H MACKAY

A PROTOTYPE DECISION SUPPORT SYSTEM FOR THE KRUGER NATIONAL PARK RIVERS RESEARCH PROGRAMME

Report to the
WATER RESEARCH COMMISSION
by the
DIVISION OF WATER TECHNOLOGY, CSIR

WRC Report No KV 74/95

A PROTOTYPE DECISION SUPPORT SYSTEM FOR THE KRUGER NATIONAL PARK RIVERS RESEARCH PROGRAMME

Heather MacKay
(Editor)

Water Quality Information Systems
Division of Water Technology
CSIR, PO Box 395
Pretoria 0001
South Africa

June 1994

WRC REPORT NO: KV74/95
ISBN : 1 86845 206 9

CONTENTS

Acknowledgements

The contributions of those members of the Kruger National Park Rivers Research Programme, who participated in the Decision Support Systems workshops, are gratefully acknowledged.

Thanks are also due to Programme members and staff of the Department of Water Affairs & Forestry who reviewed drafts of this document and provided valuable comments.

The project was supported by the Water Research Commission and the Foundation for Research Development, South Africa.

A PROTOTYPE DECISION SUPPORT SYSTEM FOR THE KRUGER NATIONAL PARK RIVERS RESEARCH PROGRAMME

1. INTRODUCTION

1.1 Background to the project

The Kruger National Park Rivers Research Programme is now entering its second phase (1994-1996). When the programme was initiated in 1988, its objective was to determine the water quantity and quality requirements for ecological maintenance in the rivers which flow through the Kruger National Park. This objective was addressed primarily through research activities, and first approximations of the ecological water requirements are now available (Bruwer, 1991; Moore *et al.*, 1991; O'Keeffe & Davies, 1991; Gore *et al.*, 1992).

The goals of Phase II of the Kruger National Park Rivers Research Programme are formally stated as:

- To inform ecological researchers and specialists, system managers and stakeholders about the water quality and quantity requirements to sustain the natural environments of the rivers which flow through the Kruger National Park (Breen *et al.*, 1993).
- To develop, test and refine models for predicting the environmental water quantity and quality requirements of rivers in southern Africa.

The approach which has been adopted within the Programme in order to address these goals is to develop structured decision support systems for river management. Essentially the Programme's activities are focused on providing information to resource managers to support them in the decision-making process. Hence the Programme should be able to identify and meet those information needs as far as possible. Through development and application of understanding of the functioning of aquatic ecosystems and their response to changes in water quantity and quality, the programme can contribute meaningfully towards sound management of river systems.

In August 1993, a project was proposed to develop a prototype decision support system (DSS) for the Kruger National Park Rivers Research Programme. The aims were to show how the decision support approach could be used:

(i) to structure and improve communications between researchers, managers and stakeholders; and

(ii) to provide information regarding management of the natural environment of rivers.

Two workshops were held in Pretoria during August and September 1993: participants represented a wide range of expertise from several disciplines in river research. (A full list of participants is included in Appendix 1).

This report describes in some detail the proceedings of each workshop, as well as work undertaken in support. It also outlines possible future development of the decision support approach within the Kruger National Park Rivers Research Programme.

1.2 The decision support approach

A decision support system (DSS) can be defined as a protocol, or a series of procedures which utilise an existing knowledge base in order to assist the user to arrive at a qualitative or quantitative answer. Such a system should be consulted by a decision-maker, but should not be used as a mechanical decision-making tool itself (Starfield & Bleloch, 1986). A DSS for the Kruger National Park Rivers Research Programme should provide a framework for the programme, so that researchers, managers and stakeholders can see where their expertise and information are complementary to the programme goals, and how they might contribute to the achievement of programme goals.

The structure and form of a DSS is shaped by the management objectives of the users. In this case, the broad objective is the sound management of the aquatic ecosystems in the rivers which flow through the Kruger National Park. Hence it is a worthwhile exercise to examine more specific purposes and objectives of a DSS for the Kruger National Park Rivers Research Programme, since this will guide us towards the development of a preliminary framework for the DSS.

1.3 Aims of the DSS approach

The catchments of the Kruger National Park rivers extend well beyond the boundaries of the park itself, both upstream towards the headwaters and downstream into Mozambique. Many water users, including formal agriculture, forestry, industry and people requiring domestic water supply, can lay valid claims to water from these rivers. As development and population numbers increase, competition for the finite water resources is becoming more intense. In its role as custodian of the water resources of South Africa, the Department of Water Affairs and Forestry is responsible for deciding how water quantity and quality allocations should be distributed amongst competing and/or conflicting water users. The needs of human water users generally can be articulated in terms of impacts on productivity, economic benefits, or direct effects on the quality of people's lives. The water requirements of aquatic ecosystems are far more difficult to identify adequately. Determination of ecological water requirements invariably involves consultation with ecologists who have specialist expertise in the different fields of aquatic science.

- Therefore, the DSS should facilitate communication between managers, researchers and stakeholders. This will allow managers to improve the quality of their decisions regarding water allocations, in particular by having access to information on the ecological consequences of proposed water allocation scenarios.

The knowledge base behind the DSS should include the best available information on the natural environments of rivers (including physical, chemical and biological aspects) which flow through the Kruger National Park. In addition, the DSS should also contain the expert judgement of aquatic scientists and the experience of ecosystem managers such as Nature Conservation and the National Parks Board.

- The DSS should be able to be used by system managers to make decisions regarding short and long term management of aquatic ecosystems in general. At times, decisions will have to be taken on the basis of the best available data or knowledge; the DSS will have to be flexible enough to allow this.

The conservation value of ecosystems cannot always be described in economic terms alone. Stakeholders (i.e. the people of South Africa) often place emotional, aesthetic or moral values on the natural environment. These values must be recognised and taken into account in setting and implementing policies for river management.

- The DSS needs to provide protocols for communication between managers, stakeholders and specialists in order to allow all to participate in the setting of long-term conservation and/or management goals for rivers, in local, regional, national and international contexts.

It has been implied (section 1.1) that one of the goals of the Kruger National Park Rivers Research Programme is to promote the flow of high-quality information among decision-makers, system managers, stakeholders and researchers. If the DSS is correctly designed, information needs can be identified well in advance of the decision-making process. Adequate time and resources can then be allocated to the collection and processing of the necessary information.

- The DSS should allow the identification and prioritisation of research activities which will meet information requirements either in advance of or during decision-making. In this way research funds can be allocated and used most cost-effectively.

1.4 Objectives of a DSS for the Kruger National Park Rivers Research Programme

The broad objectives outlined in section 1.3 arose from discussion at a workshop in Skukuza (May 1993); at meetings in Pretoria (June 1993), and in the first decision support workshop in August 1993. In the subsequent decision support workshop, the

DSS objectives were revised following discussion of the test scenarios. A list of more detailed objectives is included here with the intention of providing a more clearly defined context for later description of the operational principles and procedures of the DSS.

1.4.1 Objectives for Input to the DSS

Clearly the DSS should accept input from various sources. We have so far talked in rather general terms about decision-makers, managers, stakeholders and researchers without explicitly identifying these people and the types of inputs they might make to the DSS, or defining their information requirements. Correct identification of organisations and people who need to interact with the Programme will be an important programme activity, as will be the manner and form in which information is communicated to and from these people. If the Integrated Environmental Management (IEM) process is used as a guideline in river management issues, it can be helpful in drawing the correct people into the decision-making process at the right time. This will be discussed in more detail later.

As regards inputs to the DSS from decision-makers and managers: their information requirements usually take one of two formats:

(i) Researchers may be requested to identify the baseline water quantity and quality requirements for the maintenance of ecosystem functioning in a river. Managers would then use this information to plan water storage capacity and define future development potential in a catchment. In this case, researchers act (i.e. they state water quantity and quality goals), and managers react.

(ii) Managers may already have planned or prepared a scenario, or range of scenarios, involving possible future water availability or developments which may have ecological impacts. Researchers would be asked to predict and evaluate the consequences of such scenarios, and compare different scenarios in terms of acceptability. Here, managers act (i.e. they state water quantity or quality scenarios), and researchers react.

Often managers do not state explicitly their information requirements or the relationship of these requirements to their management responsibilities and capabilities. This is partly because managers often do not have a detailed understanding of ecosystem functioning and possible ecosystem responses to management actions. However, another reason is that practical day-to-day river management can seldom be carried out at fine scales (such as the management of individual species). Very often, all that can be managed with any confidence is the physical and chemical aquatic habitat at fairly coarse scales (~km).

Research information and scientific expertise should also be inputs to the DSS. The data complexity and coverage needed would be determined by the information requirements of managers. It is here that there must be close links with the information management sub-programme. The DSS should be used to inform researchers of specific research information requirements, and should provide agreed protocols for acceptance and incorporation of research information into the decision-making process.

- An objective of the DSS must be to formulate protocols for the translation of reasonably broad management information requirements into a detailed statement of the issues in question. These would be, in effect, detailed terms of reference for those activities which must be carried out to provide the necessary information.

1.4.2 Objectives for operational procedures within the DSS

It was suggested that the DSS should facilitate interaction:

(i) between managers at different levels and in different areas of authority and/or responsibility;

(ii) between researchers at different levels and in various disciplines; and

(iii) between managers and researchers.

There should also be protocols for appropriate feedback and interaction between managers, researchers and stakeholders at various stages of the decision-making process.

From the inception of the decision-making process to the point where the decision is taken, the DSS should be used to define clearly: the tasks required of managers and researchers; the scope, complexity and sequence of all tasks; the identification of the necessary expertise required to carry out the tasks; and the protocols for implementation, monitoring and feedback after the decision has been made. There should be a defined product or outcome at each step of the process, with provision for evaluation of the products in terms of satisfactory levels of confidence.

1.4.3 Objectives for Output from the DSS

The following were suggested as objectives for output from the DSS:

(i) A clear definition of the problem or information requirements of managers, translated into terms which can direct researchers e.g. in hydrology, habitat, community/species/ecosystem response.

(ii) If the scenarios proposed by management are judged to be unsuitable, alternative scenarios or modifications, for example altered dam release patterns, should be put forward as documented output.

(iii) Acceptance or rejection of recommendations and/or modified scenarios proposed by researchers may have consequences for long-term sustainability or maintenance of ecosystems. These consequences must be documented and communicated to managers.

(iv) Once ecologists have provided a response to managers' information requirements, they should also provide documentation on how that response should be incorporated into the decision-making process; implementation of any proposals; monitoring and evaluation of any further consequences of implementation; possible modifications.

(v) All output from the DSS, whether it is in the form of quantitative or qualitative statements, should be accompanied by a statement of the confidence of researchers in their predictions of ecological response to scenarios; the cost implications in terms of additional research, time and resources needed to improve that confidence level; and a statement of the acceptability to ecologists and stakeholders of the predicted change (if any).

2. DESCRIPTION OF THE DSS

2.1 General format

The IEM procedure is generally accepted by the Department of Water Affairs and Forestry and the Department of Environment Affairs as a framework within which decisions can be made regarding water allocations, particularly for the natural environment. As such, it enables identification of some of the key players in the decision-making process and allows the expression of research needs. **Workshop participants agreed that the IEM protocol provided a useful preliminary framework for a DSS for the Kruger National Park Rivers Research Programme, and that it should be adopted as such.** Examination of the schematic flow chart of the IEM procedure (**Figure 1**) shows that the procedure can be applied to river systems and could help to satisfy several of the DSS objectives that were identified in Section 1.4.

It was agreed that the Programme should support existing institutional decision-making procedures and their operational application, but that programme activities should focus on two aspects, namely:

(i) undertaking research to develop or improve methodologies which could add value to or improve the quality and effectiveness of decisions taken; and

(ii) undertaking research to enhance the knowledge base which is utilised in the decision-making process.

2.2 Physical nature of the DSS

The DSS approach represents a way to structure the involvement of researchers, specialists, stakeholders and managers in river management issues. This would allow the most appropriate methodologies, information, people and expertise can be accessed and utilised in river management decision-making. The DSS is not envisaged as a single, large, integrated computer model. Various models or methodologies would be used within the DSS; the output from different models would have to be compatible or at least congruent with input requirements for other information users.

A rather prosaic analogy can be used to illustrate the development of a DSS for the Kruger National Park Rivers Research Programme:

Managers and decision-makers may ask questions of ecologists regarding the natural environment of rivers. (Ecologists do not make the final policy decisions, much as they would like to, or feel best qualified to). In order to answer these questions, ecologists can make use of a number of 'tools' (methodologies). In the past, the choice of which tool to use for the job in hand was left up to the individual scientist. The choice sometimes left much to be desired, and often made the 'job card' (output) difficult for the managers to understand.

The DSS approach can be likened to the design of a toolbox. Toolboxes usually have two or three layers, and spaces for tools of different shapes and sizes. For some of the spaces, we already have the right tools. In other spaces, we have tools which do the job to some extent, but which may need modification to make them just right. There are some spaces for which we have no tools as yet, and we need to think about how we would go about acquiring or designing and using such tools.

To go with the toolbox, we need a 'workshop manual'. This manual tells a scientist how to decide which of the available tools he needs to use for the job in hand, based on the nature of the question being asked of him. It should also tell him how to use them, depending on the complexity and size of the task, and the degree of confidence required in the answer.

As stated more formally in Section 2.1, two types of research will be needed in the DSS sub-programme: firstly, research into improving the design of the toolbox; secondly, improving existing tools or designing new ones where there is a real need for them. The people who work on the toolbox itself may not necessarily be experts in river ecology. The people who work on the tools, on the other hand, probably will be experts in various aspects of river processes.

3. DSS WORKSHOP PROCEEDINGS

It was decided at meetings in June 1993 that the DSS approach should be formulated and illustrated by using a case study. The use of a case study would help to focus discussions and identify necessary components of a DSS for the Programme. A group of people (listed in **Appendix 1**) was tasked with developing the prototype DSS, and later reporting back to other members of the programme at the Research Meeting on September 27 and 28, 1993.

3.1. Workshop I (16 August)

Early on in the discussions, the site for the case study was chosen as the Sabie River, assuming the hypothetical scenario that the Madras Dam would be constructed on the Sabie River a short distance upstream from the western boundary of the Kruger National Park. Several different release patterns would be proposed. The ecological response to each release pattern would be predicted and evaluated in terms of acceptability. The detailed setting of the flow scenarios was put aside until near the end of the day's proceedings.

It was recognised that if the IEM process were to be accepted as a preliminary decision-making protocol (as agreed: see section 2.1), then four major types of activities would need to be carried out in support. These activities are:

1. Information transfer from managers, who may have been assisted previously by specialists in the formulation of proposals;
2. Scoping and initial assessment of managers' proposals, by specialists and ecologists representing stakeholders;
3. Prediction by researchers of changes to river ecology resulting from proposals; and
4. Evaluation of both the changes and their acceptability to researchers and stakeholders.

The question of information flow between each of the activities is very important, and is dealt with separately later (section 3.1.5).

3.1.1 Information transfer to and from managers

Initial input from managers to the DSS corresponds to the box in **Figure 1** (IEM procedure) denoted 'Develop Proposal'.

In the past, there has been a lack of formal, accepted structures for collaboration and transfer of information between managers, researchers and stakeholders. As discussed previously, in Section 1.4.1, managers may present information needs in two ways: either as a once-off baseline requirement for ecological maintenance, or to ascertain the ecological consequences of one or more proposed scenarios.

Ideally, the manner in which information needs are presented should be consistent and formalised. The complexity of the models or research required to respond to these needs is determined in part by the managers' questions themselves. Researchers can attempt to predict ecosystem response, given flow, water quality and land use scenarios: however, the degree of confidence in the accuracy of the predictions is also dependent on the accuracy of the information available from the managers, such as hydrological simulations.

Ordinarily, system managers can only practically manage:

- water quantity;
- water quality;
- catchment land uses which might affect either of these; and
- activities in the river channel, such as construction or removal of channel structures, bank stabilisation, dredging, establishment or removal of aquatic vegetation.

It is likely that system managers will require answers from researchers phrased in terms of currencies which are of use to them, i.e. water quantity and quality needs of ecosystems.

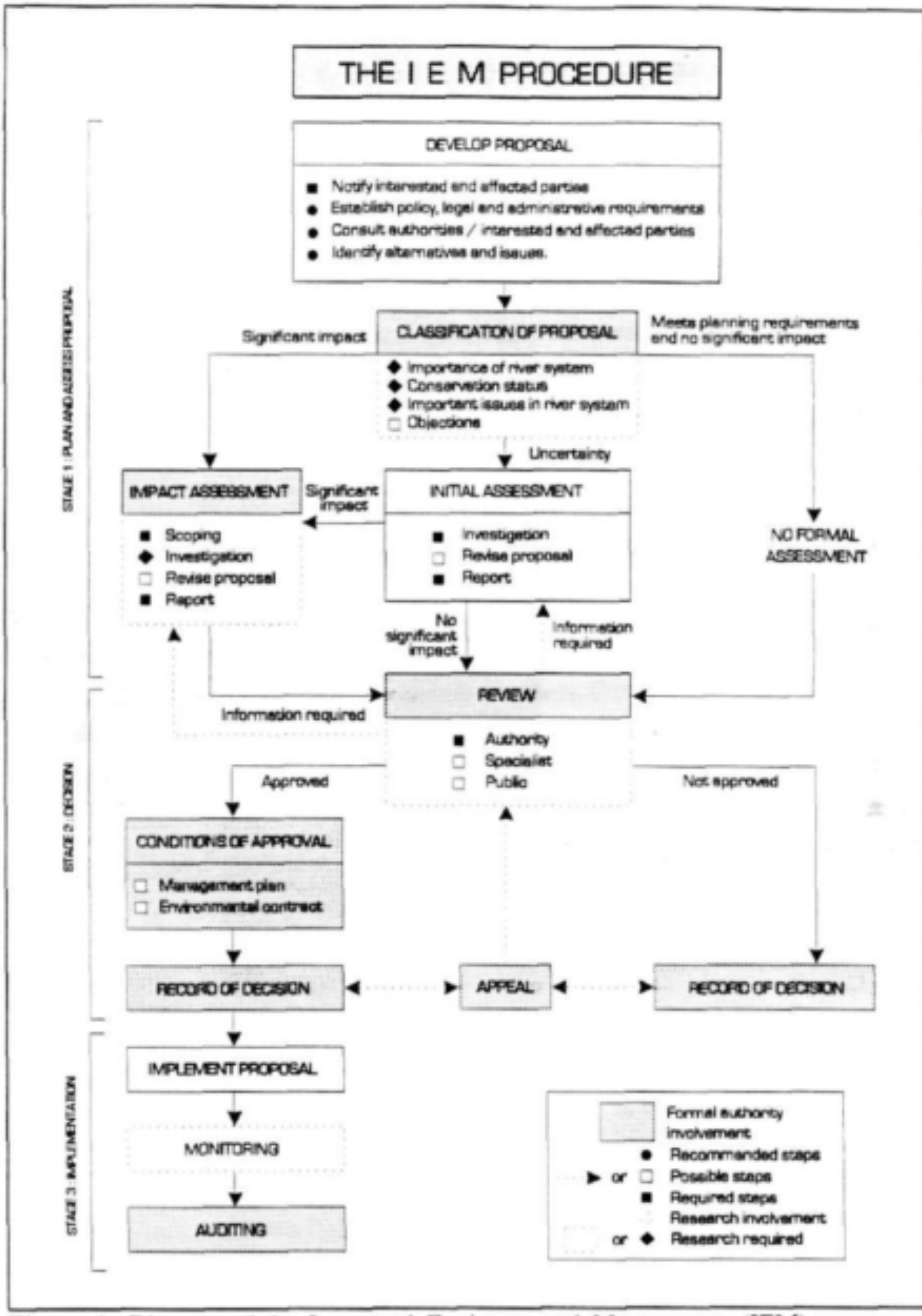

Figure 1: Diagram of the Integrated Environmental Management (IEM) process as adapted for application to river systems (adapted from Department of Environmental Affairs, 1992).

Outside the Programme, several workshops have been held, under the auspices of the Department of Water Affairs and Forestry, to assess ecological in-stream flow requirements for specific rivers. Experience gained in these workshops (Lee, pers. comm.) has shown that the manner in which hydrological information is presented to ecologists is particularly important in enabling them to predict ecological response. This will be equally true for the Kruger National Park Rivers Research Programme.

The point was also strongly made at the DSS workshop that managers had to be informed at key stages of research activities, as to the results and implications of the research projects. Within the DSS, there are expected to be several key decision points which require input from managers, stakeholders and researchers. For example, these might be decisions such as rejection of obviously unsuitable scenarios at an early stage of investigations; the proposal of alternative or modified scenarios; the allocation of additional time and resources to further investigations or collection of information. Managers should be closely involved in these decisions, which may be part of an iterative process of scenario selection and evaluation.

3.1.2 Scoping

The scoping phase, as discussed at the DSS workshop, corresponds closely to the 'Classification of Proposal' step in the IEM protocol in **Figure 1**, but also includes some preliminary assessment procedures.

The key decision to be made in the scoping phase is whether the managers' proposal will have a significant impact or not. If not, and no further action is required by researchers, then this decision could be recorded and fed back to the managers. If the impact is significant, the questions arise: how significant, and how much confidence is required in the prediction of the ecological consequences?

Researchers should have a methodology available to make an estimate of the significance and potential magnitude of the impact, whether it is considered to be positive or negative. Since this would in the first instance only be an estimate, the confidence level would not be high. If managers and researchers agree that more confidence is necessary, and that investigations or studies would be required, then the scope of such investigations should be determined and the relevant tasks identified. **Figure 2** shows a suggested flow chart for the scoping phase.

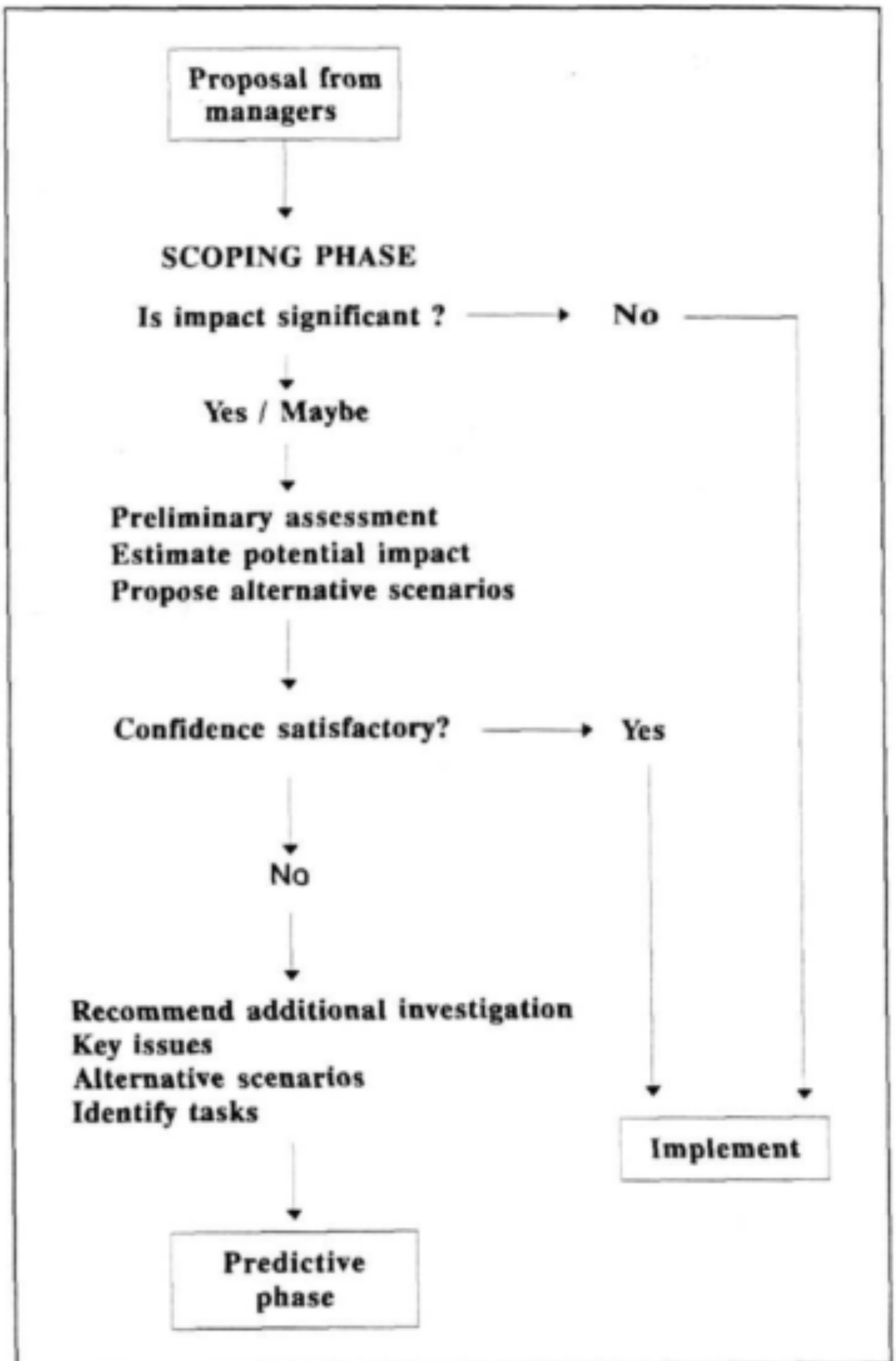

Figure 2: Flow chart for the scoping phase of the DSS.

The workshop agreed that to make a preliminary assessment of the impact, information would be required on how the proposal might affect the ecological functioning of the system or region in question. However, it is also important to decide whether the impact will be positive or negative, and what its extent and duration might be. Researchers must therefore be able to compare the present-day status of the ecosystem with the likely future status after implementation, as well as having some indication of what the 'natural' or undisturbed status might have been. Evaluation of this information would allow ecologists to assess the magnitude and extent of the impact in the longer term and will allow objective judgement of them.

Two existing methodologies were identified which have the potential to be used as preliminary assessment tools. Both focus on the ecological habitat at fairly coarse scales (km), and are able to indicate possible changes in habitat which might affect biotic species. These methods are:

(i) the RCS system developed by Dr O'Keeffe at Rhodes University; and

(ii) the Conservation Status Assessment (CSA) method developed and used by Dr Kleynhans of the TPA : Directorate of Nature Conservation.

It was agreed that past, present and future conservation status assessments would provide very useful information, but that this in itself would not be sufficient to determine the significance of the impact. Both methods involve reasonably objective measures of the status of the habitat available to aquatic biota. Yet the significance of the impact depends also on the perceived value of the river or river system to stakeholders. For example, the proposed impact might be small in extent, but the river might be considered so important in a regional, national or international conservation context, that even a small impact would be significant, possibly unacceptable. The converse could equally apply : if a river had a low importance rating, larger or more extensive impacts might be considered acceptable.

Hence it was agreed that, in addition to a methodology to measure conservation status, a tool was needed to identify the conservation importance of a river or river system according to some national conservation plan. There was considerable discussion on this issue and it was identified as an area of future research for the Programme. In whatever manner conservation importance is to be assessed, that assessment should include a vision of how stakeholders desired the river to look in the long term. This 'long-term river management goal' would serve as a yardstick against which future proposed changes could be judged.

If additional investigations were considered to be necessary, how could the research activities be defined and tasks allocated so that research is focused and cost-effective? The workshop agreed that research should focus on the key issues of environmental interest arising from the proposal. The ROIP (Relevant Environmental Impact Prognosis) procedure presently used by the Department of Water Affairs and Forestry was considered to be a potentially useful method for identification of such issues. However, some participants suggested that the method might be improved upon by modification. As there were no representatives of the Department at the workshop, discussion on this aspect was of necessity limited.

An important part of the scoping phase was agreed to be the suggestion to managers of alternative scenarios or modifications to proposals, especially if preliminary assessments of proposals were negative or proposals were considered unilaterally to be unacceptable.

3.1.3 Predictive phase

The predictive module best corresponds to the 'Impact Assessment' box in the IEM protocol (**Figure 1**). Proposals or scenarios generated by managers are usually given to researchers in terms of water quantity or direct water quality information: researchers would then be asked to predict the ecological response to these scenarios.

The workshop agreed that the approach to be followed would be similar to that shown in **Figure 3**. The hydrological characteristics of a river provide the primary driving force for the system. Once we have hydrological information, we can predict hydraulic response at given cross-sections or reaches. The hydraulics of the system drive sediment movement and geomorphological change on short time-scales (i.e.

from single, short-term events to longer time scales of about 50 years). The geomorphological characteristics of the river, together with the hydraulic regime, and the populations of instream and riparian macrophytes, shape the physical habitat for aquatic biota. Water chemistry is determined primarily by interactions between geochemical processes, anthropogenic discharges, turbulent mixing processes and dilution, thus defining the chemical habitat.

Our ability to model changes in physical and chemical habitat, over scales of metres to kilometres, is further developed than our ability to model the response of biotic communities or species to these changes. Hence it was agreed that attention should be focused on improving confidence in the modelling of habitat change at these scales. Tools are available: we need to identify those which can be used, with the approach shown in **Figure 3**, to predict habitat change for any scale of problem and at any level of detail, ranging from desktop studies to extensive (and intensive) modelling exercises. The level of detail is determined by the level of confidence required, and the methodologies and data available, which should be passed on from the scoping phase.

In order for all the aspects listed in **Figure 3** to be incorporated into a study, all the tools used should be compatible, should generate compatible information, and should be used at the same scales of spatial and temporal resolution. There was some discussion on this point: the modelling of habitat change at scales smaller than metres to kilometres cannot be carried out with great confidence. Hence researchers need to develop new predictive tools that can match spatial resolution of metres to kilometres. Such tools might be used to predict the response of communities, individual species, or indicator species to habitat change, or they might include integrated indices such as an Index of Biotic Integrity (IBI). Again, the level of detail required (e.g. individual species response) would depend on the outcome of the scoping phase.

It was agreed that an important activity for the Programme would be to identify the predictive tools presently being employed or in various stages of development, and to reach consensus on which methodologies would best be the best to use in order to address the Programme goals.

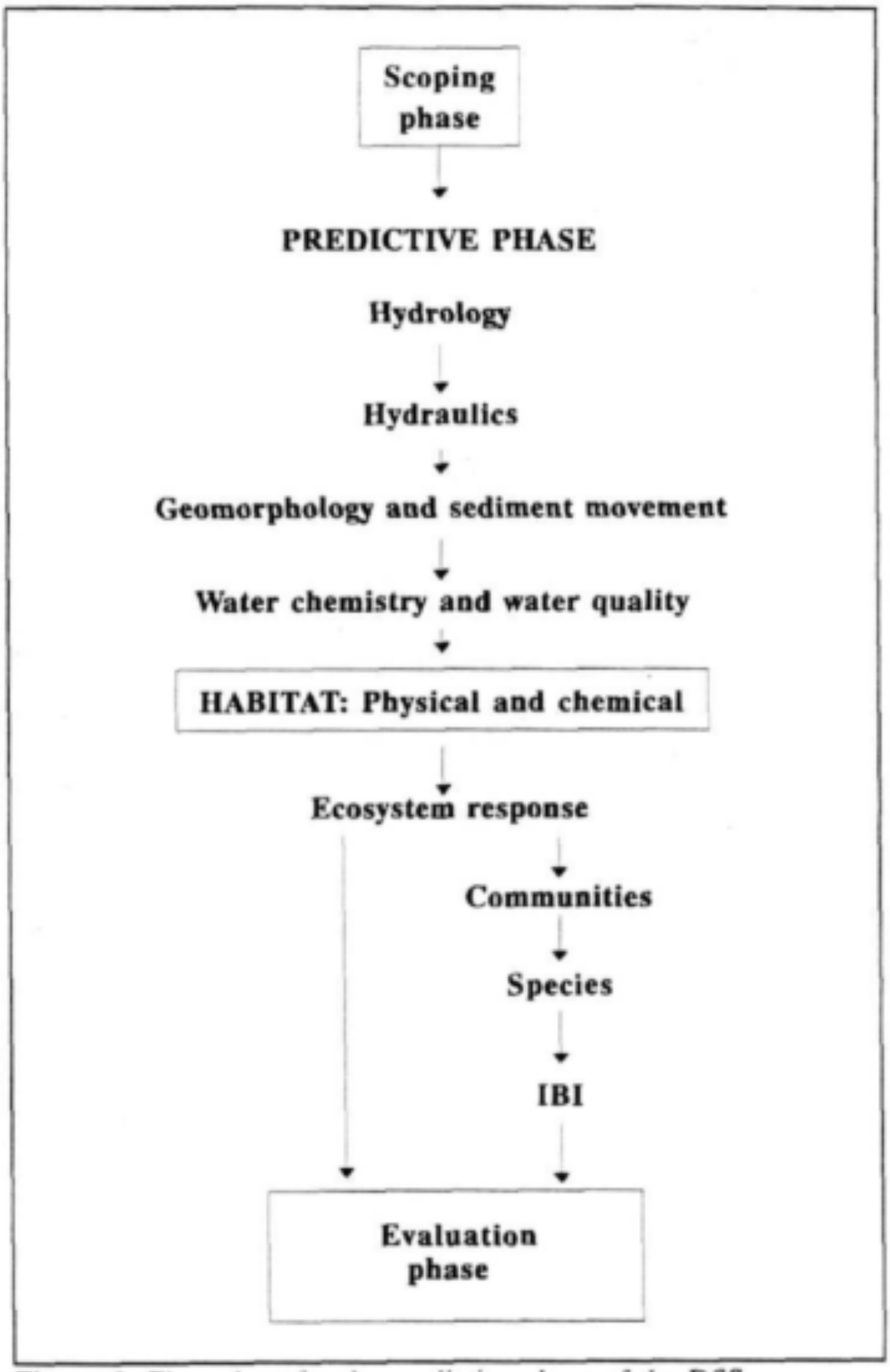

Figure 3: Flow chart for the predictive phase of the DSS.

3.1.4 Evaluation

Output from the predictive phase gives the response to the "if.....then...." questions, posed by managers and defined in the scoping phase. The next step is to be able to answer the "..... so what?" questions. The responsibility for making the value judgement on proposals (acceptable/unacceptable) should rest with the stakeholders, assisted and advised by specialists and researchers.

In the past, many researchers, ecologists or stakeholders, when faced with "if...then..." questions, have often given individual responses to one section or part of the "so what?" question. These responses, as evaluations of the acceptability or otherwise of the consequences of proposals, may have been based on the predictive techniques used, on 'gut feel' or on emotion. In any case, most of the responses are likely to have been subjective and probably would have varied widely, depending on individual value systems. The lack of coherence would not have assisted managers in the decision-making process.

The workshop agreed that, as a module of the DSS, the evaluation phase should allow researchers and stakeholders to reach consensus on their judgement of the acceptability or otherwise of proposals, and on the reasons why proposals were unacceptable. If there was unity amongst the researchers and stakeholders who represented the natural environment, then the environment would probably have a far stronger position in such negotiations in tradeoff negotiations with other water user groups.

There exists a body of techniques, known as Multiple Criteria Decision-Making (MCDM) methods, which have been found useful for use in negotiations where groups with differing priorities must come to agreement on policies for the management of scarce resources. The question was raised as to whether MCDM could be used within the environmental group, and prior to negotiations, in order for scientists and stakeholders with different points of view to reach consensus. The methodology of MCDM would allow researchers from various disciplines to rank and score scenarios of predicted change, either individually or as a group. The workshop agreed that MCDM could potentially be a very useful tool, and that it should be tested in the case study during the second workshop.

For general information purposes, a brief discussion of the Scenario-Based Policy Planning approach is included in Appendix 2: this is based on a written contribution to the workshop from Ms Leanne Scott of the University of Cape Town.

3.1.5 Information flow through the DSS

All key decisions taken and the rationale behind them need to be recorded at each stage of the evaluation and kept together with the final proposal / response so that the process may be kept as transparent as possible. It is also important not to lose information gathered at any stage of the investigation, so that in the evaluation phase users are able to respond by drawing on any level of information with which they feel comfortable. They may in fact wish to make an evaluation based on a combination of model outputs and 'gut feel'.

1. Initiation of project:

(i) Identify Manager(s). From where does request originate? To whom will the results be relayed at the termination of the project? Who will take responsibility for implementation?

(ii) Identify the nature of the question being asked - proactive / long term planning or response to proposed scenarios? Does the project allow for identification of alternatives to the proposals?

2. Scoping:

A record should be kept of

(i) The importance of the system under consideration;

(ii) The classification of the system (physical, chemical, hydrological, etc.), including where the system is relative to the management objectives set for such a system;

(iii) Key issues associated with the impact of the proposal as identified by ROIP;

(iv) Whether or not the impact is estimated to be significant; and

(v) Alternative scenarios identified (taking cognisance of other users / players).

3. Prediction:

The key issues identified in the scoping phase as well as the estimated level of impact of the proposal will determine the depth of study undertaken at this stage as well as the kind of models which should be used.

A record should be kept of:

(i) The level of detail (Superficial : "Quick and Dirty"; Moderate: Combination of modelling, available knowledge, field studies; High : intensive modelling) and the rationale behind this decision; and

(ii) The models selected. Input and output flow through each model. Level of confidence associated with variables where possible.

4. Evaluation:

(i) The criteria whereby the proposed scenarios were evaluated;

(ii) Assumptions that were made;

(iii) The weights assigned to each of the criteria;

(iv) The response to the original question;

(v) The sensitivity of the outcome to changes in the weights and the confidence associated with the chosen weights. Any proposed actions to improve the confidence levels should be stated; and

(vi) The degree of consensus which was reached.

All information outlined above needs to be relayed back to the manager(s) identified in (1) and to each of the sub-programme managers. A procedure for feedback and comment needs to be established, including a time frame.

3.1.6 Test scenarios for the second workshop:

Hydrology

Assuming that the Madras Dam was to be built on the Sabie River near the western boundary of the Kruger National Park, Mr Ben Bonthuys was asked to prepare a simulated hydrological record of monthly runoff volumes, for three possible dam release scenarios.

The runoff volumes were to be simulated for the Sabie River at the Mozambique border. There are no abstractions between this point and the western Park boundary. The contribution of the Sand River (in summer only) was ignored for the purposes of this workshop. The scenarios were:

1. Flows under maximum possible abstraction for irrigation i.e. worst case;
2. Flows which guaranteed a minimum dry-season flow rate of 1 m^3/s in the Sabie River;
3. Flows which were distributed according to the pattern measured in the Mac-Mac River (undeveloped), but the magnitude of which were always 30% of naturalised flow in the Sabie River;
4. Present-day flows; and
5. Naturalised (i.e. pre-development) flows.

Scenarios 4 and 5 were considered necessary in order to compare and evaluate possible changes arising as consequences of scenarios 1, 2 and 3.

Conservation status

Once the hydrological simulations were completed, Dr O'Keeffe and Dr Kleynhans were asked to use their RCS and CSA methods to assess the conservation status of the river under each of the five scenarios, and to bring this information to the second DSS workshop.

Other activities preceding the second workshop

Ms Leanne Scott was requested to bring relevant MCDM software to the second workshop in order to evaluate and rank the test scenarios.

Dr Heather MacKay was requested to co-ordinate with members of the Department of Water Affairs and Forestry, in order to ask them either to demonstrate the ROIP procedure for use in the scoping phase, or actually to carry it out for the test scenarios. Unfortunately, no members of the Department were able to attend the second workshop, and no literature on the ROIP procedure was available at the time. All information obtained on the ROIP process was derived from discussions with Dr Jean Lee.

3.2. Workshop II (10/11 September)

When the workshops were planned, it was intended that the DSS framework would be developed in the first workshop, and tested in a case study during the second workshop. After the first workshop, the Madras Dam on the Sabie River was selected as the case study, and hydrological simulations were provided for the chosen flow scenarios. However, as the second workshop progressed, it was found that many conceptual issues around the DSS still needed further discussion. Hence, although the case study helped to focus workshop proceedings, it was decided to give sufficient time to discussion of concepts as the need arose, rather than concentrate on achieving results in the case study at the expense of conceptual development.

The hydrological simulations and the results of the RCS and CSA analyses are thus quite specific, but during discussion of the predictive phase especially, only general principles were covered. Participants were asked to identify tools or methodologies which could potentially be of use in this phase, to describe the tools and how they could be used, their spatial and temporal resolution and their present stage of development.

3.2.1 Hydrological simulations

The purpose of generating hydrological simulations of the various scenarios was to present the participants with the "typical" problem of evaluation of a runoff scenario and comparison of different runoff scenarios. In choice of the scenarios, no account was taken of the sizes of dam required and the economic implications of dam size. Economically unrealistic options would not usually be proposed as potential scenarios.

The following runoff sequences at the Mozambique border were given:

1. Maximum use: runoff under conditions of projected domestic and irrigation use with no specific requirements specified for the Kruger National Park.
2. Fixed minimum requirements: runoff under conditions of projected domestic and irrigation use (as in Section 3.1.6) with a minimum requirement of 2.6 million m^3/month for the Kruger National Park (at the Mozambique border). This runoff would lead to a guaranteed minimum flow of 1 m^3/s.
3. 30% rule: Kruger National Park requirements were given as a set of twelve monthly proportions of the flow at the Mac-Mac River confluence, with the actual volume set to 30% of flow in the Sabie River under natural conditions.
4. Present development: runoff under static conditions of present development.
5. Natural runoff.

Flow scenarios were presented as monthly runoff volumes. **Figure 4** gives the results of frequency analysis performed on the different flow scenarios. Detailed tables of monthly flows can be found in **Appendix 3**.

Should ecologists need daily or instantaneous flow data, this could also be provided but obviously to a lesser degree of confidence.

To get daily runoff, two possible methods can be used:

(a) "Quick and Dirty" which could well be sufficient for most requirements considering the relatively coarse level of accuracy with which many of the effects can be given. This method would entail the disaggregation of the given monthly flows by the use of typical daily data from a representative flow station.

(b) The second method is the more "data greedy" method of actually simulating directly daily runoff from daily rainfall data. However, while this method could give more reliable answers, it is very dependent on the reliability of the input data, which are often not that good. Hence one should always make quite sure that the results of this much more detailed method are in fact more reliable than those derived by the first method. This is particularly important if it is acknowledged that one is normally more interested in the statistics of the flow (frequency of certain events happening) than in the absolute accuracy in time. In other words it is much more important than the data set is "realistic" as opposed to "real".

The above contribution by Mr. Bonthuys led to some discussion regarding the accuracy of and confidence in predictions. Hydrological records or simulations provide the basis for prediction of ecological response to changing water quantity conditions, and indirectly to changing water quality and hydraulic conditions. Confidence in predictions of ecological response can only be as good as confidence in the initial hydrological data, and this fact should be recognised by end users.

The presentation of hydrological information to ecologists was also discussed. Ecologists need to have an accurate idea of the frequency, magnitude and duration of extreme events such as droughts and floods. These events are the major driving forces which govern habitat availability and the composition of biotic communities in rivers. Information on baseflow in both wet and dry seasons is also important, together with the timing and magnitude of the first seasonal elevation in river flows. The workshop agreed that, within the framework of the DSS, the Programme should develop and document a protocol by which this information could be presented in a manner which would best assist researchers to predict ecological response to changing flow scenarios. A protocol would also be needed for presentation of recorded or simulated water quality information. These were seen as future activities for the decision support sub-programme.

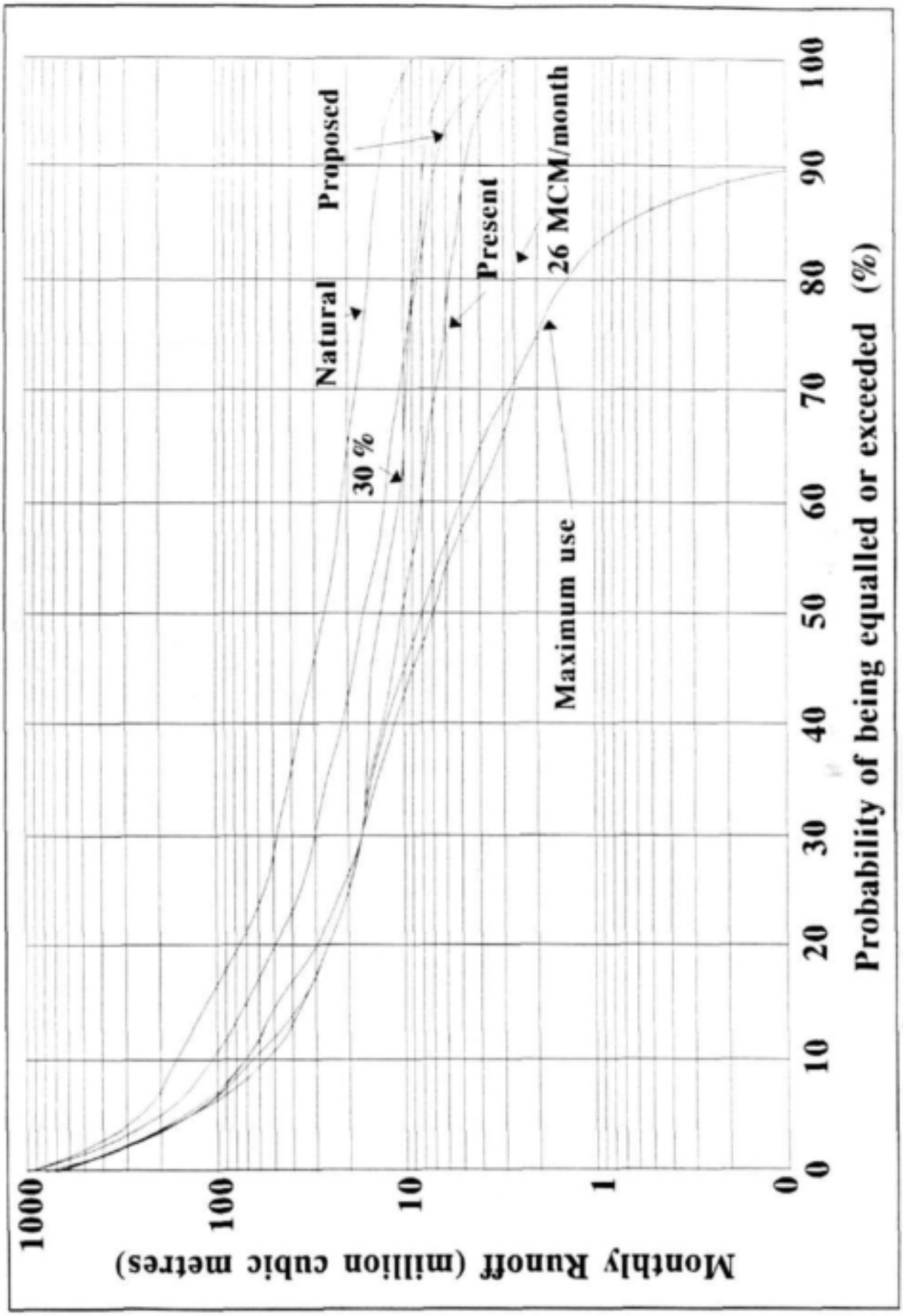

Figure 4: Summary of runoff scenarios.

3.2.2 Conservation status analyses

(a) The RCS method

The River Conservation System of O'Keeffe, Danilewitz and Bradshaw (1987), was used to assess the conservation status of the Sabie River from the headwaters to the Mozambique border, under three different management regimes:

- Present conditions with no mainstream dam (scenario 4).
- With the Madras Dam in place, and managed in such a way as to ensure that at least 30% of the natural flow is maintained in the river downstream of the dam (scenario 3).
- With the Madras Dam in place, managed so as to intercept as much of the flow as possible (scenario 1).

Hydrological simulations were provided for these scenarios, and the predicted ecological consequences of the Madras Dam options were inferred from the simulations.

Under present conditions the river has lost 32% of its mean annual runoff (MAR), mainly due to forestry in the upper catchment and direct abstraction for irrigation. If the Madras Dam is built, the major consequences, apart from a decrease in downstream flows, would be an increase in irrigated agriculture in the catchment, a major barrier to movement of fish up and down the river (assuming that a fish passage facility is not feasible on a 60m wall), and changes in the water chemistry, sediment load and temperature regime downstream of the dam. The consequences for the natural biota can only be inferred, but we now have detailed information on many of the fish species of the river, and our inferences should therefore be reasonably accurate.

Under the 30% rule (scenario 3), flow downstream of the dam would be maintained, and at low flows would be increased compared to the present regime. However, many of the intermediate floods would be intercepted and the variability of flows would be reduced. Under the maximum use scenario, flow in the river would cease during dry periods, for up to 6 months in the worst drought years.

Description of the River Conservation System (RCS)

The RCS is an expert-system-based computer model which aims to simulate the processes through which a river ecologist would asses the status of a river. The model asks 58 questions about the river, its catchment and biota, and synthesises the answers into percentage scores where 100% indicates a theoretically pristine river system and 0% a totally degraded system. The answers are given by the user in terms of a maximum and minimum, indicating the level of uncertainty of the answers. (If the maximum and minimum are the same, this indicates certainty). The model assigns weightings to each attribute of the river (see **Appendix 4**), indicating the relative importance of the attribute to the conservation status of the river. The default weightings in the model were assigned in consultation with 16 river ecologists and managers, and can be modified by the application of rules built into the model. The detailed results and tables are presented in **Appendix 4**, and include:

- An overall score for the entire river system.
- Scores for the river channel, the catchment and the biota.
- Tables listing the answers provided for each of the attributes of the river; the final weighting assigned by the model to each attribute; the final weighted scores assigned to each attribute; the research priority for each attribute, which is a combination of the uncertainty attached to the answers, and the importance of the attribute (the size of its final weighting).

Interpretation of the results

In general terms, the results indicate that the Sabie River at present has a very high conservation status (80-81%): the river channel (90-92%) and biota (88-92%) are particularly highly rated, but the catchment is fairly degraded (59%). The narrow ranges between the maximum and minimum scores suggest that we have good information about most aspects of the river. However, more knowledge is required about the amount of agricultural runoff, the endemicity of the invertebrates, and the number of indigenous macrophytes in the river.

If the Madras Dam is built and operated according to the 30% rule (scenario 3), then the conservation status will be reduced to between 67 and 68%, indicating a relatively diverse river, but one that has lost many of its unique characteristics. The regulation of the river channel and consequent changes in downstream flows and physical conditions would mainly be responsible for the reduction in the score. The biota would remain at a high conservation status (84-87%).

If the dam were to be managed for maximum interception (scenario 1), the status of the river would be reduced to between 58 and 64%, indicating a fairly large reduction in unique characteristics. The modified river would resemble many other South African rivers which have also undergone modification in one form or another. The major effects of the dam would be an increase in the irrigated area of the catchment, and the cessation of flow downstream for significant periods, reducing the river from a perennial to a seasonal system. The wide confidence limits for the biota (61-80%) reflect our poor understanding of the precise effects of these perturbations; in particular, we have no information about which species would be most likely to disappear from the river.

(b) The CSA method

Description of the CSA method

This method is essentially based on a qualitative interpretation of aquatic habitat (size, diversity, variability, predictability, and a change in any of these). Information should preferably be collected by doing an aerial survey of 5km long river segments. It is preferable that information on each of the parameters be based on the best (most detailed) data available (e.g. basic hydrological data that is analyzed to get an indication of the changes that have occurred since the original "naturalised" flows prevailed).

For the Sabie River case study only the October runoff volumes for the different scenarios were used. With the short time available to complete the assessment, October data was chosen as being an indication of the effects on the river at its most vulnerable time, i.e. low late-winter or early spring flow. As a change in the hydrology was expected to be the predominant effect, the hydrological data was analyzed in various graphical forms to get some indication of the level of habitat change (including basic statistical analysis of data). Figures and tables depicting this analysis are shown in **Appendix 5**.

For the purpose of this exercise it was decided only to use the "abiotic" part of the conservation status assessment. The following general assumptions were made at this stage:

1. If water is abstracted or regulated, sediment transport would be influenced.
2. Erosion would occur due to down-cutting (lower base flow).
3. Water quality would be changed.

The river reach considered for this exercise is that between the western Park boundary and the Mozambique border.

Results

Scenario 1 (maximum abstraction):	Class 4-5
Scenario 2 (minimum flow 1 m^3/s):	Class 4-5
Scenario 3 (30% rule):	Class 2-3
Scenario 4 (present development):	Class 2
Scenario 5 (natural runoff):	Class 1

(c) *Summary of conservation status assessments*

Both of these conservation status assessment protocols can be used as predictive tools to estimate the significance of impacts likely to arise as a result of the proposed scenarios. In each case, it can be shown that if the Madras Dam were to be built and operated according to the proposed scenarios, the Sabie River would be changed from a "special" river with a high conservation status to an ordinary river. Even at this early stage of the scoping phase, there would be justification for rejecting scenarios 1 and 2, should ecologists agree after preliminary evaluation. Alternative scenarios could be proposed based on this initial assessment.

Table 1

Scenario	RCS method	CSA method
1 (max abstr.)	58 - 64 %	Class 4 - 5
2 (min. flow)	-	Class 4 - 5
3 (30% rule)	67 - 68 %	Class 2 - 3
4 (present day)	80 - 81 %	Class 2
5 (natural)	100 %	Class 1

After some discussion, the workshop agreed that assessment of conservation status was not sufficient to enable a decision to be taken on the acceptability of scenarios. In addition, it was felt that there was definitely a need for a methodology by which to measure conservation importance according to a national plan for rivers. This could be used to reinforce and justify the decision. For example, the decision to reject scenarios 1 and 2 outright, should these lead to a result inconsistent with the national conservation importance plan for the Sabie River.

The conservation status assessment procedures dovetail well with the ROIP procedure at this point, and could be used in conjunction with a ROIP assessment in the early stages of catchment planning and scoping. The ROIP procedure involves collation of any published or available data on hydrology, water quality, fish, vegetation and other biota. All environmental aspects likely to be sensitive are listed, and unsuitable scenarios are rejected on the basis of this potentially adverse environmental impacts as well as social and economic aspects (Lee, pers. comm). The ROIP procedure could be expanded and modified to include an assessment of pre- and post-development conservation status. This should also include a statement of the conservation importance of the river and the extent to which this might be affected by the proposed development.

This activity is an area for future research in the Programme, and should be coordinated within the decision support sub-programme.

3.2.3 Key issues arising from the scoping phase

There was some discussion around the key issues which should be followed up in the predictive phase of the case study. Arising from this discussion and from the results of the conservation status assessments, the key issues which were identified as important for final evaluation of the proposed scenarios, were:

1. Flow distribution, both temporal and spatial. Information is needed, particularly regarding the occurrence and duration of no-flow periods.
2. Effect of changes in flow on patterns of sediment movement.
3. Effect of changes in flow and sedimentation on physical habitat.
4. Proportion of habitat lost/altered as a result of the proposed scenarios.
5. Biotic response to changes in water quality and temperature regime resulting from the proposed scenarios.
6. Improved quantitative information on sediment yield from the catchment.
7. Effects of changes in flow, habitat and biota on the view sites such as those at the rest camps (i.e. aesthetic impacts).

3.2.4 Prediction

Discussions on the predictive phase of the DSS were centred around the ability to predict habitat changes at scales of 1 - 10 km, principally by investigating the effects of changes in flow on the distribution of certain types of habitat such as pools and rapids. As shown in **Figure 3**, prediction of ecological response to different flow scenarios would follow a logical sequence: from prediction of changes in hydrology, to resulting changes in the hydraulic regime, the geomorphology of the channel, riparian and instream macrophyte distribution and water chemistry. This would bring us to a point where we could describe the physical and chemical habitat, presently to a resolution of 1 - 10 km. Thereafter, predictions need to be made regarding the biotic response to altered habitat. Depending on the level of detail required, this could be carried out at the community or species level, or through the use of some form of an integrated index, such as IBI. However, the workshop agreed that practical day-to-day management would only be feasible at the habitat level - it would be very difficult, if not impossible, to manage single species or groups of species.

The workshop participants discussed the level of expertise presently available in terms of predictive tools. It was agreed that with the available methodologies, it would be possible to build up "river landscape maps", where the different facets of the physical and chemical habitat could be overlaid to arrive at a final picture of the altered habitat. With this in mind, participants were asked to make a brief written contribution, within their area of expertise, to show what tools could be potentially valuable, with particular reference to the Sabie River (Madras Dam) case study, and at what stage of development these tools presently were.

(a) *Fluvial geomorphology: Present knowledge and capabilities*

The geomorphological types present along the length of the Sabie River have been identified through field observation. The range of geomorphological components identified are ecologically relevant on scales ranging from vegetational communities down to individual organisms. These geomorphological components have been structured based on the basis of functional interrelationships to form a geomorphological hierarchy. The Sabie River within the Kruger National Park has been mapped on the scale of channel type (range of 1 to 10 km river length). This is approximately equivalent to the ecological scale of plant community type. Geomorphological units associated with the different channel types have been identified and described, and the controlling variables which affect each component have been identified. This information, when combined with the functional interrelationships, provides a qualitative means of predicting channel change at the scale of channel type and geomorphological unit, in response to changes in controlling catchment variables, in particular, flow regime and sediment dynamics.

Collection of field data and the use of quantitative hydrodynamic and geomorphological models allow us to make gross predictions of inundation levels, mean flow velocities at existing surveyed cross-sections, and areas of sediment aggradation and degradation in the river. This enables us to refine our predictions of geomorphological change across the full range of scales. For example, morphological units (bars, rapids, pools etc.) located in zones where gross sediment deposition is predicted will evolve more rapidly than those which are in stasis.

Habitat may be regarded as a composite of substrate, local morphology, flow variables and biotic influences (e.g. vegetation cover). The method described above provides a means to determine approximate habitat changes in response to an imposed flow regime.

This approach is still extremely crude and largely subjective; however, it represents the first stage towards making predictions at ecologically relevant scales. A direct quantitative link between discharge and morphological change has not yet been established. Inferences are made based on quantitative predictions of gross morphological change in order to deduce smaller scale change.

The level of resolution of the monthly flow data for the scenarios presented at the DSS workshop is insufficient to allow meaningful quantitative modelling of the system as daily flow extremes are eliminated in the average monthly volumes. These extremes are very important in defining change in the different morphological units identified in the Sabie River. However, some general conclusions may be made. For example, the maximum use scenario, which results in the smallest dam, leads to regular cessation of flow during dry months. This can last for several months, and will result in abandonment of distributary channels and a reduction in extent of the riparian forest.

In order to increase confidence in predictions and improve resolution, research emphasis is now being focused on the collection of data on channel geometry and flow and sediment dynamics at morphological unit scale. Aspects such as flow resistance, the spatial distribution of sediment inputs and sediment transport rates in the river are also being investigated.

(b) *Predicting vegetation change in response to scenarios*

Vegetation change can be predicted to some extent at the spatial resolution proposed for fluvial geomorphological features. The predictive tools available include:

(i) Mapping of plant community distributions along the river and riparian zones;

(ii) Species descriptions of communities;

(iii) Species and community distribution in relation to geomorphic features at the "channel type" scale;

(iv) Species distribution in relation to water stage; and

(v) A state transition model, which allows mapping of the past, present and future condition of the river in terms of area occupied by 6 landscape states (water, sand, rock, reed, herbs, trees). The predictive capability of the state transition model is presently being improved by the addition of a rule-based model.

In order to apply these predictive tools, more information is required in the form of monthly flow distributions for each proposed management scenario, together with maps of the future state of the river in terms of the geomorphic features at "channel type" scale.

At present, the available tools can be used to predict the type of vegetation community which will potentially exist on the new geomorphic features, assuming the rates of geomorphic change remain similar to present day conditions. From this, we can say how much change will occur in the areal extent of the different plant communities, and predict qualitatively changes in species composition of riparian vegetation. The type of change, and the extent and rate of change in state (water, sand, rock, reeds, herbs, trees) can be predicted. However, these cannot yet be translated into qualitative statements on the degree of stress (e.g. twig death, shoot death, whole plant death) on trees due to periods of low or no flow.

There are several aspects about which quantitative predictions cannot yet be made. These might be necessary components of any detailed investigations in the predictive phase, depending on the level of confidence required. These include:

(i) The rate and processes of change in community composition;

(ii) The effect these changes will have on evapotranspiration losses. (This capability is being developed at present);

(iii) Quantitative change in plant species population dynamics and the impact of this on birds, fish and other biota in terms of abundance and habitat availability;

(iv) The state transitions cannot yet be translated into the geomorphic hierarchy which was developed subsequent to the state transition model; and

(v) Quantitative statements of the numbers and age of trees stressed or killed, and area of riparian zone affected, by periods of low or no flow.

(c) Predicting water quality changes in response to scenarios

If the hydrological information for the proposed management scenarios is presented as monthly runoff volumes, then only fairly general qualitative statements could be made regarding future changes in water chemistry or water quality. The areal extent of impact, and peak or average concentrations, could not be predicted without more detailed hydrological and hydraulic information.

There are many tried and tested models which could be applied to predict changes in water quality. It is possible to model the fate and impact of both conservative and non-conservative substances (though with less confidence); both dynamic (time-varying) and steady state models are available.

If the hydrological information was presented as average monthly discharge (m^3/s), it would be possible to model and map water chemistry in the river using the geomorphological and vegetation maps (physical habitat) to define the river's spatial characteristics. Average concentrations could be predicted, but not peak concentrations. A steady state, linear compartmental mixing model (such as QUAL2E) would be appropriate for this level of detail.

In order to model extreme events and peak concentrations, daily discharge data would be needed, as well as more detailed channel cross-section information. The spatial resolution of model predictions would depend on the resolution of the input data. A dynamic model such as MIKE11 would be appropriate for such modelling, where processes and concentrations change over one or more days.

Irrigation return flows and subsequent salinisation would best be modelled on monthly time scales, since these are fairly slow processes and do not normally show diel variations in either flow or concentration.

In general, our overall ability to model and predict water chemistry or water quality changes is well developed. Almost any spatial or temporal resolution can be achieved, depending on the input data, though with varying degrees of confidence in the output.

3.2.5 Evaluation

There are a number of levels at which proposed developments in the river would have to be evaluated. The river is a national resource and it is therefore not appropriate for any particular party to make a unilateral decision. In the case of the scenarios for the Madras Dam in the Sabie River, the interested and affected parties could include the ecological research community, the National Parks Board, water resource managers, other water users in the catchment and the general public. Since the other users would be making their own case for water allocation policy it falls to the ecological researchers and the National Parks Board and the stakeholders it represents, advised by researchers, to make a claim on behalf of the riverine environment. Hence for the purposes of this workshop we shall deal with the scenarios from an environmental perspective and evaluate them from an ecological or conservation viewpoint.

The evaluation of a river in absolute terms is outside the scope of the DSS. Therefore, the approach adopted is to evaluate each scenario presented by the managers against a baseline scenario which describes the desired state of the river from an environmental point of view. This was identified at the scoping stage as the long-term management goal for the river.

As a result of the scoping exercise, those scenarios which potentially would have serious environmental consequences for the river have been identified, together with the key issues which need to be addressed. During the predictive phase the nature and severity of the consequences of each scenario would have been predicted in the currencies of the key issues.

The evaluation stage of the DSS includes two separate operations: the scoring of scenarios relative to each other and in relation to the desired state, followed by the assessment of environmental acceptability of each scenario. The first operation involves synthesising information on all the consequences and then ranking their relative importance. The process is therefore partly subjective and partly objective. In contrast, the second operation is an almost completely subjective value judgement.

In terms of present capabilities, a method exists to cope with the scoring and synthesising operation (see **Appendix 2**). The method is used to define a hierarchy of criteria whereby scenarios may be evaluated. Each scenario is then assessed in terms of each sub-criterion; the weighted sum of these scores gives an overall score for each scenario (on a scale from 0 to 100). This provides a comparative evaluation (as a rank and a score) but does not tell the user anything about the acceptability of each option.

Use of the Scenario Based Policy Planning Model (SBPP) in the case study

As a test of the model for the Sabie River (Madras Dam) case study, the workshop group identified the following important criteria (weightings in brackets):

Effects at high flows (60)

Effects at low flows (100)

Effects at intermediate flows (80)

Effects on water quality (30)

The weightings reflect the expert opinion on the relative importance of the range of impacts resulting from the scenarios under consideration for each of the criteria. For example, the dam would have only a limited effect on high flows but would have the potential to intercept all low flows; therefore, low flows have a higher weighting. Each scenario was scored with respect to each criterion as in Table 2:

Table 2

Scenarios	Criteria			
	High flows	Low flows	Intermediate flows	Water quality
1	50	0	20	20
2	30	40	0	50
3	0	70	60	0
4	80	60	80	90
5	100	100	100	100

This led to the following scores being assigned to each scenario (see **Figure 5**):

Overall scores :

Scenario 1 0

Scenario 2 9

Scenario 3 30

Scenario 4 67

Scenario 5 100

Scenario 3 is preferable to present conditions at low flows because it maintains flows nearer to natural conditions. However, overall, scenario 4 is clearly the preferred option for the river. All the scenarios involving the building of the Madras Dam score very poorly.

It is of interest here that the scenario considered to be the least damaging of those on offer (scenario 3), is judged to have as great a potential impact on the Sabie River environment of today, as present-day development has had on a previously "pristine" environment. Thus the use of the interval scale provides a useful interpretation of the relative scores.

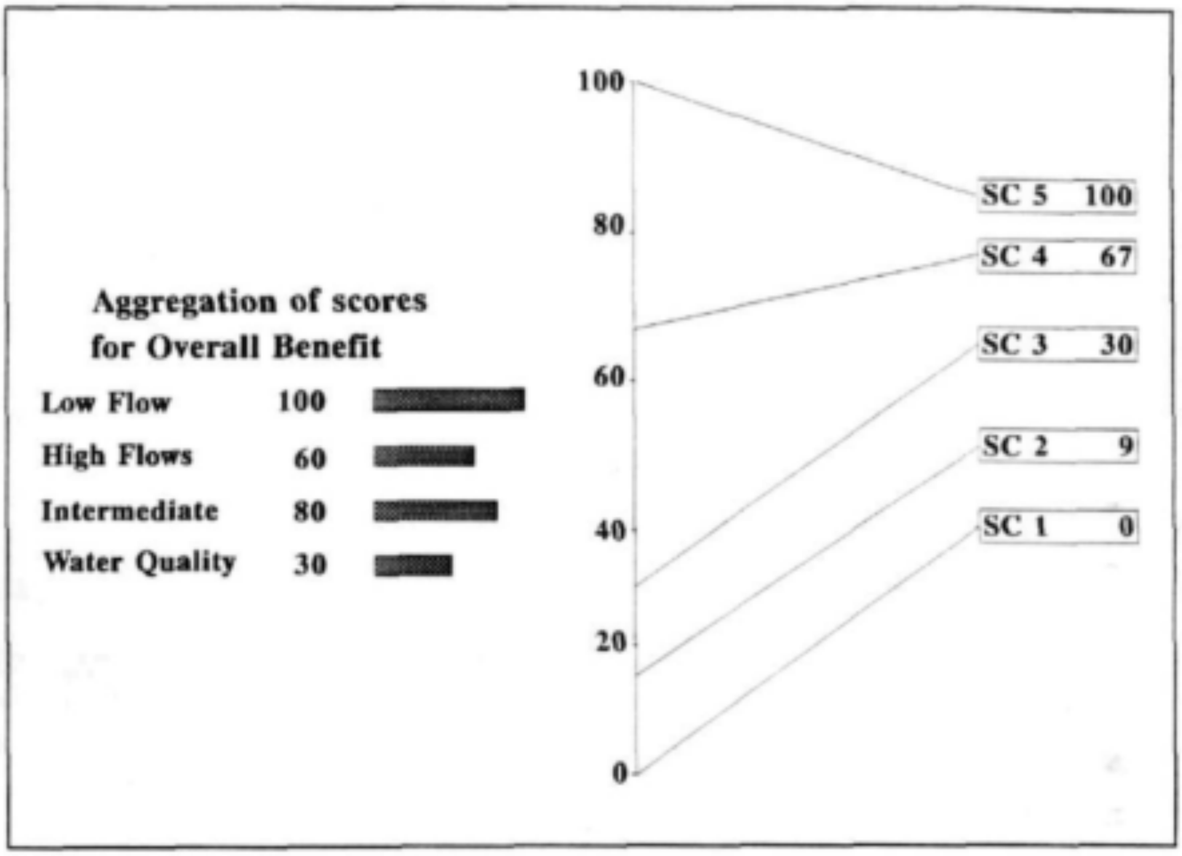

Figure 5: Graphical display of results of the evaluation of runoff scenarios.

Whilst the above method still needs to be assessed in much more detail, it provides a standard framework for synthesising the consequences of different scenarios in a manner accessible to non-ecologists.

At present, we have no method to evaluate the acceptability of proposals other than by trying for a consensus opinion of the experts involved. In this case none of the scenarios involving the Madras Dam were judged to be acceptable environmentally because all were predicted to change the Sabie River from a unique conservation resource to an unremarkable system even though many of the components would remain substantially unchanged. A suggested approach might be for each expert to assign the following categories to the ranking scale attained in the SBPP: Ideal; Acceptable; Tolerable; Unacceptable. In the above example the final evaluation could be displayed graphically as in **Figure 5**.

Further work may be needed to develop a standard procedure to accomplish this step in a manner which provides convincing results for management. In particular, attention needs to be paid to the choice of criteria on which evaluations are based. Initially the workshop participants suggested a set of criteria which included vegetation, geomorphology, water quality and biota. However, appropriate scores could not be assigned to these because the vegetation, geomorphology and water quality are all linked together in the provision of habitat, and therefore cannot be evaluated independently. After much discussion, it was decided to evaluate the scenarios on a hydrological basis. Implicit in this is an understanding of the potential impacts on the river ecology of changes in the distribution and frequency of flows of various magnitudes. This is not entirely satisfactory because the evaluation is not transparent to non-ecologists.

4. FUTURE RESEARCH AREAS FOR THE PROGRAMME

Arising from the discussions on the Sabie River case study, several areas were identified where information or an appropriate methodology is not available. It was agreed that the aspects listed below were important as future research areas for the Programme and for further refinement and development of the DSS.

4.1 Synthesis of existing information and estimates of water requirements

A considerable amount of research was carried out during the first phase of the Programme; there is a need for this information to be collated and synthesised, in order that it may be used within the DSS framework. The previous estimates of water quantity and quality requirements for the Kruger Park rivers need to be critically reviewed by managers and researchers. This would allow them to establish confidence in these estimates and to identify what additional work is required to achieve the levels of confidence required by managers.

4.2 Methodologies

In terms of the toolbox analogy used previously in this document, two types of research activities will be needed within the decision support sub-programme:

(i) Research to improve the toolbox and the workshop manual; and

(ii) Research to identify the appropriate tools and to ensure that they do the job correctly.

As regards the latter, three immediate priorities emerged from the DSS workshops and the Research Meeting in September. These were stated as research objectives:

1. Conservation importance

Objective: To determine a hierarchical methodology for defining conservation importance, that will include identification of the long-term goal for a river, and identification of currencies by which change can be measured.

2. *Predictive capability*

Objective: To develop an integrated predictive capability which can be used to inform managers about ecological response to changing flow, water quality or habitat conditions induced by changes in the catchment.

3. *Evaluation*

Objective: To develop transparent procedures for evaluating the acceptability of proposed changes in a river environment, and a procedure by which such information can be transferred to resource managers and stakeholders.

Other activities which should be coordinated within the DSS sub-programme arose out of the DSS workshops, and are listed below.

4. *Links with the ROIP process*

Objective: To ensure that DSS protocols are congruent with existing procedures, particularly the ROIP and the IEM processes, and that there is efficient dovetailing between the DSS and ROIP.

5. *Presentation of hydrological information*

Objective: To develop and document an accepted protocol for the analysis of hydrological data and its presentation to researchers, where the information is used to predict ecological response to changing flow scenarios.

6. *Presentation of water quality information*

Objective: To develop and document an accepted protocol for the analysis of water quality data and its presentation to researchers, where the information is used to predict ecological response to changing water quality scenarios.

4.3 Baseline information

In order to predict and evaluate changes in river environments arising from management activities, with appropriate levels of confidence, additional information would still be required for individual river systems. This is listed below.

(i) Information on sediment yield from the catchment, together with sediment transport and accumulation rates in the river, and sediment size distribution. Required to predict geomorphological change.

(ii) Past condition and history of Kruger Park rivers, from as far back in time as possible. Required to evaluate proposed changes and predict direction of change.

(iii) Rates of change in vegetation species composition over, say, the last 50 years. Required to predict habitat change.

(iv) Flow resistance measurements to predict geomorphological change and hydraulic conditions.

(v) Detailed channel geometry in selected reaches to predict habitat change.

(vi) Temperature regime of Kruger Park rivers. Required to compare predicted changes.

(vii) Water quality tolerances of key or indicator species or communities.

(viii) Water quantity and quality requirements during fish breeding and early life stages.

(ix) Consequences (to habitat and communities) of extreme events such as floods or cessation of flow.

5. FUTURE ACTIVITIES FOR THE DECISION SUPPORT SUB-PROGRAMME

It will be the responsibility of the decision support sub-programme to build on the IEM protocol as described in this report and to develop and obtain agreement on a detailed framework for the DSS. Thereafter, activities within this sub-programme will include:

* liaison with the research sub-programme to ensure that the correct tools are developed and appropriate information collected;
* co-ordination with managers to ensure that the DSS meets their information needs and is congruent with their established decision-making procedures;
* ensure that a continued process of DSS testing, evaluation and refinement takes place.

6. REFERENCES

BREEN CM, QUINN N & DEACON A (1993). *A Description of the Kruger Park Rivers Research Programme (Second Phase)*. Draft Copy.

BRUWER CA (ed.) (1991). *Proceedings of a Workshop on Flow Requirements of the Kruger National Park Rivers*. Department of Water Affairs and Forestry, Technical Report No. TR149.

DEPARTMENT OF ENVIRONMENT AFFAIRS (1992). *Guideline Document 1. The Integrated Environmental Management Procedure*. Department of Environment Affairs, Pretoria. 19 pp.

GORE JA, LAYZER JB & RUSSELL IA (1992). Non-traditional applications of instream flow techniques for conserving habitat of BIOTA in the Sabie River of southern Africa. Chapter 11 in *"The Conservation and Management of Rivers"*, ed. Boon, Calow & Petts. John Wiley & Sons, Chichester.

LEE J. (1993). Ninham Shand Inc.

MOORE CA, VAN VEELEN M, ASHTON PJ & WALMSLEY RD (1991). *Preliminary Water Quality Guidelines for the Kruger National Park Rivers*. Kruger National Park Rivers Research Programme Report No. 1.

O'KEEFFE JH, DANILEWITZ PB & BRADSHAW JA (1987). An "expert system" approach to the assessment of the conservation status of rivers. *Biological Conservation*, 40: 69-84.

O'KEEFFE JH & DAVIES BR (1991). Conservation and management of the rivers of the Kruger National Park: Suggested methods for calculating instream flow needs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 1: 55-71.

STARFIELD AM & BLELOCH AL (1986). *Building Models for Conservation and Wildlife*. Macmillan Publishing Company, New York.

APPENDIX 1

LIST OF PARTICIPANTS IN DSS WORKSHOPS

LIST OF PARTICIPANTS IN DSS WORKSHOPS

Mr A Birkhead	University of the Witwatersrand
Prof C Breen	Institute of Natural Resources
Mr B Bonthuys	Chunnet, Fourie & Partners.
Prof J Hearne	University of Natal
Mr G Heritage	University of the Witwatersrand
Prof C James	University of the Witwatersrand
Dr C Kleynhans	TPA: Nature Conservation
Dr H MacKay	CSIR
Dr J O'Keeffe	Institute for Water Research
Prof K Rogers	University of the Witwatersrand
Ms L Scott	University of Cape Town
Ms J Slinger	CSIR
Dr A van Niekerk	University of the Witwatersrand

APPENDIX 2

SCENARIO BASED POLICY PLANNING AND EVALUATION

APPENDIX 2

SCENARIO BASED POLICY PLANNING AND EVALUATION

This approach was formulated as part of a three year project, supported by the Water Research Commission, which aimed at systematically incorporating multiple goals, aspirations and perspectives into water management in South Africa. Consistent with the principles of Integrated Environmental Management, the procedure emphasises the participation of many interest groups in the planning process. Each of these groups may have their own agenda of competing goals which they wish to fulfil.

A major drive for the development of this approach was the need to ensure that both tangible (e.g. economic) and intangible (e.g. aesthetics, quality of life, social welfare, environmental status) issues were adequately considered in the planning and selection of water management policies.

The thinking behind the scenario based planning approach is largely drawn from the field of Multiple Criteria Decision Making (MCDM) which applies itself to the type of problem area in which there are conflicting objectives or aspirations. However, certain issues about the management of water (and other critical national resources) make it necessary to develop a new approach, namely:

(i) The ranges of options open to management are constantly changing and are not obviously defined;

(ii) The criteria whereby different management options are to be assessed require value judgements from highly diverse groups. There is no single designated decision-maker able to claim complete knowledge of all interests; and

(iii) Complex, resource-intensive studies are needed to provide some idea of the outcomes associated with different management options.

A major factor which shaped the method adopted for this process was the realisation that intangible issues can only be evaluated in a relative or comparative sense. For example no absolute and immutable value can be attached to the state of a certain lake; the evaluation is really only possible when we take into account certain benchmarks such as what the lake originally looked like, what it could be like and what it is used for. Thus the evaluations that are required in this approach are based on relative comparisons in terms of the options that are available.

A measurement technique called SMART (Simple Multi Attribute Rating Technique) is employed to compare a small number of alternative policy options. It is assumed that the goals of the problem are likely to be hierarchical i.e. that primary goals might be composed of a selection of sub-goals. Firstly all the policies under evaluation are compared and rated in terms of each of the sub-goals and then these individual ratings are combined across the hierarchy of goals by a simple weighted sum. The weights attached to each goal or sub-goal represent the perceived importance (to the assessor) of a swing from best to worst policy option for that goal or sub-goal. The weights do not reflect a measure of global importance of that goal relative to other goals.

The rating of policies for each goal or sub-goal is done by means of a thermometer scale where the best policy of those under consideration for that particular goal is assigned a value of 100 and the worst a value of 0. The remaining policy options are assigned intermediate values between 0 and 100 in such a way that the numerical gap between them represents the perceived gain or loss associated with having to accept one policy over another.

Suppose that we have a goal to minimise environmental impact and that there are three sub-goals: Preservation of aquatic organisms, preservation of riparian vegetation and preservation of large mammals. There are 6 management policy options on the table for evaluation. In terms of the impact of these proposed policies the 3 sub-goals are assigned weights which reflect their importance to the assessor.

Clearly the step which is most critical and controversial is the assignment of weights to the goals. For this reason the software which supports this approach focuses attention on the sensitivity of the outcome to changes in these weights and allows users to experiment with different sets of weights. It remains for the user to determine whether changes in weights which lead to critical changeovers in rankings of policies are within the bounds of uncertainty or imprecision of the assessments.

The above describes how different policies can be assessed by different user groups and is in fact also a means of facilitating inter-group policy negotiations.

The process is designed to reiterate in such a way that it converges to a preferred policy or set of policies. The 'Consensus-seeking' phase can be conducted directly as a group forum with representatives from different interest groups, or indirectly by policy planners and managers using the information fed to them by the different interest groups. In either way the interests of every major group, tangible or not, can be taken into account in a manner which is commensurate.

APPENDIX 3

RUNOFF SCENARIOS: HYDROLOGICAL DATA

Comparison of alternative runoff scenarios at the Mozambique border.
Monthly values for natural runoff (million cubic metres).

H.YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	25.29	129.61	127.60	40.80	22.52	33.56	30.73	17.52	15.80	13.01	11.66	10.35	478.45
1922	21.06	56.18	47.06	297.97	557.51	302.00	50.66	29.45	21.50	16.83	13.35	10.94	1424.51
1923	9.06	9.86	68.31	61.96	22.05	107.10	88.94	23.71	19.09	15.30	13.83	12.71	451.94
1924	15.48	154.51	185.65	476.26	369.46	1039.65	608.62	56.21	39.25	28.94	21.54	20.21	3015.78
1925	18.81	19.12	18.24	28.90	64.01	75.74	46.47	20.74	16.14	17.01	15.36	12.77	353.31
1926	10.94	15.16	21.00	38.25	52.77	50.19	33.05	22.37	17.29	31.87	31.76	17.83	342.48
1927	29.60	28.82	24.54	154.93	137.86	48.70	42.11	28.17	20.27	15.96	13.51	11.69	556.16
1928	10.71	11.77	22.49	43.26	91.52	193.90	127.08	28.04	20.48	16.60	14.23	13.37	593.45
1929	35.52	93.57	88.48	109.98	113.17	173.80	150.65	64.01	33.81	24.46	18.67	14.87	920.99
1930	12.37	15.12	132.76	106.94	49.79	42.75	37.08	25.22	18.49	20.32	18.78	14.29	493.91
1931	13.35	46.22	67.64	57.31	48.71	40.47	28.03	20.54	17.36	14.28	11.97	10.31	376.19
1932	9.38	22.37	59.28	107.33	83.09	52.94	39.97	24.67	17.33	14.38	11.93	10.36	453.03
1933	9.66	72.10	92.48	189.78	173.62	87.94	57.16	34.11	24.95	19.87	15.86	13.87	791.40
1934	13.35	68.36	139.58	145.64	92.54	45.91	28.23	20.92	17.09	14.70	12.55	10.93	609.80
1935	9.80	9.75	13.69	46.02	80.73	143.77	94.45	31.25	24.17	19.24	15.56	20.74	509.17
1936	26.87	52.01	108.71	263.05	934.91	467.38	74.35	37.19	26.15	19.52	15.40	12.68	2060.22
1937	10.65	10.14	33.27	50.20	38.78	25.27	48.75	38.66	18.02	15.51	13.21	19.52	321.98
1938	21.70	24.87	544.26	415.50	875.00	684.32	149.40	44.81	34.42	30.22	25.99	25.07	2875.56
1939	22.25	169.73	252.76	122.19	40.02	55.45	50.14	28.73	26.60	22.72	17.58	16.84	825.01
1940	15.98	95.55	113.95	62.94	32.37	34.23	79.40	63.36	23.33	17.41	14.35	12.29	565.16
1941	11.50	12.34	58.42	121.79	80.40	112.93	80.13	26.68	26.57	23.36	18.34	18.49	590.95
1942	19.59	34.49	48.94	42.92	34.56	55.38	131.73	92.05	30.54	25.52	26.19	28.67	570.56
1943	27.14	56.34	39.87	32.77	171.47	143.19	31.41	20.52	17.37	15.35	12.89	11.66	579.98
1944	25.35	30.21	23.42	77.61	79.75	54.24	38.46	23.78	17.58	14.01	11.58	9.90	405.89
1945	14.29	14.91	13.59	342.82	396.68	144.06	46.10	25.29	19.05	15.20	12.47	10.48	1054.94
1946	8.89	28.71	41.57	49.51	77.10	70.26	50.69	35.46	22.71	18.40	14.98	12.51	430.79
1947	13.62	49.66	165.36	130.25	50.88	201.95	147.97	32.90	23.15	17.61	14.03	11.99	859.37
1948	14.40	19.09	21.33	80.92	87.23	55.26	33.97	23.84	19.79	16.52	13.57	12.11	398.03
1949	10.99	68.81	86.11	61.16	52.76	51.10	40.38	25.80	21.89	17.74	14.61	12.92	464.27
1950	11.64	13.17	126.31	105.54	20.67	30.48	43.37	34.27	23.75	18.15	20.20	19.21	466.76
1951	25.73	24.18	37.63	46.93	34.33	39.50	34.78	21.14	17.35	16.10	14.74	12.59	325.00
1952	11.70	72.47	113.85	103.27	157.09	144.52	62.43	32.96	23.44	17.73	14.44	12.47	766.37
1953	11.16	34.51	63.55	111.67	154.88	95.19	38.54	28.58	21.31	16.55	14.06	12.58	602.58
1954	12.28	37.84	36.80	237.15	402.85	281.15	116.52	50.15	35.75	26.47	19.38	14.78	1271.12
1955	24.52	79.49	171.76	120.56	467.77	411.37	109.49	39.10	31.40	24.74	18.98	20.43	1519.61
1956	19.17	16.33	26.72	30.19	55.03	86.74	62.12	29.70	22.78	19.97	19.15	19.55	407.45
1957	25.98	29.53	47.26	725.75	452.14	46.37	35.05	28.63	19.99	15.52	12.83	15.41	1454.46
1958	15.40	31.03	57.28	90.82	146.64	88.87	27.14	19.56	15.78	14.25	11.78	11.26	529.81
1959	11.71	24.99	67.98	62.57	345.73	260.15	52.54	40.09	24.03	17.60	14.43	13.36	925.17
1960	11.81	72.12	240.64	178.58	120.88	143.03	88.84	37.86	32.21	27.39	22.37	18.84	994.57
1961	17.83	26.53	49.92	55.23	48.98	38.49	26.36	20.81	16.65	13.73	11.83	10.20	336.56
1962	9.68	148.29	155.67	51.29	34.24	29.61	24.72	20.01	21.16	21.72	18.07	13.83	548.29
1963	13.51	35.81	46.40	107.59	99.95	33.81	23.00	19.39	16.49	13.87	11.58	9.73	431.13
1964	20.66	26.18	84.34	117.52	65.50	29.01	21.83	17.11	14.39	12.14	10.34	9.53	428.55
1965	9.12	33.23	33.39	89.31	193.72	122.21	22.94	16.85	14.56	12.58	10.72	9.55	568.18
1966	16.74	22.07	52.72	104.38	233.24	150.99	138.02	115.39	33.33	23.98	18.71	14.90	924.47
1967	15.66	24.66	30.42	25.81	25.47	28.99	29.73	23.57	19.28	16.39	13.87	11.70	265.55
1968	11.42	35.17	45.78	49.82	75.92	130.86	95.97	33.41	24.58	18.86	15.00	13.03	549.82
1969	51.97	50.23	50.45	40.61	24.32	20.72	14.47	12.89	12.71	11.73	10.33	9.25	309.68
1970	9.06	18.45	39.93	198.27	152.58	42.90	35.83	26.23	20.42	16.71	13.83	13.02	587.23
1971	20.20	34.63	68.79	270.84	366.47	464.41	214.39	50.10	37.17	26.46	19.34	15.01	1587.81
1972	20.95	29.74	24.80	32.98	38.39	27.64	38.93	35.10	20.38	16.03	13.78	62.31	361.03
1973	58.98	57.47	274.20	447.59	298.73	110.46	51.70	39.98	26.74	21.91	18.00	15.01	1420.77
1974	14.31	28.58	50.28	131.76	195.52	113.19	41.19	30.54	24.57	19.22	15.23	12.89	677.28
1975	11.87	14.18	147.78	471.77	466.20	286.49	132.86	42.95	32.48	23.56	17.76	14.23	1662.03
1976	12.89	23.07	39.34	129.54	247.72	212.42	103.34	36.12	25.37	18.79	15.46	22.05	886.11
1977	19.53	19.64	94.32	348.43	315.24	197.54	110.18	33.85	23.66	18.32	14.81	12.14	1207.66
1978	12.40	42.51	47.23	39.55	29.23	29.83	27.30	16.55	14.38	12.71	11.46	10.51	293.66
1979	12.19	29.20	45.51	41.07	130.21	113.06	36.41	22.41	17.02	13.82	12.33	13.26	486.49
1980	13.26	71.42	105.29	215.20	264.10	138.99	50.76	30.59	23.07	17.80	14.76	14.17	959.41
1981	16.40	20.93	22.34	48.68	38.14	16.53	20.54	19.30	14.66	12.97	11.45	9.72	251.66
1982	9.00	12.78	14.75	16.66	15.84	19.29	22.38	18.09	14.71	12.51	10.93	9.67	176.59
1983	12.40	56.44	75.14	77.50	45.63	48.02	42.84	22.31	16.99	32.90	28.88	19.24	478.29
1984	22.20	43.74	50.61	61.58	339.74	247.83	36.81	24.54	19.47	16.03	12.99	11.18	886.72
AVG:	17.23	43.12	82.81	136.95	172.10	138.50	70.30	32.13	22.22	18.61	15.62	14.80	764.39

Comparison of alternative runoff scenarios at the Mozambique border. Monthly simulated runoff values under present development (million cubic metres).

H.YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	10.64	85.72	83.10	23.08	13.49	22.01	18.76	11.32	10.11	7.66	6.57	4.65	297.11
1922	8.93	30.92	21.49	255.07	504.75	274.16	44.20	25.61	17.59	12.60	8.91	6.43	1210.66
1923	4.15	3.88	38.95	26.96	9.00	71.25	54.01	17.71	11.96	8.98	7.93	6.52	261.30
1924	7.25	116.96	140.80	446.63	335.48	1018.35	589.04	58.00	38.15	26.31	16.22	14.52	2807.71
1925	10.74	10.27	7.70	13.36	35.45	41.32	26.29	13.94	10.07	11.65	7.10	6.56	194.45
1926	4.16	6.23	6.34	18.54	23.71	21.61	16.77	12.58	10.62	20.38	15.15	8.66	164.75
1927	18.56	11.16	9.61	107.87	89.73	34.64	31.00	20.55	14.99	10.89	8.43	6.47	363.90
1928	5.51	5.06	8.11	17.01	53.29	146.45	95.52	22.50	16.30	11.59	9.04	8.03	398.41
1929	19.45	57.81	54.55	76.52	82.33	149.66	124.42	50.08	27.79	18.46	12.48	9.45	683.00
1930	6.75	7.85	103.98	66.78	25.21	24.89	23.55	15.76	12.63	14.64	9.31	7.63	318.98
1931	7.21	24.28	32.09	27.31	27.84	25.83	17.84	14.23	11.31	9.11	6.84	5.36	209.25
1932	3.96	8.17	27.04	67.57	52.05	34.24	23.86	15.88	11.47	9.61	6.59	5.32	265.76
1933	4.20	40.91	49.22	152.14	135.94	70.24	43.08	27.00	20.72	14.30	10.24	8.94	576.93
1934	7.36	43.79	90.54	103.34	69.40	33.77	21.26	16.37	12.43	10.05	7.26	5.94	421.51
1935	4.39	3.92	4.31	23.95	45.73	100.99	66.21	22.91	17.04	13.13	9.06	13.28	324.92
1936	16.36	33.01	75.92	242.77	901.11	437.19	65.11	33.93	22.87	15.22	11.04	8.56	1863.09
1937	5.53	5.16	14.90	23.81	19.35	10.46	36.11	25.13	11.80	8.92	6.18	10.85	178.20
1938	8.45	10.87	497.24	360.66	860.78	650.59	134.96	44.12	31.72	26.58	18.65	18.28	2662.90
1939	12.29	133.59	205.38	99.05	29.98	41.78	35.08	22.85	22.52	15.00	10.93	10.09	638.54
1940	7.99	69.70	74.94	38.18	19.68	24.26	57.87	41.53	17.43	12.73	9.06	7.05	380.42
1941	6.02	5.56	35.42	74.51	44.30	93.12	59.58	21.64	20.74	15.36	11.42	11.40	399.07
1942	9.57	18.45	23.14	20.34	18.43	35.87	97.54	68.01	24.09	20.48	18.12	17.41	371.45
1943	15.56	42.37	22.06	18.60	131.76	105.61	24.08	15.66	13.85	10.34	8.05	7.05	414.99
1944	12.37	13.01	9.26	51.65	48.57	34.08	25.19	15.21	11.43	8.93	6.53	4.87	241.10
1945	6.73	5.01	4.37	286.64	335.26	116.68	33.95	20.51	14.11	10.64	7.93	5.85	847.68
1946	3.92	13.42	15.01	19.30	40.61	42.00	34.80	26.19	17.26	11.97	8.75	7.37	240.64
1947	7.49	30.92	115.00	86.18	34.02	177.80	125.56	28.36	19.00	13.31	9.41	7.94	654.99
1948	7.93	8.43	7.90	53.35	51.56	30.45	21.76	17.56	13.46	10.48	7.86	7.03	237.77
1949	4.86	43.34	49.50	31.69	27.35	34.73	27.96	18.62	14.74	11.58	9.08	7.40	280.85
1950	5.70	6.75	81.87	58.21	10.11	16.88	24.66	21.38	15.34	11.55	13.18	9.80	275.43
1951	15.47	10.02	18.10	23.10	17.89	21.49	18.97	13.99	12.12	11.22	8.30	6.61	177.28
1952	6.05	40.06	59.86	68.53	132.06	118.58	50.90	27.31	18.36	12.85	9.53	7.86	551.95
1953	5.70	19.72	28.83	59.59	112.02	73.76	31.72	22.36	15.88	11.38	9.41	7.67	398.04
1954	6.54	20.59	13.86	187.02	349.62	254.34	101.06	45.53	32.25	21.88	13.98	10.17	1056.84
1955	14.83	49.62	129.71	88.70	448.85	377.00	95.58	38.44	28.54	19.37	13.27	13.75	1317.66
1956	9.55	8.37	11.86	11.90	29.30	49.32	39.96	22.14	16.25	14.48	11.66	11.44	236.23
1957	15.06	14.79	26.02	686.19	410.33	35.69	28.91	19.74	14.67	10.82	8.02	9.33	1279.57
1958	6.73	16.79	28.72	52.62	113.73	69.95	19.69	14.93	10.69	9.94	6.54	6.53	356.86
1959	5.18	10.49	30.48	26.35	309.01	211.27	45.04	30.45	18.98	12.64	9.64	8.61	718.14
1960	5.62	40.64	184.54	135.27	97.19	117.07	71.80	31.49	29.19	20.88	15.39	11.73	760.81
1961	10.29	13.48	23.48	26.48	27.99	22.16	17.69	13.22	10.74	8.77	6.99	4.96	186.25
1962	4.15	100.50	99.11	29.64	20.88	17.17	17.51	13.42	15.94	14.64	9.90	7.40	350.26
1963	6.97	15.84	19.68	69.24	64.21	21.49	17.59	12.51	10.75	8.73	6.67	4.62	258.30
1964	10.86	9.17	43.93	65.41	39.54	18.92	14.81	10.58	9.07	7.56	5.67	4.94	240.46
1965	3.58	15.47	10.46	62.09	139.32	85.57	17.64	12.15	10.04	8.01	6.24	4.78	375.35
1966	7.66	7.82	22.81	55.46	191.55	123.91	120.88	95.37	30.44	20.12	13.74	10.07	699.83
1967	9.58	10.77	11.49	10.57	13.51	15.32	16.64	12.83	12.21	9.08	7.17	5.49	134.66
1968	4.92	16.56	17.47	22.49	43.75	91.39	71.80	26.62	18.42	13.24	9.33	8.17	344.16
1969	34.77	24.56	25.66	17.25	13.88	10.31	9.08	7.95	8.06	6.44	4.85	3.50	166.31
1970	2.98	7.17	16.74	142.23	104.57	30.33	26.84	18.68	14.51	10.46	7.64	7.37	389.52
1971	10.15	19.12	37.31	221.99	321.37	434.68	196.13	48.92	33.15	22.40	14.21	10.34	1369.77
1972	12.17	13.69	9.96	14.87	17.26	13.24	23.12	18.56	13.10	10.30	8.13	44.00	198.40
1973	33.63	34.28	235.83	407.25	262.94	94.58	50.34	33.57	22.68	18.66	11.85	9.76	1215.37
1974	8.17	15.41	26.83	87.79	152.48	90.33	32.74	25.96	19.79	13.35	9.97	7.95	490.77
1975	6.17	6.90	108.65	415.55	421.32	253.00	114.85	42.39	29.21	19.16	13.22	9.87	1440.29
1976	8.01	11.82	17.86	80.50	198.33	182.02	85.27	31.20	21.15	13.90	10.88	14.31	675.25
1977	8.57	9.71	51.84	298.16	281.86	175.29	94.89	29.39	19.47	13.71	9.90	7.40	1000.19
1978	6.96	23.19	21.00	19.68	13.26	16.87	13.89	10.15	8.51	7.52	6.08	4.73	151.84
1979	5.06	11.96	19.87	17.27	83.92	72.78	25.63	16.42	11.28	8.88	7.73	7.63	288.43
1980	6.05	38.78	59.52	181.08	226.86	115.92	42.32	27.63	18.73	13.06	10.25	9.24	749.44
1981	8.67	9.64	8.83	27.81	16.59	7.85	11.74	9.45	7.60	6.91	4.98	3.75	123.82
1982	2.74	3.83	3.73	4.24	4.20	7.11	8.43	7.79	6.54	5.42	4.45	2.97	61.45
1983	4.35	29.48	36.55	46.14	24.69	31.65	24.40	13.19	10.67	23.08	13.99	10.40	268.59
1984	11.34	23.72	22.68	36.54	303.61	215.04	31.36	21.54	14.99	11.49	8.39	6.62	707.32
AVG:	8.96	25.01	53.02	102.97	141.94	115.57	56.08	24.86	16.99	13.17	9.61	8.79	576.96

Comparison of alternative runoff scenarios at the Mozambique border. Monthly simulated runoff values under maximum use (million cubic metres).

H.YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	3.63	57.81	53.66	13.98	7.75	8.77	7.18	4.06	3.88	1.44	1.24	0.00	163.40
1922	0.76	7.63	1.60	170.10	341.67	186.73	31.90	17.23	11.19	6.32	0.13	0.43	775.69
1923	0.00	0.00	9.29	9.38	2.28	37.90	28.65	7.95	4.93	2.72	2.50	0.42	106.02
1924	0.58	90.46	112.30	315.95	246.09	673.45	402.95	43.23	28.91	18.41	7.36	3.99	1943.68
1925	0.00	2.17	2.63	2.73	20.75	23.89	13.74	6.04	4.08	4.39	1.88	0.47	82.77
1926	0.00	0.00	0.00	7.36	13.52	12.70	9.75	6.00	4.78	9.62	3.35	2.68	69.76
1927	3.33	2.60	0.38	79.45	72.03	22.40	20.03	13.06	9.11	4.57	0.00	0.02	226.98
1928	0.00	0.00	1.58	6.78	28.54	100.60	69.35	14.10	9.78	5.35	0.23	1.80	238.11
1929	5.19	31.88	30.52	61.88	64.61	97.02	86.56	36.60	19.63	11.51	3.70	3.49	452.59
1930	0.40	0.00	54.58	34.78	14.31	14.95	14.38	8.13	6.48	6.57	0.45	1.60	156.63
1931	0.45	8.47	13.25	13.38	17.89	17.43	11.07	7.34	5.48	2.89	1.62	0.00	99.27
1932	0.00	0.00	8.42	34.32	27.21	19.21	14.80	8.18	5.48	3.17	1.37	0.00	122.18
1933	0.00	15.99	24.30	103.96	87.63	40.01	27.21	16.48	12.72	7.51	1.46	2.69	339.96
1934	0.72	21.03	50.43	64.78	45.10	21.77	13.56	8.81	6.31	3.78	2.04	0.00	238.33
1935	0.00	0.00	0.00	5.80	17.12	50.56	36.08	12.84	9.76	6.18	0.28	1.63	140.25
1936	1.14	15.54	23.24	149.31	650.48	319.62	50.40	24.82	16.07	8.99	2.24	2.45	1264.30
1937	0.00	0.00	2.91	1.83	3.10	2.11	9.78	4.62	3.76	1.89	0.90	2.94	33.84
1938	0.68	0.52	297.20	234.33	539.20	416.29	86.88	31.52	22.16	16.46	8.00	6.05	1659.29
1939	1.34	80.76	125.35	61.52	19.97	27.46	22.45	13.34	13.51	7.67	2.07	0.00	375.44
1940	1.36	41.23	44.99	23.38	12.39	14.54	40.87	28.55	10.84	6.35	0.24	1.06	225.80
1941	0.00	0.22	8.00	42.18	29.32	62.29	39.56	12.79	11.93	7.82	2.33	0.48	216.92
1942	2.83	8.10	11.32	11.29	10.52	22.03	75.37	52.60	16.77	12.78	8.56	7.20	239.37
1943	4.54	31.04	12.70	9.05	87.29	75.01	16.61	9.09	7.77	4.13	2.81	0.92	260.96
1944	0.28	3.29	0.00	31.61	30.87	19.94	15.23	7.85	5.66	2.72	1.31	0.00	118.76
1945	0.00	0.00	0.00	173.17	219.96	78.19	23.75	12.85	8.15	4.42	2.71	0.00	523.20
1946	0.00	2.34	5.06	10.83	23.06	25.44	22.27	15.40	10.13	5.57	0.01	1.30	121.43
1947	0.45	14.38	69.02	55.65	22.26	117.67	84.61	18.45	11.91	6.85	0.63	1.71	403.59
1948	0.72	0.36	2.30	23.03	25.17	16.80	13.23	9.37	7.15	4.22	2.64	0.96	105.95
1949	0.00	23.52	29.20	18.76	18.64	18.32	14.43	10.23	8.23	5.21	0.23	1.43	148.20
1950	0.00	1.03	58.55	42.34	4.36	9.98	14.48	11.97	8.74	5.17	3.96	0.00	157.58
1951	1.80	2.25	6.21	12.61	10.61	13.69	12.16	7.35	6.18	4.79	3.06	0.65	81.38
1952	0.00	23.10	42.94	50.79	90.37	79.00	32.41	17.93	11.40	6.58	0.74	1.75	357.01
1953	0.00	5.37	13.90	43.61	85.39	55.88	21.72	13.78	9.42	5.17	0.51	1.55	256.30
1954	0.00	9.14	3.55	124.04	269.99	200.26	75.46	34.29	24.22	15.06	5.20	0.24	781.45
1955	2.54	30.28	97.51	68.63	298.12	261.27	67.81	27.56	20.15	12.14	4.48	3.13	893.62
1956	3.01	0.55	1.52	3.17	16.26	29.82	23.59	11.99	8.96	7.15	2.64	1.16	109.82
1957	1.91	5.85	11.34	441.28	281.49	25.53	19.96	12.38	8.64	4.60	2.80	2.91	818.69
1958	0.03	4.09	13.02	28.88	58.45	38.11	11.77	7.42	4.91	3.49	1.32	0.19	171.68
1959	0.00	0.00	16.59	16.51	186.86	134.79	29.68	19.84	12.17	6.39	0.75	2.37	425.95
1960	0.00	21.82	110.13	88.27	64.95	72.68	47.71	20.99	19.48	12.59	5.62	1.52	465.78
1961	3.44	5.13	11.28	15.53	18.70	14.57	10.50	6.52	4.97	2.55	1.62	0.00	94.81
1962	0.00	61.27	61.35	12.09	12.47	10.17	9.86	6.63	8.78	7.28	1.11	1.45	192.46
1963	0.26	6.82	8.41	41.10	41.28	12.82	10.15	5.73	4.92	2.51	1.33	0.00	135.33
1964	1.58	1.09	22.94	38.28	22.76	9.67	6.94	3.69	3.30	1.34	0.42	0.00	112.01
1965	0.00	1.11	1.26	34.32	88.26	56.01	9.90	5.09	4.17	1.78	0.91	0.00	202.81
1966	0.00	1.08	10.93	27.70	132.49	90.32	88.41	71.71	22.13	12.96	4.91	0.14	462.78
1967	2.74	2.81	2.11	2.73	4.91	6.01	7.75	5.04	5.25	2.81	1.88	0.00	44.04
1968	0.00	2.86	5.20	9.97	19.28	51.07	47.40	17.08	11.46	6.81	0.55	1.96	173.64
1969	11.94	10.67	13.25	9.75	6.82	4.27	2.92	1.30	2.05	0.16	0.00	0.00	63.13
1970	0.00	0.00	0.00	74.91	61.90	16.33	13.46	8.81	7.20	3.99	2.42	1.10	190.12
1971	2.40	5.56	16.91	134.23	216.52	309.85	143.94	36.11	24.55	15.07	5.41	0.41	910.96
1972	0.65	4.77	0.66	5.71	8.85	6.30	13.59	10.53	7.03	4.02	2.84	21.94	86.89
1973	12.94	18.78	141.88	281.99	194.28	71.34	37.89	24.29	15.90	11.16	3.07	0.00	813.52
1974	1.06	5.00	10.88	43.31	95.74	63.48	22.68	16.61	12.64	7.05	1.18	1.93	281.56
1975	0.00	1.82	75.56	254.04	284.23	189.60	93.21	31.83	21.68	12.55	4.44	0.00	948.96
1976	1.33	3.26	4.58	49.17	141.19	129.45	61.80	21.38	13.97	7.58	1.99	2.53	438.23
1977	2.10	1.75	33.37	221.48	215.45	120.38	65.27	20.16	12.70	7.38	1.12	1.43	702.59
1978	0.00	11.00	7.51	8.71	6.36	6.66	5.50	3.25	2.70	1.22	0.73	0.00	53.64
1979	0.00	0.58	8.46	6.82	61.23	53.10	15.09	8.82	5.45	2.66	2.31	1.24	165.78
1980	0.00	24.62	39.18	131.37	168.29	85.19	31.26	18.61	12.07	6.84	1.30	2.90	521.63
1981	1.66	1.33	3.10	14.76	9.77	1.98	3.99	1.95	1.83	0.64	0.00	0.00	41.01
1982	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.74	1.76	0.00	0.00	2.97
1983	0.00	6.34	17.28	32.03	16.95	16.35	12.82	6.12	4.85	12.28	3.15	0.00	128.27
1984	3.51	12.28	11.71	21.73	244.85	175.61	22.55	13.63	9.03	5.28	0.00	0.21	520.39
AVG:	1.30	11.78	29.30	65.04	95.60	77.56	37.44	15.51	10.18	6.41	2.13	1.54	353.74

Comparison of alternative runoff scenarios at the Mozambique border. Monthly simulated runoff values under 30% minimum flow (million cubic metres).

H YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	7.59	49.46	53.75	13.57	7.41	10.07	9.22	5.26	4.74	3.90	3.50	3.11	171.58
1922	6.32	16.97	14.12	162.09	301.08	186.76	31.59	16.87	10.86	6.03	4.01	3.28	759.98
1923	2.72	2.96	21.33	18.59	6.61	41.43	29.26	7.11	5.73	4.59	4.15	3.81	148.29
1924	4.64	87.60	101.04	374.31	236.35	600.83	402.66	43.05	28.59	18.08	6.96	6.06	1910.17
1925	5.64	5.74	5.47	8.67	22.71	22.86	13.94	6.22	4.84	5.10	4.61	3.83	109.63
1926	3.28	4.55	6.30	14.30	15.93	15.06	9.91	6.71	5.19	9.56	9.53	5.35	105.67
1927	9.19	8.65	7.36	58.02	44.35	20.46	19.77	12.68	8.78	4.79	4.05	3.51	201.61
1928	3.21	3.53	6.75	12.98	27.46	61.15	56.43	13.72	9.48	5.03	4.27	4.01	218.02
1929	10.66	33.11	30.53	44.34	64.55	97.54	86.23	36.22	19.34	11.18	5.60	4.46	443.76
1930	3.71	4.54	79.33	47.10	14.94	12.83	11.12	7.57	5.55	6.10	5.63	4.29	202.71
1931	4.01	13.87	20.29	17.19	14.61	12.74	8.41	6.16	5.21	4.28	3.59	3.09	113.45
1932	2.81	6.71	17.78	36.67	25.46	15.88	11.99	7.40	5.20	4.31	3.58	3.11	140.90
1933	2.90	21.65	29.57	80.49	63.46	40.11	26.88	16.19	12.48	7.21	4.76	4.16	309.86
1934	4.01	25.60	46.54	46.99	45.20	21.56	13.19	8.65	6.11	4.41	3.76	3.28	229.30
1935	2.94	2.92	4.11	16.91	25.18	47.47	28.88	9.38	7.25	5.77	4.67	6.22	161.70
1936	8.66	19.81	34.39	102.05	651.84	319.66	50.20	24.47	15.73	8.66	4.62	3.80	1243.89
1937	3.19	3.04	9.98	15.06	11.63	7.58	17.08	11.60	5.41	4.65	3.96	5.86	99.04
1938	6.51	7.46	232.49	234.28	540.28	416.13	86.72	31.21	21.85	16.29	7.80	7.52	1608.54
1939	6.67	78.59	120.93	61.32	19.85	27.61	22.27	13.12	13.53	7.34	6.27	5.05	381.55
1940	4.79	48.58	42.66	18.88	9.71	10.90	29.84	28.17	10.51	6.11	4.31	3.69	218.15
1941	3.45	3.70	19.74	44.67	25.22	55.53	31.68	8.00	7.97	7.01	6.50	5.55	218.02
1942	5.88	10.35	14.68	12.88	10.37	16.61	53.68	43.02	16.44	12.67	8.33	8.60	213.51
1943	8.14	34.35	15.99	9.83	74.44	74.71	16.24	8.72	7.57	4.61	3.87	3.50	261.97
1944	7.61	9.06	7.03	37.12	30.40	16.27	11.54	7.13	5.27	4.20	3.47	2.97	142.07
1945	4.29	4.47	4.08	142.85	202.59	78.05	23.37	12.49	7.81	4.56	3.74	3.14	491.44
1946	2.67	8.61	12.47	14.85	23.13	21.08	15.21	10.64	6.81	5.52	4.49	3.75	129.23
1947	4.09	19.36	56.25	39.69	15.26	109.59	84.32	18.12	11.58	6.56	4.21	3.60	372.63
1948	4.32	5.73	6.40	33.30	29.90	16.58	10.19	7.15	5.94	4.96	4.07	3.63	132.17
1949	3.30	29.21	36.99	19.65	15.83	15.33	12.11	7.74	6.57	5.32	4.38	3.88	160.31
1950	3.49	3.95	53.89	35.83	6.20	9.14	13.01	10.28	7.13	5.45	6.06	5.76	160.19
1951	7.72	7.25	11.29	14.66	10.30	11.85	10.43	6.34	5.20	4.83	4.42	3.78	98.07
1952	3.51	22.49	34.15	38.28	69.68	78.75	32.37	17.56	11.07	6.27	4.33	3.74	322.20
1953	3.35	10.62	19.07	33.50	66.70	55.55	21.63	13.49	9.09	4.96	4.22	3.77	245.95
1954	3.68	13.22	11.04	93.47	270.29	200.28	75.36	33.99	23.91	14.73	5.81	4.43	750.21
1955	7.38	31.12	86.63	68.35	299.09	261.22	67.42	27.39	19.93	11.82	5.69	6.13	892.15
1956	5.75	4.90	8.02	9.06	16.94	26.02	18.64	8.91	6.83	5.99	5.74	5.86	122.66
1957	7.79	8.86	14.18	407.28	280.43	25.17	19.78	12.01	8.35	4.66	3.85	4.62	796.98
1958	4.62	9.31	19.66	28.79	47.94	26.66	8.14	5.87	4.73	4.28	3.53	3.38	166.91
1959	3.51	7.50	20.39	18.77	152.48	127.19	29.78	19.54	11.84	6.07	4.33	4.01	405.41
1960	3.54	22.37	91.97	88.06	65.22	72.75	47.42	20.68	19.52	12.35	6.71	5.65	456.22
1961	5.35	7.96	14.98	16.57	14.69	11.55	7.91	6.24	4.99	4.12	3.55	3.06	100.97
1962	2.90	52.11	49.15	15.39	10.27	8.88	7.42	6.00	6.35	6.52	5.42	4.15	174.56
1963	4.05	10.74	13.92	36.16	31.30	10.14	6.90	5.82	4.95	4.16	3.47	2.92	134.53
1964	6.20	7.85	25.30	35.26	19.65	8.70	6.55	5.13	4.32	3.64	3.10	2.86	128.56
1965	2.74	9.97	10.02	46.75	73.38	38.25	6.88	5.06	4.37	3.77	3.22	2.87	207.28
1966	5.02	6.62	15.82	31.31	104.86	72.28	88.53	71.35	21.85	12.70	5.61	4.47	440.42
1967	4.70	7.40	9.13	7.74	7.64	8.70	8.92	7.07	5.78	4.92	4.16	3.51	79.67
1968	3.43	10.55	13.73	14.95	22.78	39.55	28.79	10.02	7.37	5.66	4.50	3.91	165.24
1969	20.96	15.80	15.14	12.18	7.30	6.22	4.34	3.87	3.81	3.52	3.10	2.78	99.02
1970	2.72	5.54	11.98	69.01	48.69	13.29	10.75	7.87	6.13	5.01	4.15	3.91	189.05
1971	6.06	10.66	21.22	96.00	213.91	310.57	143.64	38.01	24.22	14.75	5.80	4.50	887.34
1972	6.29	8.92	7.44	9.89	11.52	8.29	11.68	10.53	6.11	4.81	4.13	30.32	119.93
1973	21.06	17.24	100.08	280.09	194.24	71.11	38.03	23.97	15.57	11.07	5.40	4.50	782.38
1974	4.29	8.57	16.95	45.09	69.38	63.27	22.45	16.44	12.36	6.72	4.57	3.87	273.96
1975	3.56	4.25	79.84	226.54	264.51	189.48	92.90	31.60	21.34	12.22	5.33	4.27	935.84
1976	3.87	6.92	11.80	43.11	123.62	129.54	61.44	21.02	13.64	7.25	4.64	6.61	433.46
1977	5.86	5.89	28.88	206.35	215.92	120.64	65.16	19.79	12.37	7.08	4.44	3.64	696.02
1978	3.72	14.09	14.17	12.57	8.77	8.95	8.19	4.98	4.31	3.81	3.44	3.15	90.13
1979	3.66	8.76	14.45	12.32	49.48	36.79	10.92	6.72	5.11	4.15	3.70	3.98	160.04
1980	3.98	23.17	37.24	93.30	168.49	85.23	30.97	18.35	11.74	6.51	4.43	4.25	487.66
1981	4.92	6.28	6.70	20.11	12.09	4.96	6.16	5.79	4.40	3.89	3.44	2.92	81.66
1982	2.70	3.83	4.43	5.00	4.75	5.79	6.71	5.43	4.41	3.75	3.28	2.90	52.98
1983	3.72	19.05	24.59	38.51	17.54	15.14	12.85	6.69	5.10	12.62	8.66	5.77	170.24
1984	6.66	13.12	15.18	19.20	184.15	175.42	22.24	13.38	8.71	4.95	3.90	3.35	470.24
AVG:	5.31	15.58	31.11	62.00	89.69	73.90	35.75	15.00	9.83	6.84	4.70	4.62	354.33

Comparison of alternative runoff scenarios at the Mozambique border. Monthly simulated runoff values 2.6 MCM/Month scenario (million cubic metres).

H.YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	2.60	54.46	53.70	13.79	7.60	8.71	7.08	3.93	3.83	2.60	2.60	2.60	163.50
1922	2.60	2.72	2.60	166.59	341.98	186.75	31.76	17.07	11.04	6.19	2.60	2.60	774.50
1923	2.60	2.60	3.44	4.65	2.60	37.77	28.48	7.86	4.78	2.60	2.60	2.60	102.58
1924	2.60	82.42	112.47	316.51	246.27	673.77	402.82	43.15	28.76	18.26	7.18	3.89	1938.10
1925	2.60	2.60	2.60	2.60	17.41	23.79	13.59	5.89	3.93	4.33	2.60	2.60	84.54
1926	2.60	2.60	2.60	5.42	3.64	12.58	9.58	5.83	4.64	9.56	3.23	2.60	65.08
1927	2.91	2.60	2.60	77.33	71.87	22.27	19.91	12.89	8.96	4.44	2.60	2.60	230.98
1928	2.60	2.60	2.60	2.60	23.84	100.69	69.16	13.93	9.64	5.20	2.60	2.60	238.06
1929	2.60	31.09	30.57	61.76	64.58	97.26	86.41	36.43	19.50	11.36	3.52	2.60	447.68
1930	2.60	2.60	49.72	34.75	14.24	14.96	14.24	7.96	6.33	6.54	2.60	2.60	159.14
1931	2.60	2.67	13.18	13.24	17.92	17.46	10.93	7.22	5.35	2.74	2.60	2.60	98.51
1932	2.60	2.60	2.60	31.20	27.12	19.23	14.64	8.01	5.33	3.07	2.60	2.60	121.60
1933	2.60	5.55	24.35	104.23	87.53	40.05	27.06	16.35	12.61	7.37	2.60	2.60	332.90
1934	2.60	13.80	50.50	64.75	45.14	21.67	13.39	8.74	6.22	3.64	2.60	2.60	235.65
1935	2.60	2.60	2.60	5.70	3.56	49.15	35.99	12.74	9.62	6.05	2.60	2.60	135.81
1936	2.60	10.60	23.25	149.44	651.10	319.64	50.31	24.66	15.91	8.84	2.60	2.60	1261.55
1937	2.60	2.60	2.60	2.60	2.60	2.60	5.06	3.89	3.66	2.60	2.60	2.60	36.01
1938	2.60	2.60	294.22	234.31	539.69	416.22	86.80	31.38	22.02	16.38	7.82	6.00	1660.04
1939	2.60	79.62	125.48	61.43	19.91	27.53	22.37	13.24	13.52	7.52	2.60	2.60	378.42
1940	2.60	36.55	45.03	23.25	12.28	14.59	40.97	28.38	10.69	6.24	2.60	2.60	225.78
1941	2.60	2.60	4.61	39.91	29.21	62.55	39.41	12.71	11.88	7.67	2.60	2.60	218.55
1942	2.60	5.49	11.25	11.19	10.40	22.03	75.52	52.48	16.62	12.73	8.45	7.07	235.83
1943	4.39	31.09	12.55	9.05	87.47	74.87	16.44	8.92	7.68	3.98	2.60	2.60	261.64
1944	2.60	2.60	2.60	26.37	30.95	19.85	15.09	7.69	5.50	2.60	2.60	2.60	121.05
1945	2.60	2.60	2.60	157.42	220.19	78.13	23.58	12.68	7.99	4.27	2.60	2.60	517.26
1946	2.60	2.60	2.60	6.95	23.11	25.45	22.20	15.26	10.00	5.42	2.60	2.60	121.39
1947	2.60	8.00	69.14	55.56	22.21	117.85	84.48	18.30	11.76	6.72	2.60	2.60	401.82
1948	2.60	2.60	2.60	18.58	25.22	16.65	13.13	9.30	7.02	4.08	2.60	2.60	106.98
1949	2.60	15.41	29.28	18.69	18.56	18.33	14.33	10.09	8.09	5.10	2.60	2.60	145.68
1950	2.60	2.60	48.37	42.22	4.22	8.93	14.48	11.90	8.59	5.06	3.95	2.60	155.52
1951	2.60	2.60	2.60	12.12	10.59	13.60	12.01	7.19	6.06	4.68	2.60	2.60	79.25
1952	2.60	15.00	42.69	50.93	90.42	78.89	32.39	17.76	11.25	6.44	2.60	2.60	353.77
1953	2.60	2.87	10.60	43.54	85.42	55.73	21.68	13.64	9.27	5.02	2.60	2.60	255.57
1954	2.60	4.47	2.60	123.53	270.13	200.27	75.42	34.15	24.08	14.91	5.02	2.60	759.78
1955	2.60	27.77	97.60	68.50	298.56	261.25	67.63	27.48	20.05	12.00	4.30	3.06	890.80
1956	2.60	2.60	2.60	2.60	12.59	29.76	23.50	11.89	8.82	7.07	2.60	2.60	109.23
1957	2.60	3.40	11.33	441.99	281.45	25.37	19.88	12.21	8.51	4.45	2.60	2.60	816.39
1958	2.60	2.60	8.47	28.92	58.60	37.96	11.60	7.32	4.76	3.39	2.60	2.60	171.42
1959	2.60	2.60	6.90	16.42	187.27	134.69	29.73	19.70	12.02	6.25	2.60	2.60	423.38
1960	2.60	16.73	110.35	88.17	65.07	72.71	47.58	20.84	19.50	12.48	5.48	2.60	464.11
1961	2.60	2.60	8.85	15.47	18.70	14.45	10.38	6.36	4.82	2.60	2.60	2.60	92.03
1962	2.60	50.97	61.30	11.97	12.44	10.05	9.82	6.48	8.74	7.22	2.60	2.60	186.79
1963	2.60	2.60	7.02	41.20	41.29	12.65	10.09	5.59	4.78	2.60	2.60	2.60	135.62
1964	2.60	2.60	15.55	38.27	22.66	9.54	6.82	3.53	3.14	2.60	2.60	2.60	112.51
1965	2.60	2.60	2.60	29.43	88.47	55.81	9.75	4.96	4.04	2.60	2.60	2.60	208.06
1966	2.60	2.60	2.60	26.17	132.70	90.29	88.46	71.55	22.00	12.84	4.73	2.60	459.14
1967	2.60	2.60	2.60	2.60	2.60	5.12	7.69	4.89	5.15	2.67	2.60	2.60	43.72
1968	2.60	2.60	2.60	6.00	19.29	51.10	47.34	16.92	11.31	6.69	2.60	2.60	171.65
1969	9.05	10.55	13.20	9.58	6.80	4.13	2.77	2.60	2.60	2.60	2.60	2.60	69.08
1970	2.60	2.60	2.60	56.84	61.87	16.34	13.45	8.70	7.07	3.84	2.60	2.60	181.11
1971	2.60	2.87	13.84	134.43	216.65	310.16	143.80	36.06	24.40	14.92	5.23	2.60	907.58
1972	2.60	2.60	2.60	2.60	7.44	6.14	13.59	10.37	6.88	3.88	2.60	18.62	79.92
1973	12.87	18.73	142.07	282.17	194.26	71.24	37.96	24.15	15.75	11.12	2.89	2.60	815.81
1974	2.60	2.60	8.91	43.40	95.90	63.38	22.57	16.53	12.51	6.90	2.60	2.60	280.50
1975	2.60	2.60	69.69	254.41	264.36	189.55	93.07	31.73	21.52	12.39	4.26	2.60	948.78
1976	2.60	2.60	2.60	47.67	141.39	129.49	61.64	21.22	13.81	7.43	2.60	2.60	435.65
1977	2.60	2.60	29.78	221.64	215.68	120.50	65.22	19.99	12.55	7.24	2.60	2.60	702.96
1978	2.60	5.34	7.48	8.75	6.23	6.61	5.36	3.11	2.60	2.60	2.60	2.60	55.88
1979	2.60	2.60	3.40	3.97	61.47	53.01	14.95	8.67	5.30	2.60	2.60	2.60	163.77
1980	2.60	16.45	39.29	131.53	168.38	85.21	31.13	18.49	11.92	6.59	2.60	2.60	516.89
1981	2.60	2.60	2.60	10.93	9.63	2.60	3.12	2.60	2.60	2.60	2.60	2.60	47.08
1982	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	31.20
1983	2.60	4.72	4.65	17.86	16.73	16.40	12.80	5.95	4.71	12.40	2.98	2.60	104.40
1984	2.60	10.45	11.63	21.75	245.18	175.52	22.41	13.61	8.88	5.13	2.60	2.60	522.26
AVG:	2.89	10.37	27.95	63.44	95.08	77.55	37.30	15.43	10.09	6.48	3.11	3.00	352.69

Comparison of alternative runoff scenarios at the Mozambique border. Monthly simulated runoff values under the proposed rule (million cubic metres).

H.YEAR	O	N	D	J	F	M	A	M	J	J	A	S	TOTAL
1921	4.26	52.81	53.78	15.95	14.94	13.47	11.96	9.42	7.77	6.53	5.39	4.39	200.67
1922	4.68	8.34	9.88	129.27	322.09	186.78	31.45	17.01	12.02	8.93	6.76	5.04	742.25
1923	3.70	4.11	12.44	14.53	8.58	29.67	23.26	9.63	7.90	6.60	5.54	4.58	130.54
1924	4.05	63.86	85.01	309.58	246.67	674.43	402.54	42.98	28.45	17.94	10.04	7.55	1893.10
1925	5.86	6.96	8.04	9.98	20.81	21.38	16.34	10.20	7.81	6.67	5.70	4.69	124.44
1926	3.77	4.75	6.21	11.23	14.10	14.36	11.15	9.40	7.79	7.46	6.79	5.36	102.37
1927	5.35	6.62	7.98	55.02	57.65	19.61	17.53	13.70	10.02	7.62	6.16	4.92	212.18
1928	3.84	4.49	6.06	9.19	15.23	47.86	68.78	13.57	9.36	7.33	6.00	4.94	196.55
1929	5.40	15.93	30.53	61.52	64.53	97.76	86.09	36.06	19.21	11.04	7.94	6.14	442.15
1930	4.63	5.42	50.06	31.93	18.28	16.23	14.23	11.37	8.73	7.26	6.36	5.24	179.74
1931	4.23	7.65	13.29	15.82	18.14	17.88	14.04	10.87	8.66	7.06	5.77	4.53	127.94
1932	3.47	5.01	9.64	20.97	18.35	14.95	14.05	10.36	7.91	6.48	5.26	4.18	120.63
1933	3.25	11.07	17.27	54.94	83.87	40.15	26.74	16.07	12.38	8.29	6.69	5.40	286.12
1934	4.31	13.10	36.40	64.67	45.24	21.47	14.34	10.69	8.40	6.98	5.74	4.57	235.91
1935	3.57	4.12	5.11	11.75	14.82	22.42	17.55	12.20	10.04	7.84	6.31	5.38	121.11
1936	4.79	11.99	16.34	135.26	652.42	319.68	50.12	24.33	15.60	10.11	7.57	5.63	1253.84
1937	4.15	4.59	7.08	9.24	8.99	8.48	10.89	7.76	6.59	5.63	4.73	4.23	82.36
1938	3.83	5.16	227.82	234.26	540.73	416.07	86.65	31.09	21.72	16.22	9.47	7.56	1600.58
1939	6.13	72.65	125.75	61.23	20.39	27.09	22.20	13.03	13.54	8.33	6.83	5.68	382.85
1940	4.73	29.05	37.03	22.98	15.90	13.92	38.07	28.01	10.37	7.52	6.18	5.01	218.77
1941	3.96	4.80	9.59	26.79	22.63	50.19	39.09	12.55	11.76	7.92	6.57	5.52	201.37
1942	4.76	7.53	12.61	15.26	15.62	17.42	52.30	52.22	16.30	12.62	8.81	8.38	223.83
1943	7.47	27.26	15.55	13.50	78.44	74.58	17.73	12.54	9.29	7.60	6.19	4.93	275.08
1944	5.04	6.66	7.56	26.33	21.95	13.47	12.63	10.21	8.19	6.59	5.26	4.09	127.98
1945	3.47	4.37	5.30	108.75	220.65	77.98	23.21	14.20	10.30	7.94	6.28	4.83	487.28
1946	3.61	7.51	10.74	14.42	20.83	18.12	15.71	12.53	9.42	7.44	6.17	4.96	131.46
1947	4.02	10.90	30.50	43.01	22.12	118.22	84.20	17.97	11.44	8.42	6.62	5.14	362.56
1948	4.07	5.42	6.94	20.32	21.80	17.71	14.48	11.03	8.83	7.26	5.96	4.77	128.59
1949	3.76	17.40	24.99	18.16	20.36	16.58	14.27	11.61	9.50	7.63	6.26	5.16	155.68
1950	4.12	4.89	38.11	31.65	10.30	12.10	14.01	12.24	9.93	7.70	6.75	6.07	157.87
1951	5.28	6.77	11.18	15.80	15.42	16.42	15.32	11.31	8.84	7.38	6.29	5.13	125.14
1952	4.04	12.46	29.58	39.96	59.31	70.41	32.36	17.40	12.11	8.88	6.93	5.42	298.86
1953	4.16	7.28	12.55	33.11	67.48	55.41	21.59	15.11	11.03	8.34	6.60	5.22	247.88
1954	4.15	8.72	8.81	88.32	270.41	200.29	75.32	33.86	23.77	14.59	9.19	6.76	744.19
1955	5.64	19.11	94.50	68.23	299.50	261.20	67.26	27.32	19.84	11.69	8.62	6.83	889.74
1956	5.56	6.52	8.98	11.07	16.98	24.32	20.75	12.76	9.71	7.82	6.66	6.11	137.44
1957	5.56	7.59	12.29	392.69	281.36	25.02	19.70	14.70	10.67	7.97	6.36	5.34	789.25
1958	4.44	6.36	14.40	21.06	30.47	37.63	13.70	10.01	7.91	6.56	5.36	4.32	162.22
1959	3.52	5.47	16.13	20.40	141.46	134.49	29.83	19.41	11.70	8.46	6.67	5.39	402.93
1960	4.30	11.69	95.51	87.98	65.33	72.79	47.29	20.53	19.54	12.24	8.18	6.44	451.82
1961	5.28	7.24	12.97	17.43	17.99	15.83	12.94	10.41	8.30	6.74	5.44	4.28	124.85
1962	3.38	31.21	35.16	14.38	15.48	13.94	11.79	9.61	8.35	7.47	6.38	5.17	162.32
1963	4.18	8.45	11.95	29.83	35.00	16.79	12.18	9.76	8.18	6.73	5.39	4.18	152.62
1964	3.79	5.58	16.47	27.97	23.14	14.40	11.09	8.92	7.44	6.10	4.90	3.88	133.68
1965	3.09	6.59	8.71	32.62	57.88	39.30	12.65	9.41	7.68	6.28	5.03	3.99	193.23
1966	3.48	4.82	10.48	21.04	90.49	78.65	88.57	71.20	21.74	12.59	8.40	6.40	417.86
1967	5.02	6.91	9.32	10.44	10.70	9.87	9.50	8.46	7.24	6.22	5.25	4.28	93.21
1968	3.47	6.47	10.44	12.88	19.10	37.45	34.39	16.24	12.04	8.94	7.00	5.52	173.94
1969	11.37	9.29	12.55	15.08	13.10	11.31	9.16	7.56	6.27	5.23	4.33	3.54	108.79
1970	2.86	4.02	6.65	37.45	37.18	13.80	11.60	9.80	8.25	6.90	5.74	4.70	148.95
1971	4.22	6.35	12.66	84.01	216.92	310.87	143.51	35.97	24.08	14.61	8.93	6.68	869.01
1972	5.44	7.26	8.34	11.60	14.40	11.51	12.98	12.46	9.13	7.21	5.95	18.25	124.53
1973	10.06	9.59	103.01	282.56	194.23	71.02	38.09	23.83	15.43	11.03	7.89	6.18	772.92
1974	4.80	6.41	12.07	26.22	90.59	63.18	22.35	16.36	12.25	8.23	6.57	5.25	274.28
1975	4.14	5.09	51.28	248.86	264.63	189.43	92.77	31.51	21.21	12.08	8.46	6.34	935.80
1976	4.74	6.14	8.56	29.29	136.22	129.57	61.28	20.86	13.50	8.89	6.93	5.84	430.82
1977	4.84	6.25	23.55	208.82	216.11	120.75	65.12	19.64	12.82	9.38	7.11	5.34	699.73
1978	4.09	8.35	9.73	11.17	11.48	10.44	9.66	7.91	6.71	5.62	4.64	3.80	93.60
1979	3.19	6.75	10.31	10.38	46.72	39.59	15.59	11.62	8.67	6.90	5.60	4.61	169.93
1980	3.82	16.08	26.68	88.61	168.57	85.25	30.85	18.24	11.83	8.85	6.85	5.35	470.98
1981	4.40	5.59	6.94	17.12	14.34	9.25	8.37	7.46	6.37	5.36	4.38	3.51	93.09
1982	2.78	3.81	4.73	5.89	6.96	6.92	7.02	6.09	5.46	4.74	4.00	3.32	61.72
1983	2.92	10.15	15.58	32.09	21.66	15.01	13.56	10.39	8.13	10.06	6.53	5.40	151.48
1984	4.77	9.63	12.80	19.67	142.78	175.33	22.11	14.08	10.49	8.26	6.39	4.88	430.19
AVG:	4.52	11.30	26.14	57.37	90.14	75.43	36.87	16.85	11.50	8.46	6.49	5.41	350.67

APPENDIX 4

RUNOFF SCENARIOS: RESULTS OF RCS ASSESSMENT

SABIE RIVER : MOÇAMBIQUE BORDER - PRESENT CONDITIONS

The relative conservation status of this river (as a percentage) is between:
Min 80 and Max 81

The percentage score for the river itself is between: Min 90 and Max 92

The percentage score for the catchment is between: Min 59 and Max 59

The percentage score for the biota is between: Min 88 and Max 92

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
MAR	577	577	3	2	2	0
Length	185	185	4	2	2	0
Order	5	5	1	0	0	0
Extract	32	32	−9	−6	−6	0
Interbasin	0	0	−9	0	0	0
Agricrunoff	20	10	−7	−1	−3	11
Canalization	0	0	−12	0	0	0
Unregulated	100	100	14	14	14	0
Maindams	0	0	−8	−4	−4	0
Offmaindams	3	3	−4	−3	−3	0
Mainweirs	5	5	−4	−4	−4	0
Sewage	0	0	−12	0	0	0
Toxic	0	0	−16	0	0	0
Rubbish	0	0	−6	0	0	0
Ecosystems	4	4	7	7	7	0
Siltation	1	1	−5	−1	−1	0
Migration	4	4	5	5	5	0

The percentage score for the river itself is between: Min 90 and Max 92

Here is a breakdown for the catchment section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Size	644	644	2	2	2	0
Vegetation	30	30	18	9	9	0
Riparianveg	60	60	−12	−9	−9	0
Forestry	24	24	−6	−4	−4	0
Arablefarming	4	4	−7	−1	−1	0
Grazing	3	3	−4	−1	−1	0
Irrigation	4	4	−8	−2	−2	0
Towns	4	4	−7	−6	−6	0
Poplndensity	71	71	−7	−7	−7	0
Erosion	1	1	−9	−2	−2	0
Bankstability	1	1	−5	−1	−1	0
Habitatdiversity	4	4	11	11	11	0
KNP	2	2	4	4	4	0

The percentage score for the catchment is between: Min 59 and Max 59

Here is a breakdown for the biota section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Indigfish	48	48	9	9	9	0
Endemicinvert	10	5	10	9	7	45
Introdfish	4	4	-4	-3	-3	0
Angling	3	3	1	0	0	0
Otherrec	4	4	2	2	2	0
Invdiversity	4	4	11	11	11	0
Chutter	2	2	-15	0	0	0
Indigmacro	7	3	12	9	9	22
Intromacro	1	1	-18	-13	-13	0
Reddata	3	3	12	10	10	0
Biodifference	4	4	11	11	11	0
Endemicfish	4	4	17	17	17	0

The percentage score for the biota is between: Min 88 and Max 92

SABIE RIVER : MOÇAMBIQUE BORDER - 30 % MINIMUM FLOW

The relative conservation status of this river (as a percentage) is between:
Min 67 and Max 68

The percentage score for the river itself is between: Min 68 and Max 71

The percentage score for the catchment is between: Min 41 and Max 41

The percentage score for the biota is between: Min 84 and Max 87

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
MAR	360	360	3	1	1	0
Length	185	185	4	2	2	0
Order	5	5	1	0	0	0
Extract	53	53	−9	−6	−6	0
Interbasin	0	0	−9	0	0	0
Agricrunoff	40	20	−7	−3	−5	22
Canalization	0	0	−12	0	0	0
Unregulated	30	30	14	7	7	0
Maindams	1	1	−8	−6	−6	0
Offmaindams	3	3	−4	−3	−3	0
Mainweirs	5	5	−4	−4	−4	0
Sewage	0	0	−12	0	0	0
Toxic	0	0	−16	0	0	0
Rubbish	0	0	−6	0	0	0
Ecosystems	4	4	7	7	7	0
Siltation	3	3	−5	−3	−3	0
Migration	1	1	5	1	1	0

The percentage score for the river itself is between: Min 68 and Max 71

Here is a breakdown for the catchment section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Size	644	644	2	2	2	0
Vegetation	25	25	18	9	9	0
Riparianveg	60	60	−12	−9	−9	0
Forestry	24	24	−6	−4	−4	0
Arablefarming	21	21	−7	−5	−5	0
Grazing	8	8	−4	−1	−1	0
Irrigation	21	21	−8	−6	−6	0
Towns	4	4	−7	−6	−6	0
Poplndensity	71	71	−7	−7	−7	0
Erosion	2	2	−9	−4	−4	0
Bankstability	2	2	−5	−2	−2	0
Habitatdiversity	4	4	11	11	11	0
KNP	2	2	4	4	4	0

The percentage score for the catchment is between: Min 41 and Max 41

Here is a breakdown for the biota section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Indigfish	45	40	9	9	9	0
Endemicinvert	4	2	10	7	7	18
Introdfish	4	4	−4	−3	−3	0
Angling	3	3	1	0	0	0
Otherrec	4	4	2	2	2	0
Invdiversity	4	4	11	11	11	0
Chutter	3	3	−15	0	0	0
Indigmacro	5	2	12	9	9	17
Intromacro	1	1	−18	−13	−13	0
Reddata	2	1	12	9	6	30
Biodifference	3	3	11	11	11	0
Endemicfish	4	4	17	17	17	0

The percentage score for the biota is between: Min 84 and Max 87

SABIE RIVER : MOÇAMBIQUE BORDER - MADRAS DAM MAXIMUM USE

The relative conservation status of this river (as a percentage) is between:
Min 58 and Max 64

The percentage score for the river itself is between: Min 66 and Max 68

The percentage score for the catchment is between: Min 33 and Max 33

The percentage score for the biota is between: Min 61 and Max 80

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
MAR	354	354	3	1	1	0
Length	185	185	4	2	2	0
Order	5	5	1	0	0	0
Extract	54	54	−9	−6	−6	0
Interbasin	0	0	−9	0	0	0
Agricrunoff	40	20	−7	−3	−5	22
Canalization	2	2	−12	−3	−3	0
Unregulated	30	30	14	7	7	0
Maindams	1	1	−8	−6	−6	0
Offmaindams	3	3	−4	−3	−3	0
Mainweirs	5	5	−4	−4	−4	0
Sewage	0	0	−12	0	0	0
Toxic	0	0	−16	0	0	0
Rubbish	0	0	−6	0	0	0
Ecosystems	4	4	7	7	7	0
Siltation	3	3	−5	−3	−3	0
Migration	1	1	5	1	1	0

The percentage score for the river itself is between: Min 66 and Max 68

Here is a breakdown for the catchment section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Size	644	644	2	2	2	0
Vegetation	25	25	18	9	9	0
Riparianveg	60	60	−12	−9	−9	0
Forestry	24	24	−6	−4	−4	0
Arablefarming	23	23	−7	−5	−5	0
Grazing	8	8	−4	−1	−1	0
Irrigation	23	23	−8	−6	−6	0
Towns	4	4	−7	−6	−6	0
Poplndensity	71	71	−7	−7	−7	0
Erosion	2	2	−9	−4	−4	0
Bankstability	3	3	−5	−3	−3	0
Habitatdiversity	3	3	11	8	8	0
KNP	2	2	4	4	4	0

The percentage score for the catchment is between: Min 33 and Max 33

Here is a breakdown for the biota section

Subsection	Answers		Weight	Weighted Answers		Research Priority
	Max	Min		Max	Min	
Indigfish	40	35	9	9	9	0
Endemicinvert	2	0	10	7	0	18
Introdfish	4	4	−4	−3	−3	0
Angling	3	3	1	0	0	0
Otherrec	4	4	2	2	2	0
Invdiversity	3	3	11	8	8	0
Chutter	4	4	−15	0	0	0
Indigmacro	4	1	12	9	9	17
Intromacro	1	1	−18	−13	−13	0
Reddata	2	0	12	9	0	60
Biodifference	2	2	11	8	8	0
Endemicfish	4	4	17	17	17	0

The percentage score for the biota is between: Min 61 and Max 80

APPENDIX 5

RUNOFF SCENARIOS: RESULTS OF CSA ASSESSMENT

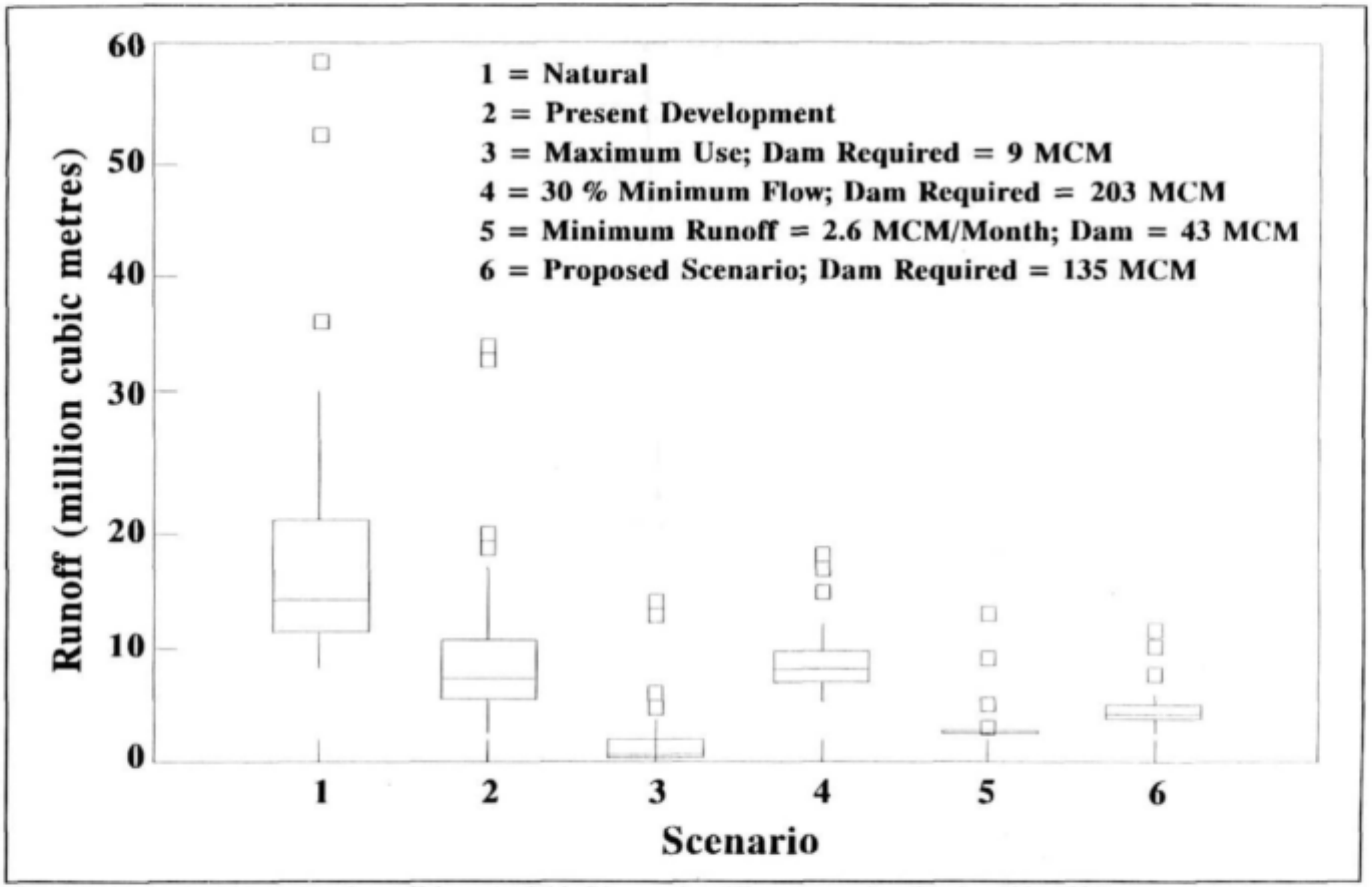

Figure 1: Box and whisker plot of runoff from the Sabie River under different scenarios (October 1921-1984).

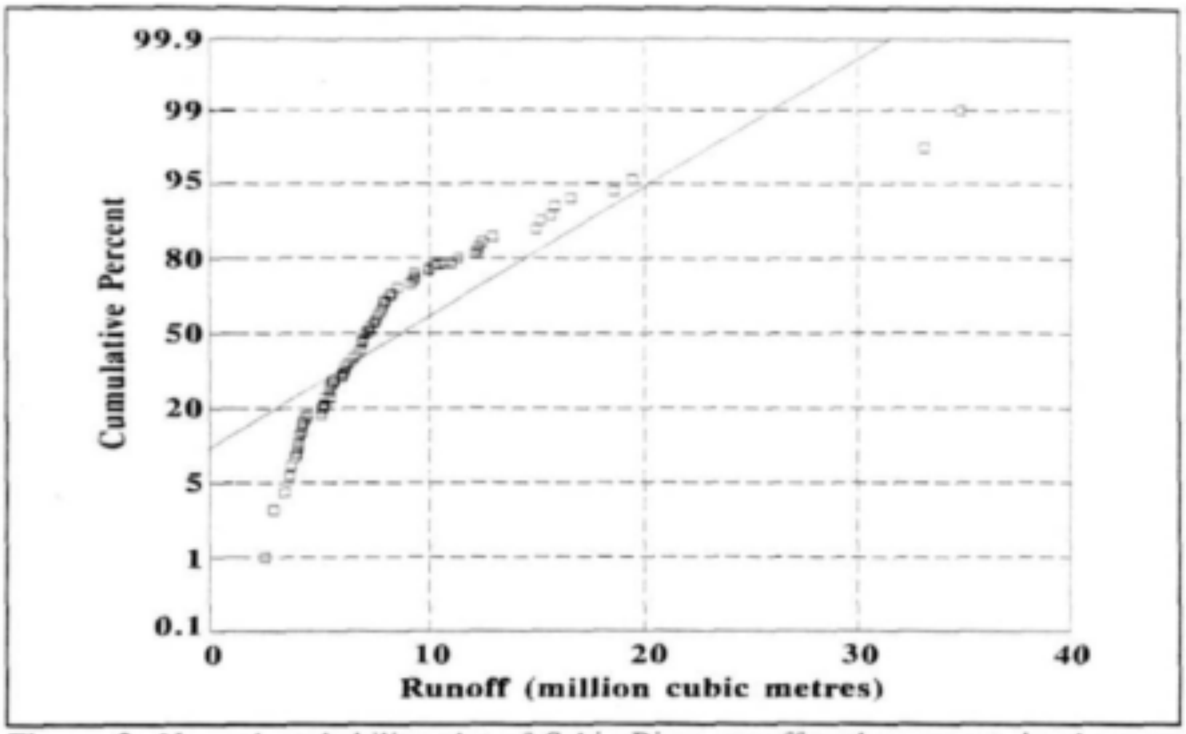

Figure 2: Normal probability plot of Sabie River runoff under present development conditions (October 1921-1984).

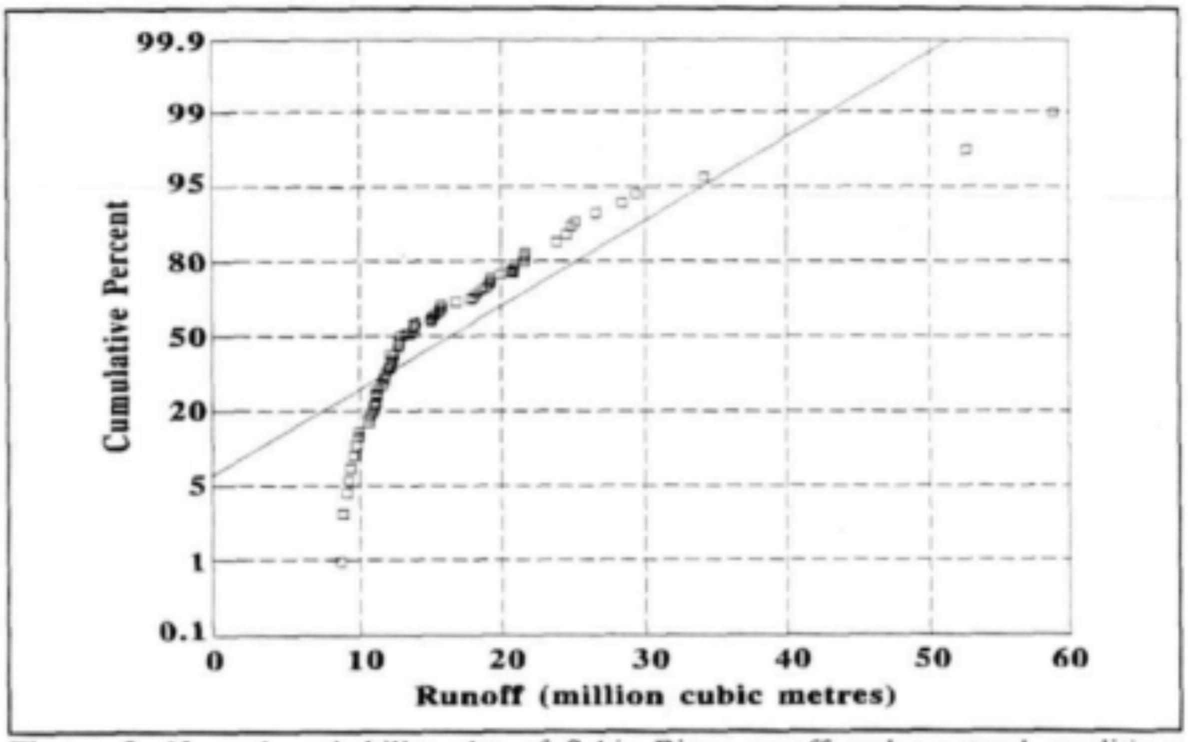

Figure 3: Normal probability plot of Sabie River runoff under natural conditions (October 1921-1984).

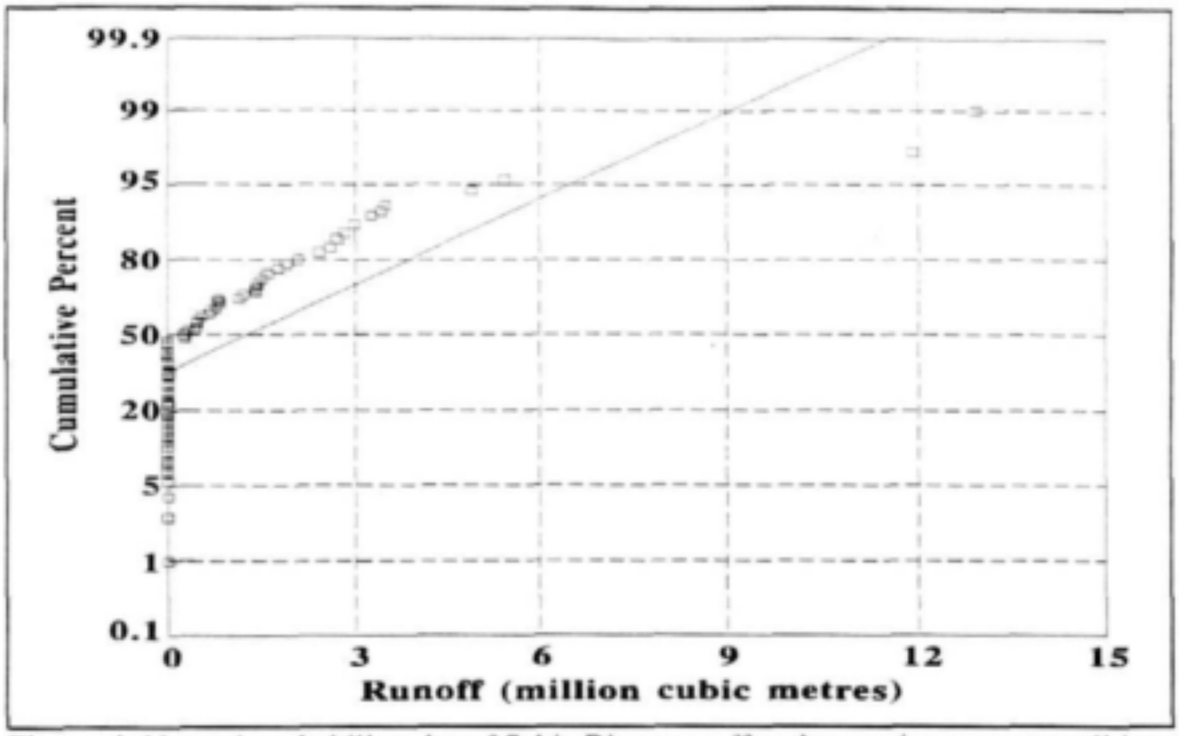

Figure 4: Normal probability plot of Sabie River runoff under maximum use conditions (October 1921-1984).

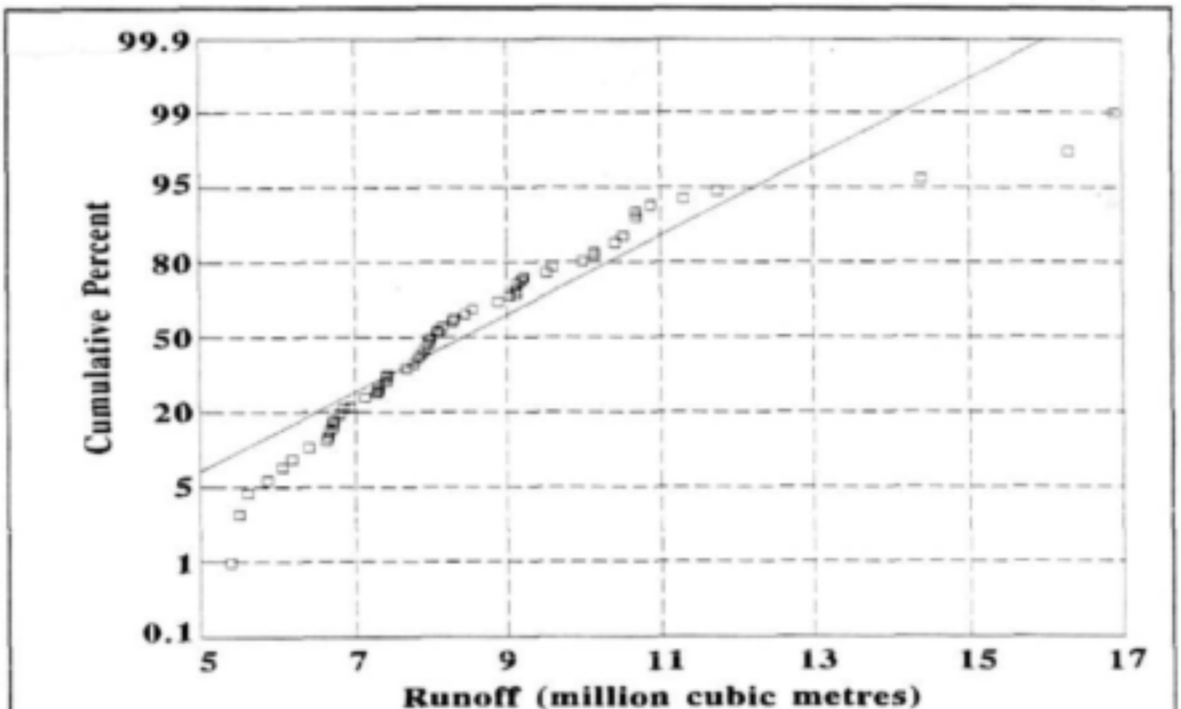

Figure 5: Normal probability plot of Sabie River runoff under minimum flow conditions (October 1921-1984).

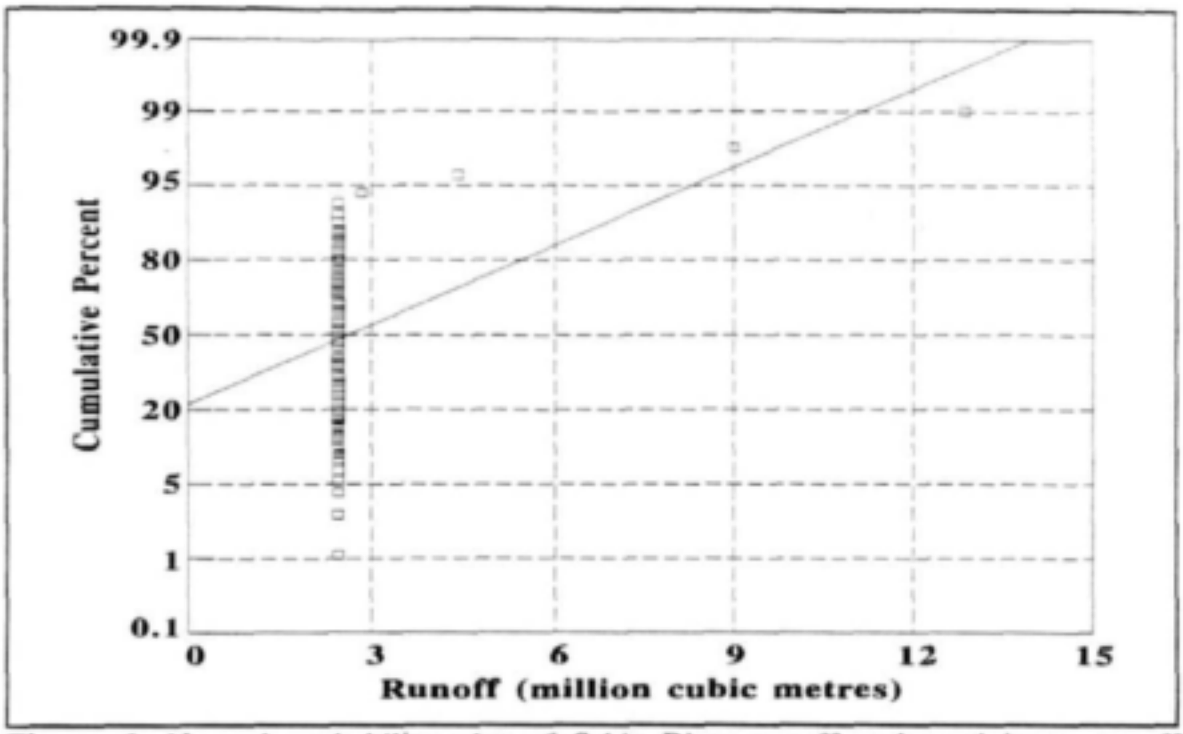

Figure 6: Normal probability plot of Sabie River runoff under minimum runoff conditions of 2.6 MCM/Month (October 1921-1984).

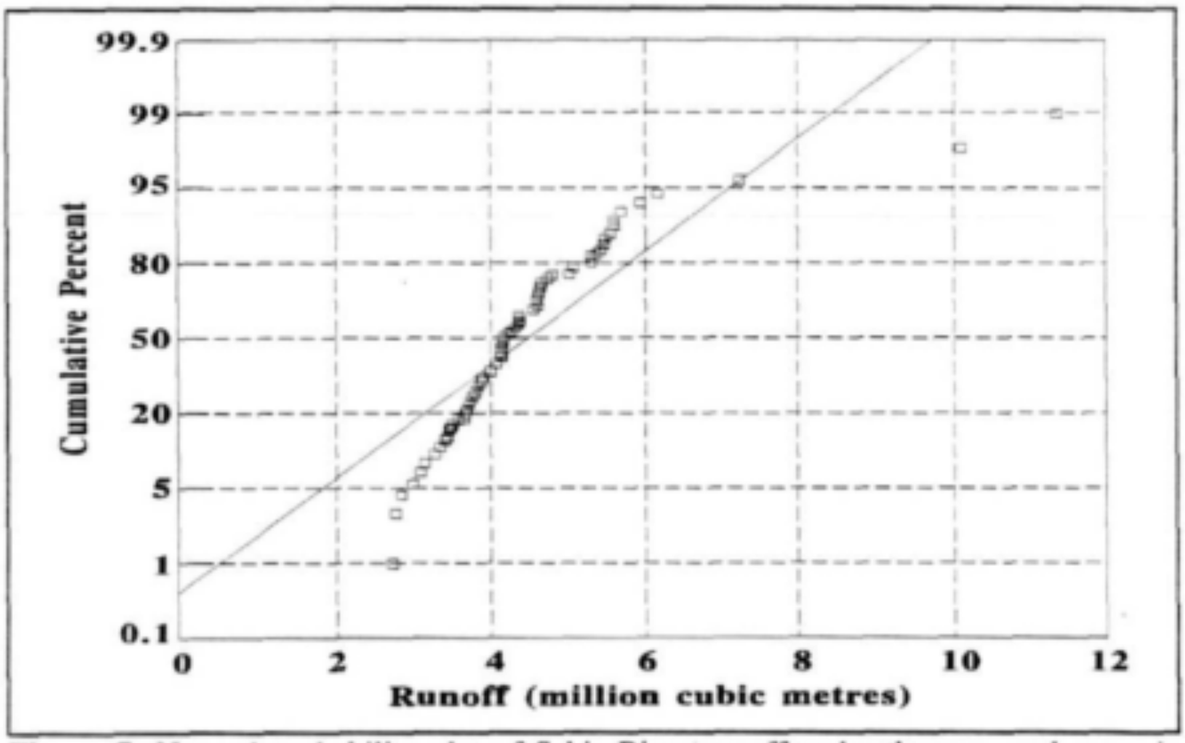

Figure 7: Normal probability plot of Sabie River runoff under the proposed scenario conditions (October 1921-1984).

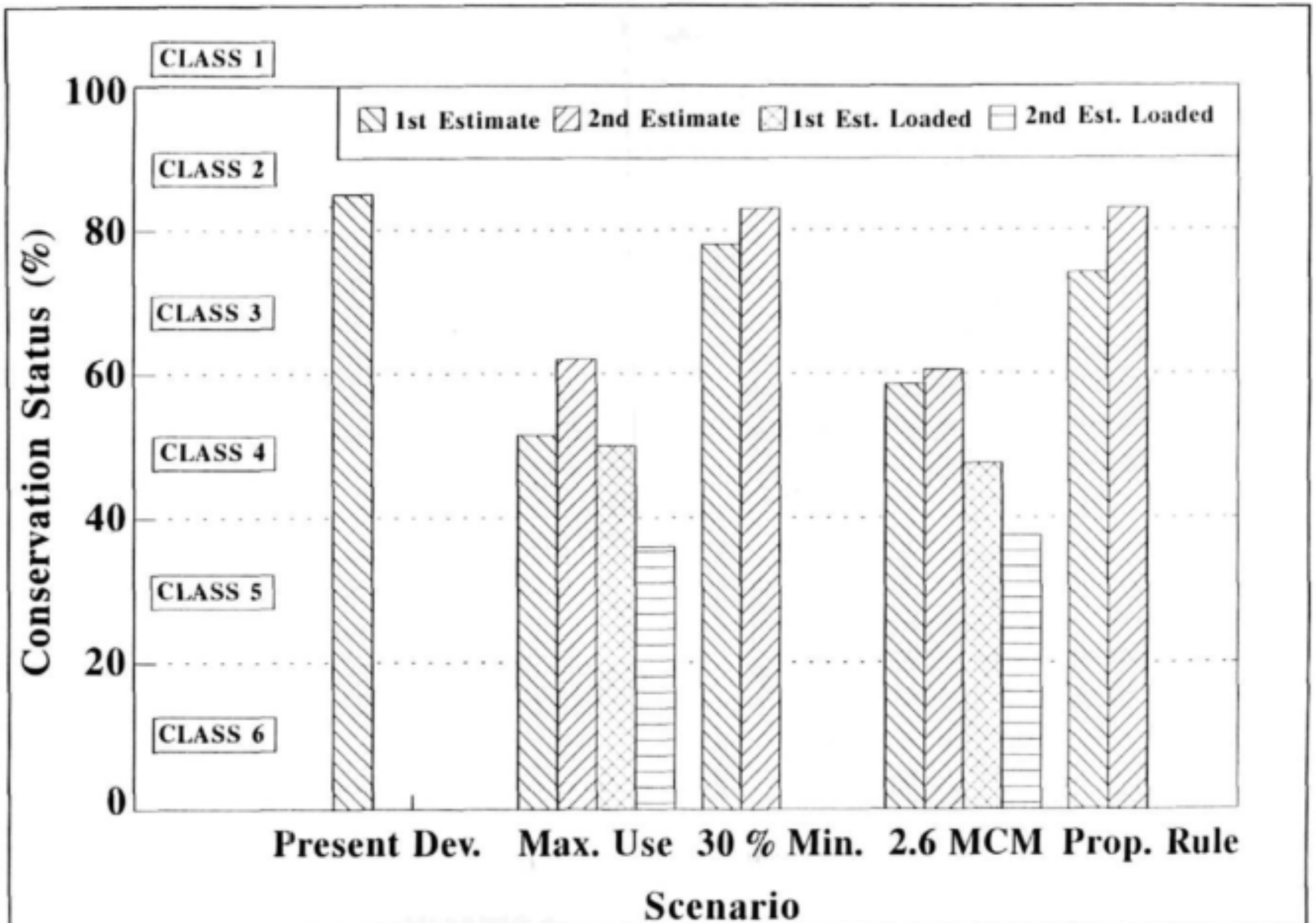

Figure 8: Histogram of conservation status for the Sabie River, based on October data for the period 1921-1984.

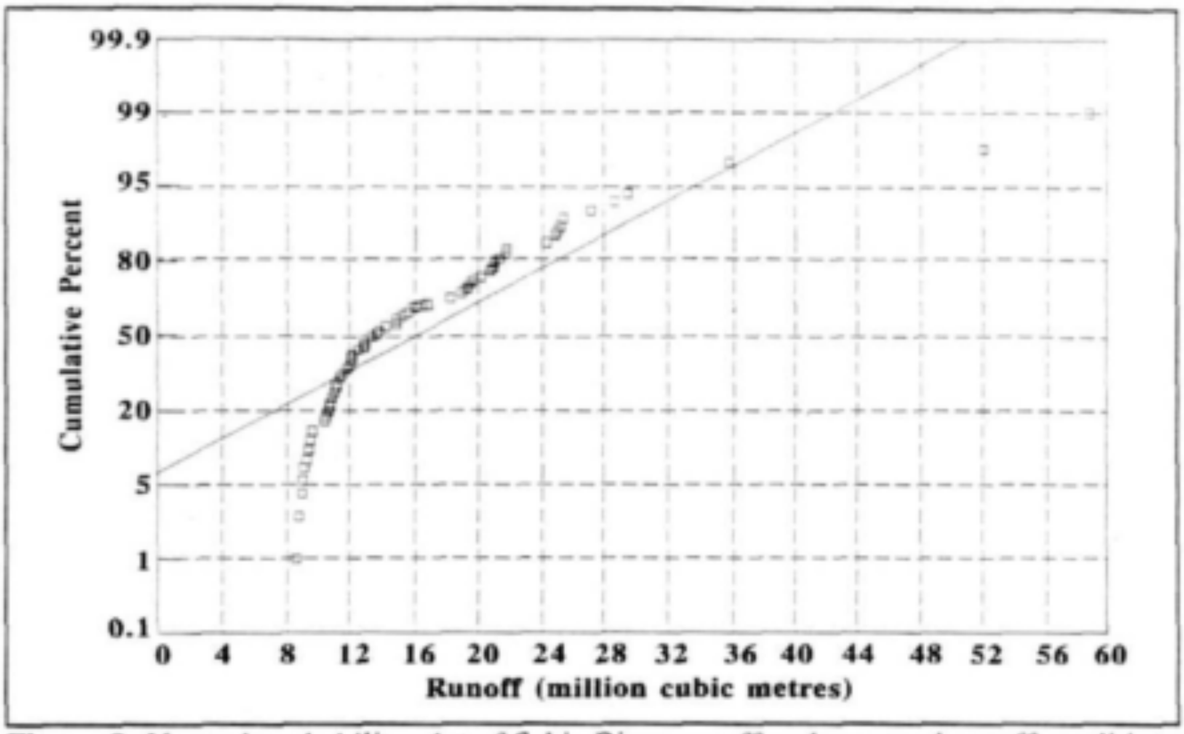

Figure 9: Normal probability plot of Sabie River runoff under natural runoff conditions (October 1921-1984).

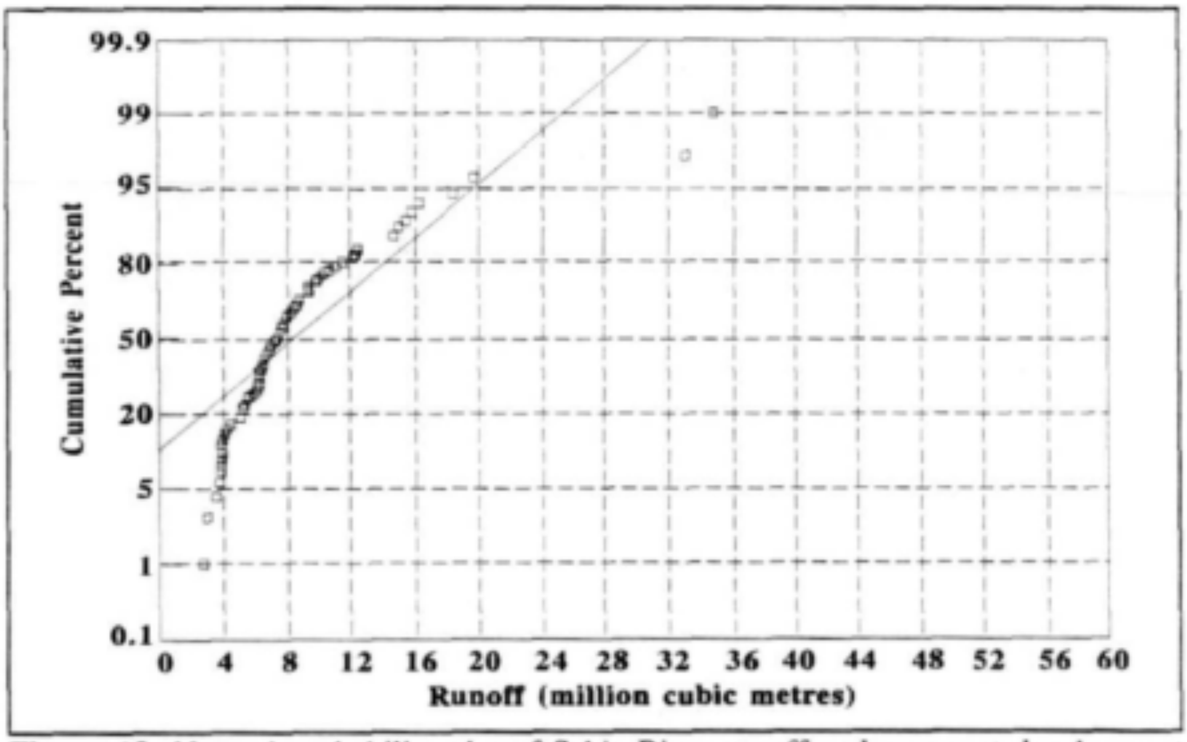

Figure 10: Normal probability plot of Sabie River runoff under present development conditions (October 1921-1984).

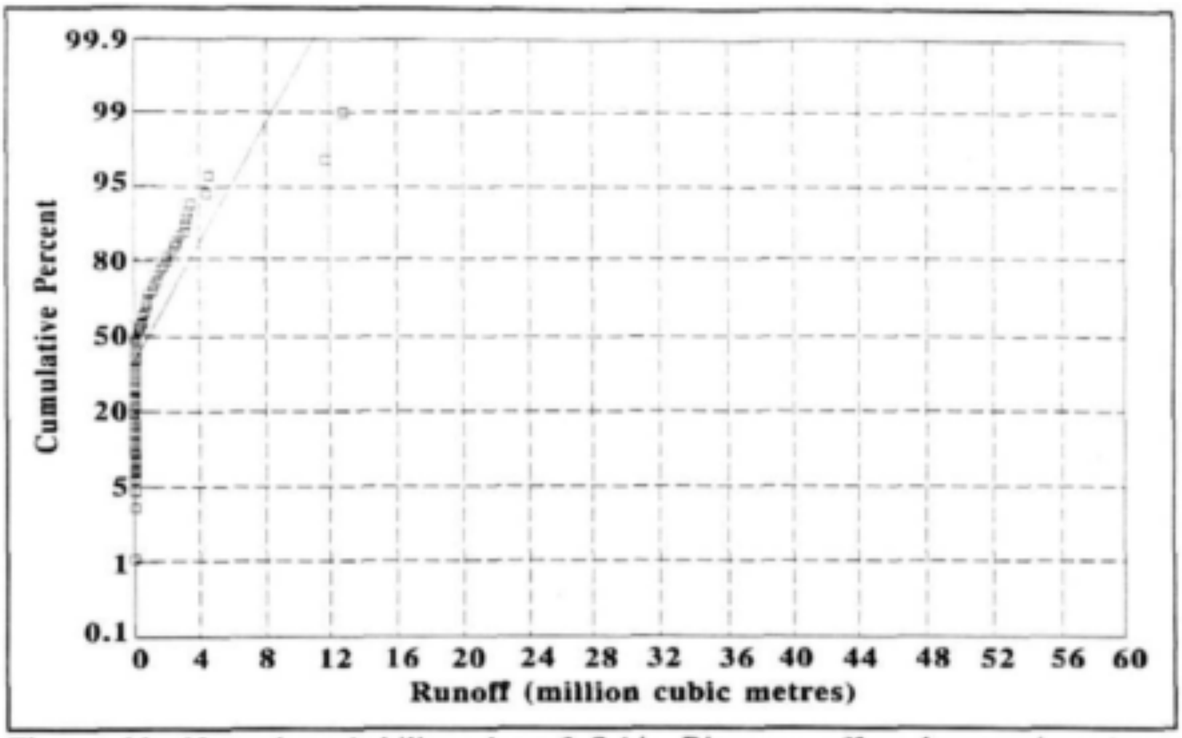

Figure 11: Normal probability plot of Sabie River runoff under maximum use conditions (October 1921-1984); dam required = 9 million cubic metres.

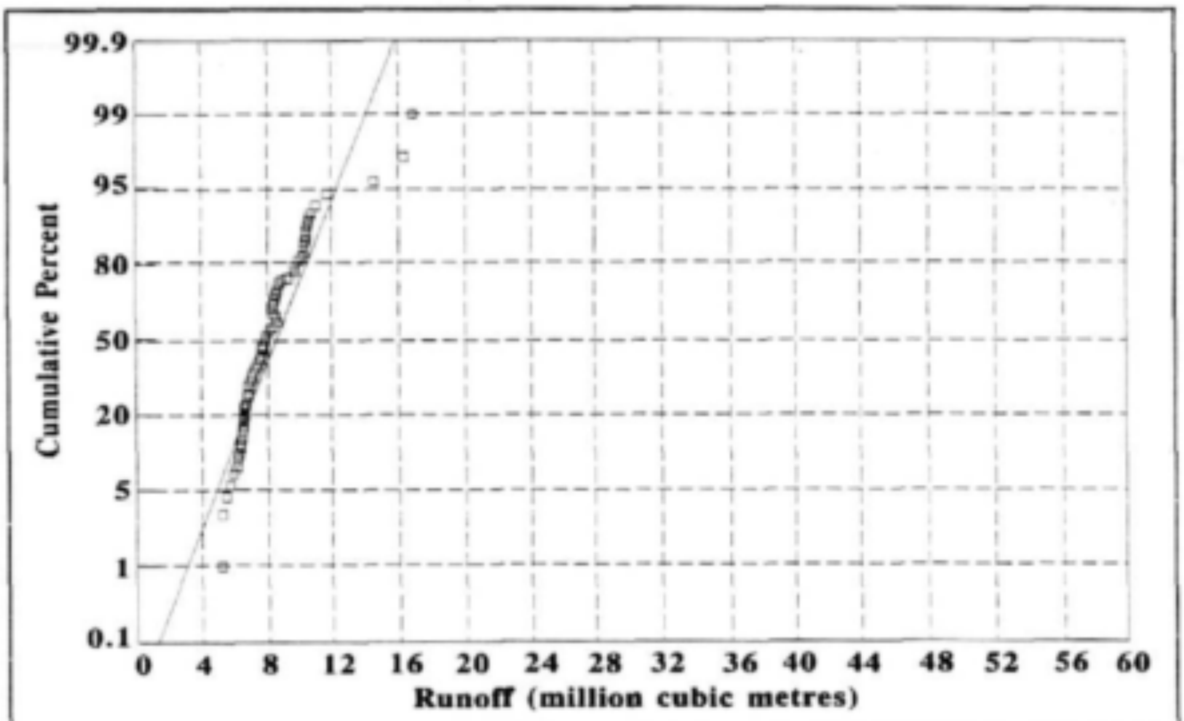

Figure 12: Normal probability plot of Sabie River runoff under 30% of minimum flow conditions (October 1921-1984); dam required = 203 million cubic metres.

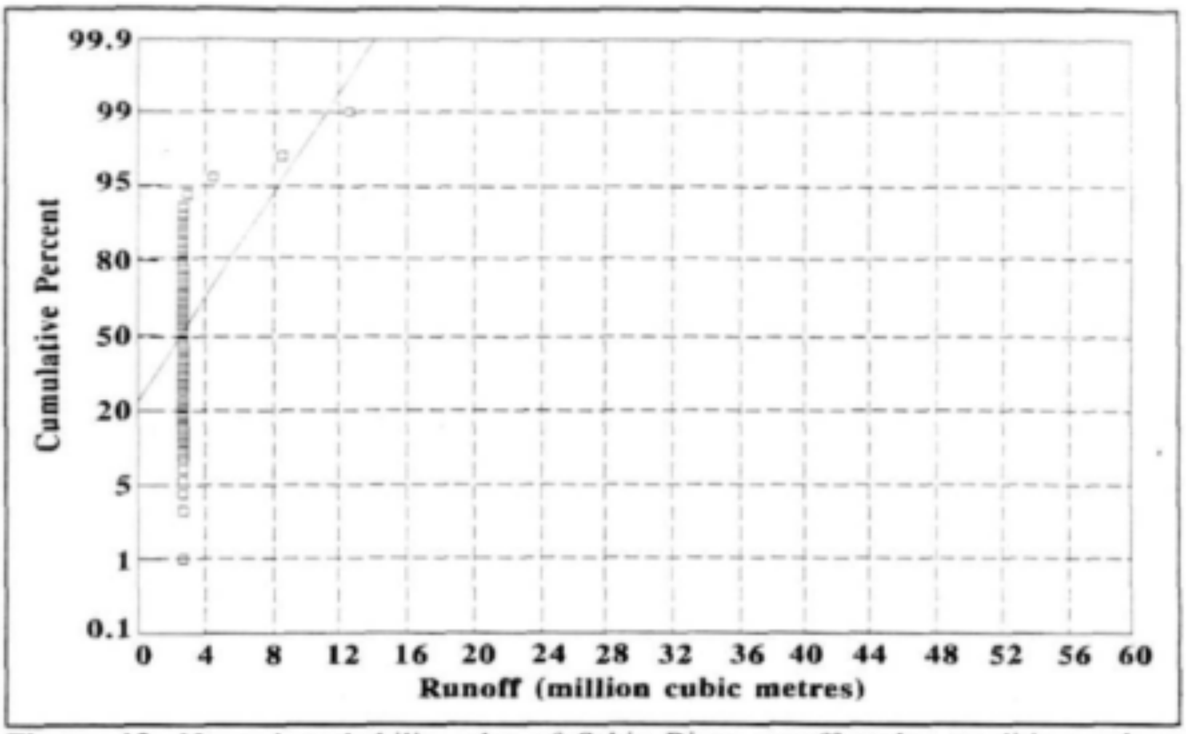

Figure 13: Normal probability plot of Sabie River runoff under conditions where minimum runoff = 2.6 million cubic metres/month (October 1921-1984); dam required = 43 million cubic metres.

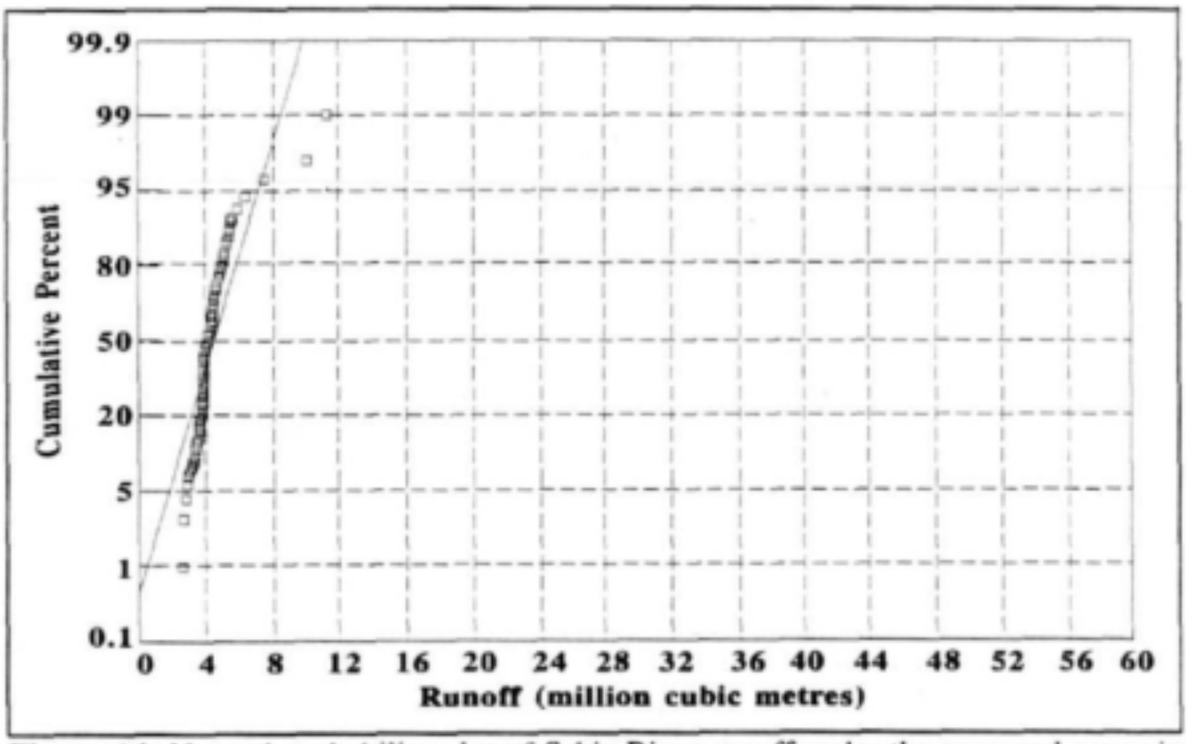

Figure 14: Normal probability plot of Sabie River runoff under the proposed scenario (October 1921-1984); dam required = 135 million cubic metres.

TABLE 1: Comparison of statistical characteristics of different Sabie River flow scenarios (October 1921-1984).

Statistic	Scenario					
	Natural	Present Development	Maximum Use	30% Minimum Flow	2.6 MCM/Month	Proposed Rule
Sample Size	68	68	68	68	68	68
Average	17.1057	8.91987	1.2646	8.5846	2.89878	4.52063
Median	18.62	7.25	6.28	8.02	2.6	4.16
Mode	18.85	4.15		6.7	2.6	3.47
Variance	85.6187	35.3714	5.75465	4.95004	2.88478	2.0498
Standard Deviation	9.26804	5.98927	2.39882	2.22487	1.52798	1.46171
Standard Error	1.16577	0.75458	0.60222	0.28081	0.19251	0.18038
Minimum	8.89	2.74	0	5.37	2.6	2.78
Maximum	58.98	34.77	12.94	16.95	12.87	11.37
Range	50.09	32.03	12.94	11.58	10.27	8.59
Coefficient of Variation	0.54	0.67	1.89	0.26	0.53	0.32

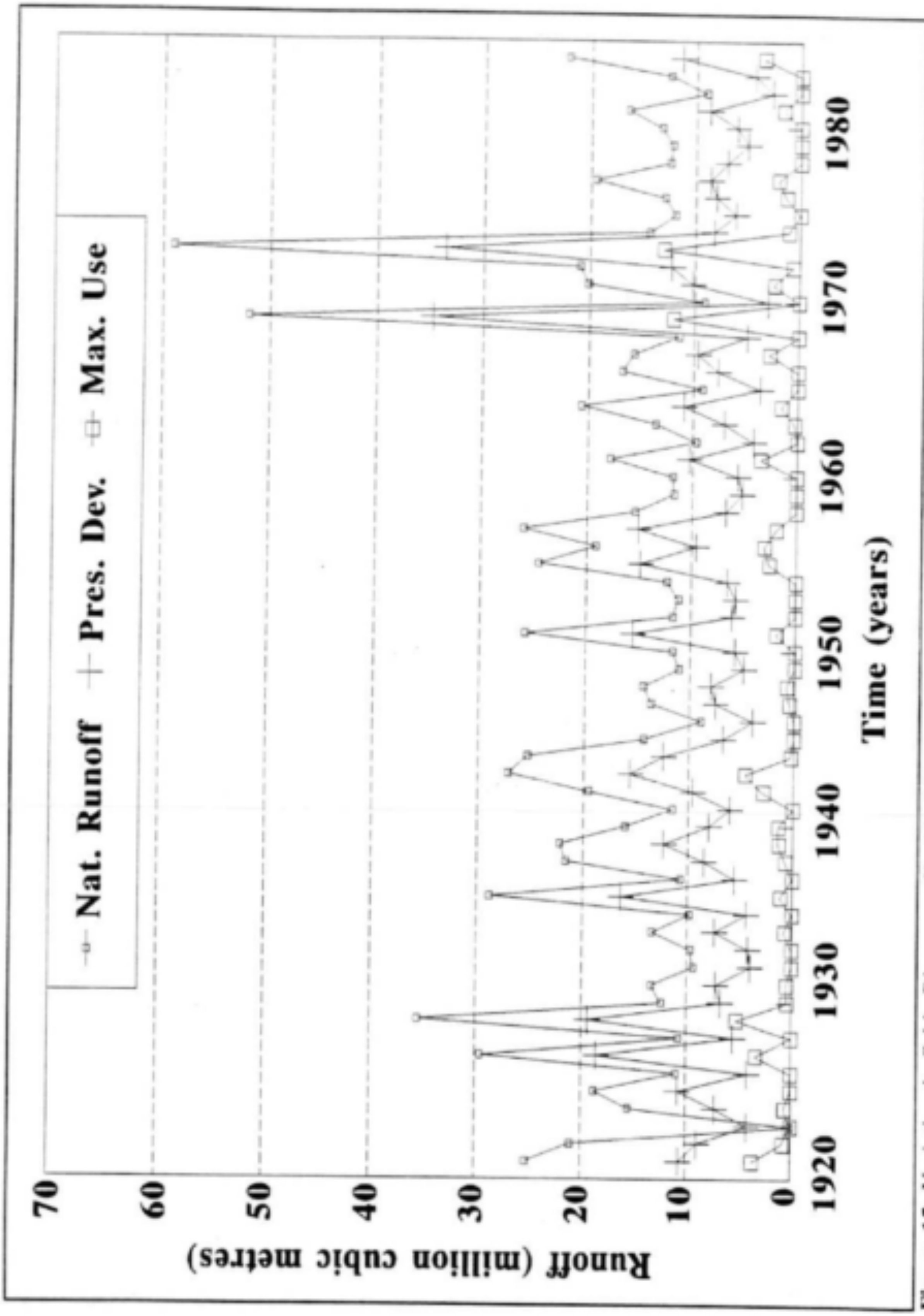

Figure 15: Variation in Sabie River runoff with different development scenarios (October 1921-1984).

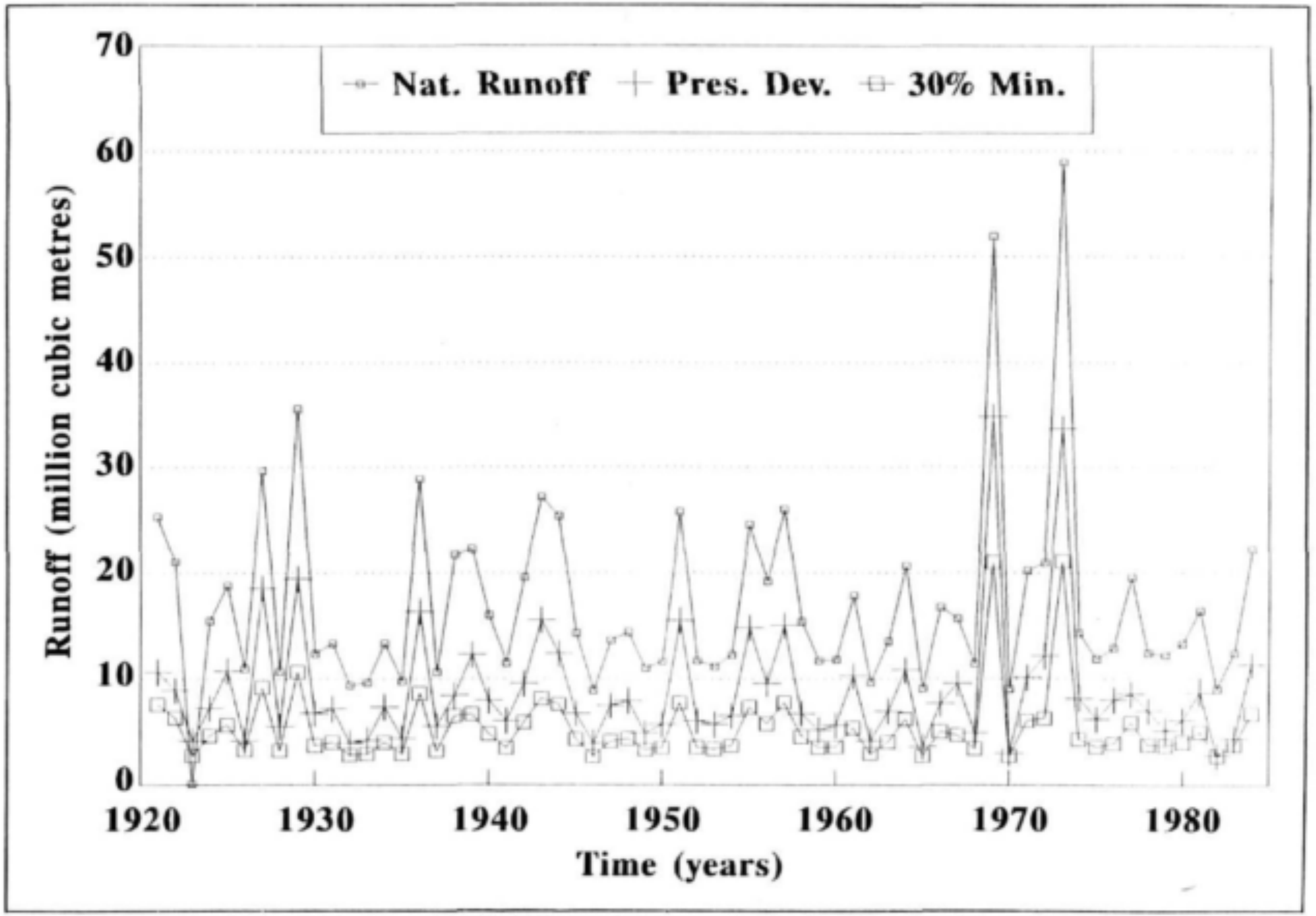

Figure 16: Variation in Sabie River runoff with different development scenarios (October 1921-1984).

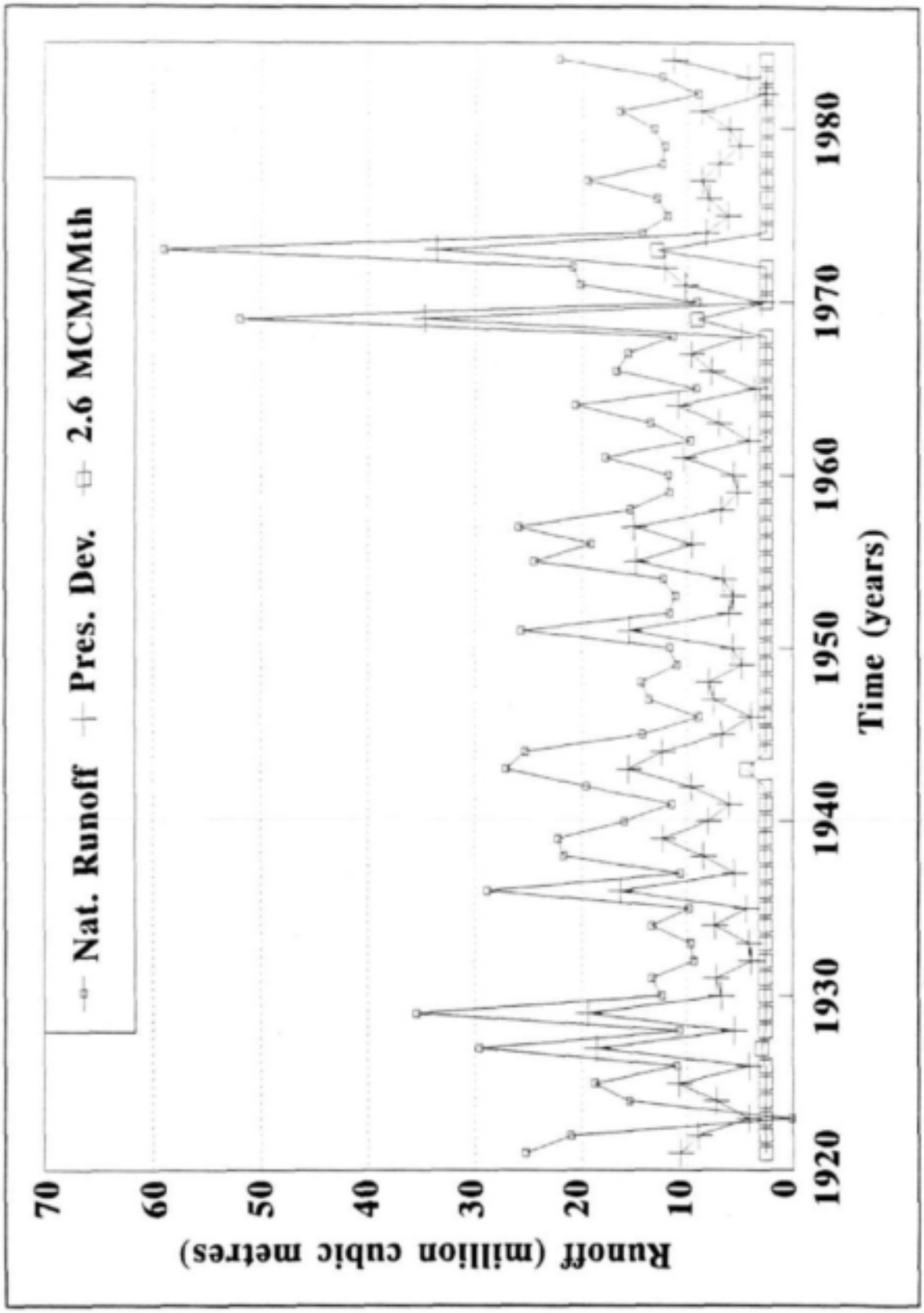

Figure 17: Variation in Sabie River runoff with different development scenarios (October 1921-1984).

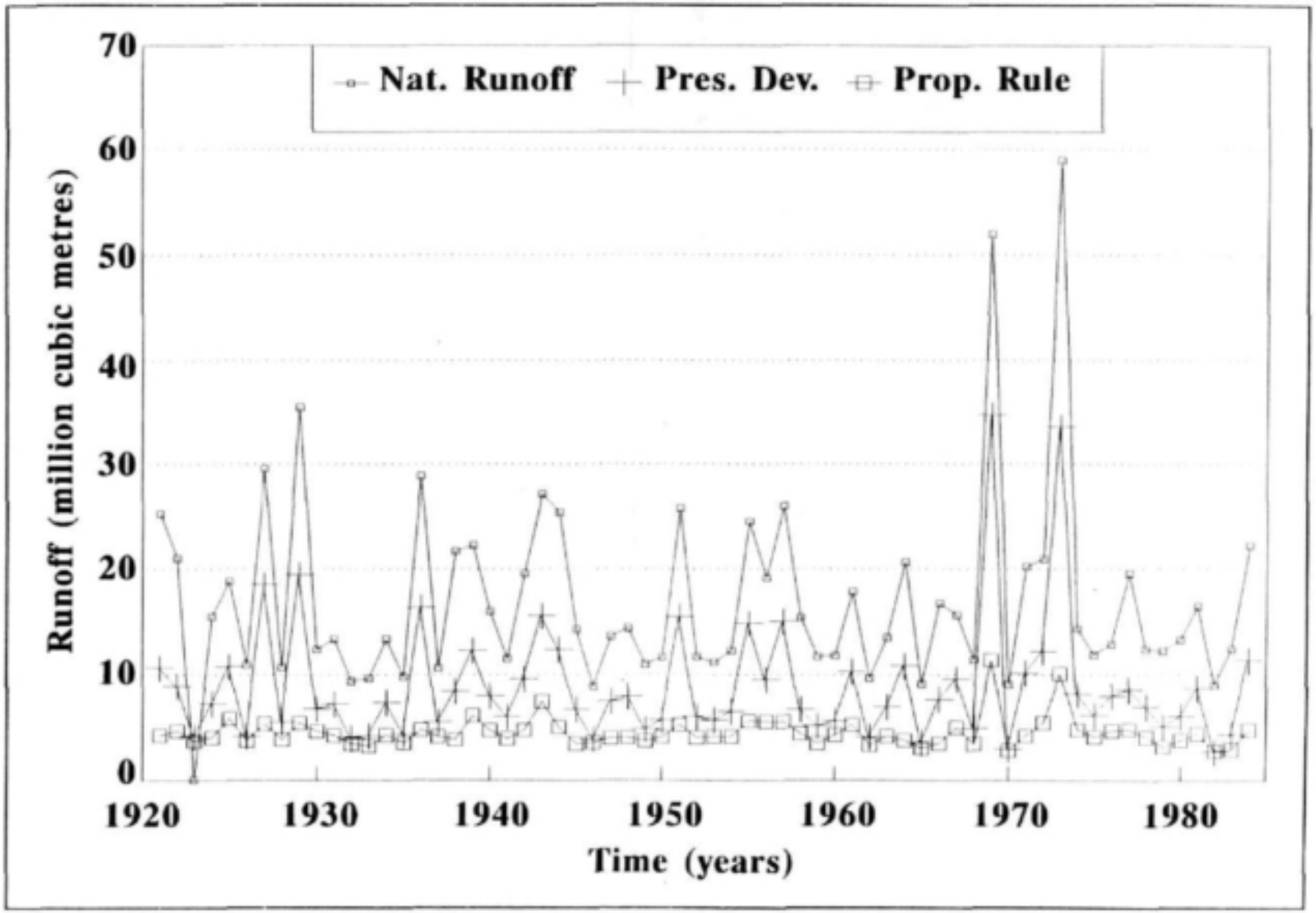

Figure 18: Variation in runoff with different development scenarios (October 1921-1984).

TABLE 2: Estimation of the Conservation Status of the Sabie River UNDER PRESENT DEVELOPMENT CONDITIONS - 1st ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	2	14	8.4	0.0	0.0
Weir overflows	0	9	9.0	0.0	0.0
Dam overflows	0	11	11.0	0.0	0.0
Roads and bridges	0	9	9.0	0.0	0.0
Rubbish	0	5	5.0	0.0	0.0
Riverbed modifications	1	12	9.6	0.0	0.0
Erosion	0	12	12.0	0.0	0.0
Flow regulation	2	14	8.4	0.0	0.0
Water quality	0	14	14.0	0.0	0.0
Abiotic Status			86.4		0.0
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 3: Estimation of the Conservation Status of the Sabie River UNDER MAXIMUM USAGE CONDITIONS - 1st ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	4	14	2.8	6.5	1.3
Weir overflows	0	9	9.0	4.2	4.2
Dam overflows	0	11	11.0	5.1	5.1
Roads and bridges	0	9	9.0	4.2	4.2
Rubbish	0	5	5.0	2.3	2.3
Riverbed modifications	3	12	4.8	5.6	2.2
Erosion	3	12	4.8	5.6	2.2
Flow regulation	4	14	2.8	6.5	1.3
Water quality	4	14	2.8	60.0	12.0
Abiotic Status			52.0		34.9
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 4: Estimation of the Conservation Status of the Sabie River UNDER MAXIMUM USAGE CONDITIONS - 2nd ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	4	14	2.8	40.0	8.0
Weir overflows	0	9	9.0	6.3	6.3
Dam overflows	0	11	11.0	7.7	7.7
Roads and bridges	0	9	9.0	6.3	6.3
Rubbish	0	5	5.0	3.5	3.5
Riverbed modifications	2	12	7.2	8.4	5.0
Erosion	2	12	7.2	8.4	5.0
Flow regulation	3	14	5.6	9.8	3.9
Water quality	3	14	5.6	9.8	3.9
Abiotic Status			62.4		49.6
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 5: Estimation of the Conservation Status of the Sabie River UNDER 30% OF MINIMUM FLOW CONDITIONS - 1st ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	1	14	11.2	0.0	0.0
Weir overflows	0	9	9.0	0.0	0.0
Dam overflows	0	11	11.0	0.0	0.0
Roads and bridges	0	9	9.0	0.0	0.0
Rubbish	0	5	5.0	0.0	0.0
Riverbed modifications	3	12	4.8	0.0	0.0
Erosion	2	12	7.2	0.0	0.0
Flow regulation	3	14	5.6	0.0	0.0
Water quality	0	14	14.0	0.0	0.0
Abiotic Status			52.0		0.0
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 6: Estimation of the Conservation Status of the Sabie River UNDER 30% OF MINIMUM FLOW CONDITIONS - 2nd ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	2	14	8.4	0.0	0.0
Weir overflows	0	9	9.0	0.0	0.0
Dam overflows	0	11	11.0	0.0	0.0
Roads and bridges	0	9	9.0	0.0	0.0
Rubbish	0	5	5.0	0.0	0.0
Riverbed modifications	1	12	9.6	0.0	0.0
Erosion	1	12	9.6	0.0	0.0
Flow regulation	2	14	8.4	0.0	0.0
Water quality	0	14	14.0	0.0	0.0
Abiotic Status			62.4		0.0
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 7: Estimation of the Conservation Status of the Sabie River UNDER THE 2.6 MCM/Mth FLOW SCENARIO - 1st ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	3	14	5.6	6.4	2.5
Weir overflows	0	9	9.0	4.1	4.1
Dam overflows	0	11	11.0	5.0	5.0
Roads and bridges	0	9	9.0	4.1	4.1
Rubbish	0	5	5.0	2.3	2.3
Riverbed modifications	4	12	2.4	60.0	12.0
Erosion	3	12	4.8	5.5	2.2
Flow regulation	3	14	5.6	6.4	2.5
Water quality	3	14	5.6	6.4	2.5
Abiotic Status			58.0		37.3
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 8: Estimation of the Conservation Status of the Sabie River UNDER THE 2.6 MCM/Mth FLOW SCENARIO - 2nd ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	4	14	2.8	40.0	8.0
Weir overflows	0	9	9.0	6.3	6.3
Dam overflows	0	11	11.0	7.7	7.7
Roads and bridges	0	9	9.0	6.3	6.3
Rubbish	0	5	5.0	3.5	3.5
Riverbed modifications	3	12	4.8	8.4	3.3
Erosion	3	12	4.8	8.4	3.3
Flow regulation	3	14	5.6	9.8	3.9
Water quality	2	14	8.4	9.8	5.9
Abiotic Status			60.4		48.2
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 9: Estimation of the Conservation Status of the Sabie River UNDER THE PROPOSED FLOW SCENARIO - 1st ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	3	14	5.6	0.0	0.0
Weir overflows	0	9	9.0	0.0	0.0
Dam overflows	0	11	11.0	0.0	0.0
Roads and bridges	0	9	9.0	0.0	0.0
Rubbish	0	5	5.0	0.0	0.0
Riverbed modifications	2	12	7.2	0.0	0.0
Erosion	2	12	7.2	0.0	0.0
Flow regulation	3	14	5.6	0.0	0.0
Water quality	0	14	14.0	0.0	0.0
Abiotic Status			73.6		0.0
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0

TABLE 10: Estimation of the Conservation Status of the Sabie River UNDER THE PROPOSED FLOW SCENARIO - 2nd ORDER

Property	Class	Weight	Result	Modification	Result
Water abstraction	2	14	8.4	0.0	0.0
Weir overflows	0	9	9.0	0.0	0.0
Dam overflows	0	11	11.0	0.0	0.0
Roads and bridges	0	9	9.0	0.0	0.0
Rubbish	0	5	5.0	0.0	0.0
Riverbed modifications	1	12	9.6	0.0	0.0
Erosion	1	12	9.6	0.0	0.0
Flow regulation	2	14	8.4	0.0	0.0
Water quality	0	14	14.0	0.0	0.0
Abiotic Status			84.0		0.0
Control programmes	0	25	25.0	0.0	0.0
Invasive species	0	23	23.0	0.0	0.0
Agriculture	0	26	26.0	0.0	0.0
Water plants	0	15	15.0	0.0	0.0
Aquatic fauna	0	11	11.0	0.0	0.0
Biotic Status			100.0		0.0