CHAPTER 8

General Summary, Conclusions and Recommendations

8.1 GENERAL SUMMARY & CONCLUSIONS

Water Resource Management and Monitoring

In the past, management of water resources was primarily based on the need to protect human health. The 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. People have, however, realized over time that under this management approach, not only the water quality deteriorates systematically, but that the entire ecosystem is at the receiving end of the anthropogenic activities in the catchment. With this recognition has come the very important realization that water is the basis of all forms of life, not just human life. Most water resource managers around the world have therefore rejected the previous approach of merely chemical water quality management, and have adopted a new and broad philosophy of integrated ecosystem management (Hohls, 1996).

Management of a river on an ecosystem scale therefore requires the assessment of the ecological integrity of the system. Ecological integrity is defined as the ability of an ecosystem to support and maintain a balanced, integrated composition of physico-chemical and physical characteristics, as well as biotic components, on temporal and spatial scale, that are comparable to the natural or unimpacted state of that ecosystem or a representative minimally disturbed site (Karr & Chu, 1997; Roux, 1999). Biological communities integrate the effects of different stressors and thus provide a broad measure of their aggregate impact. They therefore have the ability to reflect overall ecological integrity (physico-chemical, physical and biological integrity) of an ecosystem, and could be assessed by the application of biological monitoring (biomonitoring) protocols (Barbour *et al*., 1999). The evaluation of habitat quality and availability is critical to any assessment of ecological integrity, and should also be performed at the time of biological sampling (Karr & Chu, 1997). The inclusion of physico-chemical integrity (water quality) determination in a biomonitoring programme might be costly, but would improve interpretation of results, whereby the potential cause of degradation, be it habitat and/or water quality related, can be identified. This in return would simplify the identification of the potential source of the impact, and therefore also improve management of the negative anthropogenic activities in a catchment.

The Klip River Catchment

The Klip River catchment is situated in the Gauteng province of South Africa, and drains the southern Witwatersrand region. This catchment incorporates the southern part of Johannesburg, one of the most developed urban complexes in Southern Africa. This river is seen as one of the most heavily impacted river systems in South Africa, and is subjected to almost every conceivable type of pollution (DWAF, 1999). Two of its major tributaries, the Klipspruit and Rietspruit, are also considered highly impacted rivers. The Klip River must, however, still serve all recognised user groups as identified by the Department of Water Affairs and Forestry (i.e. domestic, agricultural, industrial, recreation and the natural environment).

The Klip River 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 type of stressors on the system vary to some extent between the different areas of the river. The primary point sources of pollution include mining, industrial and wastewater 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.

Physico-chemical Integrity (Water Quality)

It was evident from this study that the water quality of the Klip River is highly degraded and deviates from its natural state, due to the extensive anthropogenic activities in its catchment. The water quality guideline compliance index (GCI) indicated that the water quality of the river was excellent in the most upper reaches, but deteriorated drastically downstream. Urban runoff, gold mining and industrial activities, as well as formal and informal settlement runoff, primarily affected water quality of the upper Klip River (localities 1 to 3). Water quality variables of concern identified in the upper sections of the Klip River included: electrical conductivity, total dissolved solids, sulphates, water hardness, total alkalinity, magnesium, sodium, ammonia, phosphates and manganese. In the middle reaches of the system (localities 4 and 5), water quality degradation could be attributed to the influence of the Klipspruit water and wastewater treatment works (WWTW) effluents. Variables of concern in the middle section of the Klip River included suspended solids, turbidity, electrical conductivity, potassium, chloride, nitrates and ortho-phosphates. The impact of the polluted Rietspruit (mining, industrial, formal and informal settlement impacts) together with agricultural activities and WWTW's were identified as the major causes for the further degradation of the water quality in the lower section (localities 6 to 9) of the Klip River. Variables of concern in the lower section of the Klip River included: turbidity, suspended solids, electrical conductivity, sodium, potassium, chloride, nitrates, ortho-phosphates and iron. Levels of faecal coliforms were also high, especially in the lower reaches of the Klip River. The water quality of the Suikerbosrand, in the vicinity of locality 10, was generally much higher than that of the Klip River. The water quality guideline compliance index (GCI) was identified to be of great value to classify the general water quality of a site in terms of its compliance with a specific set of guidelines.

Physical Integrity (Physical Habitats)

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The Index of Habitat Integrity (IHI), as applied during this study, provided a wide, general perspective on the changes that took place, and the potential causes responsible for these changes in the Klip River system. The USEPA habitat assessment index (HAI) and Habitat assessment matrix (HAM) proved to be the most valuable indices for site-specific habitat assessments. Of the two, the HAI is proposed for future use, and should be adapted for application to each river system. The physical habitat condition, availability and overall integrity reflect the impact of the large human population and their associated activities in the Klip River catchment. Many instream and riparian zone habitat features were negatively impacted by these anthropogenic activities. Habitat variables of major concern and their probable sources in the Klip River catchment included the following:

- Flow modification due to WWTW effluents and storm water runoff from urban areas.
- Bank erosion due to increased flows and agricultural activities.
- Exotic vegetation encroachment
- Indigenous vegetation removal.

- Bed modification due to scouring, solid waste disposal and increased algal growth on substrates, due to nutrient enrichment.
- Instream habitat destruction (vegetation, riffles, rapids and pools) due to flow modification and agricultural activities

Refer to Figure 8.1, for a diagrammatic presentation of habitat degradation observed in the Klip River.

Based on the habitat assessment protocols applied, it is obvious that the physical habitat of the Klip River system is presently being negatively impacted by various anthropogenic activities. It can be expected that the present condition of the Klip River's physical habitat acts as a constraint to biotic assemblages.

Biological Integrity (Aquatic macroinvertebrates)

The results gained from this study indicated that the invertebrate composition of the Klip River is highly degraded from its naturally expected condition. The diversity was generally low throughout the Klip River, when compared to a site in the less impacted Suikerbosrand River. Very high abundances of invertebrates in the soft-bottom substrates, and being dominated by the tolerant Chironomidae and Oligochaeta, was indicative of nutrient enrichment in the Klip River catchment. This was especially evident in the vicinity of locality 3 of the Klip River. Furthermore, when compared to a previous study, it seems that nutrient enrichment has increased in the Klip River over the past three decades.

The SASS4 protocol was determined to be an effective biological monitoring tool, to assess both changes in water and habitat quality. It was evident, from the use of the SASS4 protocol, that the Klip River is a highly degraded river system, with conditions ranging between very poor to fair. In general, the ecological integrity of this system, based on macroinvertebrates, can be classified as being poor. The greatest areas of concern, identified with the SASS4 protocol, were locality 2 and locality 6, where significant degradation in integrity occurred. The deterioration of the ecological integrity of the Klip River was attributed to both poor water quality and habitat degradation. Flow modification, especially in the lower section of the Klip River, contributed greatly to the

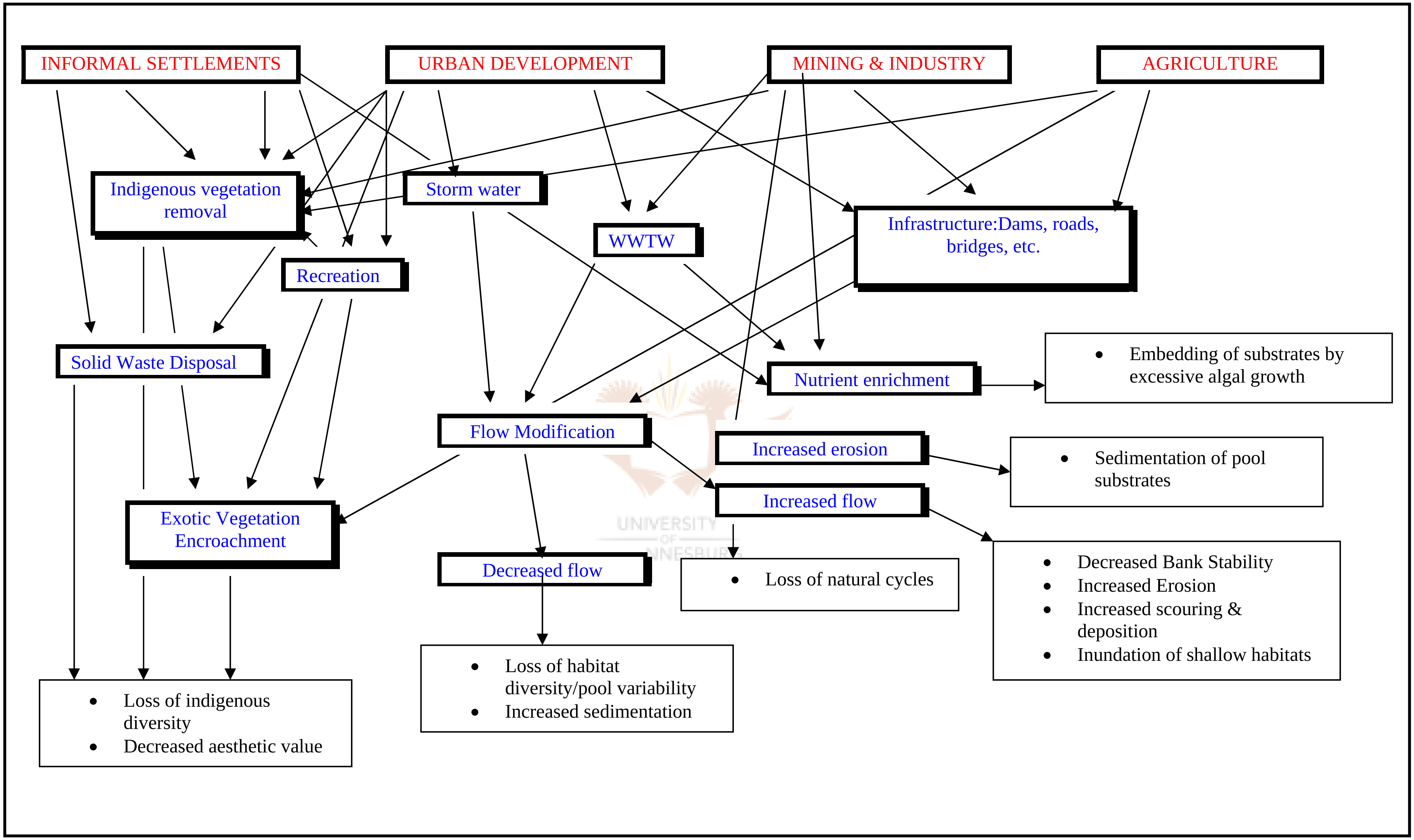

Figure 8.1: Human activities and their impacts on the physical habitat integrity of the Klip River System.

poor biotic integrity (based on invertebrates). The Suikerbosrand River, in the area of the reference site (locality 10), was found to be in fair to excellent condition, with a very good water and habitat quality.

Biological Integrity (Fish)

This study indicated that the current species diversity in the Klip River deviates from the expected conditions. The absence of the Largemouth yellowfish was of special concern. The changes and absence of fish from certain sections of the Klip River was attributed to poor water quality, as well as to habitat alterations. Flow modifications, especially due to WWTW effluents, were identified as a major cause of change in habitat diversity and condition, and contributed greatly to changes in the species diversity of some sites.

Three introduced species were observed in the Klip River, but they were, in general, not seen as a major threat to the biotic integrity of the system. This was mainly due to the lack of suitable habitat, namely slow flowing habitats, being favorable for all these species. Locality 9 was identified as the most impacted by introduced species, while high probable impacts were also identified at locality 4 and 5.

The external Fish Health Assessment Index (FHAIe) was identified to be a useful tool to apply as a rapid biomonitoring protocol. The most important organ used in this protocol to indicate environmental degradation was the gills. Skin and fins were also important indicators, while eyes and opercula were identified as the least indicative of all organs used. This index proved to be especially valuable in indicating the impact of decreased flows, as observed in the Suikerbosrand River over the study period. It is recommended that the FHAIe scores could be used as an additional metric, or replace the current metric of fish health, used in fish indices such as the Fish Assemblage Integrity Index (FAII) and the Index of Biotic integrity (IBI).

The general condition of fish, calculated in the form of condition factors (length-weight relationship), indicated that the fish of the Klip River were generally in good condition. The application of this method can be time consuming, due to the measuring and weighing of large sample sizes. Furthermore, inaccurate results can be gained by this procedure, as it is envisaged that fish may have the ability to counter weight loss via physiological processes. This method was therefore identified to be less valuable for the assessment of river health, and for biomonitoring purposes it could be excluded.

The levels of most metals accumulated by the fish of the Klip River were generally lower than those detected in fish from other river systems. Of the two areas investigated, the fish indicated that the Henley-on-Klip section of the Klip River is more polluted with metals than the Olifantsvlei section is.

From the results gained during this study it can be concluded that the biotic integrity of the Klip River System is presently, based on fish assemblage characteristics, fair to critically modified. The upper reaches of the river, where fish communities have been critically modified from their natural condition had notably poor biotic integrity. Weirs, as well as areas with very poor water quality, may act as migration barriers and prevent the recolonisation of upper reaches by native fish species. Degradation in the natural fish assemblage characteristics of the Klip River can be ascribed to both reduced water and reduced habitat quality. The primary anthropogenic activities responsible for the decreased biotic integrity in the upper catchment was identified as gold mining, water care work effluents throughout the catchment, as well as runoff from formal and informal settlements. Flow modification in the form of unnaturally high flow was also identified as a major cause of decreased biotic integrity. It is recommended that fish surveys in cold and cool water systems, such as the Klip River, be conducted annually, during the summer months, to gain more reliable results for application to fish indices.

Fish Indices (FAII – IBI – SIBI)

This study indicated that the principles of the Index of Biotic Integrity could be applied with success to the Klip River which has a relatively low species diversity (n=11), if the objective is to monitor change in biotic integrity. The objective to develop a fish index for use in the Klip River, was met by the development of the Sensitivity-weighted Index of Biotic Integrity (SIBI). This newly developed Sensitivity-weighted Index of Biotic Integrity (SIBI) was identified as a reliable index for the use of fish as indicators of biotic integrity of the cool water Klip River system, with its low fish species diversity. The SIBI was also found to be valuable for application to site-specific data, as well as for upstream-downstream investigations to assess specific impacts. It is envisaged that the SIBI could, with minor adaptations, be applied to aquatic systems other than the Klip River, and could possibly be used as an alternative fish index for South African rivers, especially when investigations necessitate site-specific evaluations. The Fish Assemblage Integrity Index (FAII) on the other hand, was found to be of great value for investigating the general biotic integrity of segments of a river. It is of great importance to include the use of multimetric fish indices in any biomonitoring program, as this would result in more comprehensive assessments of biotic integrity, and could therefore contribute to better management of aquatic resources.

It should be kept in mind that the IBI and SIBI are tools designed to be used only when the objective is to monitor biotic integrity at specific sites, and it must therefore be used appropriately. Furthermore it is stressed that these indices were applied to a relatively small data set, and that their true value would only be determined over long-term testing.

Summarized Ecological Integrity

The primary objective of the study was to determine the ecological integrity of the Klip River. The protocols applied during the study gave a reliable and good reflection of the overall ecological integrity, as well as the state of different components determining the overall integrity. The ecological integrity of the most recent assessment (February 1999) is summarized in Figure 8.2. It was decided to keep the different components determining ecological integrity (physico-chemical, physical, biological) separate and not to combine everything into one score. When expressed separate, such as in the case of Figure 8.2, it is possible to observed deterioration in overall ecological integrity at a site, and it is also evident which of the components are responsible for the degradation.

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As mentioned previously, biological communities, and thus biotic integrity, are the best indicators of overall ecological integrity, due to the fact that they integrate both water and habitat related stresses over time. Habitat and water quality assessments are indications of the conditions prevailing at the time of sampling, while biota give an indication of the conditions prevailing over the long term. Invertebrates have shorter life cycles, and in many cases have a terrestrial phase, therefore they recolonise quicker than fish may be able to do after a pollution incident. Invertebrates can therefore be seen as indicators of short-term biological integrity, while fish indicate long-term biological integrity of a river.

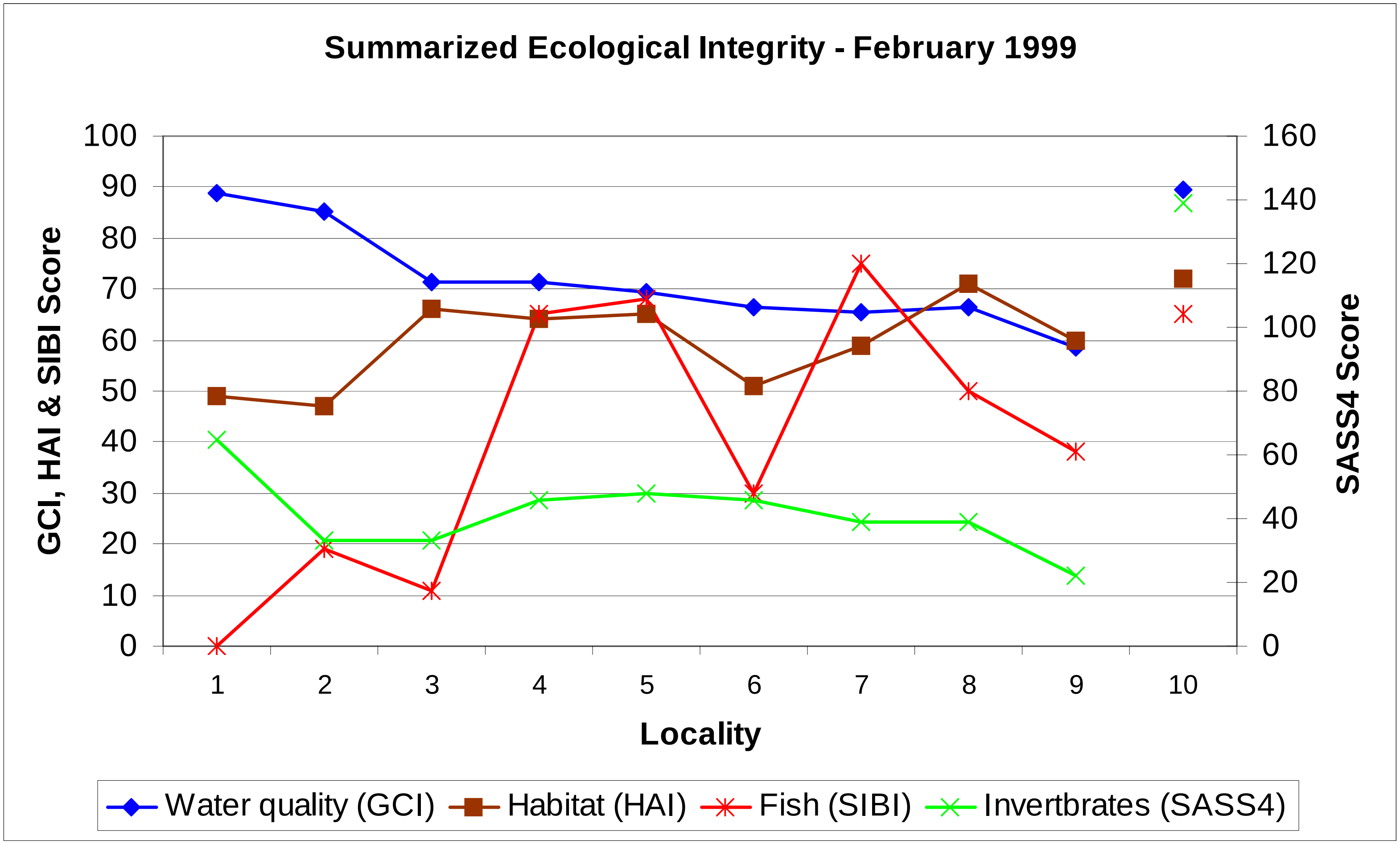

Figure 8.2: Summarized ecological integrity, comprising of physico-chemical integrity (GCI), physical/habitat integrity (HAI) and biotic integrity (SASS4 & SIBI), as determined for the selected localities during February 1999.

8.2 RECOMMENDATIONS

Water Quality

Water quality related recommendations for the Klip River include:

- That the sources responsible for water quality degradation in the Klip River be managed more effectively, to reduce their negative impact on the river.
- Focus should be placed on variables of concern as well as on those responsible for their unacceptable levels.
- That pollution should be prevented rather than the symptoms treated.
- The "polluter-pay-principle" should be effectively implemented and polluters should carry the cost of monitoring and improvement.
- A "Participatory approach" where all stakeholders become involved, should be encouraged, and current activities such as the Klip River Forum, should be enhanced and maintained in future.
- The water quality guidelines for the Klip River should be revised continuously as more information becomes available, and should also be verified by experimental studies.

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Physical Habitats

A few recommendations, to protect and improve the physical habitat condition of the Klip River include the following:

- An effort should be made to clear the riparian zone from all exotic trees, especially in the upper catchment where dense stands of Black wattle occur. This might increase water levels in these areas and enhance the growth of natural instream and riparian vegetation. Rand Water should, where possible, also include the Klip River catchment as one of their ventures with the Work for Water Programme.
- Relatively natural areas remaining in the catchment should be protected for aesthetic reasons, and a buffer riparian zone should be created along the river to enhance sustainability of the riparian zone and instream channel.

- Areas developed for new housing schemes should be well planned, to reduce the impact on the Klip River riparian and instream zones.
- The vast wetland areas in the middle reaches of the Klip River should be conserved, as they play an important role in the ecology of the system. The most important areas should be identified as soon as possible, to prevent further degradation and development.
- The people living in the Klip River catchment, and especially those in close contact with the river, should be educated and informed on how they can reduce their impact on the river.
- Authorities responsible for the management of the Klip River catchment should react with more urgency and power to limit human activities influencing this aquatic system negatively. Habitat integrity of the Klip River system should not be allowed to deteriorate further, and an attempt should be made to improve it where possible.

Biological Integrity

It is recommended that the following aspects should be considered if the biota, and especially the fish assemblages of the Klip River are to be improved:

- It can be expected that improvements of the water and habitat quality, as described above, would also lead to an improvement in biological integrity of the Klip River.
- Furthermore, it is advised that actions should be taken to rectify the habitat alterations due to the high flows. The creation of backwaters, as well as more slow-shallow and fast-shallow areas would provide better habitat for the fish, and would probably improve the biotic integrity of the system. The artificial creation of habitats would not only be beneficial to the aquatic ecosystem, but also for humans through the creation of jobs.
- Restock fish (especially rare species such as *Lb. Kimberleyensis)*, which could increase recreational value of the river (due to angling).
- Assess the bioaccumulation levels of other toxins (such as pesticides and herbicides) in fish.
- The institution of protected areas, especially in the wetlands of the middle reaches, would secure safe habitats for water birds, thereby also increasing the overall biological integrity of the system

Future Monitoring and Research needs

Monitoring

- It is recommended that a long-term biological monitoring programme be devised and implemented in the Klip River catchment. The two biological components applied in the current study, namely macro-invertebrates and fish, should definitely be included in such a programme. Other biotic components, such as riparian birds and waterfowl, as well as the periphyton, could also be considered in making the assessment of ecological integrity even more comprehensive. The potential for the use of these components in biomonitoring programmes have been proven in other countries around the world, but needs research and development in South Africa.
- An assessment of the physical habitat integrity and condition is a crucial part of biological assessments and should always be included in any biomonitoring programme.
- The localities identified during the current study should provide a comprehensive picture of the integrity of the entire Klip River Catchment, and also be adequate to identify areas and activities of concern.
- Macro-invertebrate monitoring should be conducted seasonally, together with aspects such as microbiological investigations, habitat and water quality assessments. Fish surveys could be conducted every second year during the summer season.
- Toxicity testing should also be conducted regularly on all major effluents entering the Klip River.
- Due to the great number of informal settlements along the river, it is also advised to intensify the investigations into faecal pollution, as well as enteric parasites.
- Future bioaccumulation studies in the Klip River system should also consider the assessment of chemicals other than metals in fish, and a human health risk assessment should be conducted in the near future. Due to the fact that humans consume fish from this system on a regular basis, it is also proposed that a human health risk assessment, based on the procedures stipulated by du Preez (2001) be considered in the near future.

- It is furthermore recommended that a more intensive biomonitoring study should be conducted in the Suikerbosrand River, due to its relative minimally impacted condition with regard to other rivers of the region. This information would be important to attain better baseline information of expected conditions for rivers of the region. A degradation of this river has been observed over the study period and was primarily attributed to decreased flows due to an upstream dam. The instream requirements of this river should therefore be determined and applied in an attempt to protect and conserve the integrity of the system.

Research

- Although most of South African fish species have been taxonomically described, there is still limited information available on the ecology of many species. Aspects such as optimal habitat requirements and sensitivity to environmental change of many South African species are still uncertain. Better understanding of the specific needs and requirements of each species would optimize utilization of fish as indicators of environmental degradation. Research on indigenous fish biology should therefore be continued and aimed at addressing these gaps in future, as it would increase the accuracy at which fish indices could be used to monitor environmental change. It is also recommended that investigations should be conducted to determine the sampling effort needed to collect reliable data on fish assemblages of South African river systems. This could furthermore increase the applicability and reliability of fish index results.
- There is no data available on the fish sampling effort required for accurate results on the fish assemblages of different river systems in South Africa. A study should be conducted to identify the area required, as well as the number of passes (re-sampling of same area) needed to gain a reliable indication of the fish assemblages of a site.
- The use of the newly developed fish Sensitivity-weighted Index of Biotic Integrity (SIBI) in other river systems, and especially the cold water systems of the Vaal, should be investigated. It should be considered for use in other catchments of concern to Rand Water.

- Research is also needed to verify the use, and develop indices for the use of other biotic components, such as birds and periphyton, for the use in biomonitoring programmes.
- Studies should also be conducted to investigate the potential of countering habitat and flow alterations in the Klip River, by the creation of artificial backwaters and other lacking biotopes.
- A comprehensive assessment of the conservation value of the wetlands in the Klip River should be conducted to pinpoint the importance of these components in the overall ecological integrity of the system.

8.3 REFERENCES

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