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Design of a National Programme for Monitoring and Assessing the Health of Aquatic Ecosystems, with Specific Reference to the South African River Health Programme

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ABSTRACT

Globally environmental policies increasingly emphasise the need to protect, rather than to use, the ability of ecosystems to recover from disturbances. This necessitates the adoption of response measurements to quantify ecological condition and monitor ecological change. Response monitoring focuses on properties that are essential to the sustainability of the ecosystem. These monitoring tools can be used to establish natural ranges of ecological change within ecosystems, as well as to quantify conceptually acceptable and unacceptable ranges of change.

Following a world-wide trend, a monitoring programme is being developed for assessing the ecological condition of rivers in South Africa. The approach followed for the design of the River Health Programme (RHP) consists of several phases. The main considerations that influence the design of this programme, as well as the rationale that led to its initiation, are discussed in this paper.

INTRODUCTION

Water is the basic resource upon which society relies for the quality of its life, including its health and recreation. It is also the primary resource upon which social and economic developments are based and sustained [1]. Aquatic ecosystems must, therefore, be effectively protected and managed to ensure that they retain their inherent vitality and remain fit for domestic, industrial, agricultural and recreational uses, for present and future generations. However, effective decision-making, and thus resource management, are entirely dependent on the information provided by appropriate and proper resource monitoring. Therefore, the development and application of monitoring techniques play a critical role in the ongoing process of harmonising economic development, human welfare and environmental protection.

Traditionally, information gathered to assist the management of water resources was predominantly non-ecological in nature. Monitoring actions focused largely on chemical and physical water quality variables, and regulatory efforts were aimed at controlling individual physico-chemical stressors. The presumption was that measurable improvements in water quality would result in an improvement in ecosystem condition.

However, the measurement of only physical and chemical water quality variables cannot provide an accurate account of the overall condition of an aquatic ecosystem. Chemical monitoring alone is insufficient to detect, for example, the cumulative and/or synergistic effects on aquatic ecosystems resulting from multiple stressors [2]. Many factors other than chemical water quality may have an influence on the ecological state of an ecosystem. Some examples include habitat alteration, creation of barriers that alter stream flow, water abstraction and the introduction of exotic species. Effective management of aquatic ecosystems must therefore address the cumulative effect of all these changes.

A recent development worldwide is the introduction of in-stream biological effects or response monitoring in water resources management. This type of response monitoring, commonly referred to as biomonitoring, is increasingly being recognised as an important component in the overall monitoring and assessment of water resources. The use of biological field assessments of, for example, fish or macroinvertebrate communities, provides an integrated and sensitive measurement of environmental problems and represents progress in the assessment of ecological impacts, and hence in the management of water resources [e.g. 3, 4].

In South Africa the historical lack of ecological indicators in monitoring activities is at present being addressed through the design of the River Health Programme (RHP), as a sub-programme of a proposed National Aquatic Ecosystem Biomonitoring Programme [5]. Several local advances in applied aquatic science provide a basis for integrating *in situ* biological assessment into the country's surface water monitoring and assessment strategy. These advances include the development and standardisation of rapid bio-assessment techniques and the delineation of homogeneous ecological regions, which provides a spatial framework for selecting reference and monitoring sites within the biomonitoring context.

This paper provides an overview of how biomonitoring can be structured into a monitoring design that supports water resources management. The paper draws mainly from the South African experience and the results of a test application of the South African RHP are presented.

MANAGING AQUATIC ECOSYSTEMS

An ecological system or ecosystem can be defined as "any unit that includes all of the organisms (i.e. the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycles (i.e. exchange of material between living and non-living parts) within the system" [6]. Ecosystems thus include the physical and chemical (abiotic) environments in addition to biological components. Aquatic ecosystems are those environments that provide a medium for habitation by aquatic organisms and sustain aquatic ecological processes. These ecosystems also provide drinking water for wildlife and water for maintaining riparian biota and processes.

Social, economic and ecological factors must be considered in their inter-related nature when managing aquatic ecosystems. The social element includes the concepts of beauty, value, history and relevance. These concepts must be defined by the beholder, and are derived from cultural norms and expectations as they relate to natural systems [7]. The economic element includes aspects such as resource use, manufacturing, distribution and consumption [8]. The ecological element of an ecosystem includes factors such as species distribution and abundance, the structure, stability and productivity of ecosystems and the ability of ecosystems to self-organise and evolve.

The objective of the South African Department of Water Affairs and Forestry (DWAF), as the mandated authority responsible for managing the country's water resources, is "to manage the quantity, quality and reliability of the nation's water resources in such a way as to achieve optimum, long-term, environmentally sustainable social and economic benefit for society from their use" [9]. This objective incorporates all three (social, economic and ecological) elements of ecosystems (Fig. 1). The social element is dependent on the ecological element, and the economic element is dependent on the social and ecological elements [8]. Following from this, the goals of societies must reflect the constraints and boundaries inherent to natural ecosystems. Thus, resource management should, as a first priority, not focus on how the resource can be used, but on the ecological state in which the resource should be maintained and how it should be protected to allow sustainable utilisation. It follows that integrated ecosystem management requires a proactive planning approach in which ecological well being is the governing factor and the permissible level of economic activity is the dependent variable (Fig. 1) [10].

Just as human value judgements are an integral part of assessing health, ecosystem health is based on perception and individual judgements rather than universally accepted measurements. In practice there is a need to define, then quantify what people expect and government does about ecosystem health. However, a composite indexing system for measuring **ecosystem health** is, at the current level of ecosystem science, not available. The ecosystem concept is, therefore, often broken down to its three basic components (ecological, social and economic) for separate measurement and evaluation.

In order to find a balance that will sustain ecosystem health, management decisions regarding ecosystem health rely upon expert input from each of the three ecosystem components. The collection of appropriate and adequate data, of dependable quality, is essential to generate the kinds of information that will effectively guide decision-making in the ecosystem arena. The basis, adopted by DWAF, for measuring and assessing the ecological component of aquatic ecosystems, is ecological integrity.

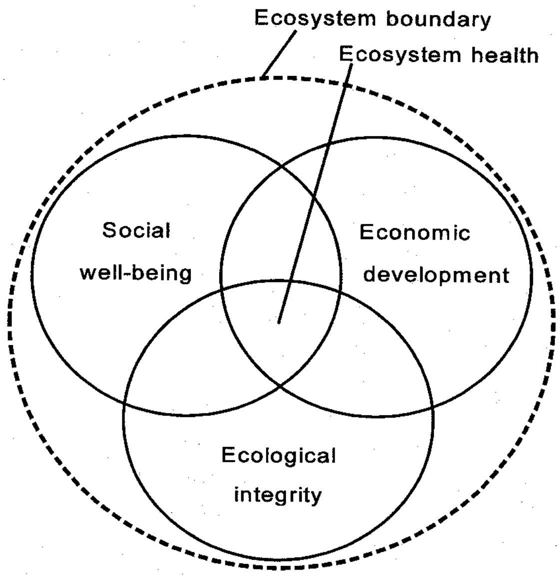

Figure 1: The inter-relatedness of the ecological, social and economic elements of an ecosystem.

INDICATORS FOR MEASURING ECOLOGICAL INTEGRITY

What is ecological integrity?

Integrity generally refers to a condition of being unimpaired, i.e. corresponding with an original condition. **Biological integrity** has been defined as the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitats within a region [11].

Similarly, **habitat integrity** has been defined as the existence of a balanced, integrated composition of physico-chemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats within a region [12]. Essentially the habitat (physical and chemical) integrity of a river provides the template for a certain level of biological integrity to be realised. It follows that habitat integrity and biological integrity together constitutes ecological integrity.

In terms of the above definitions, **ecological integrity** of a river can be defined as the ability of the river to support and maintain a balanced, integrated composition of physico-chemical habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural characteristics of ecosystems of the region.

Ecological indicators

Ecological indicators are characteristics of the environment, both biotic and abiotic, that can provide quantitative information on the condition of ecological resources [13]. Such indicators can be used to measure and quantify ecological changes in an ecosystem.

There are five major classes of environmental factors that may affect the ecological condition or integrity of aquatic ecosystems. These are chemical variables, flow regime, habitat structure, biotic interactions and energy source [4]. Alterations to the physical, chemical or biological processes associated with these factors can adversely affect the ecological integrity of the water body. Fig. 2 illustrates how the alteration of the dynamic character of any of these factors, as a result of natural events or anthropogenic activities, can have an impact on the ecological integrity of an aquatic ecosystem. Therefore, a suite of indicators ideally needs to be considered in the assessment of overall ecological integrity.

Because of resource realities, it is impossible to measure and monitor all possible contributors to overall ecological integrity. Efforts to assess ecological integrity thus need to focus on indicators that will identify perturbations in an integrated manner. Since resident aquatic communities integrate and reflect the effects of chemical and physical impacts, occurring over extended periods of time, they are regarded as good indicators of overall ecological integrity. The in-stream biological condition of a river ecosystem is, for example, determined by the nature of geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality, riparian vegetation and other factors. Employing such a broad-based monitoring approach on a national scale is more likely to be cost-effective and also provide the pertinent ecological information to water resource managers.

When designing a monitoring programme, attention should be given to aquatic community components that are representative of the larger ecosystem and are practical to measure. In determining the taxonomic group(s) appropriate for a particular biomonitoring situation, the advantages of each group must be considered along with the objectives of the programme. The taxonomic groups may also vary depending on the type of aquatic ecosystem being assessed. For example, benthic macro-invertebrates and fish are often used as taxonomic groups to assess flowing waters, while plants are used in wetlands and algae and zooplankton in lakes and estuaries. The design of a biomonitoring programme should be tailored for the particular type of water-bodies assessed (e.g. wetland, lake, stream, river or estuary) [14].

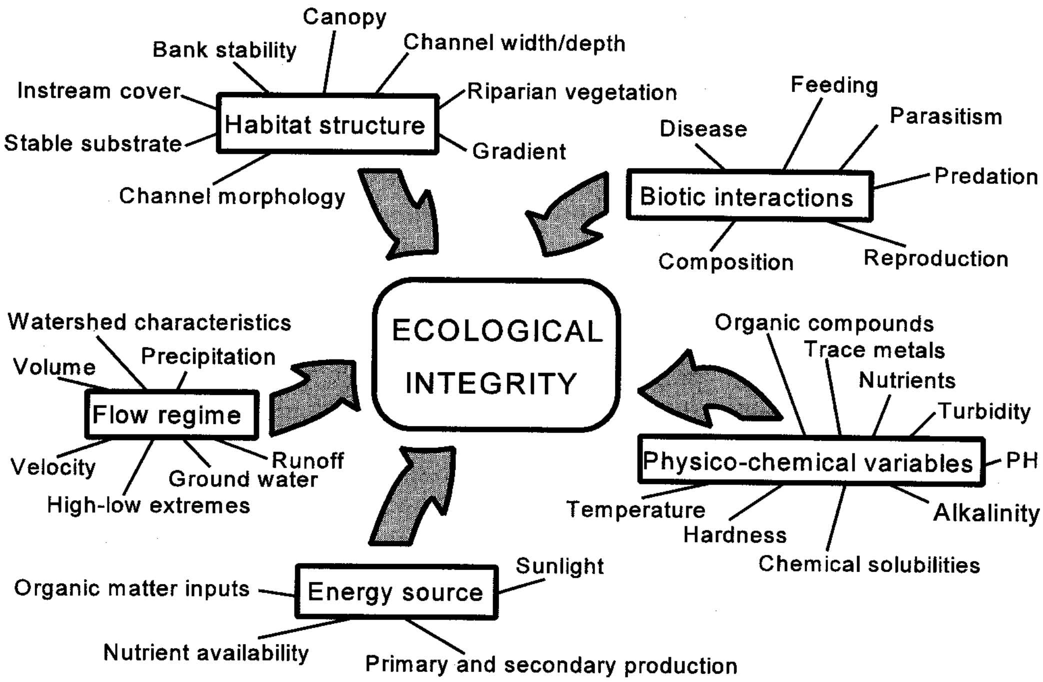

Figure 2: Some of the important chemical, physical and biological factors that influence ecological integrity (modified from [4]).

The above rationale for focussing on biological indicators does not mean that other ecological indicators should be ignored. Information derived from non-biological indicators often support interpretation of biological results. Furthermore, protecting ecological integrity requires the monitoring and protection of the physical and chemical habitats that shape the structural and functional attributes of biota. For this purpose, qualitative and quantitative information on habitat characteristics is required.

Ecological indices

For the purpose of disseminating results of a monitoring programme, the information resulting from measuring ecological indicators should be simplified to a point where it can be of use to resource managers, conservationists and the general public. This can be done with an ecological index which integrates and summarises ecological data within a particular indicator group. Ecological indices are used to quantify the condition of aquatic ecosystems, and the output format of the resulting information is usually numeric. Appropriate indicators, for example selected fish community attributes, need to be tested and justified, and linked to measuring units (metrics) that can be used to index ecological condition.

ASSESSING THE ECOLOGICAL STATE OF AQUATIC ECOSYSTEMS

Measurement versus assessment end-points

Ecological indicators can be used to **measure** changes in ecosystems, and these measurements can in turn be used to **assess** the implications (or consequences) and acceptability of such change. For the purpose of designing a monitoring programme it is, therefore, important to distinguish between measurement end-points and assessment end-points, where:

- A **measurement** end-point is the result of an actual measurement of some ecological response to a stressor(s). Measurement end-points can be seen as characteristics of an ecological indicator, for example the mortality of a fish population, that may be affected by exposure to a stressor [15]. The values generated through indices of water quality are further examples of measurement end-points.
- An **assessment** end-point is the result of an interpretation (assessment) of measured data, often in conjunction with other related data. Assessment end-points are explicit expressions of an actual environmental value which bears direct relation to the management of ecological resources. An example is where measured indicator values for impacted and unimpacted sites are assessed to express the degree and/or acceptability of impairment at the impacted site.

Environmental assessment provides a synthesis and interpretation of scientific information, and can often be linked with policy or regulatory questions and issues. Environmental assessment is usually characterised by a value added perspective, ranging from a formal, quantitative cost/benefit analysis of all alternatives to a qualitative improvement in our understanding of potential impacts or effects [13].

The measurement and assessment concepts have important implications for a monitoring programme, which must:

- reflect and describe the relationship between measurement and assessment end-points,
- describe in sufficient detail the assessment process so that different people using the same measured information will consistently arrive at the same assessment, and
- recognise that for the purpose of management decision-making, information has to be reported in the form of assessment rather than measurement end-points [13].

Area-specific benchmarks for assessment

Ecosystems are naturally dynamic, and their evolutionary histories and capabilities are never static in either structure or function. For example, hydrological regimes include variability on many time scales, and include not only the "normal" range of conditions at a site, but also the "extremes" of floods and other infrequent conditions. From an ecological point of view there is, however, nothing abnormal about these extremes. These occurrences are a natural and often crucial part of ecosystem dynamics, especially over the long-term.

When interpreting or assessing the results from an ecosystem monitoring programme, the challenge lies in distinguishing between natural and unnatural ranges of change in measured ecological values. Managers will benefit from the knowledge that an ecosystem is responding in some way that is outside its natural range of variation. This would allow remedial steps to be taken before such change becomes permanent. One way of distinguishing between natural and unnatural ranges of variation, is to establish a "natural" benchmark or reference condition with which similar monitoring sites can be compared.

In general, quality assessment requires a procedure for comparing the state of an ecosystem with a reference condition. This means that both the state of the ecosystem to be assessed and the reference conditions have to be made explicit [16].

In South Africa, establishing reference conditions is complicated by a large range of ecosystem types. The variability among natural surface waters, resulting from vast climatic, landform, land cover (vegetation), soil type and other geographic differences, favours the use of area-specific reference conditions rather than national reference conditions. Such area-specific reference conditions should describe, within the relevant geographic area, the characteristics of river segments least impaired by human activities in order to define attainable biological or habitat conditions [14]. The development of area-specific reference conditions will allow environmental conditions at any site(s) under investigation to be compared with conditions found or expected in undisturbed streams or rivers, of similar size and habitat type, and located in the same area.

As completely undisturbed environments are virtually nonexistent, and even remote waters are impacted by factors such as atmospheric pollution, "minimally impacted" sites have been used (for example in the United States) to define the "best attainable reference condition" [17]. However, care should be taken in cases where the best sites in a specific area are already considerably modified. In such cases expert knowledge and extrapolation techniques may be required to construct a hypothetical "best attainable" condition, which can be used as an area-specific reference.

Once appropriate reference conditions have been set for a particular area, standardised measurements of ecological integrity can be used and the resulting data can be compared against these reference conditions. Fig. 3 shows how the results obtained at reference sites can be used to calibrate biological indices. Whereas the reference condition represents the top end of such a calibrated scale, an almost sterile system will represent the lowest possible state [8]. An area-specific calibration of ecological state will enable the assessment of the current ecological state of any site or reach within that area. The current state for a particular site can be anywhere between the reference condition (100%) and the lowest possible state (0%).

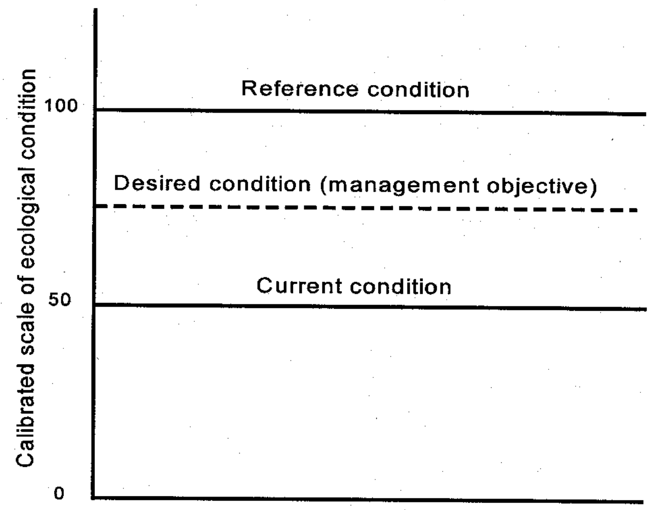

Figure 3: A conceptual model for assessing the ecological condition of an aquatic ecosystem.

Setting Resource Quality Objectives (RQOs)

The availability of quantitative information on the reference biological integrity as well as the current biological integrity of a river will contribute towards setting realistic and ecologically sound resource management goals. A third critical condition in goal setting is the future condition that the various stakeholders desire for the river; this would typically include an assessment of the social-cultural, economic and ecological importance of the resource. Once consensus is reached on a management goal for a particular river, and if this goal can be expressed in terms of a specific integrity parameters, then measurable Resource Quality Objectives (RQOs) can be allocated per ecological indicator group. In other words, the range of index scores coinciding with the desired integrity class, for each biological indicator group, become measurable and auditable RQOs. However, making choices about the RQOs entails more than the assessment of measured data, and requires input from all stakeholders [e.g. 18].

It is clear that the monitoring of ecological responses can be used to indicate the effects of changing ecological conditions. However, assessment of the monitored data is required to determine the significance of such change in terms of (a) the degree of deviation from the hypothetical "natural" ecological condition, or (b) an ecological management objective. The objective must, in turn, reflect sustainable levels of ecosystem structure, function and processes as well as the expectations of stakeholders.

THE SOUTH AFRICAN RIVER HEALTH PROGRAMME

Existing international programmes

Aquatic biomonitoring programmes are developed for various purposes, including the following:

- surveillance of the general ecological state of aquatic ecosystems;
- assessment of impacts (before and after an impact or upstream and downstream of an impact, both for diffuse and point-source impacts);
- audit of compliance with ecological objectives or regulatory standards; and
- detection of long-term trends in the environment as a result of any number of perturbations.

National approaches to the design and implementation of aquatic biomonitoring programmes have been followed over the world. The most noteworthy of existing programmes are:

- the British River Invertebrate Prediction and Classification (RIVPACS) methodology [19];
- the Australian National River Health Programme [20]; and
- the Rapid Bioassessment Protocols For Use in Streams and Rivers of the United States [21].

The programme that is being designed for South Africa incorporates appropriate concepts from these international models, yet is tailored to reflect the environmental conditions and resource realities specific to the country.

RHP design process

A monitoring programme is usually developed in response to a need for information. The programme design *per se* will, however, not provide the required information. The design needs to be implemented, and the programme must be maintained and modified through ongoing learning, to match our evolving information needs. The design will consist of tools, protocols and methodologies which will be needed in the implementation, and which will make the programme functional. Furthermore, the selection of these tools will be guided by an overall vision and the specific objectives of the programme. Finally, when the programme has been designed, many individuals and organisations may play a role in turning the design into an operational programme which will produce the information for which it has been designed.

A phased approach was adopted for the design of the RHP, to facilitate the formulation of a design framework, the conceptual development and testing, demonstration and eventual full-scale implementation of the programme [22]. The main design phases are shown in Fig. 4.

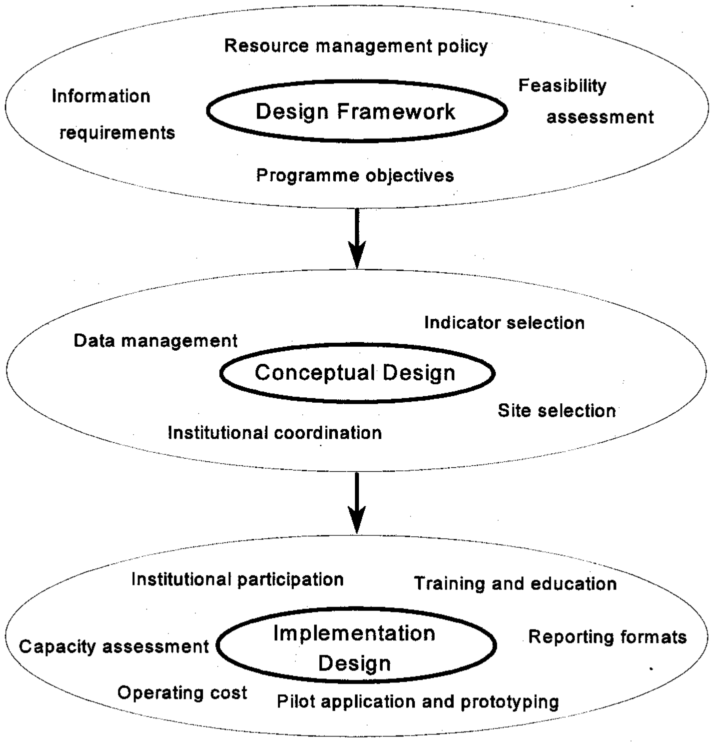

Figure 4: Phased design of the River Health Programme.

Design framework formulation

The RHP framework was based on two issues, namely:
- the qualitative and quantitative information requirements related to the management of aquatic ecosystems, as expressed by aquatic resource managers, and
- the ability of a national-scale biomonitoring programme, at the current level of scientific development, to deliver the required information.

An important outcome of the framework design was a definition of the objectives of the programme as well as the scope and specifications to which the rest of the design phases must adhere. The design specifications can be summarised as follows [5]:
- The RHP is being designed primarily as a *management information system*. The approach of designing programmes as management information systems recognises that the ultimate purpose of a monitoring programme is to produce information for a specific objective. In the case of the RHP the information must support the management of water resources.
- It is unlikely that one biomonitoring programme will meet all information needs, for example as expressed by resource managers with national, provincial, catchment or local interests and

responsibilities. As the RHP is required to provide information on a national level, its design must be specified accordingly. As such, it was agreed by managers that the primary focus of the RHP should be on the **state of health** of aquatic ecosystems.

- Although the monitoring focus of the RHP will be on biological indicators, relevant non-biological indicators should also be incorporated to have a suite of ecological indicators for assessing aquatic ecosystems.
- Models for coordination and co-participation among relevant organisations will have to be investigated. It will be necessary to pool and optimise available resources and capabilities in order to successfully implement and maintain a national programme of the complexity and specialised nature of the RHP.

The main objectives of the RHP are to (1) measure, assess and report on the ecological state of riverine ecosystems, (2) detect and report on spatial and temporal trends in the ecological state of riverine ecosystems, and (3) identify and report on emerging problems regarding the ecological state of riverine ecosystems in South Africa. Each of these objectives are discussed in more detail below [from 5].

Ecological state reporting

The level of information which could be reported is determined by the breadth and detail of the data that are collected. "Breadth" depends on the number of ecosystem processes and components (indicators) that are included in the data. "Detail" refers to the degree to which each ecosystem indicator is measured and analysed. The more detailed the available data, the better the insight that can be obtained about the functioning of the ecosystem, i.e. the interrelations among ecological components as well as their relationship to stressors [16].

Current ecological knowledge does not allow for obtaining a complete picture of ecosystem components and all the processes associated with them. Therefore, a compromise has to be made between the breadth of the information and the degree of detail. Breadth is often at the expense of detail. A broad approach can be sensitive to all kinds of stressors, however, subtle responses may not be detected. Similarly, detail is at the expense of breadth. Although diagnostic capacity depends on the detail of information, the evaluation may become too narrowly focused, with an increasing risk that important effects on other ecosystem components can be overlooked. Also, there comes a point at which too much detail can cloud the issue or make analysis unnecessarily complex [16].

Ultimately, the breadth and detail of monitoring specifications need to be tailored according to resource realities. On a national scale, the programme will be designed to measure and assess the general state and annual changes over river reaches, rather than to provide day-to-day operational answers or for measuring exact river conditions at any specific site.

Trend detection

Natural ecological variation will complicate direct comparison of monitoring results between sites. However, through the development of a spatial classification scheme, it is hoped that geographical areas could be delineated within which it is valid to compare data from different sites. Normalising the conditions at each site, relative to a reference condition for the particular geographical area, will allow direct comparison and the detection of spatial trends in the ecological state among sites.

Once the programme has been in existence for a few years, the detection of temporal trends should provide an ability to quantify changes (whether an improvement or deterioration), or to qualitatively predict ecosystem degradation.

Problem identification

The data collected through a national programme are unlikely to be sufficient to establish causal relationships with a high level of confidence, i.e. specific detail on impairment due to habitat degradation, hydrological alteration or chemical water quality deterioration. Therefore, to address questions related to emerging problems, the national programme needs to feed into regional or site-specific bio-assessment initiatives, tailored for the particular problem experienced. More detailed and frequent monitoring can be instituted to provide answers to specific questions as part of such specific studies (Fig. 5). An example of such a question may be the extent to which the quality of an effluent discharge must be improved in order to achieve a specified in-stream ecological objective.

Whereas national ecological indicator surveys should allow the detection of unacceptable change, regional detailed surveys would be required to link, with a significant level of confidence, specific causes to the change. National assessment would thus allow limited resources to prioritise regional activities and create focus on specific problem areas. Although regional biomonitoring activities will not be addressed as part of the national programme design, regional bio-assessment will be essential to complement the national information and hence to optimise decision-making competence. Provision must, therefore, be made for linking national and regional bio-assessment programmes.

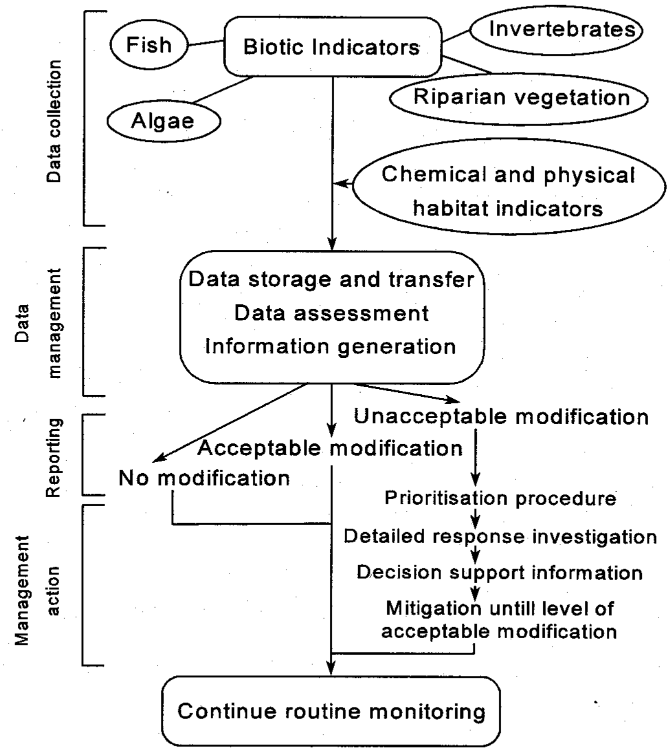

Figure 5: Flow diagram indicating the different components of a biomonitoring programme and how the results of the programme may influence management actions.

Conceptual programme design

During the conceptual design phase, aspects which were addressed included the development of:

- a spatial classification scheme, which would allow the delineation of geographical areas within which it would be valid to compare biological data from different sites [23];
- a protocol for selecting reference and monitoring sites to support state-of-the-environment (SOE) reporting [24];

- protocols for selecting and using biological and other ecological indicators to measure the health of river systems [25];
- procedures for the transfer, storage and retrieval of data resulting from the RHP [5];
- mechanisms and structures for institutional coordination, which is essential for the long-term maintenance of any national environmental monitoring programme [5].

Spatial classification scheme

A regional approach to defining reference conditions has been proposed for South Africa. Following on the outcome of a National Workshop, additional work led to the development of a three-tiered hierarchical classification scheme, as follows [from 23]:

Level 1 - Bioregional Classification: a modification of an existing biogeographic classification based on the broad historical distribution patterns of riverine macroinvertebrates, fish and riparian vegetation. This level produced 18 bioregions for South Africa.

Level 2 - Sub-regional Classification: based on patterns of river zonation within bioregions. It was envisaged that this would reflect agreement between broad geomorphological characteristics (e.g. landform, lithology, soils, hydrology, climate, basin relief, river profile morphology) and distribution patterns of fish, macroinvertebrates and, to a lesser extent, riparian vegetation.

Level 3 - River Types: which were to account for variation between rivers within a sub-region. It was envisaged that this level of the hierarchy would account for differences in factors such as river size, hydrological pattern (e.g. perennial or intermittent flow) and other geomorphological or chemical characteristics.

Reference and monitoring sites selection protocol

The RHP is being designed to allow comparison between reference and monitoring sites, where:

- **Reference sites** are relatively unimpacted sites that can be used to define the best physical habitat, water quality and biological parameters for each kind of river.
- **Monitoring sites** are commonly those sites identified as important in assessing the condition of a river or reach known or thought to be experiencing an impact on water quality or habitat degradation. In the case of SOE reporting, however, monitoring sites are randomly selected impacted or unimpacted sites that reveal the range of conditions in their types of rivers.

A detailed discussion of criteria for the selection of reference sites and a proposed protocol for selecting reference sites has been published [24].

Indicator selection protocols

A key element in the design of a biomonitoring programme is the decision as to which indicators to measure, and which indices to select to represent these indicators. While biological indicators are the main focus of the RHP, the inclusion of physical and chemical indicators will substantially increase the long-term information value of the programme.

The biological indicators most commonly used in biomonitoring are aquatic macroinvertebrates and fish. Riparian vegetation serves to link the in-stream aquatic ecosystem to the surrounding terrestrial ecosystem which, in turn, influences river processes and patterns. Although this component of aquatic ecosystems is often overlooked, riparian vegetation is considered a vital element in determining the state of aquatic ecosystems.

The state of riverine biota is a reflection of the chemical and physical habitat conditions in that river. In order to interpret the meaning of the biological index values accurately, it is necessary to gather information about the chemical and physical environment of the river. These physical and chemical indicators provide a framework within which to interpret the biological results. As an example, the community of fish or invertebrates will be very different in a river with high habitat diversity compared to one with low habitat diversity, or before and after a prolonged drought.

The non-biological indicators considered to provide the most comprehensive support framework for the interpretation of biological data are aspects of physical habitat, hydrology, water chemistry and geomorphology.

To accommodate a range of regional requirements, capabilities and the availability of resources in the implementation of the RHP, five alternative biomonitoring protocols (BPs) are being proposed (BP1 to BP5). The options range from the use of a single biological index and an associated habitat index at a site, to the use of several biological and non-biological indices. The latter option provides a comprehensive assessment of the state of the riverine communities and their environmental conditions.

Once a biomonitoring initiative has started, it would be possible to scale up or down on the BP adopted for a certain catchment, province or the country. Such a decision would depend on the resolution of information required, available resources and expertise, and the possible prioritisation of particular rivers or sites.

Data management procedures
Options for data capturing include filing and distributing hard-copy data sheets, updating and maintaining local databases, and sharing a centralised database. The last option is preferred for its long-term data security and accessibility advantages. However, the feasibility of this option would depend on a uniform data structure and reliable high-speed data links. Both of these qualifying aspects are currently receiving attention from the DWAF.

Information derived from the RHP will potentially be utilised by a very wide spectrum of users. To focus the communication of information, these audiences can broadly be divided into three levels, namely political or administrative, operational and grassroots levels.

To a large extent the success of the RHP will be determined by the effectiveness of communicating results to the different target audiences. While raw data or index values may be sufficient for the specialists familiar with interpreting biological results, these formats may be meaningless to anyone who does not have an understanding of the derivation of the index, how it reflects deviation from natural or best attainable conditions, or how to correctly interpret the value of the index. For such audiences the information reflected in the index may need to be reported in simple graphical formats.

More detailed or more generalised presentations can be made of the same data, according to the preference of the target audience. The critical factor is that the source data must be reliable, and based on scientifically acceptable and standardised collection protocols. The data assessment process must also be described in sufficient detail so that different people using the same measured data will consistently arrive at the same assessment information.

Institutional structures and coordination
The design of the RHP started as a national initiative driven by the DWAF. However, the DWAF does not have the required regional infrastructure and resources to implement and maintain the programme on a national basis. Also, the geographic framework for decision-making in South Africa is moving from the national scale down to provincial and more local scales. The information generated from the RHP will also provide decision-making support for the resource managers with a more local interest.

Therefore, to ensure the successful implementation and long-term maintenance of the programme, it will be necessary to involve regional stakeholders. As such, a model of national coordination (quality control, standardisation of procedures, etc.) and regional implementation and maintenance (data collection and ownership, coordination among regional stake holders, etc.) is currently being pursued.

Implementation of the RHP would thus require the development, within the broad RHP Implementation Design, and establishment of procedures which cater for coordination among and the specific needs of the national, provincial and regional stakeholders. Apart from technical and coordination issues, the implementation phase also needs to address the vast educational needs, capacity building, reporting formats for key audiences and funding opportunities and options in order to ensure long-term maintenance of the monitoring programme

For the purpose of implementing the RHP, it might be necessary to identify "Regional Lead Agencies". Such lead agencies may include Provincial Governments, water boards, university departments or consulting firms. While keeping within the broad design framework, each lead agency may decide independently on site selection, who would do the monitoring and be responsible for data transfer to a central body. Lead agencies may take on their work themselves, or appoint research groups with appropriate expertise.

After implementation, the role of scientists in maintaining the programme will remain significant. Although the physical aspects of conducting biomonitoring need not be done by specialists, it is essential that specialists be responsible for the interpretation of collected data. However, involvement of administrators, regulators and engineers, who must translate reported results into real world, everyday activities such as resource management and development, will increase.

Testing and implementation phase

The implementation design phase is about matching the ideals of the conceptual design with the realities of the real world, in order to create a feasible platform for implementing and maintaining the RHP. During the conceptual design phase developments are largely theoretical and substantial testing, modification, demonstration and integration are still required to mould all the concepts into an operational programme. Pilot testing also allows small-scale demonstration of the programme through reporting the generated information to key target audiences. Additional research and developmental needs will also be identified during this phase.

The final implementation design must provide the information required to implement and maintain the programme successfully. It must, therefore, address aspects such as start-up cost, operating cost, human resource requirements, training needs, institutional participation, equipment needs and maintenance requirements. As the programme is intended for national application, survey methods should not be too resource intensive, nor so complex that only specialists can conduct monitoring. Similarly, site selection should balance the realities of resource availability with obtaining sufficient data to comply with the objectives of the programme.

THE ELANDS RIVER, A CASE STUDY

For some of the indicators proposed for the RHP, indices have been developed and applied in South Africa. For the majority of the indicators, however, indices are in the early phases of conceptualisation and still need practical development and testing [5].

An approach of applying the latest developmental prototypes of the above technologies, in the context of case studies, is being followed. By doing so, a high degree of alignment and synergy between programme components can be encouraged. This also applies to a systematic and adaptive procedure for linking monitoring, assessment and management outputs. This case study demonstrates a prototype framework for linking biological response data, as generated by the RHP, through a systematic approach to river management. The relevant concepts are broadly demonstrated with the aid of the case study.

Study area and biological survey

The results of fish and invertebrate sampling on the Elands River, Mpumalanga, were assessed by means of a prototype Fish Community Integrity Index (FCII) [26] and the fourth version of the South African Scoring System (SASS4) [27], respectively. The sampling surveys took place during the second half of 1996.

The Elands River (Fig. 6) was divided into reaches, based on physical characteristics which determine habitat suitability for fish. These reaches were refined by checking them against historical fish distribution patterns. In other words, each reach represents a segment of the river in which the fish community would, under unimpaired conditions, remain generally homogenous due to the relative uniform nature of the physical habitat [26]. Each fish-based reach was assumed also to support a homogenous community of benthic invertebrates. Based on site suitability, accessibility and representativeness, surveys were conducted at between three and five sampling sites per reach.

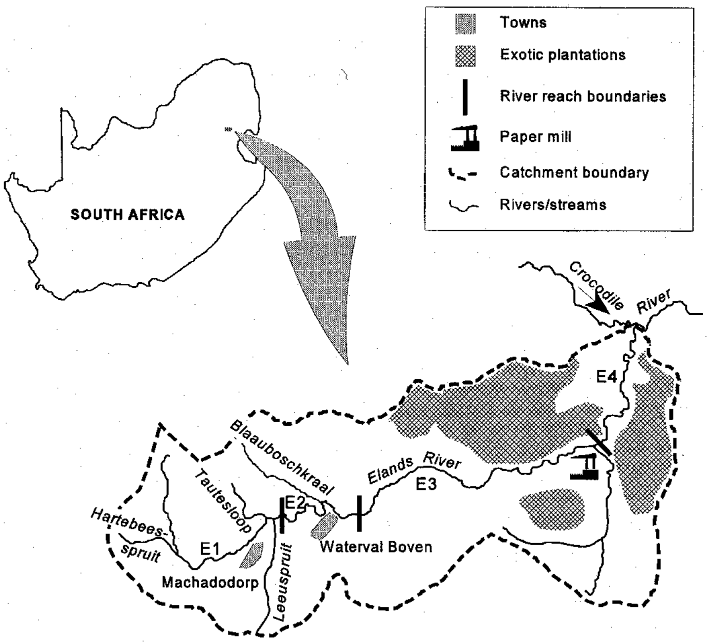

Figure 6: Location and characteristics of the study area.

Assessment framework

Monitoring results were assessed by comparing the collected data against reference conditions derived for each reach. These reference conditions approximate the best attainable biological condition for a reach, in the absence of impact from human activities. A combination of historical data and expert opinion for fish, and relatively unimpaired reference sites and expert opinion for invertebrates, was used to define the reference conditions.

To provide a management perspective to the assessment of the monitoring data, a provisional River Integrity Classification Scheme (RICS) was followed. This is shown in Table 1.

Table 1. The provisional River Integrity Classification Scheme (RICS).

River Integrity Class	Biological community characteristics (FCII and SASS4)	% of reference index score
Class A: Unmodified	Community characteristics approximate natural conditions.	>85%
Class B: Moderately Modified	Moderate change to community characteristics (lower abundances and possible loss of some intolerant species); basic ecosystem functions remain predominantly unchanged.	61-85%
Class C: Considerably Modified	Considerable modification of community characteristics and basic ecosystem functions have occurred; several intolerant species have been lost or occur only in low numbers.	40-60%
Class D: Severely Modified	Community characteristics have been seriously modified with an extensive loss of basic ecosystem functions; tendency towards domination by a few tolerant species.	<40%

Table 2 indicates the outcome when the results of the biological survey were applied to the RICS.

Table 2. The current biological integrity classes for each river reach, according to assessment of fish and invertebrate communities.

River reach (altitude in m)	River/Stream	Biological condition class	
		FCII	SASS4
E1 (>1500)	Tautesloop	A	A
	Hartbeesspruit	B	A
	Leeuspruit	D	A
E2 (1200-1500)	Elands River	A	B
	Blaauboschkraal	B	A
E3 (900-1200)	Elands River	A	A
E4 (800-900)	Elands River	A	A

Resource quality objectives and management actions

An exercise involving stakeholders to set management goals for the Elands River has not yet been undertaken. However, to take this exercise further, we assume the following hypothetical desired conditions: a) No indicator group should deteriorate from its current integrity class and b) the whole of the Elands River should at least be maintained at Integrity Class B - given the social (e.g. recreational trout angling in upper reaches) and economic (e.g. trout aquaculture and forestry) importance of the Elands River catchment, a goal of Class A for the entire river may be unrealistic and impossible to achieve. According to the above rules for goal setting, it is only the Leeuspruit in reach E1 for which the fish community needs to improve from Integrity Class D to Integrity Class B. The current low integrity class according to the FCII is associated with the presence of exotic black bass in the Leeuspruit.

The RICS will provide the range of index values for the FCII in order to comply with a goal of Class B. Based on expert and system-specific knowledge, management options could be suggested for improving the fish community characteristics accordingly. An example of a management option for the Leeuspruit is the removal of exotic black bass and/or trout and the reintroduction of the appropriate indigenous fish species. Various management options could be rated on the basis of their political and technical feasibility and perceived efficacy [e.g. 28], in order to prioritise and guide management action.

CONCLUDING REMARKS

The RHP is not intended to replace any water quality monitoring approach, but rather to expand on the approaches currently in use. Implementation of the RHP would, however, require a substantial broadening of the traditional water quality monitoring and assessment focus. It would require a far more integrated collection and analysis of data, as well as the assessment of new types and combinations of data.

In essence, biomonitoring is a scientific procedure, which can be used to provide resource information. The principal role of this monitoring information is to drive and direct the processes of decision making and management. These processes include:

- assessing information and identifying problems;
- drafting regional and national policies, regulations and eventually legislation;
- establishing criteria, standards and management objectives for combatting deteriorating environmental conditions, and
- demonstrating results in the environment [29].

In broad terms, the RHP has to contribute to science-based management of aquatic ecosystems, in support of national and regional mandates to manage the water resources of South Africa. If the nation's rivers (and estuaries, seas and impoundments) are maintained at an appropriate level of ecological integrity, then the efforts of resource managers will have been successful. The information generated by the RHP will assist in identifying those areas where water resource managers have been successful and those areas where they need to focus their attention. Through the monitoring of structural and functional attributes of ecosystems, the RHP will also provide an information base for managing the chemical, physical and biological processes that shape ecological integrity.

A systematic process which involves the collection and assessment of biological data, setting goals and quantifiable objectives for managing the biological integrity of rivers, predicting how various management options will affect components of the ecosystem, and monitoring responses to the chosen management actions, will close the loop between monitoring, assessment and management. By following this iterative cycle and improving the individual components, the balance between water resource protection and utilisation can be optimised.

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