the Sabie River at the Mozambique borber under natural conditions, compared with present water demand, averaged over the year (1985).

# 3.2 PREVIOUS ASSESSMENTS OF THE ENVIRONMENTAL WATER REQUIREMENTS FOR THE SABIE RIVER.

It is within the above framework that the South African Department of Water Affairs initiated research to assess the environmental water requirements of the Sabie River. These requirements are seen as catering primarily for the maintenance of the natural perennial river fauna and flora of the Sabie River in the Kruger National Park. However, it is equally important for the river to remain perennial upstream of the nature conservation areas. The river is extensively used by the people and livestock in the catchment for direct water use - abstraction, laundry and washing. Not only would the reduction of the river to a series of pools cause water shortages, but accumulation of pollutants would lead to health risks, and the availability of standing water as habitat for malarial mosquitoes and bilharzia snails would increase considerably. Fortunately, if the requirements of the conservation areas and Mozambique are met, by definition the upstream reaches of the river will remain perennial.

To date, three independent methods have been used to assess the environmental water requirements of the Sabie River:

a) Davies *et al.*, (1991) used a water budget method in which the consumptive and non-consumptive water uses were estimated, to provide a seasonally-distributed flow requirement. Major consumptive uses were evaporation from the river surface, and evapotranspiration by riparian vegetation, amounting to $30 \times 10^6$ $m^3$ $yr^{-1}$ for the Sabie in the KNP. Additional uses for animal drinking and staff/tourist consumption within the Park amounted to $0.5 \times 10^6$ $m^3$ $yr^{-1}$. To this consumption was added the limiting *non-consumptive requirement, which was assessed as a 0.1m depth of flow over riffles* to ensure the maintenance of riffle habitat and passage for fish.

Total baseflow requirements using this method amounted to 136.5 x $10^6$ $m^3$ $yr^{-1}$, distributed as monthly average flows of 0.6 - 5$m^3$ $sec^{-1}$. Additional biannual and longer term flood requirements were also specified.

b) Gore *et al.*, (1992) used the PHABSIM model to provide preliminary estimates of hydraulic habitat requirements for four key species in the Sabie River. They defined *Barbus viviparus*, a small cyprinid fish; *Serranochromis meridianus*, an endemic predatory cichlid fish; *Chiloglanis swierstrai*, a small rheophilic catfish; and the hippo (*Hippopotomas amphibius*), as key species covering the main types of hydraulic habitat requirements. Gore *et al.*, (1992) show habitat preference curves which imply significantly increased habitat loss rates for each species at the discharges indicated

**Table 3.2**: Discharges in the Sabie River below which habitat loss rates for selected species increase rapidly. (Discharges inferred from habitat preference curves in Gore *et al*, 1992).

| Species | Critical Discharge ($m^3sec^{-1}$) |
|---|---|
| *Barbus viviparus* | 3.3 |
| *Serranochromis meridianus* | 3.6 |
| *Chiloglanis swierstrai* | 6.8 |
| *Hippotamus amphibius* | 3.5 |

in Table 3.2. From these measurements, Gore *et al.*, (1992) conclude that the minimum discharge necessary to maintain a "minimum diversity of fish fauna" would be 2 $m^3$ $sec^{-1}$. For three of the four key species, a flow of around 3.5 $m^3$ $sec^{-1}$ would provide acceptable habitat availability (Table 3.2). Gore *et al.*, (1992) found that the relationship between increased species diversity and hydraulic diversity peaked at 6 $m^3$ $sec^{-1}$. Translated into annual water volumes to maintain survival, acceptable and ideal conditions, these flows would require 63, 110, and 189 $m^3$ x $10^6$ respectively.

9c) The third assessment of environmental flow needs used hydrological simulations of natural, present and various future impounded conditions of the Sabie River to predict possible ecological conditions (O'Keeffe and Davies, 1991). Ecological consequences of successive reductions in discharge were then assessed using the River Conservation System (O'Keeffe *et al.*, 1987), an expert-system based model, to determine the conservation status of the river under different management conditions. Recommended flows were presented in the form of a 60 year month by month simulation, relating recommended flows as a percentage of natural flows (O'Keeffe and Davies, 1991). These recommendations, if implemented, would ensure that worst historical drought conditions during the 60 year period of record would not be exceeded, and there would be a very low probability of their being repeated in consecutive years, or at short intervals. Table 3.3 shows the annual exceedance volumes at various levels of probability.

**Table 3.3**: Recommendations by O'Keeffe and Davies (1991), (in association with Chunnett Fourie and Partners), for annual flow volumes in the Sabie River at different probabilities of exceedence. (e.g. it is recommended that annual flow should exceed 127 x $10^6$ $m^3$ for at least 19 years in 20).

| % exceedence | Annual volume ($m^3$ x $10^6$) |
|---|---|
| 95 | 127 |
| 75 | 211 |
| 50 | 295 |

The worst drought in the 60 year record (1982-83) produced a runoff of 74 x $10^6$ $m^3$, and this was taken as the minimum, or survival, recommendation by O'Keeffe and Davies (1991), although the 1991-92 has now superseded 1982-83 as the worst drought on record. The 95% assured flow, 127 x $10^6$ $m^3$ should ensure acceptable environmental maintenance, while the 75% assured flow - 211 x $10^6$ $m^3$ - should ensure desirable conditions.

Having converted these three assessments to a common currency, that of annual volumes of water at survival, acceptable and desirable levels for environmental maintenance, it is

**Table 3.4**: Base flow recommendations for the Sabie River, from three different methods, aimed at maintaining environmental conditions at a survival, acceptable or desirable level. Recommended volumes are for the Sabie River immediately upstream of the Sabie/Sand confluence. (Flow volumes in $m^3$ x $10^6$ $yr^{-1}$).

| | Survival | Acceptable | Desirable |
|---|---|---|---|
| Consumptive / Non-Consumptive (Davies *et al.*, 1991) | - | 136.5 | - |
| PHABSIM (Gore *et al.*, 1992) | 63 | 110 | 189 |
| Hydrological Simulations (O'Keeffe & Davies, 1991) | 74 | 121 | 211 |
| % of Mean Annual Runoff | 12 | 21 | 35 |

interesting to compare the different recommendations, as in Table 3.4. Bearing in mind that these assessments each used different methods, based on different data, analyzed by different teams, the recommendations are very similar, and give some basis for confidence that they are appropriate base flows for the maintenance of the riverine ecosystem. Seen as a percentage of the present MAR of the Sabie River, they are not unreasonable requirements, and should be accepted as targets for management of the river's water resources.

# 3.3 LESSONS FROM THE 1991-92 DROUGHT.

Since the assessments described above, the Sabie has suffered the worst drought on record (in 1991-92), and this project team was fortunate enough to collect information on the effects on the biota of the river before, during, and after this drought, which provided a natural experiment of the effects of very low (or no) flow (see Vol 2). This volume summarises the lessons which can be inferred from the effects of the drought, in relation to the assessment of environmental flow requirements for the rivers.

If the rivers stop flowing, even for a short time, a number of species will disappear from the static reaches. These will include *Chiloglanis anoterus* and *Opsaridium zambezensis*. In addition to these disappearances, the community structure will change considerably, mainly as a change from dominance by cyprinids to cichlids. These changes do occur naturally during times of seasonal low-flows, but recover during subsequent high flow periods. The natural variability of the flow regime is therefore very important in maintaining the dynamic diversity of species in the river, and both low- and high flows are important in this regard. It is the duration and intensity of these low-flow events which are crucial to the survival of the full mosaic of species in the river. A large number of the fish species stop breeding during low-flows, and the longer that low-flow sequences continue, the longer it will take for the communities to recover. As a general rule, low or no-flow sequences of longer than two months are likely to cause changes to the community from which species will take a year or more to recover. If the river were to be managed to maintain flows at a survival level, species would disappear gradually but permanently due to lack of recruitment. Management of the flow regime should therefore concentrate on the maintenance of natural proportions of all species in the assemblage, rather than on the dangers of the immediate disappearance of species from the system.

The distribution of species in different pools at the Londolozi site in the Sand River during the drought, indicates that at least some of the species position themselves carefully during reducing flows, so as to be able to take advantage of the best possible pool habitat when flow ceases. The rate of flow reduction is therefore very important, and should be as slow as possible. Similarly, high flows (greater than bank-full) are important for replenishing and recolonising off-mainstream pools, which proved to be important refuges during no-flow periods.

Finally, the maintenance of permanently flowing reaches is of the utmost importance to ensure that there are survivors in the system from which recolonisation can take place. The upper reaches of the Sand and Mutlumuvi Rivers are such refuges, as is the main Sabie River. The failure of the Zoeknog Dam in Late 1992 was a compounding disaster for the Mutlumuvi, coming at the end of a two year drought. The fish community was only beginning to recover some five months after the dam failure. The other main stem of this refuge area, the Upper Sand River, had also been affected by the drought, and by the diversion of the entire base flow at the Champagne Castle Citrus Estates (between the Casteel and Dingleydale Dam sites) during 1991. It is likely to be this kind of simultaneous multiple degradation to the system which will eventually cause stresses from which the recovery potential of the rivers will be progressively, negatively impacted.

# 3.4 SUMMARISED FLOW SCENARIOS

## 3.4.1 INTRODUCTION

The purpose of this section is to gather together the detailed information that has been presented in the first two volumes of this report, and summarise it into a form that allows us to predict the consequences of different flows on the habitats, water quality and fauna of the Lowveld Zone of the Sabie River.

Predicting the ecological consequences of changes in the flow regime at this sort of scale (100 km of river) is an inexact science. In detail, the outcome of a drought on the fauna of a river may be different from one year to another, and will depend to a large extent on the following variables:

- The duration and severity of the drought
- The antecedent conditions in the river
- The proportions of different species in the communities before the drought
- Biotic interactions, such as competition, predation, and parasitism/disease during the drought
- Chance events, such as unusually hot weather.

Volume 2 documents the range of different outcomes in a series of pools in the same stretch of the Sand River during the 1992 drought, and demonstrates clearly the likely error of predicting a single set of consequences of a drought even in one part of a river which appears to be subject to the same set of conditions. Predictive accuracy is also reduced by the cumulative inaccuracies and uncertainties of hydrological, geomorphological and water quality simulations, all of which govern the population changes in the communities.

Having emphasised the variability of ecological systems, there are general trends which can be predicted with some confidence, and this section attempts to define those trends in response to different flows of different duration in the LZ of the Sabie River. This zone corresponds with the warm perennially-flowing reaches of the river in the Kruger Park. These predictions would apply equally to the Sand River, stretches of which do stop flowing during dry seasons. The impacts of different flows in the upper reaches of the river have not been dealt with, but would be expected to be more extreme, and would affect different species which are typical of the cooler, steeper gradient upper river.

The consequences of different flows on habitat availability, water quality, and the instream fauna are addressed in Tables 3.5 to 3.7. Predictions are partly quantitative and partly qualitative, because of the uncertainties described above. The tables are designed to provide a structured summary of the effects of a series of flow scenarios of varying duration, during

**Table 3.5:** Predicted effects of different flows for various durations, on the water levels and habitat availability in the Lowveld Zone Sabie River. This and the following tables are intended to provide a semi-qualitative picture of the effects of different flow regimes on the physical, chemical, habitat and biological conditions in the Sabie River, based on the measurements and observations made in the Sabie and Sand rivers from 1990-1993.

| Flow Scenario | Dry Season | Wet Season |
|---|---|---|
| no-flow ($0\ m^3s^{-1}$) | ▾ **Occurrence:** The Sabie River has never stopped flowing under present development conditions. ▾ **Habitat:** Runs would dry out with only pools remaining. **(water depth);** Many pools would be shallow. **(flow velocity);** Only standing water available. **(cover);** Depth is the only cover in deeper pools, with time turbidities increase. **(substrates);** The number and type of pools formed relates to the structure and substrate of the reach concerned. In rocky reaches, series of pools form. In sandy reaches, few pools form while active hippo pools are important. ▾ **Duration:** The length of time pools can survive without the resumption of flow depends largely on their substrate type but is influenced by initial volume, depth and surface area. Refuge pools formed in unfractured bedrock reaches such as those of the lower Sabie River at Mlondozi (Plate 8A & Vol 2; Plate 4 A-F), hold their water the longest. Pools in sandy reaches (Plate 3A, Vol 2) are dependent on base-flows. **(0-1 month);** Of the initial pools formed, many are shallow. *Initial pools of less than 30 cm deep evaporate in the first month while* deeper pools in sandy reaches can drain away. **(1-3 months);** By three months roughly half the pools found in bedrock reaches are dry with most of the remainder shallow. **(+3 months);** By six months, a typical bedrock reach may be dry. A detailed discussion is to be found in Vol 2. Because long stretches of the lowveld Sabie River are sandy without bedrock control, we would expect a lot of the river to dry out rapidly with prolonged drought. | ▾ **Occurrence:** As yet never recorded, reducing the Sabie to an ephemeral river. No-flow in summer would most likely occur towards the end of the dry season when the reach is at its lowest. ▾ **Habitat:** Summer habitats would be severely reduced in pools with a stoppage of flow no matter how brief, exactly when the biota is seasonally active. Evaporation rates would be much higher in summer and the lowveld Sabie River. Because the dry season is still to follow, most natural pools would dry before the next season. **(water depth);** Runs would dry out. Many shallow pools would be formed. **(flow velocity);** Only standing water available. **(cover);** Initially only the cover of pool substrate and depth, as pools become shallower and the biota gets concentrated, turbidity becomes important in some pools. **(substrates);** As discussed (see dry season). Substrate type and channel structure affect pool persistence. ▾ **Duration:** Prolonged no-flow would further alter the structure of the riparian strip and hence nature and quality of the reaches structure and habitats. **(0-1 month);** More than half the number of refuge pools formed would be lost in the first month due to high temperature. **(1-3 months);** Most pools would dry by the end of three months. **(+3 months);** The reach would be dry. Hippo pools, weirs and dams would be the last important local refuges for some of the biota. |
| extreme drought flows ($0\text{-}1\ m^3s^{-1}$) | ▾ **Occurrence:** For two months in 1992 (the worst drought on record). Extreme drought low-flows extended to over 6 months during the 1992 dry season (April-October). ▾ **Habitat:** Some pools isolated within the river bed. These are still connected to base-flows and offer stable *refuge as long flow persists (Vol 2; Plate 3A).* **(water depth);** Water levels are reduced by up to ±60 cm from typical base-flows (Plate 4A) resulting in very shallow runs. Water depths over riffles are very shallow (<10 cm). Pools are the only deep habitats remaining. **(flow velocity);** Flows in general are very sluggish while in riffles, the available water trickles between the substrate. **(cover);** The rivers reaches are exposed, with little marginal cover available (Vol 1; Fig. 3.7a). **(substrates);** Little sediments are transported. ▾ **Duration: (0-1 month);** Extreme low-flows are most likely to be reached in September-October in drought years. **(1-3 months);** In more dry years, extreme low-flows tend to manifest earlier (August-October) **(+3 months);** The total failure of the preceding wet season results in extreme drought flows for the most of the dry season. | ▾ **Occurrence:** As yet never been recorded. ▾ **Habitat:** Habitat area and quality reduced to a minimum as the reach approaches no-flow. Stranded marginal vegetation at the time of renewed plant growth, and the lowered water-table can be expected to alter the structure of the *riparian strip, impacting reach structure.* **(water depth);** *Reaches would be* reduced to shallower pools and very shallow runs. **(flow velocity);** Flows would be sluggish in runs with flow through, rather than over, riffles. **(cover);** No flooded marginal vegetation and clear shallow waters will expose the biota. **(substrates);** No transport or sorting of sediments would occur. Coarse substrates would remain clogged from the previous dry season. ▾ **Duration: (0-1 month);** Even in the short term, the effects of a summer low-flow of this magnitude would have long felt ecological implications. **(+3 months);** Extended summer low-flows of this magnitude preempt no-flow conditions in the following dry season. |



Table 3.5 cont.

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| drought flows (1-3 $m^3s^{-1}$) | ▾ *Occurrence: The Sabie River system is naturally drought prone, with dry season low-flows of this magnitude occurring every few years.*<br>▾ **Habitat:** The volume of habitat available is greatly reduced. **(water depth);** Base-flow levels are further reduced by up to ±30 cm. **(flow velocity);** Flows are generally sluggish. **(cover);** Almost no edge vegetation is inundated which reduces the amount of cover available to the biota (Vol 1; Fig. 3.6c). Relatively more cover remains available in reaches with rocky substrates or where tree roots have stabilized the banks. **(substrates);** Very little sediments are transported. Algal scum develops in sluggish runs while coarse sediments silt up.<br>▾ **Duration:** Uninterrupted low-flows follow on from the wet season low-flows. **(0-1 month);** Short term drought flows are most likely to originate at the end of the dry season (September-October), **(1-3 months);** with longer term drought low-flows developing earlier (August-October). **(+3 months);** A natural long term drought could extend for up to six months (May-October). | ▾ **Occurrence:** Intense summer drought and the extreme drought low-flows as recorded in the summer of 1991-92, are rare to unnatural.<br>▾ **Habitat: (water depth);** Water level is reduced by up to ±80 cm from typical wet season base-flows. **(flow velocity);** Flows are sluggish. **(cover);** Very little cover is available with waters clear, very shallow and isolated from the marginal vegetation. **(substrates);** Substrates remain silted and commonly covered in algal scum.<br>▾ **Duration:** As with extreme low-flows, drought flows tend to persist reflecting chronic rain failure. Summer drought flows are of particular concern, as the biota is seasonally active and because the following dry season is still to follow. **(0-1 month);** Flows of this magnitude and duration could be expected with a partially failed wet season or through the delayed onset of summer rains (October-November). **(+3 months);** With persistent summer rain failure these conditions can result in the early onset of the dry season (March-May) as seen in 1991-92. |
| low-flows (3-6 $m^3s^{-1}$) | ▾ **Occurrence:** Within the range of expected base-flows for the lowveld Sabie River during winter (Plate 3A & 4B).<br>▾ **Habitat:** All habitats are available with the low water level restricting the biota to the channel. **(water depth);** Vast areas of these reaches are now shallow. **(flow velocity);** Flow is generally placid. Moderate velocities are only expected at scarce but now shallow riffle habitats. **(cover);** Clear, low-flow waters conditions reduces cover, which is further reduced by limited access to marginal vegetation. Cover loss is greater moving downstream both due to more extreme water level reductions and the dominance of reed versus grass components in edge vegetation (Vol1; Fig. 3.5). **(substrates);** The extensive shallows and sandy runs begin developing an algal scum.<br>▾ ***Duration: (0-1 month) & (1-3 months);*** *Periods of low-flow interspersed by* freshets are usual both at the end of (April-June), and at the onset of the wet season (November-December). **(+3 months);** Four months of uninterrupted base-flow stretch throughout the hight of the dry season (July-October). | ▾ **Occurrence:** Typical of moderate and periodic drought in the system.<br>▾ **Habitat:** Habitat conditions would be comparable with low-flows experienced in the reach during the dry season during normal years. The summer active marginal vegetation may show zonational changes such as the colonization of exposed sand banks by grasses and herbs. Changes in the structure of the riparian strip are expected. **(water depth);** Wet season water levels of this magnitude would be ±50 cm below levels typical of seasonal low-flows. **(flow velocity);** Flow velocities will remain placid at all but riffle areas where moderate flows are expected. **(cover);** Very little instream cover is available with reduced access to the marginal vegetation fringe. **(substrates);** Silting and algal scum persistence reduces the quality of many substrate types.<br>▾ **Duration: (0-1 month);** This depends on the nature of the drought. One or two rain events would break the intensity of a developing drought, effectively re-setting the reach. **(1-3 months);** A single rain event would greatly increase the resilience of the reach. **(+3 months);** Complete failure results in profound ecological effect. |
| low-flows to freshets (6-20 $m^3s^{-1}$) | ▾ **Occurrence:** During the dry season, discharges of this magnitude are freshets. Freshets above 10 $m^3.s^{-1}$ would be rare, but more likely intermediate between both wet and dry seasons (April-June and July-October).<br>▾ **Habitat:** All habitats are available, while there is a terrestrial input of food and nutrients *into the system.* ***(water depth);*** *Water levels rise up to ±80 cm* above base-flows (Plate 3 B & C). **(flow velocity);** Moderate flow velocities as the reach is flushed. **(cover);** Cover within the reaches increase, both because of increased turbidities and access to marginal vegetation, restricted during low-flow periods. **(substrates);** Movement of sand in sandy runs evident. Flushing of accumulating fines in quiet waters increases turbidities.<br>▾ **Duration: (0-1 month);** Freshets during the dry season are by definition short lived. Discharge is elevated for approximately seven days following an event (Vol 1; Fig. 4.7). **(1-3 months);** Elevated flows of this duration are highly improbable for the Sabie River and would alter the character of the system. | ▾ **Occurrence:** Low-flows of this magnitude during the wet season are those most commonly seen in the lowveld Sabie reaches between flow events.<br>▾ **Habitat:** All habitats are available. **(water depth);** Low-flow water levels are ±50 cm higher than those of dry season low-flows. **(flow velocity);** *Moderate flow conditions are available.* **(cover);** Marginal vegetation (herbs and grasses) are bounded by their tolerances to the highest flows often experienced in the reach. Wet season high flows define their zonation. A moderate amount of marginal cover is available, providing unique cover otherwise denied to the biota. **(substrates)** Algal scums are stripped and sand transported in runs while fines are moved from some areas, *re-sorting substrates. Flows as low as five* times that of preceding flows move sediments and sort bed materials.<br>▾ **Duration: (0-1 month);** Low-flows typical of the wet season are of short duration as rain events continuously flush through the system. The monthly low-flow average gradually rises to a peak in February. **(1-3 months);** Low-flows of this duration may be possible in seasons approaching drought. ***(+3 months);*** Extended or managed wet season low-flows would be unnatural and remove much of the dynamics that drives this seasonal system. |

Table 3.5 cont.

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| **Freshets to floods** ($>20\ m^3s^{-1}$) | ▾ **Occurrence:** Rare to unnatural to the system under present conditions.<br>▾ **Habitat:** Most habitats would be made available. **(water depth);** Water levels could rise some meters before flooding the banks. **(flow velocity);** Aseasonal high velocities would flush the system with atypical ecological effects. **(cover);** Marginal vegetation would be flooded at the wrong time in its growth cycle. **(substrates);** The sorting and transport of the reaches would proceed aseasonally.<br>▾ **Duration: (0-1 month);** A late or early flood is the most likely of events to occur naturally. Their disruptive effects would probably be measured within a season. **(1-3 months);** Long-term elevated flows would alter the ecology as we understand it considerably. This condition is not possible under present climatic conditions. | ▾ **Occurrence:** Pulses of high-flow or freshets, and large events or floods are typical and unique to this season.<br>▾ **Habitat:** The first freshets of the season are particularly important in re-setting the system. All habitat are made available, including many temporary areas, rich in nutrient input. Flows are highly dynamic and fundamental in the restructuring of the channel. **(water depth);** Water levels can briefly rise some meters, flooding its banks in some areas. **(flow velocity);** High flow velocities are recorded throughout the main channel. **(cover);** Although floodplains are not features of the mid- and lower Sabie River, extensive reedbeds do occur. These are flooded during high flows. (Vol 1; Fig. 3.4). **(substrates);** During high flows the movement of bed-load is important. Channel re-structuring processes take place.<br>▾ **Duration: (0-1 month);** These flows are by definition of short duration. **(1-3 months);** Protracted periods of high flow are not possible under present climatic conditions. |

░ = Flow magnitudes & flow types most commonly associated with the lowveld Sabie River reaches, under present development conditions.

**Table 3.6:** Physico-chemical conditions at different seasonal discharges in the Sabie River lowveld.

| Flow Scenario | Dry Season | Wet Season |
|---|---|---|
| ***no-flow***<br>**(0 $m^3s^{-1}$)** | ***(at isolation)***<br>▾ **Salinity:** 130-170 µS/cm<br>▾ **pH:** 6.8-7.6<br>▾ **TSS:** 0.0003-0.0007 g/l<br>▾ **Turbidity:** 1-6 NTU<br>▾ **Oxygen:** >60% saturation<br>▾ **Temperature:** 21.5-25.4°C<br><br>***(after 3 months)***<br>▾ **Salinity:** 300-600 µS/cm<br>▾ **pH:** 7.4-9.1<br>▾ **TSS:** 0.0007-0.0018 g/l<br>▾ **Turbidity:** 1-62 NTU<br>▾ **Oxygen:** 7-156% saturation<br>▾ **Temperature:** 18.1-25.3°C<br><br>**(after 5 months)**<br>▾ **Salinity:** 590-900 µS/cm<br>▾ **pH:** 8.5-9.7<br>▾ **TSS:** 0.016-0.053 g/l<br>▾ **Turbidity:** 63-610 NTU<br>▾ **Oxygen:** 7-414% saturation<br>▾ **Temperature:** 28.8-33.6°C<br><br>▾ **Comments:** Only isolated pools remain. The water quality deteriorates over time. Smaller pools can become unacceptably saline (450 µS/cm; DWAF, 1993) or alkaline after 3 months. Shaded pools show low daytime oxygen levels which can result in nighttime fish kills. In exposed pools, dissolved oxygen supersaturates the water due to the presence of algal blooms. After five months isolation, pools are more mineralised (up to 900µS/cm), alkaline (up to pH 10) and much more turbid due to the concentrated action of fish and the development of algal blooms. Much warmer water temperatures are recorded, while dissolved oxygen levels can be even more extreme. | **(at isolation)**<br>▾ **Salinity:** ±130-170 µS/cm<br>▾ **pH:** ±7-8<br>▾ **TSS:** ±0.0003-0.0007 g/l<br>▾ **Turbidity:** ±1-6 NTU<br>▾ **Oxygen:** ±>60% saturation<br>▾ **Temperature:** ±28-35°C<br><br>**(after 3 months)**<br>▾ **Salinity:** ±600-900 µS/cm<br>▾ **pH:** ±9-10<br>▾ **TSS:** ±0.02-0.05 g/l<br>▾ **Turbidity:** ±60-600 NTU<br>▾ **Oxygen:** ±10-410 % saturation<br>▾ **Temperature:** ±28-37°C<br><br>**(after 5 months)**<br>▾ **Salinity:** ±700-1600 µS/cm<br>▾ **pH:** ±9-10<br>▾ **TSS:** ±0.02-0.05 g/l<br>▾ **Turbidity:** ± 60-600 NTU<br>▾ **Oxygen:** ±10-410% saturation<br>▾ **Temperature:** ±28-40°C<br><br>▾ **Comments:** Isolated pools would form. Water quality would deteriorate to extremes more rapidly in the summer months, with pools showing much higher temperatures. After three months, smaller pools would have dried, while the salinities (450 µS/cm; DWAF, 1993) and alkalinities (up to pH 10) of larger pools would have increased to unacceptable levels. Daytime dissolved oxygen in shaded pools would be very low, resulting in nighttime fish-kills. Supersaturated daytime dissolved oxygen levels would occur in exposed pools due to algal blooms. After five months, pools would be more mineralised (>1600µS/cm), alkaline (up to pH 10) and much more turbid. The increase in turbidity is due to the concentrated action of fish and the development of algal blooms. |
| **extreme drought flows**<br>**(0-1 $m^3s^{-1}$)** | ▾ **Salinity:** 150-180 µS/cm<br>▾ **pH:** 7.6-8.2<br>▾ **TSS:** 0.0023-0.0065 g/l<br>▾ **Turbidity:** 2-3 NTU<br>▾ **Oxygen:** >60% saturation<br>▾ **Temperature:** 18.7-27.9°C<br><br>▾ **Comments:** Dry season extreme drought flows may develop poorer oxygen regimes and become moderately warmer than typical low-flows. Very high nutrient concentrations have also been recorded, but in general the water quality is still acceptable. | ▾ **Salinity:** ±150-180 µS/cm<br>▾ **pH:** ±7.5-8<br>▾ **TSS:** ±0.002-0.007 g/l<br>▾ **Turbidity:** ±2-3 NTU<br>▾ **Oxygen:** ±>60% saturation<br>▾ **Temperature:** ±28-35°C<br><br>▾ **Comments:** Extreme drought flow in the summer months could results in very poor oxygen levels and high water temperatures than those typical of "wet season" flows. Nutrient levels may also be elevated, but in general, the water quality is still acceptable. |

Table 3.6 cont.

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| **drought flows**<br>**(1-3 $m^3s^{-1}$)** | ▼ ***Salinity:*** *120-140 μS/cm*<br>▼ **pH:** 7.1-7.9<br>▼ **TSS:** 0.0036-0.0064 g/l<br>▼ **Turbidity:** 3-5 NTU<br>▼ **Oxygen:** >80% saturation<br>▼ **Temperature:** 14.2-18.4°C<br><br>▼ **Comments:** The water quality of dry season drought flows are good and similar to those of other flows between 1-6 $m^3s^{-1}$ which are clear, neutral and with moderate dissolved salt levels. Drought flow waters are less oxygenated than typical low-flows. | ▼ **Salinity:** 110-130 μS/cm<br>▼ **pH:** 7.9-8.3<br>▼ **TSS:** 0.003-0.005 g/l<br>▼ **Turbidity:** 5-8 NTU<br>▼ **Oxygen:** >80% saturation<br>▼ **Temperature:** 25.5-32.1°C<br><br>▼ **Comments:** The water quality of "wet season" drought flows would remain fair, being similar to other low-flows (1-6 $m^3s^{-1}$). Waters would be clear, neutral and with moderate levels of dissolved salts. Summer flows of this magnitude would nevertheless be less oxygenated and much warmer than dry season drought flows. |
| **low-flows**<br>**(3-6 $m^3s^{-1}$)** | ▼ **Salinity:** 90-140 μS/cm<br>▼ **pH:** 7.4-8.1<br>▼ **TSS:** 0.0015-0.0093 g/l<br>▼ **Turbidity:** 2-7 NTU<br>▼ **Oxygen:** >90% saturation<br>▼ **Temperature:** 15.2-24.5°C<br><br>▼ **Comments:** The water quality of dry season low-flows are good. Low-flows of between 1-6 $m^3s^{-1}$ have waters which are clear, neutral and with moderate dissolved salt levels. Low-flows above 3 $m^3s^{-1}$ are better oxygenated than lower flows while winter low-flows are cooler than wet season low-flows. | ▼ **Salinity:** ±90-140 μS/cm<br>▼ **pH:** ±7-8<br>▼ **TSS:** ±0.002-0.009 g/l<br>▼ **Turbidity:** ±2-7 NTU<br>▼ **Oxygen:** ±>90% saturation<br>▼ **Temperature:** ±25-30°C<br><br>▼ **Comments:** The water quality of wet season low-flows are good and similar to those of other flows between 1-6 $m^3s^{-1}$ which are clear, neutral and with moderate dissolved salt levels. Low-flows above 3 $m^3s^{-1}$ are better oxygenated than lower flows, while summer low-flows are warmer than dry season low-flows. |
| **low-flows to freshets**<br>**(6-20 $m^3s^{-1}$)** | ▼ **Salinity:** 80-140 μS/cm<br>▼ **pH:** 7.3-8.2<br>▼ **TSS:** 0.0014-0.228 g/l<br>▼ **Turbidity:** 2-469 NTU<br>▼ **Oxygen:** >90% saturation<br>▼ **Temperature:** 16.5-28.3°C<br><br>▼ **Comments:** Elevated flows in the dry season transport a lot of suspended solids resulting in very high TSS and turbidity measures. These flows may be more turbid than similar wet season low-flows due to less ground cover and riparian vegetation growth. The water quality is good. | ▼ **Salinity:** 80-120 μS/cm<br>▼ **pH:** 7.4-7.5<br>▼ **TSS:** 0.026-0.06 g/l<br>▼ **Turbidity:** 22-52 NTU<br>▼ **Oxygen:** >90% saturation<br>▼ **Temperature:** 21.4-27.5°C<br><br>▼ **Comments:** The water quality is similar to that of wet season low-flows and is good. Summer low-flows are less turbid than corresponding dry season flows due to better developed ground cover and active riparian vegetation growth. |
| **freshets to floods**<br>**(>20 $m^3s^{-1}$)** | ▼ **Salinity:** ≤60 μS/cm<br>▼ **pH:** ±7-8<br>▼ **TSS:** ±0.0173-0.228 g/l<br>▼ **Turbidity:** ±90-500 NTU<br>▼ **Oxygen:** >90% saturation<br>▼ **Temperature:** ± 17-25°C<br><br>▼ **Comments:** Winter flood waters would show extremely high TSS and turbidity. Salinities and temperatures would be slightly reduced. | ▼ **Salinity:** ≤60 μS/cm<br>▼ **pH:** 7.4-7.6<br>▼ **TSS:** 0.048-0.052 g/l<br>▼ **Turbidity:** 64-86 NTU<br>▼ **Oxygen:** >90% saturation<br>▼ **Temperature:** 23.5-25.2°C<br><br>▼ **Comments:** Summer floods waters show slightly reduced salinities and temperatures and increased turbidities. TSS and turbidity are higher, but not as extreme as for similar aseasonal flow events. |

**Table 3.7:** The response of the biota to different seasonal discharges for different durations in the Sabie River lowveld.

| Flow Scenario | Dry Season | Wet Season |
|---|---|---|
| **no-flow**<br>**(0 $m^3s^{-1}$)** | ▾ **Lotic Fish:** High mortalities. Surviving fish in stressed condition. No breeding.<br>▾ **Lentic Fish:** Increased mortalities, stressed condition. Very little breeding.<br>▾ **Migratory Fish:** No migration possible as fish are confined to pools.<br>▾ ***Fish Assemblage Changes:***<br>**Cichlids:** Absolute numbers reduced but they remain the most abundant group.<br>**Cyprinids:** Reduced to remnants with local extinctions.<br>**Silurids:** Reduced or locally extinct.<br>▾ **Macroinvertebrates:** Flow dependent species disappear.<br>▾ **Indicators:**<br>**(when flow ceases)** *Oreochromis mossambicus* is the most numerous species. Flow dependent species would be most impacted (Table 3.8), while those of shallow water would suffer heavy losses. All species confined to drought pools, concentrated and exposed to rapidly deteriorating water quality conditions. Most Trichoptera and Ephemeroptera are lost with flow cessation as are the oxygen sensitive fishes *Chiloglanis anoterus* and *Opsaridium zambezense*.<br>**(after 1-3 months)** Stunted *O.mossambicus* breed. *Tilapia rendalli* suffers high mortalities. Increased predation by *Clarias gariepinus* and birds.<br>**(after 3-5 months)** Very few pools survive. Most mortalities are the result of the pools drying out. Water quality is poor, remaining fish are emaciated. Only *Labeo molybdinus* and *C.gariepinus* and other deep pool species may attain breeding condition prior to the first summer rains. The LZ is reduced to a handful of hippo pools and man-made weirs. | ▾ **Lotic Fish:** *High mortalities. Some local extinctions as most pools dry up.* Surviving fish are in poor condition. No breeding.<br>▾ **Lentic Fish:** High mortalities. Most species found in persistent pools remain in a fair condition. Limited or no breeding.<br>▾ **Migratory Fish:** No migration possible as fish are confined to pools.<br>▾ **Fish Assemblage Changes;**<br>**Cichlids:** The most abundant group.<br>**Cyprinids:** Reduced to remnant populations. Some local extinctions.<br>**Silurids:** Reduced to remnant populations. Local extinctions.<br>▾ **Macroinvertebrates:** Flow associated taxa disappear.<br>▾ **Indicators:**<br>**(when flow ceases)** The cichlid *O.mossambicus* is the most abundant fish in pools. Flow dependent species such as *O.zambezense* and *C.anoterus* are lost due to poor oxygen regimes and increased water temperatures.<br>**(1-3 months)** *T.rendalli* losses condition with deteriorating water quality and dies out before pools finally dry. Minnows reduced to remnant population with *Barbus toppini* and *Barbus paludinosus* the most resilient.<br>**(3-5 month)** *C.gariepinus, O.mossambicus* can survive to the last because of they have axillary air breathing structures. |
| **extreme drought flows**<br>**(0-1 $m^3s^{-1}$)** | ▾ **Lotic Fish:** Increased mortalities. Fish in poor condition. No breeding.<br>▾ **Lentic Fish:** Good survival in placid reaches. Most fish remain in good condition. Breeding continues except in more sensitive species as water quality deteriorates.<br>▾ **Migratory Fish:** No migration.<br>▾ **Fish Assemblage Changes:**<br>***Cichlids:** Most abundant population.*<br>**Cyprinids:** Reduced to remnant population.<br>**Silurids:** Reduced to remnant population.<br>▾ **Macroinvertebrates:** Most flow dependent species much reduced. Diversity and density reduced.<br>▾ **Indicators:** *O.mossambicus* continues to breed in sluggish reaches, but in stunted form. The gobi *Glossogobius callidus* also breeds. *T.rendalli* copes with deteriorating conditions but ceases to breed. Cyprinids, particularly the flow sensitive species, are very stressed and concentrated with high mortalities (Table 3.8). Many species, particularly the more mobile ones move to the deeper or larger pools or select cover in anticipation of the cessation of flow. Flow sensitive species congregate at or below the last riffle areas in greatly reduced numbers. | ▾ **Lotic Fish:** High mortalities with surviving fish in poor condition. No breeding.<br>▾ **Lentic Fish:** Increased mortalities *with fish stressed and in poor condition.* Limited breeding.<br>▾ **Migratory Fish:** No migration.<br>▾ **Fish Assemblage Changes:**<br>***Cichlids:** Still the most abundant species following previous dry season.*<br>**Cyprinids:** Further reduction of dry season numbers.<br>**Silurids:** Further reductions of dry season low numbers.<br>▾ **Macroinvertebrates:** Flow dependent taxa much reduced.<br>▾ **Indicators:** *O.mossambicus* continues to be the most abundant species but breed in a stunted form. *G.callidus* continues to breed in quiet waters but *T.rendalli* does not breed. Flow sensitive species (*O.zambezense & C.anoterus*) suffer high mortalities due to high temperatures and low oxygen regimes. Shallow water cyprinids suffer because of reduced cover (*Barbus viviparus & Barbus marequensis*). *B.marequensis* move from the runs to riffle area where *Chiloglanis paratus* was previously most abundant. The remaining fish species are concentrated and await improved conditions. Lowveld temporary river minnows *B.paludinosus* and *B.toppini* prosper should these flows become more frequent. |

Table 3.7 cont.

| | | |
|---|---|---|
| **drought flows** ($1\text{-}3\ m^3s^{-1}$) | ▼ **Lotic Fish:** Increased mortalities and poor condition of many species. No breeding.<br>▼ **Lentic Fish:** Good survival and condition. Increased breeding potential at higher temperatures.<br>▼ ***Migratory Fish:*** *No migration.*<br>▼ **Fish Assemblage Changes:**<br>**Cichlids:** Increase greatly.<br>**Cyprinids:** Reduced.<br>**Silurids:** Reduced.<br>▼ ***Macroinvertebrates:*** *Reduced dry season community.*<br>▼ **Indicators:** Increased breeding success of the cichlids *T.rendalli* and *O.mossambicus*. *O.mossambicus* is particularly prolific in the LZ assemblage by the start of the wet season in November. *B.viviparus* and *B.marequensis*, the most numerous wet season shallow water species, are greatly reduced due to continued cover loss in shallow habitats. All minnow species concentrated and confined to pools. Flow dependent species continue to decline. | ▼ **Lotic Fish:** Increased mortalities. Most species stressed and in poor condition. No breeding.<br>▼ **Lentic Fish:** Good survival rates with fish mostly in good condition and breeding.<br>▼ **Migratory Fish:** Little to no movement expected.<br>▼ **Fish Assemblage Changes:**<br>**Cichlids:** Most abundant and increasing in number, following the dry season.<br>**Cyprinids:** Decrease further from dry season numbers.<br>**Silurids:** Decrease in numbers.<br>▼ ***Macroinvertebrates:*** *Wet season, flow sensitive taxa reduced.*<br>▼ **Indicators:** The cichlids *O.mossambicus* and *T.rendalli* breed profusely in sluggish runs and pools, dominating the lowveld assemblage. Sensitive species dependent on flow (*C.anoterus* & *C.anoterus*) in poor condition. Fish are concentrated. Reductions in *B.marequensis* and *B.viviparus*, normally the most abundant shallow-water cyprinids, due to reduced cover and therefore increased mortalities. The minnows *B.toppini* and *B.paludinosus*, typical of lowveld tempory rivers, increase in importance should these low wet-season flows become common. |
| **low-flows** ($3\text{-}6\ m^3s^{-1}$) | ▼ **Lotic Fish:** Good survival and condition. No fish in breeding condition and no breeding.<br>▼ **Lentic Fish:** Excellent survival of fish in good condition. Ideal breeding conditions at higher temperatures results in prolific breeding.<br>▼ **Migratory Fish:** No migration expected.<br>▼ **Fish Assemblage Changes:**<br>**Cichlids:** Increased.<br>**Cyprinids:** No change.<br>**Silurids:** No change.<br>▼ **Macroinvertebrates:** Full range of dry season species.<br>▼ **Indicators:** Reduction of protected shallow habitat leads to the reduction in *B.viviparus* (adults) and *B.marequensis* (juveniles). Flow dependent species (Table 3.8) are stressed while the oxygen sensitive *O.zambezense* and *C.anoterus* are reduced far more than *C.paratus* which seems to tolerate low-flows. | ▼ ***Lotic Fish:*** *Good survival with adequate habitat available. Most species in* good condition, most in breeding condition. Little breeding at these low-flows unless preceded by a freshet.<br>▼ **Lentic Fish:** Excellent survival potential with fish in good condition in slower flows. All cichlid species breeding.<br>▼ **Migratory Fish:** Little migration expected but some seasonal/local movements possible.<br>▼ **Fish Assemblage Changes:**<br>**Cichlids:** Marked increase.<br>**Cyprinids:** No change in numbers.<br>**Silurids:** Slight reduction in numbers.<br>▼ **Macroinvertebrates:** Full range of wet season species present.<br>▼ **Indicators:** Cichlids increase rapidly in warm and placid reaches, particularly *O.mossambicus* and *T.rendalli*. After a summer freshet, the minnows attain breeding condition, but little spawning is expected as high flows are few or reduced in magnitude. The water quality of flushing flows is an important spawning cue, and the amount of marginal vegetation flooded is an important factor in breeding success. The larger cyprinids, *B.marequensis* and the Labeos, do not spawn. Lower and hence warmer summer flows stress *C.anoterus* and favour *C.paratus*. |

Table 3.7 cont.

| | | |
|---|---|---|
| **low-flows to freshets** ($6-20\ m^3s^{-1}$) | ▾ **Lotic Fish:** Good survival and improved condition of all species. Early summer month freshets result in species coming into breeding condition early. No breeding if these aseasonal flows occur in the cooler months (prior to September).<br>▾ **Lentic Fish:** Good survival and condition. Breeding starts when the waters are warmer, in the dry season summer months (September-November).<br>▾ **Migratory Fish:** Little migration although early summer flushes may result in some recolonization migrations.<br>▾ ***Fish Assemblage Changes:***<br>**Cichlids:** Increase in the latter phase of the dry season.<br>**Cyprinids:** No change in abundance.<br>**Silurids:** No change in abundance.<br>▾ **Macroinvertebrates:** Full range of dry season species.<br>▾ **Indicators:** Cichlids benefit from the improved water quality of dry season freshets. Although higher flows would reduce the amount of habitat available to them *O.mossambicus* and *T.rendalli* would still be most abundant species by the end of the dry season. Cyprinids, particularly those dependent on flow and those needing cover in shallow habitats would thrive with reduced mortalities. Chiloglanids would maintain pre-dry season abundances. The highest attainable dry season diversities and abundances are expected under these flow conditions. | ▾ **Lotic Fish:** Excellent survival potential. All species in good condition. All species in breeding condition with some serial spawning.<br>▾ **Lentic Fish:** Good survival potential with fish equally in good condition. Some breeding.<br>▾ **Migratory Fish:** Some migration and local movement takes place. Some recolonization of reaches impacted during the dry season.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Persist at levels attained so far.<br>***Cyprinids:*** *Increase slightly.*<br>**Silurids:** Increase slowly.<br>▾ **Macroinvertebrates:** Full range of wet season species.<br>▾ **Indicators:** Summer low-flows provide good access to most habitats. Young-of-the-year of flow dependent cyprinids, *O.zambezense*, *B.marequensis* and *L.molybdinus*, increase, especially if higher flow events have occurred. Some flow dependent and marginal to flow species (eg. *B.viviparus*) spawn to a limited degree. *Barbus radiatus* and *Barbus annectens* that prefer quiet pools with cover do well. Cichlids continue breeding if placid flows persist. *C.anoterus* survives normal summer low-flows, although *C.paratus* and *C.swierstrai* are more suited to warmer low-flow conditions. |
| **Freshets to floods** ($>20\ m^3s^{-1}$) | ▾ **Lotic Fish:** Good survival potential. Species maintain condition although not in breeding condition. No breeding unless very close to the onset of the summer season.<br>▾ **Lentic Fish:** Increased mortalities as disrupted early summer breeding and the flushing of young fish from runs. Fishes surviving in backwaters in good condition. If the waters are warm prior to the floods, breeding is disrupted.<br>▾ **Migratory Fish:** No migration of fish is expected in winter. If flood flows occurred during the summer dry season months, early fish movements are expected.<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Reduction due to scouring of channel habitats.<br>**Cyprinids:** Remain relatively abundant due to reduced dry season mortalities.<br>**Silurids:** No change.<br>▾ **Macroinvertebrates:** Full range of dry season species but some mortality due to scouring.<br>▾ **Indicators:** The early summer dry season breeding success of cichlids is disrupted by aseasonal flood flow, scouring reaches of breeding nests and young fish. Both *T.rendalli* and *O.mossambicus* affected. Early rains reset the system, bringing cyprinids into early condition which result in early spawning (October-November). The effects of aseasonal flood flows on the natural functioning of the Sabie River lowveld are not known. Dry season floods together with elevated base flows reduce the mortalities of small shallow waters species that require cover (*B.marequensis* and *B.viviparus*). They achieve very high abundances if followed by a good wet season. *C.anoterus* could resist dry season reduction of its winter LZ range. | ▾ **Lotic Fish:** Excellent survival potential. All lotic species in good condition, with all species in breeding condition and breeding. Some flood dependent spawners spawn massively.<br>▾ **Lentic Fish:** Reduced survival potential in flowing reaches. Those that find refuge from flow remain in good condition. Breeding is disrupted.<br>▾ **Migratory Fish:** Potamadromous or migratory fish move extensively within the catchment while the catadromous species migrate from fresh to salt water to breed (Table 3.10). Migrations serve both to recolonize (juveniles and adults) and to provide suitable spawning and nursery sites (adults).<br>▾ **Fish Assemblage Changes:**<br>**Cichlids:** Decrease.<br>**Cyprinids:** Increase dramatically.<br>**Silurids:** Increase.<br>▾ **Macroinvertebrates:** Full range of flow related species but some mortality due to scouring.<br>▾ **Indicators:** Cichlid breeding is disrupted. Breeding sites scoured and surviving young-of-the-year move into backwaters. Most seasonal lotic species are cued to spawn. Repetitive or high flood flows result in great increases in the larger flood spawning fishes. Labeos (*Labeo rosae*, *Labeo congoro*, *L.molybdinus* and *Labeo ruddi*), the yellow fish *B.marequensis* and the larger silurids *C.gariepinus* and *Schilbe intermedius* all spawn freely, as do the characoids *Hydrocynus vittatus* and *Brycinus imberi*. Young-of-the-year of the minnow *Barbus afrohamiltoni* and *L.rosae* may increase to form significant proportions of the fish assemblage. *C.anoterus* extends down into the cooler and strong flowing LZ waters matching the abundance of *C.paratus* at LZ rocky rapids. *C.swierstrai* is common in runs with sand in transit. |

░ = Flow conditions most typical for the Sabie River Lowveld under present developmental conditions.

the wet and dry seasons. We envisage that these tables will be useful to scientists, conservationists, and managers in assessing the effects of modified flows as a result of impoundment and increased water abstraction. We have therefore included the effects of a range of flows which have not normally occurred in the Sabie, and of standing water only, which has never yet occurred, but may do in the future.

### 3.4.2 CHARACTERISTIC FLOWS IN THE SABIE RIVER LOWVELD

Simulated discharges as well as actual mean monthly flows recorded during the course of this study are presented in Figure 4.4a (chapter 4; Vol 1). Flow in the Sabie River fluctuates seasonally but remains perennial in its lowveld section.

The first rains are expected in November whereafter mean monthly discharge increases rapidly to a peak in February. Dry season base-flows are re-established by May, some six months later. Wet season mean monthly flows can be misleading as they are skewed by frequent high flow events.

Tables 3.5-3.7 are structured on the following characteristic flows: Typical **summer low-flows** (6-20 $m^3s^{-1}$), are interspersed by flow peaks called **summer freshets** or **floods** (>20 $m^3s^{-1}$). Single events last several days before base-flow is restored. **Persistent summer low-flows** (3-6 $m^3s^{-1}$) are natural but confined to times of drought. The **summer drought flows** (1-3 $m^3s^{-1}$) of 1992-93 reduced the lowveld Sabie to its lowest recorded level. **Extreme drought flows** (0-1 $m^3s^{-1}$) and **no flow** (0 $m^3s^{-1}$) have yet to be recorded in the Sabie, but do occur in the Sand River. Typical **winter low-flows** (3-6 $m^3s^{-1}$) are normally uninterrupted by higher flows for some months. Winter **freshets** (6-20 $m^3s^{-1}$) do occur in the dry season but **winter floods** (>20 $m^3s^{-1}$) are not natural to the system. Sporadic **winter drought flows** (1-3 $m^3s^{-1}$) are characteristic during very dry winters, while **extreme winter drought flows** (0-1 $m^3s^{-1}$) were only recorded during the 1992-93 drought. **No flow** has never been recorded even during the winter dry season.

### *3.4.2.1 FLOWS AND HABITAT*

The habitat available in the Sabie River lowveld at different discharges is intimately related to the structure of the river, details of which are given in chapter 3 (Vol 1). The lowveld section of the Sabie River is moderately large (5th order) and of gentle gradient (1.7-3.3 $m.km^{-1}$). From edge to edge, the water surface covers approximately 30 m within a single channel, but braided sections do occur. Most reaches are sandy run-pool sequences with limited coarse substrate. Riffle areas are progressively scarce further downstream. Occasional control points of bedrock and boulders occur where geological dykes cut across the channel. The riparian strip spans about 100-400 meters flanked by tall riparian trees and extensive reed-beds (Fig. 3.4; Vol 1). During freshets and especially floods water levels reach the reed-beds and the riparian strip.

Table 3.5 lists the effects of different flows on the availability of habitat:

* **Water depth:** During normal years, low-flow in winter results in shallow runs (±1 m) with only pools offering deep habitats. Summer low-flows in contrast are ±50 cm deeper. Summer floods can temporarily raise the water level some meters, but a rise of some 80 cm would constitute a freshet in the dry season. During drought flows (1-3 $m^3s^{-1}$), water levels are reduced by some 30 cm from normal dry season low-flows. Should the river ever stop flowing, runs would gradually reduce in depth until only pools remain. Initially, many shallow pools would result, and the survival of these pools would depend on the duration of the drought.

* **Flow velocity:** Flow velocities in the lowveld river are governed by its moderate gradient, as well as the water depth and width of the channel. During normal low-flows, scarce riffle areas are the only areas of higher velocity. At the height of winter low-flow and in drought conditions, flows in runs become sluggish, resulting in algal mat development and very little sediment transport. Freshets increase the rate of transport, and wet season freshets and floods can increase flows in general to high levels effectively scouring the channel,

sorting and transporting sediments. In early summer, these increased flows are important in resetting the water quality and habitats in the river.

* **Cover:** Marginal vegetation has an important role in providing cover to the biota. The lowest limits colonised by terrestrial plants is largely governed by the water level of summer low-flows (6-10 $m^3s^{-1}$). During winter low-flow (3-6 $m^3s^{-1}$) little marginal vegetation cover is available for the fauna. Coarse substrates too provide excellent cover. This type of cover is more important towards west where loose-substrate riffles occur. Similar reduced flows in summer have marked effects on spawning sites and the survival of young-of-the-year of most seasonal breeding fishes. At very low flows turbidity is very low and only deep pools provide cover. Isolated pools can become turbid due to concentrated fish activity, or by algal blooms.

### *3.4.2.2 FLOWS AND PHYSICO-CHEMISTRY*

Like the physico-chemistry of the catchment in general (chapter 5: Vol 1), the water quality of the lowveld Sabie River is good. The effects of different flows are tabled in Table 3.6. In normal years, the waters are neutral (pH 7-8.2), with moderate dissolved solids (0.001-0.228 g/l) and well oxygenated (>90%). Turbidities vary according to the season with low low-flow turbidities (2-7 NTUs) and higher turbidities recorded after rain (up to 470 NTUs). Events during the normal dry season are particularly turbid.

Under extreme drought (0-1 $m^3s^{-1}$), waters tend to become warmer, less oxygenated and slightly eutrophic. Temperature increases are particularly high (up to 35°C) in the hotter summer months with drought flows. If flow stops, the potential for water quality changes over time are very great. No flow during the hotter summer season results in increased evaporation and therefor more rapid deterioration of the water quality. Extremes in salinity (1600 µS/cm), pH (9-10), oxygen (<15% saturation), temperature (up to 40°C), as well as increased nutrient levels are expected (Table 3.6).

### *3.4.2.3 FLOW AND THE ICHTHYOFAUNA*

Of the 49 species of fish found in the Sabie-Sand catchment (see chapter 7; Vol 1), populations of 36 species are resident in the lowveld reaches of the Sabie River, and define the Lowveld Zone. Differences in flow effects microhabitat available, breeding potential, and movement of the biota (Table 3.7).

* **Flow microhabitat needs:** Flow microhabitat requirements of both juveniles and

**Table 3.8:** Flow micro-habitat needs of the lowveld target species.

| Taxonomic Group | Species | Flow Microhabitat | | | | | |
|---|---|---|---|---|---|---|---|
| | | out of flow | | next to flow | | in flow | |
| | | J | A | J | A | J | A |
| Characins | *Micralestes acutidens* | | | * | | | * |
| Cichlids | *Oreochromis mossambicus* | * | * | | | | |
| | *Pseudocrenilabrus philander* | * | * | | | | |
| | *Serranochromis meridianus* | * | * | | | | |
| | *Tilapia rendalli* | * | * | | | | |
| Cyprinids | *Barbus annectens* | * | * | | | | |
| | *Barbus marequensis* | | | | * | * | |
| | *Barbus radiatus* | * | * | | | | |
| | *Barbus trimaculatus* | | | * | * | | |
| | *Barbus unitaeniatus* | | | * | * | | |
| | *Barbus viviparus* | | | * | * | | |
| | *Labeo molybdinus* | | | | | * | * |
| | *Opsaridium zambezense* | | | | | * | * |
| Silurids | *Chiloglanis anoterus* | | | | | * | * |

adults for target species are summarized in Table 3.8. Target species were either abundant (accounting for 6% of the catch on any field trip), or of special interest (*Serranochromis meridianus* is endemic). All the cichlids and two deep pool minnows preferred quiet waters away from flow while a suite of minnows enjoyed quiet waters close to flowing water. Five species required faster current at either juvenile or adult stages.

* **Flow requirement for breeding:** All the lowveld species are seasonal breeders coming into condition in the warmer summer months, with the possible exception of *C. anoterus*. Species can be divided into lotic or lentic breeders depending on whether flowing

**Table 3.9:** Flow requirements of lowveld target species for seasonal breeding.

| Taxonomic Group | Species | Lentic Breeders | Lotic Breeders | |
|---|---|---|---|---|
| | | out of current | | in current |
| Characins | *Micralestes acutidens* | | | * |
| Cichlids | *Oreochromis mossambicus* | * | | |
| | *Pseudocrenilabrus philander* | * | | |
| | *Serranochromis meridianus* | * | | |
| | *Tilapia rendalli* | * | | |
| Cyprinids | *Barbus annectens* | | * | |
| | *Barbus marequensis* | | | * |
| | *Barbus radiatus* | | * | |
| | *Barbus trimaculatus* | | * | |
| | *Barbus unitaeniatus* | | * | |
| | *Barbus viviparus* | | * | |
| | *Labeo molybdinus* | | | * |
| | *Opsaridium zambezense* | | | * |
| Silurids | *Chiloglanis anoterus* | | | * |

water is required for successful breeding (Table 3.9). Of the target species, only the cichlids breed independent of flow. Many of the minnow species do breed in quiet waters but only after a flow event following physico-chemical cues or access to flooded marginal vegetation. While some species are able to attain breeding condition during extreme drought and breed during the first rain event (*C. gariepinus* and *L. molybdinus*), the first freshet/flood of the summer season is needed to restore the water quality and make habitat available for the majority of seasonal species. Seasonal spawning minnows attain breeding condition within the first month following rains. Extensive spawning can be expected with each subsequent flow event.

* **Movement:** Flow, particularly summer flow events are important for fish movements. Table 3.10 categorises movements for all LZ species. Most lowveld species have been shown to move at some stage during their lifespan. These movements are important in breeding (two catadromous & 24 potamadromous species) and dispersal (juveniles of 7 potamadromous species). Labeos are particularly geared to seasonal flow-induced migrations. Species that show both juvenile and adult migrations are often the first fish to recolonise defaunated reaches following droughts.

* **Seasonal discharge and patterns in fish abundance:** During normal rain year, the LZ assemblage shows very distinct seasonal shifts in abundance in the two most abundant taxa (Fig. 2.12). Lentic breeding cichlids successfully breed as waters warm but prior to and irrespective of the first summer rains. They dominate the lowveld assemblage by the end of the dry season (October-November). The high flows of the wet season disrupt the breeding of the cichlids while allowing the cyprinids and other seasonal species to breed successfully. By the end of the wet season, cyprinids normally re-dominate the lowveld assemblage.

Summer drought effectively locks the lowveld assemblage into the pattern typical of the late dry season, where cichlids dominate. Summer drought is followed by an extreme dry season which further reduces most fish numbers. Predation is much higher for some shallow water/marginal vegetation species while mortalities are higher for many lotic species due to

**Table 3.9:** Flow requirements of lowveld target species for seasonal breeding.

| Taxonomic Group | Species | Movement Type | | | | |
|---|---|---|---|---|---|---|
| | | Non-migratory | Potamodromous | | Catadromous | |
| | | J & A | Juveniles | Adults | Juveniles | Adults |
| Anguillids | *Anguilla mossambicus* | | | | * | * |
| | *Anguilla bengalensis* | | | | * | * |
| Characins | *Brycinus imberi* | | | * | | |
| | *Hydrocynus vittatus* | | * | * | | |
| | *Micralestes acutidens* | | | * | | |
| Cichlids | *Oreochromis mossambicus* | | * | * | | |
| | *Pseudocrenilabrus philander* | * | | | | |
| | *Serranochromis meridianus* | * | | | | |
| | *Tilapia rendalli* | | * | | | |
| Cyprinids | *Barbus afrohamiltoni* | * | | | | |
| | *Barbus annectens* | * | | | | |
| | *Barbus eutaenia* | | | * | | |
| | *Barbus marequensis* | | | * | | |
| | *Barbus paludinosus* | | | * | | |
| | *Barbus radiatus* | * | | | | |
| | *Barbus toppini* | | | * | | |
| | *Barbus trimaculatus* | | | * | | |
| | *Barbus unitaeniatus* | | | * | | |
| | *Barbus viviparus* | | | * | | |
| | *Labeo congoro* | | | * | | |
| | *Labeo cylindricus* | | * | * | | |
| | *Labeo molybdinus* | | * | * | | |
| | *Labeo rosae* | | * | * | | |
| | *Labeo ruddi* | | | * | | |
| | *Mesobola brevianalis* | * | | | | |
| | *Opsaridium zambezense* | | | *[1] | | |
| Gobies | *Glossogobius callidus* | | | *[2] | | |
| | *Glossogobius giuris* | * | | | | |
| Mormyrids | *Marcusenius macrolepidotus* | | | * | | |
| | *Petrocephalus catostoma* | | | * | | |
| Silurids | *Chiloglanis anoterus* | * | | | | |
| | *Chiloglanis paratus* | | | * | | |
| | *Chiloglanis swierstrai* | | | *[3] | | |
| | *Clarias gariepinus* | | * | * | | |
| | *Schilbe intermedius* | * | | | | |
| | *Synodontis zambezensis* | | | *[3] | | |

The movements catergories are modified from Deacon (1995) excepting; 1 = Bok and Cambray (1995), 2 = Skelton, 1994 & 3 = Weeks, this report).

stress and disease. Besides a few notable exceptions discussed, lowveld species are resilient to drought which refelcts a pre-adaptation to drought. This must be explained by their region of origin. Never-the-less under no-flow conditions, duration of isolation is important due to deteriorating refuge conditions where even the cichlids are affected. *T.rendalli* eventually declines, while *O.mossambicus* classically dominates under extreme drought conditions, but is stunted in size.

With unusually wet years, cyprinid dominance is still expected, but the species makeup will reflect higher flows with the relative increase of some species, such as the Labeo, *L. rosae* and the minnow *B. afrohamiltoni.*

# 4. FUTURE MONITORING REQUIREMENTS

## 4.1 OBJECTIVES OF A MONITORING PROGRAMME FOR THE SABIE-SAND RIVER SYSTEM

It is impossible to manage any system effectively without the necessary information, and therefore an effective monitoring programme is the cornerstone of any management plan for the Sabie-Sand rivers. The monitoring programme must ensure that the right kinds of information are collected, in enough of the right places, at the right frequency, and are then analyzed and presented in a manner that will initially help managers to take informed decisions, and subsequently allow them to evaluate the consequences of those decisions objectively.

Four kinds of cost considerations dictate how comprehensively the above aims can be achieved: the money available to get the necessary monitoring equipment, to set it up and maintain it; the manpower to visit the sites and take the measurements/samples; the available expertise to design the system, operate the equipment, and analyze and present the results; and the environmental costs associated with equipment and structures in the field or destructive sampling of biota.

To be useful, a monitoring system has to operate efficiently for the long term, so that the funding, manpower and expertise must be assured, and any monitoring equipment must be durable or easily replaceable. Durability and environmental costs are particularly important considerations in the KNP, where natural vandals ranging from elephants to baboons abound, and where unsightly structures or barriers in the rivers are especially undesirable. For example, a continuous flow-gauging weir is expensive to set up, and is an unsightly and environmentally costly barrier, but is durable, with low maintenance costs, requires little manpower to operate, but some specialist input to analyze and present. Water chemistry samples, unless automatically collected, entail few environmental or capital costs (if an analytical laboratory is available), but require frequent collecting trips, and are expensive to analyze, requiring considerable specialist input.

The obvious agency to carry out monitoring of the Sabie-Sand rivers within the KNP is the National Parks Board, since they have jurisdiction, permanent personnel with much of the required expertise, and much of the required equipment. It must be acknowledged that their resources are already stretched, and that some of the specialist expertise (eg water chemistry, hydrology, aquatic invertebrates) would need to be imported, so that any additional monitoring activities would have to be carefully designed for minimum extra work and cost. Outside the Park the responsibilities are more diffuse, but the Mpumalanga Department of Nature Conservation may be the most appropriate organisation to oversee the monitoring programme. The DWAF at present operates the hydrological gauging weirs and collects and analyses water samples for chemical analysis, within the framework of a national monitoring programme. There would be no need to change this arrangement since the DWAF is well equipped and makes the data freely available to any interested party.

Since this report deals only with some of the environmental components of the Sabie-Sand rivers, the proposed monitoring system will also be confined to those aspects of the rivers, and the processes which help to maintain them. The purpose of the monitoring system would therefore be to provide information on the status of the biota of the rivers, and on the status of the physical and chemical processes that affect the biota. Aspects of the rivers such as the riparian vegetation, the large animals associated with the rivers, groundwater relationships, and human use of the rivers are being addressed by separate projects, and will not be discussed here in detail, although their importance is stressed. Specifically, the objectives of the monitoring programme would be as follows:

- To measure the relative density and diversity of the fish and invertebrate communities of the rivers, so as to document changes at different spatial and temporal scales. So that, for example, there would be baseline data before, during, and after on the abundance of different fish species in a drought, and also so that long-term trends in changing fish communities can be recognised.
- To document the size and shape of the river channels and the variety of habitats within them, so that long term changes in channel morphology and the availability of suitable habitat in response to changing flow patterns can be quantified.
- To measure the changes in important physico-chemical attributes of the rivers, so as to recognise seasonal and long term changes in the water quality of the rivers.
- To gauge the flow of the rivers so that the natural patterns of seasonal, drought/flood, and wet/dry sequences can be recognised, and the effects of impoundment and increased abstraction can be followed.

The level of detail of the proposed monitoring activities should be governed by the necessity for an early warning system, rather than for a comprehensive explanation of processes in the river. Monitoring activities should provide a "red flag" to signal undesirable changes in the river, without necessarily identifying the cause of the problem. Once a problem is identified, more detailed studies will be required to examine the causes and scope of the problem.

## 4.2 PRESENT MONITORING ACTIVITIES

The present long term monitoring activities on the Sabie-Sand can be summarised as follows:

- Continuous flow gauging at 12 gauging weirs, with record lengths varying from 47 to 5 years. The gauges are distributed from the upper reaches to the Mozambique border, with 10 outside the KNP and 2 inside. Four of the gauges are on the Main Sabie, one is on the Sand and 7 are on other tributaries.

- At these gauging weirs and 3 other sites within the KNP, water samples are collected on average every 2 to 3 weeks, and are analyzed for a suite of major ions, salinity, phosphates, nitrates + nitrites, and ammonium. These samples have been collected since the mid-1960's at some sites, but only since 1983 at others. More recently, metal concentrations in the sediments have also been measured every 6 months at the sites within the Park.
- Irregular fish surveys have been carried out on all parts of the Sabie-Sand since 1963 (Gaigher, 1969). The surveys within the KNP are now more regular, but information on fish distributions upstream of the Park is still sporadic.
- Benthic invertebrates have similarly been sampled sporadically since the early 1960's, but at present there is no regular programme to update previous surveys.
- Aerial photography coverage of the Sabie-Sand catchment has been updated every 10 years since 1940, at a scale of 1:30 000 - 1: 75 000. False colour infra-red photographic surveys have been flown annually since 1981 over selected sections of the river within the KNP.
- Fixed point photography sites on the Sabie and Sand Rivers within the KNP have been recorded in since 1985, but there are no sites on the rivers outside the Park.

# 4.3 ADDITIONAL MONITORING REQUIREMENTS

Within the KNP, the Sabie and Sand Rivers are being adequately monitored with respect to hydrology, water chemistry, and fish communities. Some aspects of water quality, particularly water temperature and suspended sediments, have only recently begun to be monitored. Building up a long-term database on water temperatures is extremely important, since temperature is a key determinant of biotic performance. The Sabie River has been described as a cold finger of water flowing into the Kruger Park, (due to its high gradient from the escarpment to the lowveld), and any impoundment on the mainstream will fundamentally alter the temperature regime (see section 2.3.2). The collection of data on sediment transport is fundamental to an understanding of the erosion and deposition processes which govern the dynamics of channel formation, and these will also change fundamentally if a dam is built on the mainstream. Sediment transport information during floods is particularly valuable.

Outside the Park, little or no information on temperatures and sediments has been collected, and in addition, there are at present no established sites for fixed point photography, apart from those which have been photographed quarterly at 9 sites established during this project. Fixed point photography, apart from monitoring the changes in vegetation and channel form over time, also builds up an invaluable library of flows at different stages. If this can be linked to discharge measurements at a nearby gauge, such photographs provide a visual document of the effects of different flows in the river, which is often more valuable than more rigorous information. Fixed point photography is an ideal example of a monitoring method which is cost-effective in every way, being cheap, requiring little skill to operate or to interpret, and causing no environmental effects. Fixed point photographs were taken during this study at all quarterly monitoring sites throughout the study period, including many sites outside of the KNP. Examples of which can be seen in Appendix I.

# 4.4 CONCLUSIONS AND RECOMMENDATIONS

For a comprehensive monitoring exercise, which would provide information on the major environmental aspects of the rivers and riparian zones, the following metrics, samples and records need to be collected:

Hydrology
Water chemistry
Geomorphology
Ecological or habitat integrity
Riparian vegetation
Social use of the river

Fish

Invertebrates

These do not include aspects such as catchment land-use, health-related microbiological sampling, or the use of water for domestic, farming or industrial purposes. These are all beyond the scope of this report. The social use of the river is also beyond the scope of this project, but a monitoring exercise would aim to evaluate the direct use of the river by people, and their requirements for the state of the river, the riparian zone, and its resources. Any environmental monitoring programme should be centred around the natural resource needs of the population in the catchment, and the social use is therefore an essential prerequisite for further planning.

Of the list above, only hydrology and water chemistry are adequately measured throughout the catchment for environmental purposes. Within the Kruger Park, fish are regularly sampled, and fixed point photographs provide some idea of habitat and channel changes over time. Depending on the resources available, some or all of the following activities should be undertaken throughout the catchment, to ensure an adequate database from which to assess long-term changes in the rivers, and to act as warning systems should particular problems arise:

- Regular invertebrate sampling, using the SASS4 rapid biomonitoring system. At least once per year, and preferably twice a year in the wet and dry seasons.
- Resurveys of existing rated transects to check on channel changes, approximately every 10 years.
- Initial surveys to measure the ecological integrity of the rivers, using the methods of Kleynhans (in press), followed by resurveys every 10 years.
- Transect surveys through the riparian vegetation, to check on species changes over time, regeneration, and mortality amongst mature trees. (Details to be provided by the researchers at the Centre for Water in the Environment, Wits University).

In addition, the following activities should be extended from the Park to be carried out throughout the catchment:

- Regularly fish sampling, at least once a year, using the Index of Biotic Integrity approach presently being developed by Dr Andrew Deacon of the National Parks Board. Samples should be collected at the same time each year, to allow for seasonal changes in fish communities (described in Volume 1 of this report). A May survey would best reflect the success of the preceding wet season prior to dry season reductions, while the rivers are easily fishable.
- Regular fixed point photographs, once a year at the same time of year (preferably in winter during low-flow conditions).

The more sites that can be regularly monitored, the more accurate will be the picture of changes in the rivers, and the more likely it will be that problems will be identified at an early stage. However, a realistic minimum number of sites that would provide information on the different parts of the system (inside and outside the Kruger Park, would be eight, at the following locations (Site numbers are those used during this project, and are referenced in Volume 1):

- Upper Sabie, site 3, downstream of Sabie town.
- Sabie River at Mkhuhlu, site 6.
- Sabie River below the confluence of the Sand, site 9.
- Sabie River at Mlondozi, near the Mozambique border, site 20.
- Upper Sand River at Rooiboklaagte, site 11.
- Sand River at Londolozi, site 14.
- Mutlumuvi River at New Forest, site 19.
- Marite River downstream of the proposed Inyaka dam, site 21.

Before any decisions are taken to finalise a monitoring design, it would be useful to take account of two new initiatives that are being planned at present:

- The national biomonitoring programme: This is an initiative of DWAF, and a site selection and sampling protocol is being planned. The Sabie River is being considered as a pilot test catchment for the programme. The recommended sampling procedure will include the use of SASS4, IBI, an index of riparian vegetation, and a habitat diversity assessment. Any monitoring programme for the Sabie River should obviously be compatible with the planned national biomonitoring programme.

- A research project to link biotic responses to abiotic factors in the Sabie River: This is an initiative of the Kruger National Park Rivers Research Programme, and will be undertaken during 1996. A major aim of the project will be to develop a model to predict the effects of changing flow regimes on the geomorphology, and therefore habitat diversity, and therefore fish communities of the Sabie. A fish sampling programme designed to verify the predictions of the resulting model would considerably improve the accuracy of predictions, and therefore any fish monitoring programme should take account of the data requirements of the model.

# 5. CONCLUSIONS AND MANAGEMENT OPTIONS TO MAINTAIN THE CONDITION AND ASSEMBLAGES OF THE SABIE-SAND SYSTEM

## 5.1 INTRODUCTION AND SCOPE

This project concentrated on the instream fauna and water quality of the Sabie-Sand rivers, and the conclusions and recommendations in this section are therefore largely confined to these aspects of the river. The findings of the project are related to the effects of planned impoundments on the rivers, and to the consequences of reduced flows. The solutions to the problem of maintaining the ecological integrity of the Sabie-Sand system lie largely outside the river itself: they revolve around the management of the catchment as a whole. Land-use patterns, increasing population, increasing irrigation, and associated sources of pollution are at the root of the problems in the rivers, and managing the rivers themselves is akin to treating the symptoms rather than the causes.

Recommendations for the management of the catchments, while essential for the maintenance of the rivers, are beyond the scope of this report, and are only mentioned in passing. This section draws conclusions about the effects of impoundment (both positive and negative) and the consequences of long-term flow reductions on the instream fauna and water quality of the rivers. Even these conclusions will need to be examined in the light of geomorphological changes (erosion and sediment deposition) resulting from changes in the flow regime. Such changes will inevitably effect the availability of different habitats which, together with local hydraulic conditions and water quality, govern the distribution and abundance of the biota in the river.

The final two sections suggest some general and specific management policies and aims which will help to mitigate the effects of impoundments and flow reduction, and further work which will improve our ability to predict future changes in the biota as a result of these changes.

## 5.2 THE SABIE RIVER

The results of this three year survey have shown that all the species that were recorded in the river during Pienaar's (1978) survey are still present in the River, and that the riverine fauna of the Sabie still appears to be as diverse as ever. Some of the larger species, such as the tiger fish and *Labeo rubropunctatus*, may be present in only low numbers, and this is a result of the lack of extensive deep habitat in the river. This survey was conducted mainly during times of very low flow, and may therefore have given a biased picture in this regard. For similar reasons, the floodplain spawners, such as *Labeo rosae*, are also scarce in the system, since they rely on over-bankfull flows to provide breeding habitat. The assemblages had yet to recover from the drought when sampling stopped in May 1993, so it is difficult to say how long full recovery may take. It is certain that, if low-flow conditions become the norm, the assemblages in the Sabie will change considerably.

Water quality in the Sabie is still excellent, and in some aspects is considerably better than the drinking water supplied in much of South Africa. It is important to remember that we are not dealing with an original state of the river, since mine dump pollution virtually wiped out the natural fauna in the middle reaches earlier in the century. The recovery of the fauna has been remarkable, and has only been possible because of the presence of refuge tributaries in the system. One cannot help wondering if the same level of recolonisation would be possible if similar pollution were to reach the Sabie now. There are still species (such as *Barbus brevipinnis, Barbus argenteus, Amphilius natalensis* and *Amphilius uranoscopus*) which are missing from the reaches between Sabie town and Hazeyview. This is a result of the historic mining pollution, and the presence of cascades and waterfalls which prevent these weak swimmers from recolonising these reaches.

## 5.3 THE SAND RIVER

The middle reaches of the Sand River have been reduced to seasonal flow during most years, with the result that the assemblages are significantly different from those of the perennial reaches. This makes the maintenance of the perennial upper warm tributaries of vital importance as refuges for recolonisation. The drought, the construction and subsequent collapse of the Zoeknog Dam on the Mutlumuvi, and the diversion of the upper Sand by the Champagne Castle Citrus Estates during 1991, all combined to degrade conditions in these upper reaches. If such multiple events and conditions were to become more frequent, the survival of natural assemblages in the upper and middle portions of the Sand River would be put at risk.

## 5.4 THE EFFECTS OF DAMS

At present, with no significant impoundments on the Sabie-Sand system, the options for managing the flow regime for the environment are extremely limited. Normally, dams are seen as having a detrimental effect on the natural ecology of a river, but in the case of rivers that are already impacted, dams can provide opportunities for rehabilitation. In the case of the Sabie-Sand, low-flows in particular are seriously affected in the Park by upstream abstractions. Impoundments provide the chance to augment irrigation water, and to provide compensation flows to the Park.

Most of the proposed dams are probably too small and too remote from the Park to provide effective low-flow augmentation. However, the Madras Dam, on the Sabie mainstream and very close to the Park's western boundary, would have severe effects on the water quality, temperature and sediment transport within the Park, and is also large enough to intercept all but the largest floods. The option of choice, from an environmental point of view, would be the Inyaka Dam in the Marite tributary. This would have consequences for the Marite, but is far enough from the Park for conditions downstream in the Sabie to recover. It is large enough to provide compensation flows to the Park, and would not intercept high flows, since the site is in a tributary of the system. Compensation flows should be linked to the dam inflows, as suggested by O'Keeffe and Davies (1991). The conclusions of O'Keeffe and Davies (1991) should be seen as part of an ongoing assessment of the flow requirements for the rivers. There is an IFR workshop planned for the Sabie River in 1996, and further work emerging from the Kruger National Park Rivers Research Programme will also increase the resolution and confidence of these estimates.

The confluence of the Marite and the main Sabie River is about 20 km downstream of the Inyaka dam site. Changes to the hydraulic habitats, water temperature and water chemistry will be severe throughout this stretch of the tributary, unless great care is taken to provide adequate base-flows, and periodic floods through the dam.

Existing and proposed impoundments on the Sand River are all remote from the Kruger Park and associated private reserves, but affect the important perennial upper tributaries of the Sand, which act as refugia during droughts. The construction phase of the Zoeknog Dam, during which flow downstream ceased, and large areas of catchment were cleared, caused considerable reduction in riverine fauna downstream, as did the subsequent collapse of the central section of the dam.

# 5.5 THE EFFECTS OF CONSISTENTLY REDUCED FLOWS

Whether dams are built or not, it seems most probable that the flows in all the rivers of the Sabie-Sand catchment will continue to be reduced as demand increases, particularly for domestic and irrigation supplies. This reduction will have the greatest impact on low-flows, and during droughts, when supplies are at their lowest and demand remains stable or increases. Irrigation pumping on the main Sabie River can already reduce the flow in the Kruger park to a trickle during the dry season. This section therefore summarises the effects of long-term reductions in flow on the instream fauna, and on water quality.

## 5.5.1 FISH ASSEMBLAGES

The effects of flow reductions on the fish assemblages of the Sabie-Sand have to be seen in the framework of the different zones of the rivers, and during the wet and dry seasons. In the Foothill Zone (FHZ), there are less seasonal effects, and the consequences of reduced or no-flow would be the reduction or disappearance of flow-sensitive species (such as *Chiloglanis anoterus*). Pool and marginal species will continue to survive and will dominate the fish assemblages. In the Lowveld Zone (LZ), where seasonal changes are marked, a permanent reduction in flow will result in the continued dominance of the dry season assemblage, dominated by cichlids, and the permanent reduction of cyprinids and other flow-dependent species. Lower flows in the dry winter season will result in stressed assemblages, no breeding and the disappearance of flow-dependent species, especially in rivers which cease to flow.

Generally, mean water temperatures will increase as flow is reduced, and there will be a shift of some of the more flow- and temperature- sensitive elements of the LZ assemblages further upstream. Depending on water releases from the Inyaka Dam, the Sabie River immediately below the Marite confluence could become a refuge for flow-dependent LZ species. This depends on the assumption that the main water abstractions for irrigation and domestic supply would be at and downstream of Mkhuhlu.

### 5.5.2 INVERTEBRATE COMMUNITIES

Many invertebrate species are extremely sensitive to flow conditions. During drought conditions in 1992 the average number of taxa was half that during the wetter conditions in 1990, and densities were reduced by an order of magnitude. Riffle species, which require flowing water between and over cobbles, are particularly vulnerable to reduced or no-flow, but species of the marginal habitats are also affected as the water's edge recedes from the vegetated river margins.

A permanent reduction in flow, with probable periods of no-flow during droughts, would result in the disappearance of many species, particularly mayflies, caddisflies, and simuliid flies. The resulting communities would resemble those typically found in temporary rivers, such as the middle reaches of the Sand River. The loss of biodiversity in these circumstances is not confined to invertebrate species, since they form a crucial part of the food base for other organisms, particularly fish and amphibians, and make significant contributions to the processing of organic matter.

The change from flowing water to static conditions will also provide opportunities for the increase of those species which favour stagnant water. These unfortunately include mosquitoes and Bilharzia host snails. The Sand River is already a centre for bilharzia transmission, but it is unlikely that the Sabie is at present.

### 5.5.3 WATER QUALITY

Water quality throughout the Sabie-Sand system is generally good, with the exception of some of the temporary reaches of the Sand and its tributaries in areas of high population density. Up to the present, reduced flows have not resulted in water quality deterioration beyond acceptable limits, except in isolated pools during drought conditions. Reduced flows will however result in less dilution of the effluents and irrigation return flows that reach the river. The Marite, in particular, has not historically suffered from the mining and urban developments that have affected the Sabie, and the building of Inyaka Dam will considerably reduce the high quality water which at present helps to dilute the additives to the Sabie River. Increased farming, and the introduction of more water borne sewerage will mean that the salt and nutrient concentrations in the Sabie-Sand will inevitably rise in the future. However, concentrations at present are remarkably low, and should not reach critical levels for many years. The presence of dams also provides the option of making releases to dilute effluents during critical periods.

The effects of the Inyaka dam on temperature, sediments and water quality in the Marite have already been mentioned. These effects are unlikely to extend into the main Sabie, but the Marite is perhaps the most important refuge for cold water species, because it has never been polluted, and it is inhabited by the only viable populations of *Barbus brevipinnis*, a regional endemic, and by populations of three restricted cold-water species, the minnow *Barbus argenteus*, and two catfish species - *Amphilius natalensis* and *Amphilius uranoscopus*.

## 5.5.4 PERENNIAL REFUGES

The Sabie-Sand has suffered extreme droughts and chemical pollution from mining during its history, and yet all the fish species which have ever been recorded are still present in the rivers. There is therefore a considerable resilience in the system, and this is a consequence of refuge areas in which populations can survive during critical periods, followed by recolonisation during favourable conditions. The maintenance of these refuge areas is therefore crucial to the continued ecological integrity of the system.

From the point of view of perennial flow, the most important remaining refuge reaches in the LZ are:

- The main Sabie River, which has always been perennial throughout its length.

- The upper reaches of the Sand and Mutlumuvi tributaries

(At the start of the study, the Mutlumuvi was the most important refuge in the Sand sub-catchment, but the construction and subsequent collapse of the Zoeknog dam has effectively destroyed its refuge value, at least in the medium term).

In the FHZ, the most important refuge is the Marite River (see section 5.5.3), because the middle cool-water reaches of the Sabie are still without several species as a result of historical mining effluent, and the inability of these species to negotiate cascades and waterfalls. The Inyaka Dam will pose a threat to the Marite as a refuge, unless care is taken in the construction and management of the Dam.

# 5.6 RECOMMENDATIONS

## 5.6.1 GENERAL

- The overriding priority for the Main Sabie River is to maintain a perennial flow to the Mozambique border.
- Throughout the system, the maintenance of perennial flows in refuge areas is crucial to the ability of the fauna to survive critical low-flow periods.
- Flow variability is a defining characteristic of these rivers, the low-flows and the floods being equally important for the maintenance and control of different aspects of the fauna. Any flow management policy should therefore attempt to build in as much of the natural between and within season variability as possible.
- Education and information: There is an urgent need to inform people in all parts of the catchment about the values of maintaining the resources of the rivers in the long term. In particular, the schizophrenic separation of river management and research within the Kruger Park and outside the Kruger Park needs to be overcome. The

interconnectedness of the rivers from their headwaters to the sea in Mozambique is a fundamental characteristic of the rivers. The ecotourism value of the nature reserves draws huge economic benefits into the catchment as a whole.

- Following the development of the national biomonitoring programme, a coherent monitoring programme, including hydrological, geomorphological, water quality and biological aspects should be implemented throughout the catchment, to build on the extensive database developed through the KNP Rivers Research Programme.
- As a matter of general policy, all new dams should incorporate multiple release ports at different levels, to provide options for water quality and temperature mixing, and to avoid the release of anaerobic or unnaturally cold water from the base of the dam.

## 5.6.2 SPECIFIC

- The adoption of the "Inyaka Dam, Limited Use" policy (see section 2.3.2) will cause only minor ecological disruption to the Sabie River ecosystem, and will provide new options for low-flow augmentation.
- The Inyaka Dam will, however, have significant effects on the unique fauna of the Marite River, unless care is taken during construction, perennial flows are maintained, and the temperature of water releases is controlled within natural limits.
- Madras Dam, if it is built, would have very severe effects on the downstream riverine ecosystem, through flow reduction and changed water quality, unless a strict water release policy was ensured. In the latter case, it could provide the best options for environmental flow releases into the Kruger Park.
- To provide for augmentation of low-flows in the Sand River, the building of the New Forest Dam on the Mutlumuvi, and a transfer facility to the Dam from Inyaka, could be considered. In addition, the repair, or at least stabilisation of the broken Zoeknog Dam should be a priority, since further high flows will transport more sediments from the wall down river.

- Strict control of any fish stocking in Inyaka dam will be necessary, especially to prevent the introduction of bass species, which would have a catastrophic effect on the smaller indigenous species in the upper rivers.
- It would be possible to reintroduce the fish species that are missing from the upper middle reaches of the Sabie River (site 3) due to historic mining effluent. These would include: *Barbus brevipinnis; B. argenteus; Amphilius natalensis; A. uranoscopus.* (see table 7.5, volume one).
- Even in temporary rivers during the dry season, it is necessary to ensure some base-flow from time to time, to top-up pools and improve water quality, since these are the last refugia for many species, including many of the large mammals which depend on them for drinking.

## 5.6.3 FURTHER INFORMATION REQUIRED

- Model development to predict the effects of changes in the flow regime on erosion/deposition processes; channel forms; hydraulic conditions; habitat diversity and availability; and finally changes in the instream biota.
- Breeding requirements of fish: Because of logistical constraints, this project collected habitat information for adult and juvenile fish only, and there is a dearth of knowledge of the requirements to initiate breeding, to maintain eggs, and to provide for larval development. Provision of adult habitat is pointless unless the complete life-cycle can be maintained.
- Migration and local movement patterns of fish, and their importance to the life-cycles of different species. The building of dams and weirs in the rivers creates barriers to movement, and divides the rivers into discrete sections.
- A socio-economic analysis of the long-term values of the natural resources of the rivers, without which it is difficult to motivate for their maintenance in the face of urgent short-term water requirements.

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