National Biomonitoring Programme for Riverine Ecosystems

Framework document for the programme

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1. PROJECT OVERVIEW

1.1 Introduction

The Department of Water Affairs and Forestry has commissioned the CSIR to manage a project for the design of a monitoring programme to monitor the health of aquatic ecosystems in South Africa - a "biomonitoring" programme.

The project is planned to take place over a 3 year period, and will draw on the resources and knowledge of institutions and experts throughout the country and, where necessary, abroad.

1.2 Design methodology

The approach of designing monitoring programmes as management information systems recognizes that the ultimate purpose of a monitoring programme is to produce information which is used by water resource managers to manage water systems. The generic process used to design monitoring programmes as management information systems is described in more detail in **Appendix B.**

A modular approach is being used in this project for the design and testing of the biomonitoring programme, in order to facilitate development, testing and demonstration. The design is being carried out in three phases, each consisting of several components as indicated below.

PHASE 1 - Specification of Information Expectations:

- Specification of the management information requirements, both from a water quality and water quantity perspective, for aquatic ecosystems management;
- Specification of information on aquatic ecosystems health that can be produced by a biomonitoring programme;
- Develop a consensus on the compromises that would need to be made in the course of matching management information requirements with the ability of a biomonitoring programme to deliver the required information.

PHASE 2 - Detailed Implementation Design:

- Design of the required monitoring network, i.e. monitoring sites, variables to measure and frequency of monitoring;
- Detailed design of data collection procedures;
- Detailed design of data analysis and information reporting mechanisms and procedures.

PHASE 3 - Development, Testing and Demonstration:

- Development of biomonitoring methodologies required by the detailed design in cases where these are not currently available;
- Testing of components of the design as these are defined;
- Piloting and demonstration of the complete biomonitoring programme on a small scale to prepare for full scale implementation.

1.3 Target group

The monitoring programme is being designed to meet the information requirements of the primary users, namely water resources managers in the Department of Water Affairs and Forestry, tasked with the duty of ensuring the sustainable use and health of South Africa's aquatic ecosystems. These managers require information for the performance of a variety of management functions such as resource use planning, operations and control, including pollution control.

2. PURPOSE OF THIS DOCUMENT

This document serves to report on Phase 1 of the project (as outlined above), and documents the results of the thinking and development that took place during it. As the project progresses, it is almost certain that some of the ideas and concepts presented here will change, and reference should always be made to the latest available information.

The bulk of this document provides general background information for the project, including many important concepts relating to the management of aquatic ecosystems. It also provides the draft specifications for the framework that will be used for the detailed design of the monitoring programme.

This document should be read by those who become involved in the project as part of the technical design team, as well as providing an overview for managers and others involved in the overall design process.

3. BACKGROUND

3.1 The mission of the DWAF

The Department of Water Affairs and Forestry (DWAF) is the primary agency responsible for water resources management in South Africa. With respect to water quality its mission is to ensure the fitness of South Africa's surface water, groundwater and coastal marine resources, for water uses and for the protection of aquatic ecosystems, on a sustainable basis (DWAF, 1986). The DWAF views aquatic ecosystems as a primary resource upon which development and other uses are based and sustained.

3.2 DWAF's water quality management principles and approaches

The DWAF has adopted a number of policies and strategies with regard to water quality management, which have been elsewhere described in some detail (DWAF, 1991). Of these, a number have been highlighted below because of their relevance for aquatic ecosystems management.

The basic geographic unit of water quality management is the *river catchment*. Catchment management must integrate land use effects with physical characteristics of the catchment and with external factors, such as economics, to plan and control water quality. Successful water quality management relies on integration of these diverse factors into a holistic management system.

A key aspect in the management of water quality in a catchment is the formulation of *receiving water quality objectives*. These objectives are a statement of the quality in a water body that must be maintained. Objectives are set with the requirements of both water users and aquatic ecosystems in mind; as well as various other considerations such as technological, economic, political and social factors which affect the use of the water and the quality of the water in the water body.

In managing the effects of developments on water quality, a *precautionary approach* is adopted, in which active measures are taken to avert or minimise potential risk of undesirable impacts on the environment. Therefore, when developments are proposed, it is required that probable impacts on the health of people and the resource must be predicted, as well as the environmental and economic benefits. This precautionary approach is applied in all the water resource decisions made by the DWAF.

4. MANAGEMENT OF AQUATIC ECOSYSTEMS

Sustainable resource management requires that the biosphere be viewed as an entity consisting of three integrated compartments, namely social, economic and environmental. No compartment can be sacrificed for any other without a decrease in the overall quality of human life. The guiding principle for integrating these compartments is *ecosystem health* - the health of human populations and their environments, jointly (Vallentyne and Munawar, 1993). In other words, healthy places result in healthy people and healthy people in healthy places.

4.1 Introduction

In the past, management of water quality was primarily based on the need to protect human health. Depending on the uses made of water - both direct and indirect - it's quality had to comply to norms acceptable to human health standards, typically established by microbiologists and health workers, and managed according to engineering methodologies.

Over time, as human activities intensified and spread, they have had an increasing impact on the quality of water, and on the ecological systems, or *ecosystems*, that the aquatic environment sustains. Recognition of these impacts has spurred increasing interest in describing the relationship between people and their environment. With this has come the realisation that water is the basis for **all** forms of life - not just human. Moreover, many of the uses and benefits that people obtain from water resources are dependant on healthy, functioning ecosystems. Furthermore, being able to provide the conditions for such ecosystems implies that the systems are in balance. Balanced systems are required to provide sustained use of water resources.

This development started in scientific circles, and is now shared by the wider community. This has lead governments to develop policies to protect aquatic ecosystems, and means that water quality managers, must adopt the broad philosophy of integrated ecosystems management, rather than the previous, narrower one of chemical water quality management.

The basis for aquatic ecosystems management is therefore more than just the protection of human health - it is the **protection of the water resource base.** To support this, ongoing, comprehensive monitoring, tied to effective management, of all aspects of aquatic ecosystems is needed.

4.2 Aquatic ecosystem concepts

A number of concepts, which are unique to aquatic ecosystems and of relevance in providing background information, are briefly described below. Most of these concepts originated in scientific research, but are of increasing importance for those who need to be able to assess and manage the health of aquatic ecosystems. Additional clarification and more detail of these terms will be found in the literature cited.

4.2.1 Biological diversity

The term *biological diversity*, or *biodiversity*, originated in the study of terrestrial ecosystems. One formal definition for biodiversity is "the variety and variability among living organisms and the ecological complexes in which they occur" and "encompasses different ecosystems, species, genes, and their relative abundance" (OTA, 1987, as quoted by Angermier and Karr, 1994). Such a definition means that biodiversity is broader than just species diversity. This means that the protection of biodiversity implies actions beyond species protection - the ecosystem forming the basis for those species also requires protection.

4.2.2 Biotic integrity

A formal definition for *biotic integrity*, or *biointegrity*, is "the capability of [an ecosystem for] supporting and maintaining a balanced, integrated and adaptive community of organisms, having a species diversity, composition and functional organisation comparable to that of the natural habitats of the region" (Karr and Dudley, 1981).

Biotic integrity can be viewed as a relative measure, typically by assessing the degree to which the biological condition of a system has been modified relative to its natural state. Biotic integrity offers a better basis than biodiversity for assessing ecosystem health because it:

- takes into account processes between biological components, and
- is associated with naturally evolved systems.

4.2.3 "Natural" aquatic ecosystems

One basis for determining the degree to which an ecosystem has retained its biointegrity is to examine equivalent ecosystems in their "natural" (or "pristine") state. However, because of the widespread and ongoing impact of human activities, very few systems can be said to be "natural". Such systems may exist in the older national parks or upland, mountain catchments, although even such areas can be impacted by atmospheric deposition. In practice, the concept of "best attainable" ecosystems, representing areas which are minimally impacted, can be used as an equivalent measure.

4.2.4 Cause-effect relationships in ecosystems

In the assessment of water quality and ecosystem health, two differing, but equally valid, approaches can be used (Thorton *et al.*, 1994). One can measure variables which are assumed to be associated with a stress - the stress-oriented approach - or, in some way, to reflect the results or effects of changes - the effects-oriented approach.

The stress-oriented approach is the more well known one - it starts with the characterisation of the stressor (for example, a measured water quality constituent) and describes exposure pathways to the expected effects on the ecosystem. This approach is a predictive one and relies upon known cause-effect relationships between stressors and ecological effects.

The complementary approach is a retrospective one, which is usually more appropriate to the type of wide-scale ecosystem health monitoring required in this programme. In this approach, various biological indicators are measured and, from these measurements, an assessment can be made about the health of the aquatic ecosystem.

4.3 Factors affecting aquatic ecosystem health

A wide range of human activities can impact on aquatic ecosystems, such as:

$ point source discharges (for example, from factories or sewage treatment works)
$ non-point source runoff from agriculture, urban or mining areas
$ alteration of channel characteristics via sedimentation or siltation
$ changes in the stream flow regime through dams or diversions
$ removal of riparian zone vegetation
$ introduction of exotic or alien species

Human activities can thus impact on both instream organisms and the habitats in which they occur. Ecosystem management must therefore encompass the effects of many changes; for example, impacts of discharges on water quality, creation of barriers reducing stream flow, to land use changes affecting habitat, etc.

4.4 Approaches to management of aquatic ecosystems

The behaviour of water quality constituents and their interactions, while complex, has been well studied in the past and can be monitored and predicted with some degree of confidence. In contrast, management of aquatic ecosystems is less well developed.

Because aquatic ecosystems are highly complex and variable, many differences in response to different stressors are possible under different circumstances. Most predictions relating to ecosystem behaviour carry a high degree of uncertainty. For this reason, management of aquatic ecosystems needs to be adaptive and flexible (ANZECC, 1992). In particular, managers need to be able to make effective decisions without access to detailed knowledge. Thus, ecosystem management presents demanding challenges.

4.4.1 Barriers to effective management

A number of actual or potential barriers exist when implementing ecosystem management on a national scale (GAO, 1994):

C Noncomparable and insufficient data, generally resulting from uncoordinated and incomplete data collection programmes
C Scientific uncertainty relating to understanding of ecosystem behaviour
C Difficulties in "trading off" ecological and socioeconomic considerations
C Disparate missions and planning activities across different responsible organisations (on national, regional and local levels).

Clearly these types of barriers cannot be dealt with in the short term, and it should be borne in mind that the data collection and reporting activities of a biomonitoring programme are one small part of a much broader framework.

4.4.2 Overseas approaches

In Australia, the national government has adopted a policy of ecologically sustainable development which aims at maintaining sustainable ecosystems and preserving genetic diversity. In terms of water quality management, the goal is to protect biological diversity and maintain ecological processes and systems (ANZECC, 1992). In practice, it is realised that all development is likely to cause the loss of some genetic component of biodiversity, to reduce overall population of some species and to interfere to some extent with ecosystem function. Therefore, protecting biodiversity means ensuring that these impacts associated with development do not threaten ecosystem integrity.

In the United States of America, there are a number of federal agencies who play a role in ecosystem management. For various reasons, each has developed its own approach to, and priorities for, ecosystem management. In a report to Congress on the subject, the GAO (1994) has clearly spelt out the need to adopt a single goal. The current working definition that it reports on is the goal of "preserving, restoring, or, where those are not possible, simulating ecosystem integrity as defined by the composition, structure and function that also maintains the possibility of sustainable societies and economies."

The GAO also recommends a four step approach of (1) delineating the boundaries of ecosystems, at several different scales, (2) understanding the ecologies of these ecosystems, including conditions, impacts and trends, (3) making management choices about desired conditions and types of activities on a coordinated basis, and (4) adapting management to new information received from research and monitoring.

In the United Kingdom, efforts around ecosystem management have been based on the development of the RIVPACS system. This system allows for the assessment of actual data gathered from test sites, against a baseline established at reference sites, thereby providing an assessment of the biological condition of a river.

4.4.3 Aquatic ecosystems management in South Africa

In South Africa, the recent change in government has brought with it many changes in approach and legislation in all spheres of life and consequent changes in approaches to management of social, economic and environmental sectors. The Department of Water Affairs and Forestry has published a White Paper outlining its fundamental policy on the environment (DWAF, 1994) as part of its approach to managing water supply and sanitation. Parts of this policy are quoted fully in **Appendix A**, and its key principles are summarized below:

- Protection and conservation of the natural resource base is imperative
- The environment should not be regarded as a "user" of water in competition with other users, but as the base from which the resource is derived and without which no development is sustainable
- The concept of water as having economic value should be extended to it also having intrinsic environmental value

It is realised that application of these principles will involve the following actions:

- Developing an understanding of the resource characteristics
- Monitoring of the resource
- Implementing protection measures, where necessary
- Applying simple environmental impact assessment procedures
- Auditing of development projects to ensure that the guidelines are being applied

Water monitoring and, in particular, biomonitoring, has a key role to play in providing information to support the above actions.

Although the DWAF's policy on aquatic ecosystems does not view it as a competing water use, protection of aquatic ecosystems must nonetheless consider the direct and indirect uses of the services derived from it. Therefore, the health of aquatic ecosystems must be maintained at levels that will also protect the uses.

The goal of aquatic ecosystem management that has been adopted by the DWAF is:

> "to **protect** the health of aquatic ecosystems. Therefore the DWAF will seek both to **maintain** existing, healthy ecosystems, as well as to **improve** those ecosystems, which are, in some way, impaired, in order to restore their biological integrity."

Implementation of appropriate management actions may require the setting of short-term management objectives in order to reach this goal in a practical and cost-effective manner.

5. BIOMONITORING CONCEPTS

5.1 The role and purpose of biomonitoring

Traditionally, water quality monitoring actions have focused on physical and chemical measurements. It is widely recognised that the use of other indicators, in addition and complimentary to traditional chemical and physical water quality monitoring techniques, can greatly enhance the assessment and management of aquatic ecosystems. Consequently, biological monitoring, or *biomonitoring,* is an important tool in assessing the condition of aquatic ecosystems.

Information on and understanding of environmental change is necessary to allow for the protection and remediation of ecosystems. With current knowledge however, normal limits of variation in South African ecosystems are virtually unknown. This lack of historical and current environmental data makes it difficult to define clearly the nature and extent of environmental change.

It is clear that sufficient and appropriate information is necessary to allow managers to make rational and equitable decisions with respect to water resource management. This information can only be derived from statistically and scientifically defensible monitoring designs. The best way to identify measurement parameters that can serve as vital signs of ecosystems, and define the limits of their variation, is through long term biomonitoring. The resulting data sets will be analysed to provide the basis for defining normal limits of variation or diagnosing ecosystem impairment.

5.2 Definition of biomonitoring

In the operational context, the term *aquatic biomonitoring* is used to refer to the gathering of biological data in both the laboratory and the field for the purposes of making some sort of assessment, or in determining whether regulatory standards and criteria are being met in aquatic ecosystems.

Biomonitoring of aquatic communities can be subdivided into a number categories, as follows (Roux *et al*, 1993):

- *Bioassessments* are based on ecological surveys of the functional and/or structural aspects of biological communities.

- *Toxicity bioassays* are a laboratory-based methodology for investigating and predicting the effect of compounds on test organisms.
- *Behavioral bioassays* explore sub-lethal effects of fish or other species when exposed to contaminated water; usually as on-site, early warning systems.
- *Bioaccumulation* studies monitor the uptake and retention of chemicals in the body of an organism and the consequent effects higher up the food chain.
- *Fish health* studies deal with causes, processes and effects of diseases; and can form a complementary indication of overall ecosystem health.

Apart from information derived from monitoring of in-stream biotic communities, the evaluation of the health aquatic ecosystems must also include other system descriptors. The assessment of the available *habitat* is crucial when comparing biomonitoring results from different sites. The characterisation of geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality and riparian vegetation all form essential components in aquatic ecosystem health assessment.

5.3 The use of ecosystem indicators

The overall condition, or health, of aquatic ecosystems is determined by the interaction of all its physical, chemical and biological components. Because of the lack of resources, it is usually impossible to monitor all these components, and therefore indicators are used instead. Indicators can be defined as "characteristics of the environment that provide quantitative information on the condition of ecological resources, the magnitude of stress, or the exposure of a biological component to stress" (Thorton *et al.*, quoting Olsen, 1992).

Indicators are usually selected on the basis of their ability to:

- represent the overall status of the environment
- permit the detection of trends, through their sensitivity to a range of stresses
- be measured and interpreted relatively easily.

5.4 The use of ecosystem indices

One of the challenges of biomonitoring is to simplify various ecological data to the point where they are useful to resource managers, conservationists, politicians and the general public. This has resulted in the development of a number of relatively simple and rapid assessment techniques by which biological and other data can be presented numerically. These techniques are generally referred to as "indices", and are used to quantify the status of aquatic ecosystems by summarising data on the ecological health status of aquatic communities and their environment.

Ecosystem indices do not attempt to explain the reason for changes to ecosystems, nor do they account for the complexity of interactions between physical, chemical and biological components. They are simply a tool for organising and abstracting ecological data so that these can be understood by non-specialists.

5.5 Assessment of aquatic ecosystem health

5.5.1 The concept of assessment

Aquatic ecosystem health, like human health, cannot be measured directly. Instead, only indicators of health can be measured and, in turn, used to assess the "health" status. Therefore, for the purpose of designing a monitoring programme, it is important to distinguish between measurement end-points and assessment end-points.

A *measurement end-point* is the result of an actual measurement of some characteristic or component of the aquatic ecosystem - for example, the numbers of mayfly at a particular location - via a bioindicator. It usually does not provide any information on what the implications of such measurements are for the aquatic ecosystem health.

An *assessment end-point* is usually the result of an interpretation (assessment) of measured data, often in conjunction with other related information, to arrive at an end-point which can be related to aquatic ecosystem health. Any number of assessment end-points can be arrived at, for example: creation of health "categories" by grouping sets of biological data; comparison between measured and desired aquatic communities; estimates of costs associated with managing ecosystems from measured to desired states, etc.

These 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;
- Recognise that for the purpose of management decision-taking the information has to be reported in the form of assessment rather than measuring end-points.

5.5.2 Assessment relative to a reference point

Arriving at an assessment usually requires two different type of data: first, a "baseline", or reference point, which is usually associated with some desired or ideal state; and, second, measurements of the actual condition that needs to be assessed.

Unlike water quality, where the reference point is pre-determined standard (or guideline), usually based on the use which is made of the water (see **Appendix C**), the assessment of aquatic ecosystem health requires a different type of reference.

The ideal approach to assessing the health of aquatic ecosystems would be to compare the measured values, or indicators, against similar measurements taken at an equivalent, but "pristine" site i.e. a habitat whose physical and chemical characteristics are unaffected by any human activities. However, as mentioned earlier (see 4.2.3), because of the widespread and ongoing impact of human activities, very few - if any - systems are "pristine". The best compromise is the use of minimally impacted sites to define a "best attainable" reference condition. Such sites are typically linked to a specific region with similar physical and biological characteristics.

The assessment of measured data against a "best attainable" reference condition allows the "health status" to be derived, and can also provide the basis for assessing trends. Both of these assessment end-points would be important in a monitoring programme to assess aquatic ecosystem health.

5.5.3 Reference site selection

In South Africa, there are currently two initiatives to determine regions which could form the basis for reference site selection.

- *Physiogeographic regions* represent relatively homogeneous regions of similar climate, soil, geology, natural vegetation, land form and land use (Omernik, 1987, as quoted by Peterson, 1989).
- *Biogeographic regions* represent regions of similar conditions in terms of large-scale patterns of riverine flora and fauna. These regions can be further divided into sub-regions, thereby grouping mountain-stream or lower-river zones of many rivers (Eekhout *et al.*, in prep.).

Once suitable regions (and, if needed, sub-regions) have been delineated, the next step is to establish reference sites within each that represent the best attainable condition for that type of region. Measurements at these sites do not necessarily represent pristine, or totally undisturbed, conditions (see 4.2.3), but do represent a point or area with minimal impact from human activities (Peterson, 1989).

6. MANAGEMENT REQUIREMENTS

6.1 Background

In order to assess management requirements, discussion sessions were held with a number of senior water quality managers within the Department of Water Affairs and Forestry (see **Appendix D** for list of those interviewed) who are to be the primary users of information from the biomonitoring programme. This section summarises their stated information expectations and the extent to which this planned biomonitoring programme is expected to be able to meet such expectations. Two aspects which relate to this summary are presented below.

First, it was recognised by these water quality managers that the Department has shifted its focus from only managing water quality to a broader perspective of water resource management. It was therefore clear that there is a need to understand how water quality management fits into this new framework; for example, a large amount of money spent improving existing effluent control mechanisms may not lead to a corresponding improvement in the ecosystem health if, say, the sediment layer is badly contaminated. It was also recognised that a wider and deeper insights into the demands and requirements of this new "water resource management" approach is needed. The requirements outlined below should be interpreted in this light.

Second, although the task of this project is to develop a **national** monitoring programme, many requirements were put forward which would probably be better addressed by regional or local monitoring programmes.

6.2 General requirements for biomonitoring programmes

A number of requirements for biomonitoring programmes *in general* were given. These have been split into two sections: firstly, those with a **national** focus; and, secondly, those with a **regional** or **local** focus.

National requirements

- C to determine the **status** of protection - this implies a need to rate or classify systems in some way so as to assign to a relative value to the status of the system
- C to determine **trends** in the status of ecosystems ie. are they improving, recovering, stable, declining etc.

Regional / local requirements

- C to identify where **impacts** are taking place, for example, a decline in sensitive species could act as an early warning system using an integrated index-based system
- C to help setting of specific **objectives** for rivers, perhaps based on a river classification scheme
- C to measure and evaluate the impact of **developments** (planned and actual) on ecosystems
- C to monitor the implementation of a development in order to provide data for **predictive modelling** purposes, especially for determining the impact of other, similar developments.

6.3 Scope of the biomonitoring programme

In the previous section, it was noted that managers have stated a wide range of information needs. Clearly, as the role of aquatic ecosystems management develops, such needs will continue to expand. Nonetheless, it is important for the design phase of this monitoring programme that a clear direction be decided on - the failure of monitoring programmes in the past is often linked to a poorly focused goal, or an ad hoc method of development. Further, it is unlikely that one biomonitoring programme will meet all the stated needs. Because the current biomonitoring programme is required to provide information on a national level, its focus cannot be simply on measuring the effects of particular impacts on resources as such impacts are, by nature, ad hoc. For the same reason, cause-effect monitoring is also not appropriate for a national programme. These type of biomonitoring programmes are best suited for local or even regional applications, and a number of such programmes have already been instituted by the Department and other organisations.

On this basis, it was agreed by managers that the primary focus of the first stage of the design should be on a national biomonitoring system to report only on the status of **rivers.** It was noted, however, that, in the long term, monitoring of many different types of resources will ultimately need also to be included in the monitoring programme i.e. dams, estuaries and wetlands.

6.4 Reporting on the biomonitoring programme

Reporting of the success of management activities should be in terms of both interim and long term objectives.

The type and format of information that water quality managers will need includes:

- The relative pristine **status** of each resource, reflecting "the state of the environment"
- The presence of any **trends**

Data should be presented both in tabular and spatial format (eg. via a GIS, with areas or resource being colour-coded).

6.5 Use of information

The information reported on a **national** level will be used by managers for:

- Evaluation of the management of impacts to answer the question "have management actions improved the situation?"
- Evaluation of the suitability of guidelines, in terms of their ability to protect the environment

Additional information that should be derived from **regional** or **local** level programmes would be used by managers for:

- Site specific analyses
- Determining cause-effect relationships between impacts and changes in the environment (particularly with respect to the relationship between chemical water quality and ecosystem health)
- Setting of environmental objectives
- Evaluation of the suitability of guidelines, in terms of their ability to protect the environment

It should be noted that such information is unlikely to be available from a national monitoring programme.

6.6 Management requirements that will be met by the programme

The primary purpose of biomonitoring on a national level will be to support management actions to protect and preserve the biological integrity of natural systems, including the taking of corrective action when the health of such systems is threatened or degraded.

Information that will ultimately be derived from final biomonitoring programme, to support management of the aquatic environment, could be used for:

- Situation analyses (e.g. the "health status" of a catchment)
- Assessment of the effectiveness of management actions at a location, by measurement in terms of objectives (where these exist), guidelines, or values associated with an equivalent, "undisturbed" site
- Comparison of the status of different catchments
- Comparison of the status of different resource types (eg. rivers, wetlands, etc.)
- Deciding on the allocation of resources for the protection of the health of aquatic ecosystems

It also recognised by the Department that there are a number of regional and local biomonitoring programmes already in place, operated by the Department and other bodies. Information derived from these programmes may be of use at a national level.

7. SPECIFICATION OF A DESIGN FRAMEWORK

7.1 Scope of the monitoring programme

The broad purpose of water quality monitoring is to provide information to water resources managers and other stakeholders which they can use to assess the fitness of water for use and to make decisions required for water resource management.

> **The specific long-term goal of the biomonitoring programme will be to directly measure, assess and report on the *health status and trends* of aquatic ecosystems, including those of rivers, dams, wetlands and estuaries, in South Africa.**

The data collected by the programme could also be used to support:

- assessments of the likely impacts of changes in water quality and or flow regime on the health of aquatic ecosystems
- the formulation of scientifically defensible environmental quality objectives, based on ecological characteristics
- regional audits of the status of aquatic ecosystems.

7.2 Information users

The programme must be designed to meet the information requirements of the primary users, namely water resource managers in DWAF, tasked with the duty of ensuring the sustainable use and health of South Africa's aquatic ecosystems.

Secondary users of the information provided by the biomonitoring programme could include any or all of the following:

- National, provincial and local environmental protection and nature conservation organisations responsible for water resources management, or concerned with aquatic ecosystems;
- Effluent producers having to comply with requirements aimed at protecting the health of aquatic ecosystems;
- Interested and affected individuals and groups in academic institutions, non governmental organizations, community based organizations and the general public.

7.3 Geographic coverage

In order for the biomonitoring programme to meet its stated purpose, it is clear that an effort on a national scale is required. However, the variability of conditions across the country - in terms of climate, geography and the influence of human activities - will require the use of region-specific reference conditions as opposed to a single, national reference condition.

The scale of the biomonitoring programme, in terms of the number and location on monitoring sites, will have to take into account the concept of biogeographic regions, or physiographic regions. Location of individual monitoring sites will then have to be determined within the context of these regions.

Because of the different approaches that will be needed to monitor and manage the different types of aquatic resources, the initial biomonitoring programme design will focus on the development of a system for monitoring of riverine ecosystem health.

7.4 Assessment end-points of aquatic health

The role of both reference sites and water quality criteria in determining the health status (and trends) of aquatic ecosystems needs to be well defined. In addition, the assessment methodology should be well defined and take into account:

- Use of appropriate ecosystem indicators
- Use of appropriate ecosystem indices

7.5 Reporting of information

The method and format used to present the information collected as part of a monitoring programme is critical to the success or failure of the programme. It is at this point that information users will judge whether or not the programme meets their information expectations.

While the data collected by the programme must have a sound scientific background, it needs to be presented in a clear, accessible and understandable format. Original data must always be available, if needed, to motivate conclusions and assessments. The optimal use of ecosystem indices will facilitate this need, and techniques and methods must be developed to present these in an easily understandable format.

The programme must be designed in such a way that the GIS platform of the Department of Water Affairs and Forestry can be used as one of the principle mechanisms by which information can be reported and used.

7.5.1 Prototype biomonitoring report

Development of the format whereby information on the general health status of aquatic ecosystems could be reported on national, regional and catchment scales in South Africa, will be done by means of "prototype reports". This reporting format must be developed on an on-going basis, and revised at key points in the project in order to provide a verified and documented link between management needs and expectations, and the capability of the monitoring programme to meet those needs.

7.6 Design team composition

The technical design team for the project will be composed of managers, scientists and researchers from a number of organisations, including universities, consultancies, national and provincial departments, and various others. This multi-disciplinary team will be managed by the CSIR, who are responsible to the DWAF for the overall project.

8. TERMS OF REFERENCE FOR TECHNICAL DESIGN

This report completes the definition of the specifications required for the design of a national programme to monitor the health of aquatic ecosystems. The next steps are documented in the terms of reference for the project and other supporting documentation.

The first step for the technical design team is to develop the design framework presented here to a level of detail at which the technical and practical feasibility of its implications can be tested. Once this has been done, it can be decided whether the design framework need to be modified or whether it can serve as a basis for the implementation of the monitoring programme.

9. TERMINOLOGY

A number of key concepts applicable in water quality and aquatic ecosystems management are described in previous sections of this document. Additional terms are presented below; either for background purposes or to provide further clarification.

biodiversity is the "variety and variability amongst living organisms and the ecological complexes in which they occur" (OTA, 1987, as quoted by Angermeier and Karr, 1994).

an *ecosystem* is a dynamic changing entity. Essentially, it includes the diversity, distribution, abundance, and activity, of life in a region, as well as the interaction between these and other physical components (Kevan 1995).

ecosystem health can be compared to human health in that a decrease in health can be quantified in terms of indicators, or symptoms, such as reduced species diversity, shortened food-chain length, reduced population stability etc. (Roux *et al*, 1993).

The term *aquatic ecosystem* has been defined in the South African context as "water that is used as a medium for habitation by aquatic organisms and for aquatic processes, as a source of drinking water for wildlife and as a source for water for maintaining riparian biota and processes." (DWAF, 1995)

the *pristine* condition of an ecosystem can be defined as that existing at a point or area with minimal impact from human activities, such as point or non-point source pollution, altered flow regimes, riparian zone alteration, etc.

riparian zone is the area adjacent to a river or stream with a high density, diversity and productivity of plant and animal species relative to nearby uplands (EPA, 1994).

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APPENDIX A

Extracts from the White Paper on:
"Water Supply and Sanitation Policy"

Extract from
White Paper on: "Water Supply and Sanitation Policy"
Department of Water Affairs and Forestry - November 1994

"The Department of Water Affairs and Forestry's policy on the environment is based on the unity and indivisibility of all aspects of human life and the total environment in which human development occurs. It is therefore a contradiction to talk of sustainable development from the perspective of service provision without ensuring that the environment from which the resource is derived is protected and sustained. In this regard the "indivisibility" of water as a natural resource is clearly evident - each activity or call on the resource has an impact and an effect. The environment should not therefore be regarded as a "user" of water in competition with other users, but as the base from which the resource is derived and without which no development is sustainable. Protection and conservation of the natural resource base is therefore imperative. Even the simplest and smallest of projects thus requires attention. The concept of water as having economic value should therefore be extended to it also having intrinsic environmental value.

The Department will compile guidelines for sustainable development in the near future, after due consultation. The guidelines will aim to ensure that, in all development irrespective of size, the following issues are addressed:

- The resource characteristics are understood,
- Abstraction is sustainable and does not degrade the resources,
- Provision is made for monitoring the resource,
- Protection measures are implemented where necessary,
- Simple environmental impact assessment procedures are applied,
- An auditing function is established to review development projects and to ensure that the guidelines are being applied.

Further policy perspectives of the Department in relation to environment are:

Conservation and demand management In a semi-arid country such as South Africa, different users are increasingly having to compete for water resources. This could lead to long term degrading of limited sources of water which will be difficult if not impossible to rehabilitate. An important element of both water supply and water resource management is the establishment of a culture of conservation and the introduction of stringent demand management strategies to reduce water usage and the stress on resources.

Consultation Arising from the unity and indivisibility of human development and the environment, the role, opinion, and local wisdom of communities and other interested and affected parties is essential in ensuring the sustainability of both development and the environment. Of particular importance is the role of women and youth."

APPENDIX B

Monitoring systems design approach

MONITORING SYSTEMS DESIGN APPROACH

1. Background

One of the constraints to effective management of water resources is often the timeous availability of information on the status of these resources and the implications this has for the fitness for use and the sustainability of the resource. Despite the fact that large amounts of money and other resources are often allocated to water resources monitoring programmes, too many of them produce little or no information which can be used in effective management. Such programmes are said to be suffering from the "data-rich but information-poor" syndrome, usually as the result of being "data collection" orientated, rather than goal-orientated.

To either avoid or overcome these problems an approach has been developed to design water resources monitoring systems as *management information systems*. Such an approach is being used to design the DWAF's programme to monitor aquatic ecosystem health, otherwise known as its "biomonitoring" programme, and is briefly summarised below.

2. The Components of a Monitoring System

A monitoring system consists of several components, i.e.:

- sample collection;
- laboratory or field analysis;
- data handling;
- data analysis;
- reporting;
- information utilization.

Because most monitoring programmes view the production of data as the end point, only the first three components, i.e. the data generation portion, are usually considered in the design of the system. The approach of designing monitoring programmes as management information systems recognizes that the ultimate purpose of the monitoring programme is to produce information which is used to manage water resources and therefore gives equal weight to the last three components, namely the information generation portion of the monitoring system.

3. The Design Process

The generic process used to design monitoring programmes as management information systems are made up of the following steps:

Step 1: Define information needs of management

- identify information needs of management policies, decisions, systems and operational practices;
- summarize information needs of agency
- relate information needs to a monitoring strategy;
- define reporting and information utilization procedures desired by management;
- determine appropriate statistical means for producing the desired information.

Step 2: Define information that can be produced by monitoring

- statistically characterize the "population" to be sampled;
- review statistical methods applicable for generating the desired information, including their data requirements;
- state what information can be produced;
- compare information sought with information that can be produced.

Step 3: Design monitoring network

- document sampling locations;
- determine what constituents to measure;
- compute sampling frequency.

Step 4: Document data collection procedures

- field sampling operations and procedures;
- laboratory analysis methods and operations;
- data storage and retrieval system.

Step 5: Document information generation and reporting procedures

- data analysis hardware and software;
- reporting formats and frequency;
- information utilization procedures.

4. Role Players in the Design of a Monitoring Programme

The design approach described above requires that water resource managers as information users, those who will be responsible for producing the information and the monitoring systems designers should be working in close collaboration. Their respective roles are the following:

Water resource managers as information users:

These are the principle clients for the information being produced and should be closely involved, particularly in the first and second steps of the design process:

- ! As part of the first step they must use their knowledge and experience of water resources management policies, decision-making, and operational requirements to help the monitoring systems designers specify the information expectations to be satisfied by the monitoring programme and the preferred way that information has to be reported are determined.

- ! As part of the second step they must participate in making the trade-offs between the desired information and the information that can realistically be produced by a monitoring programme.

Monitoring Systems Designers

These people are responsible for the overall design framework, the process required to complete the design of the monitoring programme and the project management aspects.

- ! Their involvement is intensive during steps one and two during which they are responsible for the final design specification which forms the conclusion of these steps.

- ! During the remaining steps their functions are mainly that of project management and quality control to ensure that the actual design is completed according to the design specifications.

Technical Specialists

These people have a thorough knowledge of, and experience in, the various scientific and technical disciplines required to design and implement a monitoring programme.

- ! Their role starts during step two where they have to assess to what extent it is scientifically and/or technologically feasible for a monitoring programme to provide the information required by water resources managers. If it is not feasible they must participate in discussions with managers to find acceptable trade-offs.

- During steps three to five they are the principle people responsible for the detailed design work.

APPENDIX C

Water Quality Concepts

NB: This section uses concepts and definitions from the National Aquatic Guidelines - some may have been changed after their inclusion here.

WATER QUALITY CONCEPTS

Basic water quality concepts

To ensure that they effectively serve their purpose, water quality monitoring programmes need to be designed as management information systems. To support the design of a national programme to monitor the health of aquatic ecosystems, it is important to define some water quality and related concepts as they are used in South African water quality management policy and practice by the Department of Water Affairs and Forestry.

The term *water quality* is used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for use and its ability to maintain the "health"/integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents which are either dissolved or suspended in water.

The term *constituent* is used generically for any of the properties of water and/or the substances suspended or dissolved in it. In the international and local literature, several other terms are also used to define the properties of water or for the substances dissolved or suspended in it, for example water quality variable; characteristic; determinand; etc.

Fitness for use and related concepts

Part of DWAF's mission is to maintain the fitness for use of water on a sustained basis. The *fitness for use* of water is a judgement of how suitable the quality of water is for protecting of the health of aquatic ecosystems, or for its intended use. The concept of fitness for use is central to water quality management in South Africa and to the design and implementation of water quality monitoring programmes.

Water uses and aquatic ecosystems

The DWAF's mandate requires it to protect and maintain the health of aquatic ecosystems. It also has to ensure fitness of use for the four broad categories of water use are recognized in the South African Water Act, namely:

- domestic purposes
- industrial purposes
- agricultural purposes
- recreational purposes.

The water quality requirements of these water uses and those for the protection of the health of aquatic ecosystems, form the basis on which the overall fitness for use of water is judged.

Water quality characteristics and requirements

In order to determine the water quality requirements for aquatic ecosystems, it can be characterized in terms of those factors relating to water quality:

- Typical water quality problems which affect the health of aquatic ecosystems;
- The role that water quality plays in sustaining the health of aquatic ecosystems;
- The nature of the effects of poor water quality on aquatic ecosystems;
- The norms which are commonly used as yardsticks to measure the effect of water quality on aquatic ecosystems;
- The water quality constituents which are of concern;
- Any other site- or case-specific characteristics of aquatic ecosystems which may influence its water quality requirements.

Determining fitness for use

To be able to make judgements about the fitness of the water for protecting aquatic ecosystems, one needs to:

- Characterise the particular aquatic ecosystem from a water quality perspective;
- Determine the water quality required to protect aquatic ecosystems;
- Obtain information on the key constituents and other factors which determine the fitness of water for protecting the health of aquatic ecosystems;
- Establish, if possible, how the health of aquatic ecosystems will be affected by the prevailing water quality;
- Determine whether possible adverse effects of water quality can be mitigated for.

The fitness for use of water can range from being completely unfit for use to being 100% or ideally fit for a specific use.

Water quality can affect the health of aquatic ecosystems, or water uses, in many different ways. It is therefore necessary to use different norms, such as the effects on species loss; riparian zone degradation, etc. as yardsticks when making judgements about the fitness for use of water.

Water quality criteria

It is clear that water quality alone cannot be used as the basis for judging the health of aquatic ecosystems. Nonetheless, the use of predetermined guidelines or criteria for aquatic ecosystems can serve to ensure that the quality of water meeting such guidelines does not constrain ecosystem maintenance or development.

In South Africa, such guidelines are in the process of being developed ("Water Quality Guidelines for the Natural Aquatic Environment"), and are due to be published by the DWAF at the beginning of 1996.

Water quality criteria are scientific and technical information provided for a particular water quality constituent, expressed as chronic and acute adverse effects on aquatic ecosystems. They take the form of numerical values and/or narrative statements intended to provide long-term protection to the resource base. South African water quality criteria have been derived on the assumption of both long-term and continuous exposure to water of a given quality.

The *No Effect Range (NER)* and the *Target Water Quality Range (TWQR)* being developed in the guidelines are not water quality criteria *per se* but are rather management objectives which have been derived from numerical or narrative criteria. As a matter of policy the Department will strive to maintain the quality of South Africa's water resources within the No Effect Range. Therefore, the NER is referred to as the Target Water Quality Range (TWQR) in the South African Water Quality Guidelines. The Target Water Quality Range (TWQR) is thus the in-stream water quality required to protect aquatic ecosystems.

APPENDIX D

Water Quality Management Interviews

The following water quality managers were interviewed as part of the process of determining water quality requirements:

- C Andrew Brown, Deputy Director: Water Quality Management, Department of Water Affairs and Forestry

  Wouter van der Merwe, Manager: Scientific Services, Department of Water Affairs and Forestry

- C JLJ (Sakkie) van der Westhuizen, Director: Water Quality Management, Department of Water Affairs and Forestry

- C Henk van Vliet, Director: Institute for Water Quality Studies, Department of Water Affairs and Forestry

The following questions were used as a basis for discussion on management information needs for aquatic ecosystems management:

1. What do you understand under the concept of "the health of an aquatic ecosystem".
   - What makes up an ecosystem; what would its boundaries be? what different types of ecosystems need to be managed?
   - How will you know whether or not it is healthy?
   - What kinds of measuring sticks do you think one should use to determine its health? e.g. biodiversity, integrity etc.; and what the perceived advantages/disadvantages of each?
   - Can one, after this discussion, formulate a quantitative definition for "ecosystem health"?

2. What are the purposes and/or benefits of maintaining healthy ecosystems?
   - What is the goal(s) of ecosystems management?
   - Are there specific policy and/or legal requirements/implications of this goal?
   - Who are the important stakeholders (I&APs); what are their expectations?
   - Are specific benefits to be derived from maintaining healthy ecosystems for the utilization and management of water resources in general and water quality in particular?

3. How will DWAF go about meeting the goal of ecosystems management, in terms of:
   - Selecting and prioritising management interventions
   - Setting water quality guidelines

- Setting receiving water quality objectives
- Evaluating the impacts of effluent discharges
- Measuring compliance
- Reporting on the state of water resources

4. How will DWAF report to the stakeholders on the success of its ecosystems management?