CHAPTER 1

INTRODUCTION

1.1 WATER, THE CRITICAL NATURAL RESOURCE

From ancient times until today, civilisations have developed among rivers and lakes. Apart from the life-sustaining needs of water, it has also for thousands of years played an important role in recreational activities such as relaxation and angling. Water is furthermore of great spiritual value to most religions, especially as a symbol used during baptism. In the Bible, the word water is mentioned approximately three hundred and fifty times. Even the most hardened of animals need some sort of moisture to stay alive. Water is also a crucial component in the provision of food for humans and animals. In fact, our own body cells consist of more than seventy- percent water. This on its own emphasises the importance of water, which can be seen as the basis of all life forms.

In liquid form, water covers approximately 70% of the total surface of the planet as oceans, lakes, estuaries and rivers. The proportional distribution of water on earth is estimated at some 1,42 thousand million cubic kilometres (Davies & Day, 1998). If all were available for human consumption, this thesis is probably of little significance, but the truth is that very little of it is directly available as fresh water. More than 97% of the above mentioned figure resides in oceans as salt water (unfit for direct human consumption), and 2,2% occurs as ice sheets on the planet. The proportion of water that is both fresh and in liquid form is almost “vanishingly” small: less than 1% of the total (Davies & Day, 1998). If all of this were available for human consumption, there would probably still be ample to sustain the present human population of the world. The reality is, however, that a great proportion of this water is degraded to a state not fit for human use, resulting in “large” amounts of money being spent daily to purify and transport water for agricultural, industrial and other human driven uses.

1.2 MANAGEMENT OF THIS CRITICAL NATURAL RESOURCE

In the past, management of water resources was primarily based on the need to protect human health. The water quality of an aquatic ecosystem was generally managed within the acceptable norms for the uses of the specific water body, usually based on human health standards. As human activities have intensified and spread over the past few decades, the water quality of rivers, such as the Klip River, has been increasingly impacted and impaired. During recent years there has been an increasing awareness of, and concern about, the pollution of water resources across the world. People have also realised over time that not only has the water quality deteriorated, but that the entire ecological system or ecosystem is at the receiving end of the anthropological activities in its catchment. Recognition of these impacts has spurred increasing interest in describing the relationship between people and their environment. With this has come the very important realisation that water is not just the basis for human life, but in fact for all forms of life. For an aquatic ecosystem to provide a sustainable water resource, the entire aquatic ecosystem should be in balance. This has led to the realisation that managers should adopt the broad philosophy of integrated ecosystem management, rather than the previous, narrower one of chemical water quality management (Hohls, 1996). Resource planners, policy makers and researchers now recognise that a new ecologically-based approach is urgently needed to monitor the health or ecological integrity of aquatic resources.

New approaches towards achieving sustainable exploitation of water resources have been developed internationally. It is widely agreed that a properly developed policy framework is a key element in the sound management of water resources. A number of possible elements for such policies have been identified, especially during the preparation of Agenda 21 as well as various follow up activities (Helmer & Hespanol, 1997). Agenda 21 adopted some conceptual statements concerning water resources, but which apply to water pollution control as well as to other elements of water resource management. Two central statements were "*Fresh water should be seen as a finite and vulnerable resource, essential to sustain life, development and the environment*" and "*Water should be considered as a social and economic commodity with a value reflecting its most valuable potential use*". The latter statement suggests an overall concept for prioritising water-related development activities.

The present definition of water pollution is one of manmade or man-induced (anthropogenic) alteration of the chemical, physical, biological, or radiological integrity of water (Karr & Chu, 1997). It no longer defines pollution as the chemical contamination of water. Rather, it is a more comprehensive definition that includes any human actions (or the result of a human action) that degrades a water resource. Thus, humans may degrade or pollute water resources either by chemical contamination or by destruction of aquatic habitats. They may furthermore pollute by withdrawing water for irrigation, by over-harvesting fish populations, or by introducing exotic species that alter the structure of resident aquatic communities (Karr, 1994).

Prevent pollution rather than treating the symptoms of pollution. Past experience has shown that remedial actions to clean up polluted sites and water bodies are generally much more expensive than applying measures to prevent pollution from occurring. Although in many countries wastewater treatment facilities have been installed and improved over the years, water pollution remains a problem. In some situations, the introduction of improved wastewater treatment has only led to increased pollution from other media, such as wastewater sludge. In many countries, however, an increasing proportion of water pollution originates from diffuse sources, such as the agricultural use of fertilisers. The best management approach to minimise non-point source pollution would be the principle of "best environmental practice".

The “polluter-pay-principle”, where the cost of pollution prevention, control and reduction measures are borne by the polluter, is not a new concept. It has, however, not yet been fully implemented. This is despite the fact that it is widely recognised that the perception of water as a free commodity can no longer be maintained.

The “participatory approach” where all relevant stakeholders become involved in pollution control should always be encouraged in any water management programme. This approach involves raising awareness of the importance of water pollution control among policy-makers and the general public. Open access to information on water pollution should be given. This principle is directly related to the principle of involvement of the general public in the decision-making process, because a precondition to participation is free access to information held by public authorities. Open access to such information helps to stimulate understanding, discussion and suggestions for the solution of water quality problems (Helmer & Hespanhol, 1997).

Another important element in a water management strategy is the formulation of realistic standards and regulations. However, the standards must be achievable and the regulations enforceable. In most cases, water quality guidelines have been unrealistically developed, for instance when it was based on the toxicity of a variable to tolerant (hardened) or semi-sensitive fish species. Is this good enough for the preservation and conservation of our sustainable resources? Will this be adequate to secure and conserve our more sensitive species, or is our attitude still: "what's the issue about the loss of a species?". In effect the loss of a species, even in a small stretch of a river, is the degradation of integrity and will definitely have rippling effects on a system. In many cases, it is not possible to even measure these changes, but they will most surely have a negative influence on the ecosystem as a whole.

Water quality criteria are developed by scientists and provide basic scientific information about the effects of water pollutants on a specific water use. They also describe water quality requirements for protecting and maintaining an individual use such as irrigation, recreation and aquatic life. In the development of criteria to protect aquatic life, various aspects need to be considered due to the fact that within aquatic ecosystems a complex interaction of physical and biological cycles exist. Anthropogenic stresses, particularly the introduction of chemicals into water, may adversely affect many species of aquatic flora and fauna that are dependent on both biotic and abiotic conditions. Water quality criteria for the protection of aquatic life may take into account only physico-chemical parameters, which tend to define a water quality that protects and maintains aquatic life, ideally in all its forms and life stages; or they may consider the whole aquatic ecosystem.

In many countries/situations, money and manpower is to a greater/lesser extend applied to enforce these (sometimes) unfair or unrealistic guidelines. The question should thus be asked if these resources should not rather be directed towards the monitoring of the effects of prevailing circumstances on the biological communities dependent on the water. Humans, and their health, are obviously included in this category of dependence. Is the current justice system strong and effective enough to address the issues concerning this important life-sustaining resource?

More recently within the concept of the ecosystem approach to water management, attempts have been made to address criteria that indicate healthy aquatic ecosystem conditions. In addition to traditional criteria, new criteria try to describe the state of resident species and the structure and/or function of ecosystems as a whole. In developing these criteria, the assumption has been made that they should be biological in nature. In some countries, such as the UK and USA, research is under way in the development of biocriteria that express water quality criteria quantitatively in terms of the resident aquatic community structure and function. Biocriteria are defined as measures of "biological integrity" that can be used to assess cumulative ecological impacts from multiple sources and stress agents (Davis & Simon, 1995). In many countries, considerable efforts have been made to identify key species that may serve as useful integrative indicators of functional integrity of aquatic ecosystems. Ongoing research suggests that such criteria and indicators should include both sensitive, short-lived species and information about changes in community structure resulting from the elimination of key predators (Davis & Simon, 1995).

A major advantage of the integrated water quality objectives approach to water resource management is that it focuses on solving conflicts between various demands placed on water resources, particularly in relation to their ability to assimilate pollution. The water quality objectives approach is sensitive, not only to the effects of an individual discharge, but to the combined effects of the whole range of different discharges into a water body. The application of the ecosystem approach in water management has led to the development of objectives for safeguarding the functional integrity of aquatic ecosystems. The functional integrity of aquatic ecosystems is characterised by a number of physical, chemical, hydrological, and biological factors and their interactions.

1.3 ECOLOGICAL / FUNCTIONAL INTEGRITY OF AQUATIC ECOSYSTEMS

An *ecosystem* can be defined as any unit that includes all of its organisms 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 within the system (Odum, 1971). It thus includes all the physical and chemical (abiotic) components in addition to the biological components. The *Ecological Integrity* of an ecosystem can be defined as the ability of the system to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components, on temporal and spatial scale, that are comparable to the natural or unimpacted state of that ecosystem. It thus refers to the structure and functioning of an ecosystem under natural conditions or a state unimpaired by anthropogenic stresses (Roux, 1997; Roux, 1999). From the above mentioned, it can therefore be deduced that the overall ecological integrity of a system is determined by four main aspects, namely its physical, physico-chemical and biological (biotic) integrity and energy source input (Figure 1.1). In nature, these aspects cannot be seen as separate entities, as they are inter-linked in a complicated system wherein they are affected, and to a great extent determined, by one another.

A study to determine the ecological integrity of a system should therefore investigate as many of the different components of the ecosystem as possible. From the above, it becomes clear that a reference condition is also imperative in the determination of its ecological integrity. General approaches in the determination of a reference condition is the use of reference sites, historic data, experimental data and professional judgement (Hughes, 1995).

The physical integrity of an aquatic ecosystem will therefore refer to the extent of habitat alterations, in comparison to its state under natural, unimpacted conditions. Investigations into habitat integrity should be carried out in the following two aspects, namely habitat structure and flow regime (Figure 1.1). Human alterations of habitat structure could occur as siltation, or be seen in the condition of the riparian vegetation, width/depth of water, bank stability, channel morphology, gradient, instream cover, canopy, substrate, current and sinuosity. Flow regime, on the other hand, is influenced by human and natural factors and include changes in land use, velocity, high/low extremes, precipitation, runoff and ground water (Figure 1.1). The manipulation or alteration of any of the above-mentioned factors from their natural condition, will therefore imply that the physical integrity of the system is degraded. For example, anthropogenic activities such as overgrazing could lead to increased turbidity, which could result in the siltation of the habitat of certain fish or invertebrates species. The factors determining physical integrity are those often used in habitat indices (Davis & Simon, 1995). It should however not be confused with some habitat assessment indices that only investigate the condition and/or availability of habitat to aquatic biota.

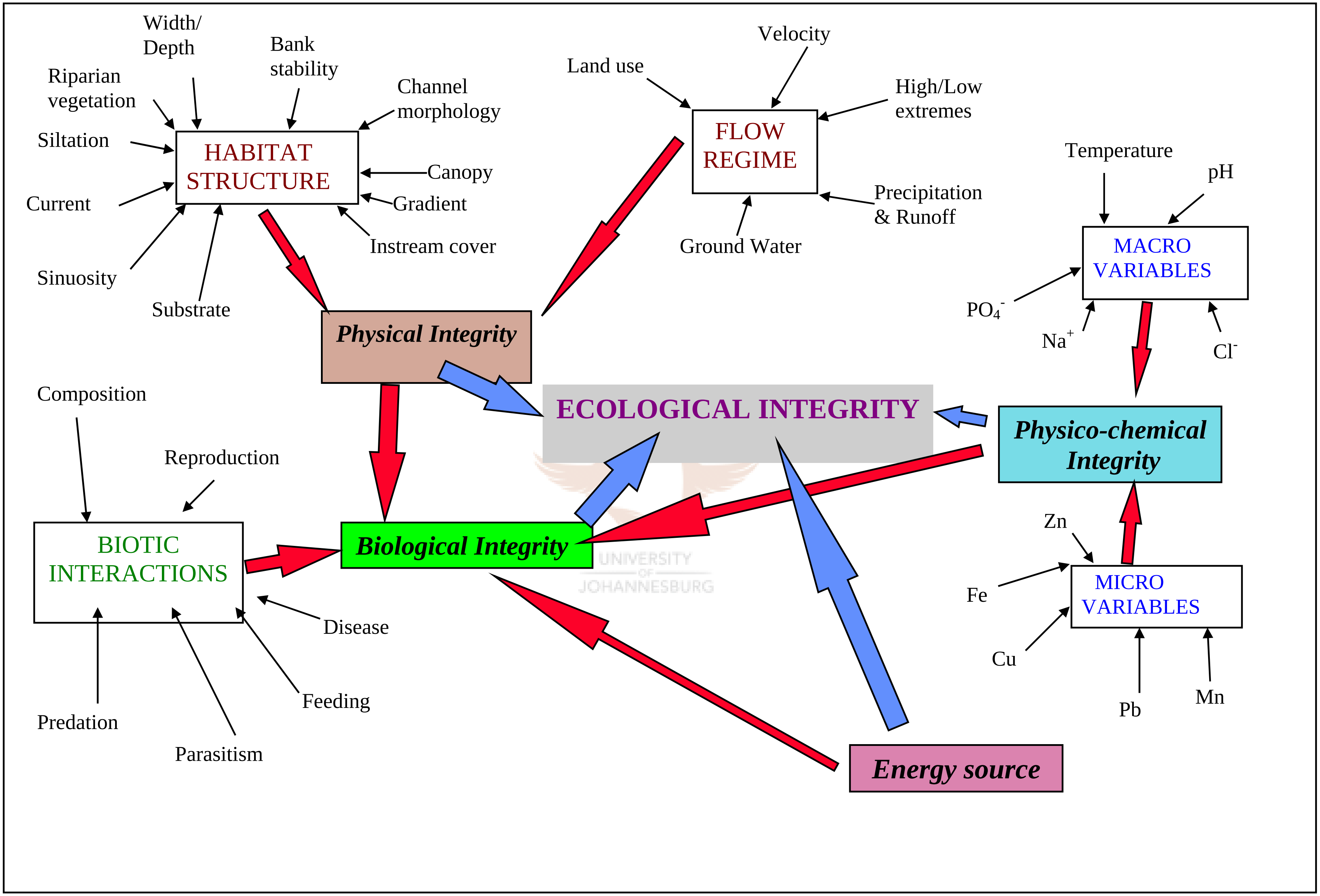

Figure 1.1: Factors influencing the *Ecological Integrity* of an aquatic ecosystem [adopted from Karr (1994) and Roux (1999)] .

The physico-chemical integrity of an aquatic ecosystem is determined by the current water quality of the system in comparison to the unimpacted state or expected state according to guidelines set for the system. Investigations should be made into as many variables of the two primary attributes, namely trace elements and macro physico-chemical variables. Trace elements will include variables such as metals (Al, Fe, Cu, Pb etc.) and biocides, while macro variables refer to aspects such as pH, temperature, phosphate concentrations, etc. The presence and compositions of such variables, under impaired conditions, in comparison to their presence and composition under natural or unimpaired conditions, would therefore determine the physico-chemical integrity of the specific water body. Pollutant-containing effluents, emanating from industries, would for instance alter the water quality of a river, thereby also decreasing the physico-chemical integrity of the system.

Biotic integrity of a system refers to the present state of the biotic assemblage in relation to its condition under natural, unimpacted circumstances. According to Karr (1994), the biotic integrity can be influenced by variables such as water quality, habitat structure, energy source, flow regime and biotic interactions. Factors within a biotic assemblage, which can be changed due to anthropogenic activities, include species diversity, trophic composition, individual abundance and the condition or health of the biota present in the system. It includes all the groups of living organisms, such as fish, other aquatic vertebrates, benthic invertebrates, periphyton and aquatic vegetation. Certain key indicators, known to reflect the biotic integrity, are usually selected for application in a biomonitoring programme (Karr, 1981).

The ecological integrity of an aquatic ecosystem is thus a complex system wherein interaction occurs between the different components of the aquatic ecosystem. A shift in the balance of the system, due to anthropogenic impacts, will be reflected by the affected component/s, which in turn influence other components and therefore the overall ecological integrity. It is obvious that all factors responsible for ecological integrity of a system cannot be investigated. Biological communities have the ability to reflect overall ecological integrity (physical, chemical and biological integrity) (USEPA, 1996) and could therefore be used effectively to monitor overall ecological integrity. Due to interaction between the different components in an ecosystem, a change in one component is usually reflected by another component. Certain key indicators are therefore usually selected to be included in a biomonitoring programme (USEPA, 1996).

1.4 BIOMONITORING

What is Biomonitoring?

Biological monitoring (biomonitoring) is the use of a biological entity as a detector, and its response as a measure, to determine environmental conditions. As an important supplement to chemical sampling, biological measurements can reflect both current conditions and temporal changes in water bodies, including the cumulative effects of successive disturbances. Biological criteria are benchmarks for water resource protection and management decision-making. Expressed as numeric values or narrative expressions, they measure attainment of biological integrity. In turn, biological integrity describes the most robust aquatic community to be expected in a natural condition in a water resource, relatively unaffected by human activities (USEPA, 1996). The primary goal of biological monitoring is thus to measure and evaluate the consequences of human actions on biological systems.

Two major categories are of importance in the biological monitoring of aquatic environments. The first category comprises the *bioassays* (early warning or alarm systems, ecotoxicological tests, bioaccumulation tests, biodegradation tests, eutrophication tests). The second category, *bioassessment*, covers the methodologies related to analysis of the biological communities. Bioassays are experimental, while bioassessments are observational in approach (USEPA, 1996).

The history of biomonitoring

<u>International</u>

The fact that humans have a negative impact on the environment they live in, has been realised even from Biblical times. Aristotle was aware of the effect of organic pollution, and a sixteenth-century author made mention of the pollution caused by tin mines (Hynes, 1994). It was however less than a century ago in Germany that Kolkwitz and Marsson (1908, 1909) codified the study of microbiota into a system that could be used to gauge the severity of organic pollution. This "Saprobiensystem" was further expanded and explained by Kolkwitz in 1950, and then numerous Europeans changed it into quite a complex edifice in which individual species of animals and plants were allotted points on a scale of tolerance to organic pollution. These points were then added up to give a score to the habitat being sampled. In the period of 1927/1928, Richardson conducted a study on the effect of organic pollution by the cattle industry on macroinvertebrates of the Illinois River. It produced similar ideas of zones of degradation and recovery that could be characterised by benthic biota. These early attempts at designing codified systems that could produce numerical results were primarily floristic and faunistic, although some authors had already introduced the idea the community structure is relevant, and not merely the list of species. Nevertheless, the idea persists that a list of the numbers of species is informative, although it is often combined with measures of abundance of each species. Many biologists have furthermore used their special knowledge of particular groups to assess pollution. The search for indices of various types still continues today in many countries around the world (Hynes, 1994). Everyone is searching for the perfect index, the answer to aquatic management problems.

During the mid 1980's, the need for cost effective biological survey techniques was realised in the United States of America because of rapidly dwindling resources for monitoring and assessment. This was also the birth of rapid bioassessment protocols (RBPs) as they searched for cost-effective, yet scientifically valid assessment methods. These methods were also to provide for multiple site investigations, quick turnout of results which are easily translated to management and the public (USEPA, 1996). Rapid bioassessment protocols are at present used with great success in many countries as tools for biomonitoring.

National

Biological indices have been used fragmentally by some scientists in South Africa during the past few years. Chutter has used the concept of biotic indices in South Africa as early as 1972 (Hynes, 1994). He later adopted an invertebrate assessment index used by the British Biological Monitoring Working Party (BMWP) for the use under South African conditions. This index, called the South African Scoring Index (SASS) is the most widely tested and applied biotic index in South Africa. It is also presently one of the most famous rapid bioassessment protocols used in the country (Murray, 1999). The newest version (SASS5) has been released in 2001, and is developed to comply with international quality control standards (Dickens & Graham, 2001).

Traditionally, monitoring of South African aquatic ecosystems, performed by the Department of Water Affairs and Forestry (DWAF) was also based primarily on the measurement of physical and chemical water quality variables. Management strategies applied were based on the assumption that if the water quality of a system was managed within certain prescribed guidelines, the entire aquatic ecosystem would be in a "healthy" condition. The present viewpoint of the DWAF is a more integrated ecosystem management approach, which includes the overall response of the environment to stressors, arising from both natural and human-induced processes. The new approach will include biological monitoring through the application of Rapid Biomonitoring Protocols (RBP's). This is to evaluate the complete condition of an aquatic ecosystem and to determine its *Ecological Integrity*, as described by the River Health Programme (RHP) (Roux, 1997). The RHP has been implemented with great success in most regions of South Africa during the period of 1995 to 1999 (Murray, 1999). One of the primary objectives of this study was to establish protocols for Rand Water's biomonitoring programme of the Klip River, also to be implemented in other rivers of concern to them.

The new water laws of South Africa have also portrayed the acceptance and implementation of an ecosystem approach in our water management strategies. The National Water Act (Act No 36 of 1998) states that the National Government is the trustee of the country's water resources. Water resources are a national asset to be utilised in the best interest of all citizens in a sustainable manner, to guarantee the needs of future generations. The needs of the environment are also guaranteed in the Act, flowing from the Constitutional right of all to a safe and healthy environment. This means that the government is tasked to ensure that water resources as well as water users are protected, and the enabling mechanism to do so is the National Water Act. This act requires the registration of all water users to establish where, and how much water is being used in the country, and the nature and extent of water use in a catchment. Users are required to apply for a permit that entitles them to use water within the terms and conditions of the licence. Resource directed measures (Chapter 3 of the National Water Act) must be taken to ensure sustainable use of this vulnerable resource (DWAF, 2000). In the Water Law, the Reserve is identified as that quality and quantity necessary to protect basic human needs and aquatic ecosystems. The setting of resource quality objectives provides a rigorous numeric or descriptive statement of the requirements of the reserve for that particular water resource, in measurable, enforceable terms (DWAF, 1999). The ecological integrity of a river is generally defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of the region (Karr *et al*., 1986).

Why Biological Monitoring?

The status of living systems provides the most effective and direct measure of the integrity of water, the resource on which all life depends. Biological monitoring is an essential element needed to assess the environmental health of aquatic ecosystems and to protect biological resources (Karr & Chu, 1997). Biological organisms are diagnostic in determining the health of aquatic ecosystems and they can be measured quantitatively. Ecologically, the concept of niche space provides the theoretical framework for the understanding of environmental health. The organisms that inhabit aquatic ecosystems are the fundamental sensors that respond to any stress affecting that system. The health of an aquatic ecosystem is reflected in the health of the organism that inhabits it. Any stress imposed on an aquatic ecosystem manifests its impact on the biological organisms living within that system (Loeb, 1994). There is, furthermore, substantial and widespread evidence that the historic monitoring approaches did not protect water resources adequately, and that biological monitoring has repeatedly proved to be sensitive and reliable as an assessment tool (Karr, 1994).

Selection of the appropriate biotic assemblage

The selection of the correct assemblages, and the attributes of the assemblage will, to a great extent, determine the value of biomonitoring. The biota in water, and on land, differs greatly in their physiological sensitivity to various chemicals. Also, they differ in the assortment of chemicals necessary for growth. The most effective method to obtain reliable results is obviously to study all organisms in the food web that live in a given area. The more lines of evidence from which one can draw conclusions, the more reliable the result. One cannot, however, monitor all the organisms within the system, and it is therefore important to select the correct organism/s. Those that are important in the transfer of nutrients and energy through the food web are usually of great value to detect changes. These organisms, if eliminated or greatly reduced, will have great effects upon the cycling of nutrients (Patrick, 1994). The most commonly used biotic assemblages are fish, macro-invertebrates and periphyton.

Fish

Fish communities possess various characteristics that render them important in the assessment of river health. They occupy positions throughout the aquatic food web and are typically present in all but the most polluted waters. Because fish often range over considerable distances, they have the potential to integrate diverse aspects of relatively large-scale habitats. Fish can therefore provide an integrative view of watershed conditions. Compared to other aquatic organisms, fish are relatively long-lived and are therefore useful to provide a temporal dimension of conditions. They are also relatively easy to identify, and after data is gathered, fish can be released again. For the general public, fish are also the most well known of aquatic organisms, and they are more likely to understand information about the condition of the fish community than of other taxa such as invertebrates. There are, however, obviously also some difficulties in using fish as biomonitors. Among the problems are the selective nature of some sampling gear for specific biotopes and for certain sizes and species of fish, the mobility of fish on spatial and temporal time scales, and the labour intensity of fish sampling (Karr *et al.*, 1986). The advantages of using fish assemblages in biomonitoring can be summarised as follow (USEPA, 1996):

- Fish are good indicators of long-term (several years) effects and broad habitat conditions because they are relatively long-lived and mobile.
- Fish assemblages generally include a range of species that represent a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, piscivores). They tend to integrate effects of lower trophic levels; thus, fish assemblage structure is reflective of integrated environmental health.
- Fish are generally at the top of the aquatic food web and are consumed by humans, making them important for assessing contamination which may affect human and animal health.

- Fish are relatively easy to collect and identify to the species level. Most specimens can be sorted and identified in the field by experienced fisheries professionals, and subsequently released unharmed.
- Environmental requirements of most fish are comparatively well known. In some countries, life history information is extensive for many species, and information on fish distributions is commonly available.

Macroinvertebrates

Like fish, the distribution and activities of benthic macroinvertebrates vary greatly, both spatially and temporally, over virtually all scales in polluted and non-polluted lothic systems. In relation to fish, advantages for incorporating benthic invertebrates into biomonitoring programs include their smaller size and limited mobility, which facilitates logistics of sampling and experiments, and an acknowledged sensitivity of many invertebrates to diverse pollutants. A disadvantage of invertebrates (compared with fish) is that they have a stronger seasonal cycle being more abundant and/or active at certain times of the year. Invertebrates also tend to have shorter life cycles, and streams generally contain many more taxa of invertebrates than fish. The latter attributes provide a mixed blessing: shorter life cycles suggest more rapid responses at the community level but greater temporal variability, and more taxa per site means more effort must be expended on taxonomic identification. The benefit of this additional effort is more data for detecting differences through time or among sites (Stewart & Loar, 1994). In general, the following advantages are attached to the use of invertebrates in biomonitoring (USEPA, 1996).

- Macroinvertebrate assemblages are good indicators of localised conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well suited for assessing site-specific impacts (upstream-downstream studies).
- Macroinvertebrates integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately one year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.
- Degraded conditions can often be detected by an experienced biologist with only a cursory examination of the benthic macroinvertebrate assemblage. Macro-

invertebrates are relatively easy to identify to family level; many "intolerant" taxa can be identified to lower taxonomic levels with ease.

- Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear, and has minimal detrimental effects on the resident biota.
- Benthic macroinvertebrates serve as a primary food source for fish, including many recreationally and commercially important species.
- Benthic macroinvertebrates are abundant in most streams. Many small streams (1st and 2nd order), which naturally support a diverse macroinvertebrate fauna, only support a limited fish fauna.

Which attributes (metrics/criteria) of the assemblage must be used in the assessment of biotic integrity.

The success of biological monitoring programmes and their use to define and enforce biological criteria is tied to identify biological attributes that provide reliable signals about resource condition. Knowledge of natural history and familiarity with ecological principles and theory guide the definition of attributes and the prediction of their behaviour under varying human influences. But successful biomonitoring depends mostly on demonstrating that an attribute has a reliable empirical relationship – a consistent quantitative change- across a range, or gradient, of human influence. Some major biological attributes have been proven to serve as reliable indicators in diverse circumstances. The bottom line however, still is that metrics should be based on sound ecology and adapted only with great care when carried over from one system to another (Karr & Chu, 1997).

Other important aspects to consider in biomonitoring programmes

Originally, biological monitoring was developed to detect effects from single point source discharges, or, perhaps, effects resulting from multiple discharges originating within one drainage basin. However, some recent studies suggest that trends within an ecosystem may also be driven by events geographically distant from the ecosystem itself. If long term monitoring is thus not carried out on a global scale, changes on a global scale might be confused with cumulative impacts within a more limited region. Besides the question of sample size for these studies, concern should also focus on the scale (or size of sampling unit) needed to address the change and the correlation between units. Scales that are too small may be erratic, while a larger scale may not exhibit enough variation to detect the changes. Larger scales require longer time to establish baselines (Cairns & Smith, 1994).

Monitoring is costly and cannot be carried out in great detail at every level of biological organisation – every population, community and ecosystem - globally. However, in initial stages of development of a biological monitoring programme, it is important to determine which types of data are most informative under each set of circumstances. Several benefits can be derived from this exercise.

- The most informative and important end points can be selected from an array of attributes. These attributes will have a high correspondence in response to other crucial attributes.
- Attributes that are unique and have low redundancy with other attributes can be determined, and their significance to the continuation of data gathering can be evaluated.
- Consistency of trends from multiple lines of evidence can be determined in order to increase confidence in the implications of the changes being measured.

Estimation of redundancy must be done carefully because the information that appears redundant for short-term monitoring may not be so for long-term monitoring to establish trends, cycles, and the like (Cairns & Smith, 1994).

Habitat and Water Quality assessment

Karr and Chu (1997) state that human activities degrade water resources by altering one or more of five principal groups of attributes – water quality, habitat structure, flow regime, energy source, and biological interaction – often through undetected yet potentially devastating effects on water resources. This means that the evaluation of habitat quality is critical to any assessment of ecological integrity and should be performed at each site at the time of the biological sampling. The quality of the instream and riparian habitat influences the structure and function of the aquatic community in a stream. The presence of a degraded habitat can sometimes obscure investigations on the effects of toxicity and/or pollution (USEPA, 1996). The water quality, and especially biota-specific variables such as temperature, oxygen saturation and pH, should also be measured during biological sampling. This could be of great value in understanding the observed biotic assemblage condition at the site under investigation.

1.5 OBJECTIVES OF THIS STUDY.

The Klip River catchment is situated in the Gauteng province of South Africa, and drains the southern Witwatersrand region. This river is one of the most heavily impacted river systems in South Africa and is subjected to almost every conceivable type of pollution (DWAF, 1996). It is exposed to various anthropogenic activities from its source to its confluence with the Vaal River. No areas of the river are therefore pristine or close to its natural condition. The primary point sources of pollution include gold mining activities and waste water treatment work (WWTW) effluents. Diffuse pollution sources originate primarily from slimes dams, rock dumps, degraded sewerage networks, industries, solid waste disposal sites, informal settlements and agricultural activities. The biological integrity of the Klip River system is expected to be considerably impaired.

Present alterations to the system include:

- a completely modified hydrological regime – strong seasonality of rainfall in this area is cancelled by more constant contribution from treated wastewater and urban runoff;
- a changed chemical composition of the water – rain water largely reaches the river via urban run-off, effluent discharge, WWTW discharges and mine drainage;
- changed instream morphology brought about by the building of weirs, bridges, recreational facilities etc.; and
- degradation and destruction of natural riparian habitats as a result of formal and informal urbanisation, and industrial, agricultural and domestic activities close to the river bank.

Although highly impacted, this river must serve all recognized user groups as identified by the Department of Water Affairs and Forestry, being domestic, agricultural, industrial and recreational. It is therefore of cardinal importance to investigate the ecological integrity of this aquatic ecosystem. Any information on this system will be of great value in the development of a management programme for this catchment, if its sustainability is to be assured.

The primary objective of this study was therefore to determine the ecological integrity of the Klip River System.

Secondary objectives include the following:

- To develop a multimetric index, using fish from the Klip River, which would indicate the ecological integrity of the system.
- To compare the results of different biotic indices to determine if there is any correlation between the results of indices based on different biota.
- To apply existing indices for the determination of physical and biological integrity and to investigate the possibility of modifying these indices for the specific system to ensure optimal results.
- To investigate the water quality of the mentioned river and to indicate possible problematic areas.
- To establish a foundation for the implementation of biomonitoring in the Klip River and other rivers in the region that can be used by Rand Water in its catchment management programme which is aimed at source water protection.
- To contribute to the National River Health Programme of South Africa.

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