River Biomonitoring:

General Information

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1. Introduction

The National Water Act (No. 36 of 1998) of South Africa has provided the legal framework for resource protection, particularly with the provision for the Ecological Reserve. The Ecological Reserve is "*the quality and quantity of water requires to protect aquatic ecosystems in order to secure sustainable development and use of the relevant water resource*" (National Water Act No. 36 of 1998, Chapter 1, Section 1.1.xviii.b).

Department Water & Sanitation (DWS), as custodian of all water resources in South Africa, is the controlling authority for resource protection and enforcing statutory requirements (in terms of legislation, policies and guidelines) by implementing both resource-directed measures and source-directed controls. Resource-directed measures include:

- the development of water quality guidelines for various users (e.g. domestic use; aquatic ecosystems; livestock watering, etc.);
- the development of a classification system to assess degrees of resource-use and consequent ecological health or degradation;
- the development of a National River Health Programme with appropriate biomonitoring methods, such as aquatic biomonitoring, and;
- the development of methods to quantify the Ecological Reserve.

Source-directed controls are exemplified by licenses, which specify allowable resource-use, such as water abstraction, effluent discharge, and land-uses that result in stream-flow reduction.

However, DWS is increasingly enforcing resource-directed measures, such as aquatic biomonitoring and toxicology, through its inclusion in Water Use Licences (WUL). Although it might currently not be the case that these protocols are required for Gold Fields various mining operations in terms of their WULs, it is important to note the advantages of conducting aquatic biomonitoring in surface water resources on which it may potentially impact.

In-stream bio-assessment surveys, commonly referred to as aquatic biomonitoring, are used to assess the health of water resources. The in-stream indicators monitored during a biomonitoring survey act as signals of deteriorating conditions or "*red flags*"; thereby indicating a problem, but without providing any definite causal links. This is why aquatic biomonitoring is always complimentary to toxicology assessments and hydrochemistry sampling, and its interpretation.

Inevitably, due to the life cycle of aquatic macro-invertebrates, results from aquatic biomonitoring are able to "*look back in time*" and would reflect impacts that occurred in a particular river segment as far back as six weeks (due to the life cycle of some aquatic macro-invertebrates within the water environment), whilst results from toxicology and hydrochemistry sampling reflect only water quality at the time of sampling.

2. 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 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 – preferably conducted twice per year in a wet and dry season, respectively.

The resulting data sets will be analysed to provide the basis for defining normal limits of variation or diagnosing ecosystem impairment.

3. 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:

- *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.

4. 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*".

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. 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.

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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 tools for organising and abstracting ecological data so that these can be understood by non-specialists.

6. Assessment of aquatic ecosystem health

6.1. Assessment relative to a reference point

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

Unlike water quality, where the reference point is a pre-determined standard (or guideline), usually based on the use of the water, 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, 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.

6.2. 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.

- *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 subregions, thereby grouping mountain-stream or lower-river zones of many rivers.

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, but do represent a point or area with minimal impact from human activities.

7. Toxicology

7.1. Background

Aquatic toxicology is the study of toxic effects of chemicals on living organisms in the aquatic environment. In the past, most organisations have generally been relying on chemical monitoring alone, for water quality management. This is a combination of end-of-pipe discharge standards for polluters (e.g. industries), and collecting water chemistry measurements from water bodies (e.g. rivers and dams). Different organisations, commerce and industry have historically developed an extensive water quality network, based on routine sampling of water bodies and analysing samples for their chemical profile.

Although this information is very valuable, it is not sufficient to assess the actual impact of pollution on aquatic biota. Information on the chemical and physical structure of a pollutant will therefore not indicate its toxicity (or how poisonous it is) to aquatic organisms in their natural habitat. If this information is required, laboratory-based experiments, called toxicity tests, are carried out using living organisms which are sensitive to pollution, e.g. certain species of fish, algae and riverine macro invertebrates (or river insects), and the water flea *Daphnia*. These tests then provide scientifically derived limits for particular chemicals or effluents, which, provided they are not exceeded, will protect aquatic resources.

Toxicological data are therefore used to interpret water chemistry information by determining concentrations at which organisms respond, and provide a powerful basis for the interpretation of biomonitoring data.

7.2. Applications of toxicological data

The South African Water Quality Guidelines for Aquatic Ecosystems were derived from international toxicological databases, and there are options for site-specific modifications of national guidelines based on using local indigenous organisms in toxicity tests. Methods for quantifying ecological requirements for water quality, as part of Ecological Reserve assessments, include requirements for toxicity data. The development of guidelines and procedures for the release of complex industrial wastewaters, which will include toxicological procedures, has been initiated and is likely to be undertaken within the next two years.

Aquatic toxicology, particularly applied within Ecological Risk Assessment (ERA), is of most use to those who discharge wastewaters or whose activities contribute to non-point source pollution. Industry, mines, agriculture, and sewage works would all be potential users of the technology of aquatic toxicology. Water resource managers, such as DWS, as well as water boards and irrigation boards, could make use of this technology both in developing and refining water quality guidelines, setting site-specific guidelines, investigating the effects of single variables and/or whole effluents, and including toxicological end-points in discharge licenses. Industries which produce effluent that is discharged into river directly, or via municipal sewage works, could be required to use toxicological methods to check compliance with license conditions. In-stream testing of indigenous organisms could be used by resource managers, in conjunction with biomonitoring, to check whether resource objectives have been met.