# THE SABIE RIVER: PROTECTING BIODIVERSITY IN AN INTERNATIONALLY IMPORTANT CONSERVATION AREA

## 1. BACKGROUND

### Study area: location and geography

The Sabie-Sand River Basin in southern Africa covers 7000 km$^2$. The main river, the Sabie, is 230 km long, and is itself a major tributary of the Incomati system, which discharges into the Indian Ocean in Mozambique.

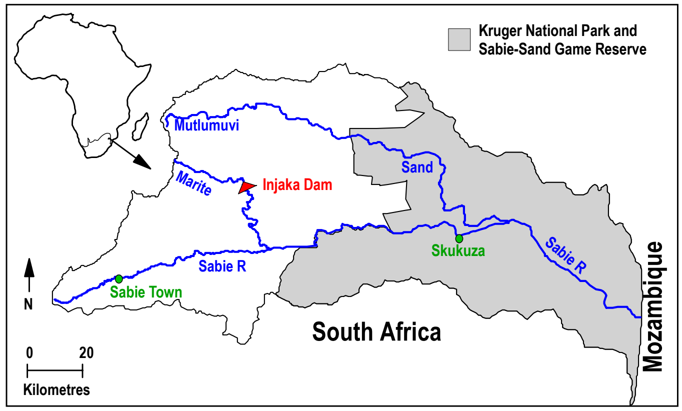



Figure 1. The Sabie-Sand River System in South Africa

The Basin is in a summer rainfall area, with a generally warm to hot, sub-tropical climate. Almost half of it falls within the protected areas of the Kruger National Park (KNP), the Sabie-Sand Game Reserve and four smaller nature reserves. Anthropogenic activities upstream of the protected areas are leading to degradation of the river within these conservation zones. This is of concern not only because of the National Parks status of the downstream reaches, with KNP being the flagship wildlife reserve of South Africa, but also because the Sabie River is the most biologically diverse river in southern Africa. The vision for the KNP is to ‘maintain biodiversity in all its natural facets and fluxes and to provide human benefits, in keeping with the mission of the National Parks Board, in a manner which detracts as little as possible from the wilderness qualities of the KNP’. In line with this, the vision for the rivers is to ‘maintain the intrinsic biodiversity (hydrological, geomorphic and biotic) of the aquatic ecosystems as an integral component of the landscape, and where necessary restore or simulate natural structure, function and composition’.

### Proposed water-resource developments

Existing water shortages and projected future development of the agricultural and forestry industries upstream of KNP, together with increasing domestic needs of an expanding population in the Basin, prompted the Department of Water Affairs & Forestry (DWAF) of South Africa to assess several potential water-resource developments in the Basin between 1985 and 1991. The most economical alternative was deemed to be construction of Injaka Dam on the Marite River, which is a tributary of the Sabie River, together with the Bosbokrand Transfer Pipeline that would transmit water to the Sand River sub-catchment. This is now referred to as the Sabie River Government Water Scheme. In 1996, the Transfer Pipeline was completed and construction began on Injaka Dam, with impoundment completed in 1999.

### The need for an Environmental Flow Assessment (EFA)

During planning of the Water Scheme, the need to conserve important aquatic ecosystems in the conservation areas was recognised. The potential threat to the downstream aquatic ecosystems prompted DWAF to commission an EFA. Since this was commissioned late in the process it could only assist in finalisation of dam design, guidance on downstream flow regimes and definition of the operating rules for the dam.

## 2. ENVIRONMENTAL FLOW APPROACH USED

The EFA benefited from two major scientific endeavours underway at that time in South Africa. First, since the mid-1980s there had been a major objective at the national level to develop environmental flow methods relevant to African situations. It was felt that the single-species approaches prevalent at that time were inappropriate, because the objective was to manage the condition of the whole river ecosystem including the natural river resources depended on by subsistence users. It was also recognized that for most EFAs in Africa there were likely to be a paucity of data, poor understanding of the river ecosystem, limited funds and, because of burgeoning human populations and the need for water developments, little time in which to make the assessments. By the mid 1990s, an approach that could meet these needs had been developed. Called the Building Block Methodology (BBM), it could be used in data-rich and data-poor situations, employing a mix of available data, newly collected data, expert opinion and local wisdom about the river. Because the water managers needed motivation for every flow asked for, the approach 'built' a flow regime from scratch, with each kind of flow requested (the building blocks) justified in terms of its role in maintaining the river. The flow regime was designed to maintain the river in a pre-defined Desired State. All flows were described in terms of their timing, magnitude, duration and frequency, so that the total volume of flow required could be quantified.

The method was designed mainly for use in the planning stages of new water-resource developments, thus becoming part of the greater process of environmental impact assessment (Box 1). It could also be employed for reserving water for environmental maintenance where no dams existed or were planned, or for rehabilitation of degraded rivers.

**Box 1. Integrated Environmental Management and engineering phases for a water-resource development, showing the related environmental and BBM activities**

| IEM/engineering Phase | Environmental Activity | BBM Activity |
|---|---|---|
| 1. Reconnaissance | Issues assessment | Bulk water estimate for environmental maintenance; synthesis of all existing information |
| 2. Pre-feasibility – definition of a number of development options | Impact assessment of each development option | Production of a recommended EF:<br>• definition of the study area, study sites and Desired State;<br>• analysis of hydrological and hydraulic data for each site;<br>• assessment of habitat integrity and conservation importance;<br>• studies of channel morphology, water quality; riverine biotas and subsistence use;<br>• workshop where the specialists jointly reach consensus on a recommended modified flow regime to sustain the Desired State. |
| 3. Feasibility – selection of one option and in-depth analysis of it | Environmental impact assessment completed | Refinement of EFA; hydrological analyses of the implications of the EF on water yield of the option; scenario meetings to define other options |
| 4. Design | Design of environmental management plan | Baseline studies for the monitoring programme; input into dam design |
| 5. Construction | Implementation of environmental management plan | Baseline studies continue; monitoring; input into operating rules for dams |
| 6. Operation | Environmental audit | Monitoring; validation of EFA; adjustment of flows or Desired State if necessary |

The second scientific endeavour was the Kruger National Park Rivers Research Programme, which began in 1988 as the largest and most comprehensive multidisciplinary river research programme ever undertaken in South Africa. Its principle aim was to develop both interdisciplinary understanding of the KNP rivers and implementable management systems for them. More than hundred scientists and managers took part in the programme over its ten year life, in disciplines as varied as hydrology, fluvial geomorphology and river ecology.

The two groups came together in the Sabie EFA in the mid-1990s, where the BBM was applied in an exceptionally data-rich situation. Eight sites, situated on the Sabie, Sand, Marite and Mutlumuvi Rivers, were selected to represent different parts of the river system. Specific flow-related data were collected at intervals over one hydrological year by a team of specialists (Box 2), and combined with available data to produce a synthesis of current understanding. Thirty-six people, mostly scientists, engineers and water managers, then met in 1996 to define the flows required to maintain the Sabie River at a desired level of health (Desired State), using the structured workshop process described in the BBM Manual.

**<u>Box 2. River specialists involved in the Sabie River Environmental Flow Assessment</u>**

| | |
|---|---|
| Channel form | Hydrologist, geohydrologist, hydraulic modeler, fluvial geomorphologist, habitat integrity specialist |
| Water quality | Aquatic chemist |
| Biology | Botanists for vegetation; zoologists for fish, invertebrates, frogs |
| Subsistence Use | Sociologist |

They adhered to a four-level Desired State hierarchy of statements, which defined the river attributes to be maintained at each site. These statements for sites within the conservation areas were guided by the KNP vision. The Level 1 statement for the KNP reaches was 'To promote natural river ecosystem health and diversity in line with the principles of integrated catchment management'. Level 2 was 'To ensure river diversity as part of catchment diversity in such a way as to allow natural fluctuations over space and time in structure, composition and function'. Level 3 consisted of a target river health category for each reach, e.g. some reaches had a target of Category B, which aimed for a largely natural river with few modifications (Box 3).

**Box 3. Ecological Management Classes for South African rivers. Rivers presently in a more degraded state, in Classes E or F, have to have D or above as a targeted Management Class**.

| Class | Abiotic and biotic components of the river ecosystem |
|---|---|
| A | Negligible modification from natural; negligible risk to sensitive species |
| B | Slight modification from natural; slight risk to sensitive species |
| C | Moderate modification from natural; moderate risk to sensitive species |
| D | High degree of modification from natural; high risk to sensitive species |

Level 4 consisted of discipline-specific statements for each site. For instance, the desired status of the channel morphology and riparian vegetation at Site 4 was 'To ensure that the processes that have resulted in the present geomorphology and riparian vegetation structure and distribution are maintained within a naturally-occurring (i.e. climate induced) range of change'. It was also stated that 'the river should be managed so as to ensure that no further directional change takes place favouring sedimentation at the expense of water, rapid and rock habitat'. Essentially, the scientists were beginning to organize and articulate a common understanding of the complexity and dynamic nature of the river, and also beginning the process of converting this knowledge into measurable management objectives. This critical process developed further after the BBM application, as outlined below.

**Outputs of the EFA**

The principal outputs of the BBM application were tables of recommended flows for each site. These were divided into low and high flows, and maintenance and drought years (Box 4). Maintenance years were seen as years when all riverine species would survive and most (except those adapted to very wet or very dry conditions) would reproduce. Drought years were seen as infrequent years when species would survive but most might fail to reproduce.

The EFA workshop completed the pre-feasibility phase of the IEM.

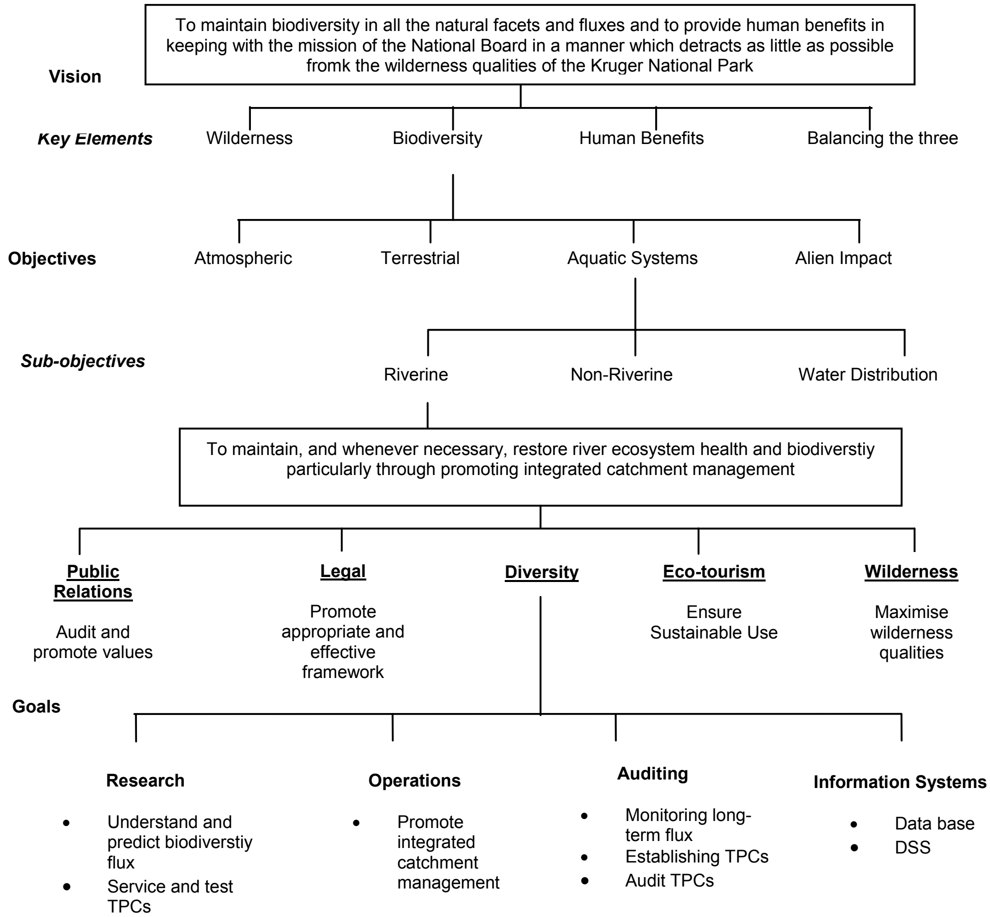
**Further developing the science-management interface**

Three of four challenges identified as facing scientists and managers concerned with managing the Sabie were now being addressed: interdisciplinary interaction was strong; a first-draft visions and objectives hierarchy had been developed; and a flow regime to meet the objectives had been recommended. The fourth challenge remained: to monitor river response to the proposed flow regime and audit that response against management objectives. To do this, the objectives hierarchy was further developed, with the introduction of 'thresholds of probable concern' (TPCs). These are goals that sit lower in the hierarchy than visions and objectives, detailing what should be measured to assess if the river has moved beyond acceptable change (Box 5). TPCs were set for channel morphology, vegetation, fish, invertebrates, avifauna, the riparian corridor (as a migration route), water quality and the flow regime. The TPCs for the flow regime are based on the BBM outputs – flows should not fall below those specified in the EF workshop. One TPC for channel morphology uses indicators to reveal if there is a directional loss of bedrock habitats over a 20-year prediction period. One example of a vegetation TPC is 'a negative *J*-curve population structure in pool-rapid channel types for *Breonadia* salicina', a tree species that germinates only in bedrock areas in the macro-channel. A possible fish TPC could address maintenance of a riffle-dwelling species, as riffles are the high point of channels and likely to dry out first with reduced flows. The over-riding criterion for TPCs is that they specify something that can be measured (indicators) and the range of values within which the measurements would fall.

| Building Blocks | | Oct | Nov | Dec | Jan | Feb | | Mar | Apr | May | June | Jul | Aug | Sep | Total Volumes | % Natural MAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **MAINTENANCE** | Magnitude ($m^3s^{-1}$) | 3.0 | 4.0 | 5.0 | 6.0 | 9.0 | | 8.0 | 7.0 | 6.0 | 5.2 | 4.5 | 4.0 | 3.4 | | |
| | Depth (m) | 0.82 | 0.89 | 0.96 | 1.02 | 1.17 | | 1.12 | 1.07 | 1.02 | 0.97 | 0.93 | 0.89 | 0.85 | 170.3 mcm | 28.7 |
| Baseflows | Volume (mcm) | 8.0 | 10.4 | 13.4 | 16.1 | 21.8 | | 21.4 | 18.1 | 16.1 | 13.5 | 12.0 | 10.7 | 8.8 | | |
| Higher Flows | Magnitude ($m^3s^{-1}$) | 6.0 | 8.0 | 30.0 | 12.0 | 50.0 | 130.0 | 12.0 | 10.0 | | | | | | | |
| | Depth (m) | 1.02 | 1.12 | 1.83 | 1.30 | 2.21 | 3.15 | 1.30 | 1.22 | | | | | | | |
| | Duration (d) | 3 | 3 | 7 | 5 | 1.0 | 14 | 5 | 5 | | | | | | 47.5 mcm | 8.0 |
| | Return Period (y) | 1:1 | 1:1 | 1:1 | 1:1 | 1:1 | 1:3 | 1:1 | 1.1 | | | | | | | |
| | Volume (mcm) | 0.4 | 0.5 | 7.6 | 1.3 | 17.7 | 73.1 | 0.9 | 0.6 | | | | | | | |
| | | | | | | | | | | | | | | Totals | 217.8 mcm | 36.7 |
| Capping Flows | | | | | | None specified | | | | | | | | | | |
| **Drought** | Magnitude ($m^3s^{-1}$) | 2.0 | 2.5 | 3.0 | | 4.0 | | 3.7 | 3.3 | 3.1 | 2.8 | 2.5 | 2.3 | 2.1 | | |
| | Depth (m) | 0.73 | 0.77 | 0.82 | | 0.89 | | 0.87 | 0.84 | 0.82 | 0.80 | 0.77 | 0.76 | 0.74 | 91.2 mcm | 15.4 |
| Baseflows | Volume (mcm) | 5.3 | 6.5 | 8.0 | | 9.7 | | 9.9 | 8.6 | 8.3 | 7.2 | 6.7 | 6.2 | 5.4 | | |
| Higher Flows | Magnitude ($m^3s^{-1}$) | | 5.0 | 6.0 | | 8.0 | | 7.0 | 6.0 | | | | | | | |
| | Depth (m) | | 0.96 | 1.02 | | 1.12 | | 1.07 | 1.02 | | | | | | | |
| | Duration (d) | | 3 | 3 | | 3 | | 3 | 3 | | | | | | 2.3 mcm | 0.4 |
| | Return Period (y) | | 1:1 | 1.1 | | 1:1 | | 1:1 | 1:1 | | | | | | | |
| | Volume (mcm) | | 0.3 | 0.4 | | 0.5 | | 0.4 | 0.3 | | | | | | | |
| | | | | | | | | | | | | | | Totals | 93.5 mcm | 15.8 |

**Box 4. Draft maintenance and drought EFs for site 4, Sabie River.** **MAF=Mean Annual Flow. mcm=millions of cubic meters of water**

## Box 5. A simplified objectives hierarchy for management of KNP rivers



TPCs are thus scientifically described endpoints beyond which significant directional change in biodiversity could be expected. They are based on hypotheses that use the full extent of the present knowledge base to define trajectories toward these undesirable states. Movement of indicators along any of these trajectories provides an amber light that a threshold is being approached, thus triggering further investigation and remedial management action where necessary before a possibly irreversible threshold has been crossed. An example of such a threshold could be the complete loss of an endemic species from the system.

## 3. MANAGEMENT ACTIONS

Two main sets of activities followed: those related to operation of the water development, including how the EF could be ensured in the river downstream of the dam and other water demands managed; and those addressing monitoring of the river and the feedback to management.

### Operation of the development

One of the Original BBM sites on the Sabie River was used to specify the flow regime that should continue in the river within the KNP. Of the natural mean annual flow of 594 million cubic meters (mcm) of water at that site, 170 mcm would form the EF requirement in a specific pattern of high and low flows. This would ensure good base flows during the critical dry season, higher base flows during the wet season and a range of small to medium floods. The EF allocation would be supplemented by all floods greater than the 1-in-3 year flood. These were not included in the BBM output as they cannot be managed by any present in-channel structure and so will pass through the system anyway. Operating rules for Injaka Dam were drawn up and decision-support models (Box 6) developed to manage both the water-resources of the Basin and the delivery of EF flows to the Sabie River.

**Box 6. Decision support models**

- Water allocation model – indicates the quantities of water available for use
- Curtailing water use and rationing – indicates when rationing must be introduced and its severity
- River flow management – indicates the real time quantities and timing of flow releases to be made from the Injaka Dam to meet the EF requirement at the BBM site.

### Monitoring and adaptive management

Monitoring of TPCs was institutionalised by KNP in 1999 and is funded by a multi-party agreement. The focus is on aiding management of ecosystem heterogeneity and dynamism. Specialists track any movement toward TPCs, with awareness of possible false negative and false positive results, and results are tabled at catchment management meetings with action taken as necessary.

### Progress made

A number of developments have influenced progress – and sometimes lack of progress - since 1999. In 2000, a flood with an estimated return period of 1:100 years flowed down the Sabie. This extreme event, or ‘large infrequent disturbance’, scoured out and modified large parts of the river ecosystem. Values of many indicators were pushed far beyond the TPCs articulated at that time, and the TPCs are now being re-defined. Good rains over the two years following the flood led to strong base flows in the river during the dry seasons, and so the impact of Injaka Dam was not felt and there was a weak imperative to develop the management structures that would release flows for EF needs. In 2003, drought conditions have resulted in flows being below the TPC on several occasions, but staff changes at many political and management levels have retarded the establishment of a formal Catchment Management Agency that could implement the EF allocation. A certain amount of roll-back has occurred, especially within DWAF, with weak transfer of the concept and practicalities from the EF development group at Head Office to the regional implementing office.

## 4. LESSONS LEARNT AND KEY CHALLENGES

The EFA should be done before the dam is built and should inform decisions about the location, design, and indeed the viability, of the proposed project.

Developing and applying methods for quantitatively assessing EFs for complex river ecosystems is difficult, but implementing these flows is even more so. Delivery of the EFs is likely to take place within a complex network of other water inflows and abstractions, guided by a range of legislation, and requires sophisticated management. In the case of the Sabie River, the structures are in place to demand the EF allocation, and general management awareness of the concept of EFs and use of TPCs is good, but EFs are not necessarily being delivered. There has been no automatic carry-over from inception to implementation, and an implementation plan is now needed to kick-start the delivery and management of EFs. Components of this plan should include: monitoring both the delivery of EFs and if they achieve their objectives, and increasing the awareness and support of politicians, the public and catchment stakeholders.

If the objectives hierarchy is to be effective within such an implementation plan, management structures need to be able to manage heterogeneity, test the efficacy of their practices and react to monitoring results that reveal TPCs are being approached. Adaptive management is difficult for large government (or other) organisations, as these tend to be prescriptive with rigid rules. A culture needs to be developed that facilitates response to findings from monitoring programmes, otherwise reports could be written and recommendations made to no effect.

Monitoring heterogeneity does not have to be complex and costly. In the KNP, the parsimonious selection of indicators that nevertheless cover a wide range of ecosystem components is designed to allow a cost efficient strategic rather than reactive approach to management.

**References**

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**Websites**

http://www.parks-sa.co.za/frames.asp?mainurl=sitemap/sitemap.html – website of the Kruger National Park with links to Scientific Services and the Management of the Park, including River Health.

http://water.ccwr.ac.za/knprrp/index.html - Website of the Kruger National Park Rivers Research Programme