THE ASSESSMENT OF THE INFLUENCE OF TREATED UNDERGROUND MINE WATER ON THE BENTHIC FAUNA IN A PORTION OF THE BLESBOKSPRUIT RAMSAR SITE

By

CHARL VAN DER MERWE

MINI-THESIS

Submitted in partial fulfilment

of the requirements for the degree

MAGISTER ARTIUM

In

ENVIRONMENTAL MANAGEMENT

In the

FACULTY OF ARTS

at the

RAND AFRIKAANS UNIVERSITY

SUPERVISOR: DR J M MEEUWIS

May 2003

ACKNOWLEDGEMENTS

The following people are gratefully acknowledged for their motivation, guidance and support:

Dr J M Meeuwis
Mr E A Marshall
Carmen, Cariné & Charl

This project was only possible with the co-operation of many individuals and institutions, as mentioned in the text, and I wish to record my gratitude to all.

My sincere thanks to Ms. René Swanepoel for her patience when typing this report.

---oOo---

SUMMARY

The increased demand on resources and particular on water in South Africa is, inter alia, owing to the high population growth, urbanisation and concomitant industrial development. A decrease in water quality impairs the sustainable use of water, economic development and environmental health.

Although water quality monitoring in the past focused mainly on the determination of the chemical and physical variables it is currently accepted as inadequate to determine the "health" of an aquatic ecosystem. This study does not concentrate on the impact of the chemical and physical variables on the ecosystem but rather determines the biological affect of treated underground mine water pumped into an aquatic ecosystem.

The causes of water pollution can be point source in origin, for example, from water purification works and mines or it could also be from a diverse source such as stormwater, agricultural activities, seepage from various sources such as dumpsites, slimes dams and even from some geological formations. Mining, as one of the major job creators in South Africa, is also one of the major sources of pollution of aquatic systems. This is, in particular, relevant to worked out mines, older mines and marginal mines.

The area of investigation is a portion of the Blesbokspruit Ramsar Site on the East Rand and, with its large bird specie diversity, appears to be a healthy system. This study shows that there is extensive debilitation of water quality in this portion of the Blesbokspruit which is further being impaired by the treated underground water pumped into the Blesbokspruit by the Grootvlei Mine.

The purpose of this study was to determine the probable hazard of the polluted water of the Blesbokspruit for biota by making use of benthic faunal studies. Previous studies (Adendorff, 1997; Chutter, 1998 and Davies & Day, 1998) proved that the benthic fauna decrease with an increase in water pollution. The water quality of the Blesbokspruit in the test area was compared with the water quality standards for natural water set by the National Department of Water Affairs and Forestry as well as the water quality targets as set by Rand Water. The water quality of the test area was below standard when compared with both sets of standards. Biomonitoring also indicated that, because of the low counts of invertebrates, compared to the high counts of invertebrates in pristine aquatic systems, that this system is under pressure.

This study indicates that the water quality of the Blesbokspruit Ramsar Site seriously impacts upon the benthic fauna and that the treated mine water from Grootvlei Mine, which is being pumped into the system, leaves this system stripped of all benthic fauna over an undetermined area. From this study it is also clear that managerial standards are urgently needed for water quality control and that water quality management should not only take the data of chemical water analysis into account but biological compounds should also be considered.

---oOo---

OPSOMMING

Die toenemende vraag na bronne, en veral na water in Suid-Afrika is, onder andere, as gevolg van die hoë bevolkingsgroei, verstedeliking en gepaardgaande industriële ontwikkeling. Verswakte watergehalte beperk die volhoubare benutting van water, ekonomiese groei en omgewingsgesondheid.

Alhoewel watergehalte monitering in die verlede hoofsaaklik op die meting van chemiese en fisiese veranderlikes gefokus het, word dit huidiglik aanvaar dat dit onvoldoende is. Chemiese en fisiese veranderlikes is op sigself nie voldoende genoeg om die algemene "gesondheid" van 'n akwatiese ekosisteem te bepaal nie. Hierdie studie konsentreer dus nie op die impak van chemiese en fisiese veranderlikes op die ekosisteem nie, maar bepaal die biologiese uitwerking van gesuiwerde ondergrondse mynwater in 'n akwatiese ekosisteem gepomp.

Die oorsprong van water besoedelstowwe kan puntbron van aard wees, soos byvoorbeeld, watersuiweringswerke en mynuitvloeisel. Dit kan ook van verspreide oorsprong wees soos stormwater, landbou aktiwiteite, sypeling van verskeie bronne soos stortingsterreine en mynhope en ook vanaf geologiese formasies. Mynbou, as een van die grootste werkverskaffers in Suid-Afrika, is ook een van die grootste bronne van besoedeling van akwatiese sisteme, veral ten opsigte van uitgewerkte myne, ouer myne en marginale myne. Alhoewel die ondersoekgedeelte van die Blesbokspruit Ramsar-gebied aan die Oos-Rand, met sy groot spesie diversiteit van voëls, gesond voorkom, dui die studie aan dat daar alreeds grootskaalse verswakking van watergehalte in die gedeelte van die Blesbokspruit Ramsar-gebied is. Die watergehalte word verder verswak ten opsigte van die bentiese fauna, deur die ondergrondse mynwater wat deur Grootvlei Myn gepomp, gesuiwer en in die Blesbokspruit gestort word.

Die doelwit van die studie was om die moontlike gevaar wat die besoedelde water van die Blesbokspruit vir biota inhou te bepaal deur gebruik te maak van bentiese fauna. Vorige studies (Adendorff, 1997; Chutter, 1998 en Davies & Day, 1998) het bevind dat die bentiese fauna verskeidenheid verarm met 'n toename in besoedeling. Die water kwaliteit van die Blesbokspruit in die toetsgebied is vergelyk met die water kwaliteit standaarde vir natuurlike water soos gestel deur die Departement van Waterwese en Bosbou en met die water kwaliteitsdoelwitte soos gestel deur Rand Water. In die geval van beide standaarde was die water van die toetsgebied van 'n laer standaard. Die lae spesie diversiteit telling dui ook aan dat die sisteem onder druk is.

Die studie dui aan dat die watergehalte van die Blesbokspruit Ramsar-gebied die bentiese fauna nadelig impakteer en dat die gesuiwerde mynwater wat in die stelsel gepomp word die stelsel ontdaan maak van enige bentiese fauna, oor 'n onbepaalde gebied. Dit spreek duidelik dat bestuursmaatstawwe ten opsigte van water kwaliteitbeheer dringend nodig is en dat watergehaltebestuur op vergelykende data vir sowel chemiese samestelling as biologiese samestelling, moet staatmaak.

---oOo---

---oOo---

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

"In nature there is nothing contingent, but all things are determined from the necessity of the divine nature to exist and act in a certain manner."

Benedict Spinoza (1632 – 1677)

Close to the economic and industrial hub of Gauteng Province and approximately 30 km from Johannesburg International Airport, is the world acknowledged Blesbokspruit Ramsar Site near Springs on the East Rand. This Wetland is of international importance because of the large variety of local and migrant bird species it supports. This research will deal exclusively with the benthic fauna, as an important link in the food chain of the Blesbokspruit and the impact of polluted underground water, pumped by Grootvlei Mine, on the benthic fauna. The Blesbokspruit Wetland flows through Springs and, from its various points of origin, is subjected to modern land use planning and management. The town of Springs originated during the early 1900's because of mining activities, such as shallow coal mining and deep gold mining of which Grootvlei Mine, on the banks of the Blesbokspruit Wetland, is still active today. However, in order to mine, Grootvlei Mine has to pump up to 80 megalitre (Ml) of polluted underground water per day out of the mine. This water is treated on surface to a licensed standard issued by the Department of Water Affairs and Forestry, and then released into the Blesbokspruit Wetland.

Benthic fauna are organisms without backbones that live on or in the bed of a stream or water body and includes worms, leeches, snails and insects. The use of these organisms as monitors of water quality is convenient and economical as they are relatively easy to collect and identify (Wessels, 1974) and can improve the interpretation of water quality monitoring that was once only based on chemical and physical data collected and analysed in a laboratory (Davies & Day, 1998). Biological monitoring, with benthic fauna as the agent, is especially powerful under conditions of toxic, intermittent or mild organic pollution and habitat alteration where changes in water quality are not easily detected by chemical analysis (Barton & Boston, 2001).

Water bodies can generally be divided into standing (lentic) and running (lotic) systems. This classification is useful because different suites of organisms inhabit lentic and lotic ecosystems (Davies & Day, 1998). As is so often the case, there are intermediates that do not clearly fit into either category. Wetlands are therefore enigmatic ecosystems as they are neither fully lentic nor lotic and are not easily classified and as such have remained largely unstudied (Cowling *et al*., 1997).

The word “wetland” is a generic term which is used to group those features of the landscape that are commonly referred to as marshes, floodplains, vleis, pans and sponges as a single type of ecosystem. There are many definitions of what constitutes a wetland (Huntley, 1991, Cowling *et al.*, 1997 and Davies & Day, 1998), but for the purpose of this study the following definition of a wetland will prevail: “water dominated area with impeded drainage where the soils are saturated with water, which fluctuate with the wet and dry seasons to form a complex mosaic of patches of open water dominated by patches of *Phragmites australis* and stands of *Typha capensis* vegetation in which a characteristic fauna and flora abounds (Cowling *et al.*, 1997 and Fuggle & Rabie, 1999).

Wetlands are characterised by particular communities of organisms. Plants form the basis of the food chain in virtually all ecosystems, including wetlands. These plants, floating or rooted, are fed upon by small grazing animals such as insects and snails, while decaying material is decomposed by micro-organisms. These rotting particles, with the bacteria, fungi and algae adhering to them are eaten by filter feeders and deposit feeders. These animals are collectively called collectors. Detrivores, on the other hand, are animals that feed on larger chunks of decaying tissue and its associated aggregate of micro-organisms. Small predatory invertebrates feed upon the grazers, collectors and detrivores and are in turn fed upon by larger invertebrates, fish and birds. The whole complex of “who eats whom” is termed a food web. The plankton and fish form a second food web consisting of freely drifting organisms. Phyto plankton (minute plants) are fed upon by zoo plankton (minute animals) which in turn are fed upon by filter feeding invertebrates and fish. These two food webs are interlinked because part of the food supply of the benthos (the animals living on the bottom = benthic fauna) comes from a rain of particles from the open water above, the domain of the plankton and fish, while some fish feed on the benthic organisms living on the bottom. **Benthic fauna is therefore an important link in the wetland food web.**

Wetlands form some of the most productive land on earth and the biodiversity of some wetlands approaches that of tropical rain forests because they provide abundant supplies of both nutrients and water for a diverse population of species (Kupchella & Hyland, 1993 and Davies & Day, 1998). Wetlands are also subjected to various threats, usually man-made in origin, such as reclamation, canalisation, siltation, water excess and industrial and agricultural pollution. Huntley, (1991) and Fuggle & Rabie, (1999) describe wetland degradation as of considerable concern because it impinges upon life-support systems of all living organisms, including local, regional and global scales.

Industrial pollutants, such as chlorides, nitrates, phosphates, sulphates and sodium, are generally point source in origin as they are usually discharged through pipes and ditches into bodies of water, at specific locations. Upon entering water, the chemical nature and concentration of pollutants will usually change as a result of four natural processes: dilution, biodegradation, biological amplification and sedimentation (Williams & Feltmate, 1992). Wessels (1974) established in his studies that sediments become anaerobic when water bodies are overloaded with contaminants and the resultant destructive impact on benthic faunal communities is severe.

Studies undertaken by Adendorff, (1997); Chutter, (1998) and Davies & Day, (1998) also proved that the benthic fauna specie diversity decrease with an increase in water pollution. Three parameters are used to indicate aquatic ecosystem health viz. a) chemical; b) physical and c) biological. In this study only biological parameters viz benthic fauna, were used to indicate the health of the system, before, at the point and past the point of discharge of the treated polluted water.

The main aim of this study will be to determine the health of the benthic fauna in the Blesbokspruit after it has been exposed to underground polluted water which has been pumped and treated by Grootvlei Mine to remove the iron oxide, before it is released into the Blesbokspruit. According to Davies & Day (1998), the status of the benthic fauna, as one of the primary consumers in this system, will determine the health of the system because some macro invertebrates, e.g. mayfly nymphs, are more susceptible to pollution than others, e.g. syrphids. The hazard of the polluted water will thus be measured in terms of biotic indicators of water quality because the decline of the invertebrate faunal assemblage is an indication of not only the water quality at the time of the sampling but also on the conditions that have pertained at the site over the entire lifespan, which may last from days and up to ten weeks or more, depending on the specie, of the assemblage.

This study is therefore important because biological monitoring provides a “picture” of both the past and the present conditions in a water body. This is because the organisms in this study, the benthic fauna, that are alive in the system must have been able to survive whatever chemical conditions the vlei has been subjected to in the past eight weeks (24.04.2002 – 19.06.2002). From an environmental management point of view, this information should assist in the determination of the pollution plume and decisions concerning the optimal management of pumped treated polluted mine water.

2. STATEMENT OF THE PROBLEM

2.1. The Problem

Various factors impact on the water quality of the Blesbokspruit, but the water quality is measured in terms of the cost of purification for human consumption (de Fontaine, 2002). In this study the water quality will be measured in terms of suitability for reproduction and survival of water organisms such as benthic fauna. The problem to be investigated can thus be defined as:

- the condition of the polluted underground water pumped by Grootvlei Mine and treated by the mine on surface to remove the iron oxide, before releasing the water into the Blesbokspruit Ramsar Site.

- the origin of the polluted water pumped from underground by Grootvlei Mine into the Blesbokspruit Ramsar Site and the degrading factors impacting on this water; and

- the influence of this treated polluted underground mine water on the benthic fauna of the Blesbokspruit.

Just as a fish-kill indicates that a toxic spill may have occurred, so the invertebrates present in an aquatic system will reflect good or poor water quality from their point of view. Chemical analysis of the water in an aquatic system gives an accurate measure of the pollutants at the moment of collection. Biological monitoring, as in this study of benthic fauna, provides a picture of both the past and present conditions of the wetland. This is because the organisms that are alive in the vlei must have been able to survive whatever chemical conditions the vlei has been subjected to in the eight weeks (23.04.2002 – 19.06.2002) of the study.

2.2. Factors Enhancing the Problem of the Underground Water

The Blesbokspruit Ramsar Site on the East Rand, is located between 28°29’E to 28°32’E and 26°12’S to 26°23’S, is approximately 21 km long as depicted in Figure 1, and is subject to various external pressures such as informal and low cost housing development (Du Plessis, 2002), open cast mining for clay (personal observation, 2002), the new Welgedacht Water Care Works (Du Plessis, 2002), increased stormwater run-off from residential areas, invasive plants and illegal dumping of domestic and other waste. The study area is also directly being impacted upon by the pumping of treated underground polluted mine water by Grootvlei Mine.

Figure 1: *The Blesbokspruit Wetland Study Area on the East Rand depicting the sample and monitoring points*

The Blesbokspruit flows from its various points of origin through built-up areas and, up to the end-point of the Ramsar Site, is subjected to modern land use planning and management. However, this urban area is also subjected to uncontrolled illegal dumping of pollutants, uncontrolled informal settlements and invasive plant species. The dense reed beds in the vlei allow the water to slow down and some of the pollutants to settle in the mud. The reed beds absorb some of the dissolved nutrients and minerals present in the water. Because of the flat topography of the land, (a fall of 0,92m over a distance of 4900m in the study area), siltation of the system and the nutrient rich water from the sewage water care works, the lateral expansion of the reeds increases annually (8m expansion has been observed over a five year period from 1997 at the Grootvaly/Blesbokspruit Wetland Reserve, Personal observation). To counteract this spreading of the reeds, a centre channel was sprayed by aerial application with a combination of herbicides in February 1999 and February 2001. The assumption was that, as the reeds die down, there will be less resistance to the water flow with the result that the system will drain quicker (Marshall, 2002). This appears to have been successful as the system was not as inundated with water during the 2001/2002-rainy season, which had a 5% higher than normal precipitation, of 760 mm.

The Ramsar Site is also subject to agricultural impacts from cattle and irrigated farm land. During spring, cattle from a neighbouring farm are allowed to graze in the wetland at the Grootvaly/Blesbokspruit Wetland Reserve. This action enhances the opening of the reedbeds which creates a habitat for various water birds. This action is not sustainable for as soon as the reeds get too high and hard, the cattle don't graze and prefer the adjacent grass veld which is currently over utilised (2002; Personal observation). However, the known main concern, is the pumping of treated underground water by Grootvlei Mine and its resultant impact on the benthic fauna.

The factors influencing the changes in the Blesbokspruit are depicted in Figure 2. This conceptional model by Walmsley (1995), clearly indicates that development e.g. mines, plays a major role in the long term impact in ecosystem health and benthic fauna assemblage. As the salinity increases, the submerged aquatic microphytes decrease with the associated waterbird decrease which, as in this case, might have a negative impact on the Blesbokspruit Ramsar Site. This site was proclaimed because of its abundance and species diversity of water birds.

This study area has been selected because the action of Grootvlei Mine, to pump treated polluted underground water, impacts directly on a declared Ramsar Site with such adverse results that the Ramsar Site was placed on the Montreaux Record as discussed under 3.6.1. This was done because the character of the wetland has been altered to such an extent that the birdlife population declined (Anon, 2002). The cause and the origin of the polluted water pumped by Grootvlei Mine which impacts on the benthic fauna will be investigated in the following paragraphs.

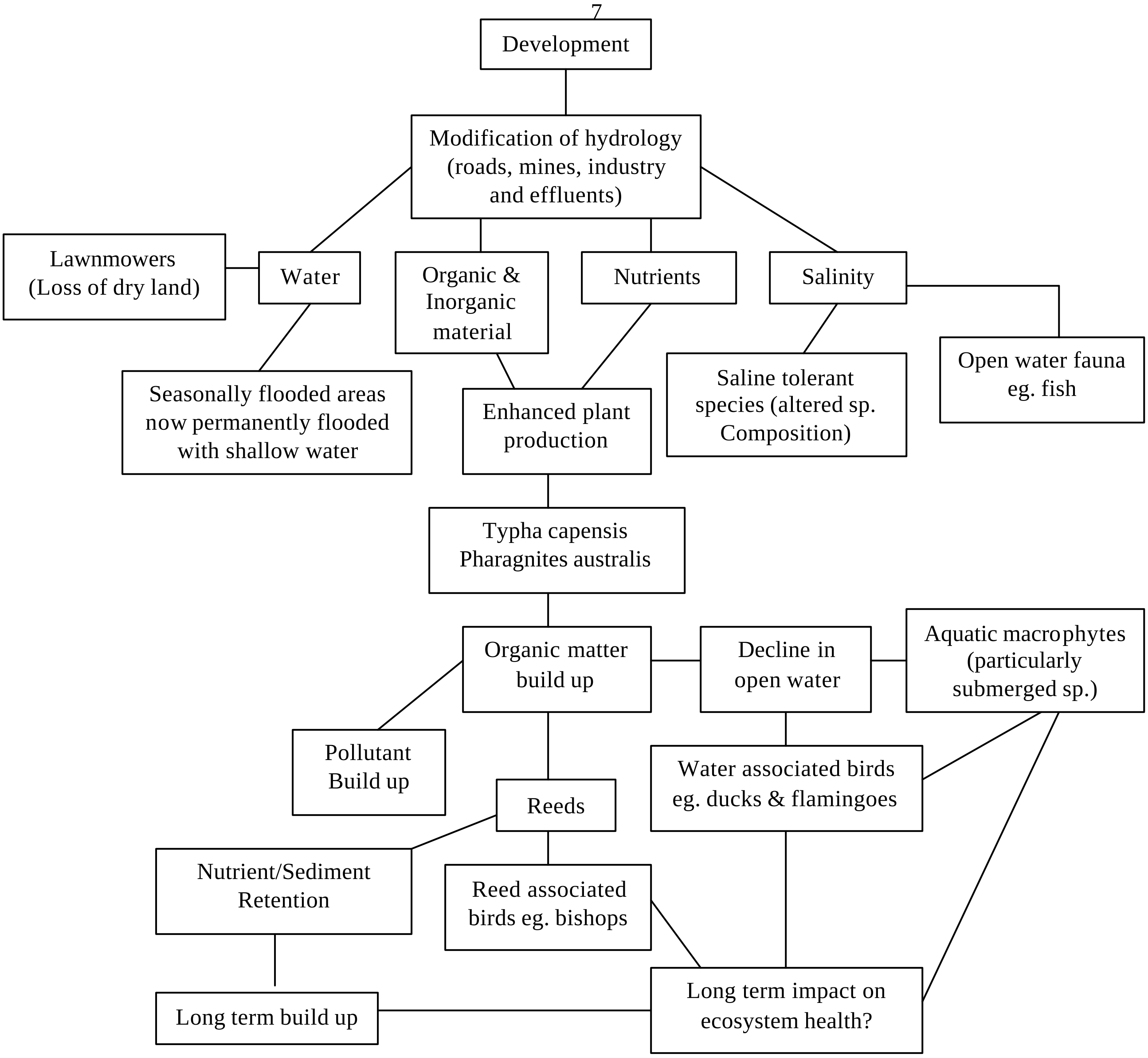

Figure 2: *A conceptual model of the factors influencing changes in the Blesbokspruit Wetland*
Source: Walmsley (1995)

2.2.1 Factors affecting the Quality of the Underground Mine Water which is pumped into the Blesbospruit and cause an impact on the benthic fauna.

According to Scott (1995), one of the major factors contributing to water degradation is the reaction of water with sulphide minerals, producing the so-called Acid Rock Drainage. The Witwatersrand Supergroup sediments contain varying proportions of sulphide minerals, the predominant sulphide being pyrite (FeS_2). In many of the gold bearing reefs this mineral may form up to three percent (by mass) of the rock.

Mining of the Witwatersrand Supergroup sediments has produced the following:

- On surface; rock piles as well as sand and slime dumps.
- Underground; backfilled rock piles and spoil heaps in stopes and haulages.

These all contain pyrite which, in the broken and crushed rock, is now exposed to air and water, and so oxidises. Due to this oxidation the rocks and accumulations have characteristic red and yellow staining and discoloration from secondary iron oxide minerals and mineraloids. The acid content of water that passes through such accumulations increases. Thus the reactivity of the water increases and in its passage, it reacts with other minerals, either to generate more acid or to neutralise the existing acid. The total dissolved solid (TDS) content of the water rises. The water may be characterised by one or more of the following: Low pH, high TDS, high sulphate (SO_4) content, or high heavy metal content (particularly Fe, Mn, Ni or Co) which are pumped by Grootvlei Mine.

Owing to the variable nature of the recharge sources and to the many different places where acid formation can occur, water degradation is diffuse and no one source can be identified as a major contributor to the overall degradation of the water. Surface degradation and subsurface degradation both contribute to the overall lowered water quality of the Blesbokspruit.

♦ Surface degradation

- Surface water, through intimate interaction with mine wastes, takes on a very similar identity to the water found in the mines;
- Groundwater which is affected by seepage from mine waste heaps, has the same chemical identity as the water in the mines;
- Reef outcrop areas that have not been mined, nor developed in any way, were found to have acid water draining from them. These water sources contribute to water flowing into the mine cavities. The mine waste heaps are often located above shallow surface workings and reef outcrops and is thus in hydraulic communication with the deep mine cavities. Seepage may be lost vertically to the mine openings or may contaminate surface water streams which flow between the mine wastes and impact on the benthic fauna.

The area is highly industrialised and densely populated thus the surface streams carry a wide variety of effluent in addition to mine waste-derived seepage. The Blesbokspruit is not in a pristine condition because of various point source and non-point source pollution and the stream loss to the subsurface water also contributes a diffuse pollution load which ends up in the mine. Boron, as an element used in hard detergents and which is common in waste-water streams, was also detected in the mine water but not in the surrounding groundwater samples.

♦ Subsurface degradation

A proportion of the water recharging the mines arrives from surface in the mine via geological structures from a number of widely distributed small drips, trickles and seeps.

- This water has passed through different geological horizons where mineral water interactions will have caused further degradation from what may have started on surface. Seepage recharge in the Grootvlei Mine area rarely enters the mine directly, but first via the Karoo or dolomites where reactions (predominantly neutralisation in the dolomite) can change the chemistry of this source of poor quality water.
- On the East Rand, shallow underground coal mining has taken place in many areas. One such flooded mine is within 500 m of Grootvlei No. 3 Shaft (personal observation). Many of these old coalmines are flooded and contribute seepage to the gold mine workings below. The groundwater in the vicinity of such coalmines shows increased sulphates which lowers the pH of the ground water.
- In the mines these diverse water flows pass through a variety of conditions, such as backfilled waste rock, loose ore in stopes and haulages that have never been removed and fine material that has collected in the mine workings. These materials are pyrite bearing, and the water flows are exposed to pyrite in many of their courses. The mines are open to air circulation and even in abandoned sections, natural air circulation, owing to up-draught shafts, ensures that there is enough oxygen for oxidation of the pyrite. In addition the warm, humid underground conditions encourage bacterial development. Bacteria can catalyse the oxidation of the pyrite increasing the rate of this acid forming reaction (Scott, 1995). Thus the water further deteriorates on its passage underground by reaction with sulphide minerals and mixing with stagnant water lying in disused mine openings. This low quality water is eventually pumped to surface and treated by Grootvlei Mine.

Low pH water has the ability to leach other sulphide minerals and some of the oxide minerals in the ore. The other base metal sulphides in the reef, in addition to iron, contain elements such as; Ni, Pb, Cu, Co and As, while some of the leachable oxides are uranium bearing. The water thus has a low pH, characteristic high iron and sulphate content and may also be contaminated with one or more of the heavy or transition metals e.g. copper (Cu), lead (Pb), Iron (Fe) and manganese (Mn) and uranium or its daughter products e.g. thorium (Th238) and lead (Pb214), (De Wet, 1990).

The presence of precipitated iron oxides, which are evident wherever mine water accumulates or flows underground, suggests that many of the trace metals will be removed from the water since they co-precipitate readily with the iron oxides (Drever, 1982 as cited by Scott, 1995). This polluted water is treated by Grootvlei Mine and then discharged into the Blesbokspruit and might impact on the benthic fauna.

According to Scott (1995) historical data shows that springs fed the Blesbokspruit in the vicinity of Grootvlei. These springs were derived from the water in the dolomites and were controlled by topography or by water emanating from chert bands in the dolomite. This is schematically depicted in Figure 3.

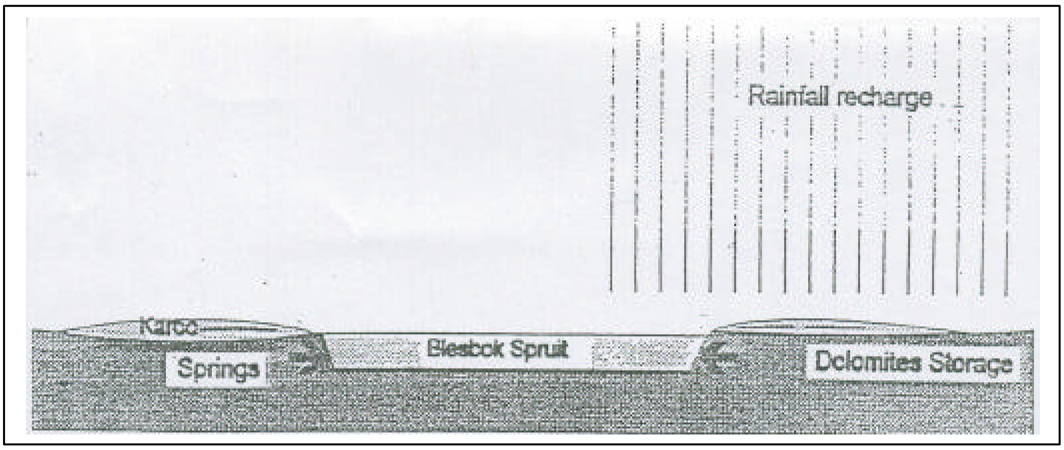

Figure 3. *The flow situation between the Blesbokspruit and the dolomites before mining and industrial development*

Source: Scott, 1995

After mining created the mine aquifers and a downward hydraulic gradient was established due to pumping, water from the dolomites flowed downwards into the underground workings, from where it was pumped. Thus a proportion of all the water that was available to feed the Blesbokspruit now flows underground. The schematic depiction of the situation is given in Figure 4.

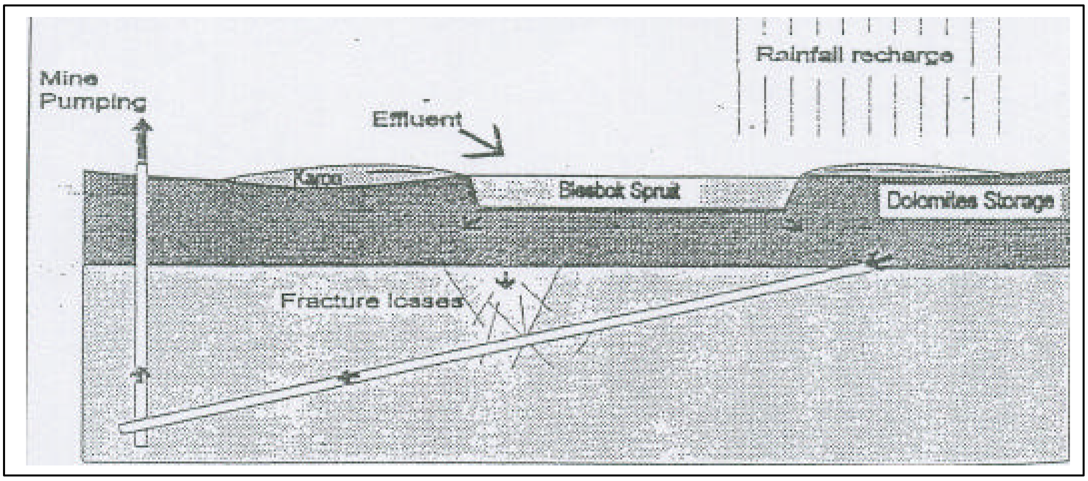

Figure 4. *The flow situation between the Blesbokspruit, dolomites, mines and industrial and sewage effluent, since mining and industrial development*

Source: Scott, 1995

2.2.2 Pumping Rate

Underground water has been consistently pumped from the East Rand mining basin since the beginning of the previous century and records of water ingress into these mines dates back to 1909 when Grootvlei abandoned the sinking of their No. 1 shaft at 112 meters owing to an estimated 10 Megaliters (Ml)/day ingress. Further development by Grootvlei was abandoned at that stage owing to lack of funds (Scott, 1995).

Most of the mines in this area have had to pump polluted water from underground, to either dewater areas where development was intended, or to keep the existing workings from flooding. The water was pumped from settling sumps, launders or dams underground at enormous cost to the mines. Dolan (1961) quoted in Scott (1995) has noted that as mining became deeper, more water had to be pumped; he quoted figures which are shown in Table 1 along with more recently recorded volumes as well as historical estimates made by du Toit (1921), as quoted by Scott (1995), Walmsley (1996) and Grootvlei (2002) for comparison.

Table 1: *Pumping rate to dewater East Rand Mines*

Period	Pumping Rate MI/day	Pump Station
1916 to 1920	38	Not available
1925 to 1931	31	Not available
1952 to 1959	93	Not available
1983 to 1986	58.22	Not available
1987 to 1990	63.65	1548 (mbd)(Sallies Mine 1983)
1999 to March 2002	84.905	773 mbs (Grootvlei)

Source: Scott (1995) & Grootvlei Mine (2002)

- Quality of the Water Pumped

The quality of the water being discharged should comply with the objectives stipulated by licence issued to the mine by Department of Water Affairs and Forestry. Table 2 stipulates the requirements and an analysis of the underground water undertaken in February 2002. From Table 2 it is clear that the underground water quality does not comply with most of the variables in the objectives set.

Table 2: *Water Quality Comparison between the licence requirements of Grootvlei Mine and the water pumped into the Blesbokspruit*

Variable	Objective	Underground water quality
Electrical conductivity	400mS/m	314mS/m
PH	6.5 – 8.5	6.4
Suspended solids	25mg/liter	Not available
Dissolved oxygen	>9mg/liter	2.3 mg/liter
Chemical oxygen demand	35mg/liter	30 mg/liter
Sodium	290mg/liter	206 mg/liter
Sulphate	2200mg/liter	1641 mg/liter
Chloride	210mg/liter	186 mg/liter
Iron	1.0mg/liter	133 mg/liter
Manganese	1.0mg/liter	3.5 mg/liter
Aluminium	0.5mg/liter	0.926 mg/liter

Source: Grootvlei Mine (2002)

♦ Quality of the Instream Water

Effluent contributions to the river system take place at various point sources, as depicted in Figure 1. These disposal volume records are summarised in Table 3.

Table 3: *Other disposal volumes from point source into the Blesbokspruit*

Effluent Disposal Point	Megaliter/day: 2001
Sappi – P1	30
McComb Water Care Works – P2	12
Anchor Water Care Works – P3	28
TOTAL	70

Source: Directorate: Civil Engineering, Springs Service Delivery Centre, 2002

The instream water is also sampled by Rand Water at various points in the Blesbokspruit (Figure 1). The quality of the water as sampled on 15 May 2002 is summarised in Table 4.

Table 4*: Water Quality of the Blesbokspruit in the sample area compared with the water quality standards set for aquatic ecosystems by DWAF 1996 and Rand Water, water quality objectives for the Blesbokspruit catchment*

SAMPLE POINT						
Elements (Mg/1)	B4	B5	B16	B15	Water Quality Standard Aquatic eco-systems	Rand Water (Acceptable)
Ammonia	1.59	2.26	0.24	0.24	≤ 7	0.1 – 1.5
COD	32.60	53.60	25.40	22.20	Not available	20 – 35
Chloride	52.25	131.25	130.00	125.50	≤ 0.2	80 – 150
Conductivity	60.20	114.00	140.00	156.75	Not available	45 – 70
Faecal coliforms	-	-	-	-	Not Available	
Iron	0.36	0.09	0.16	0.21	Should not vary by 10%	0.1 – 0.5
Manganese	1.86	0.23	0.65	1.05	≤ 180	0.2 – 0.5
Nitrate	1.58	0.34	0.23	0.14	0.5 - 2.5	1.0 – 3.0
PH	7.92	8.06	8.25	8.19	Should not vary by 5%	6.5 – 8.5
Phosphate	0.59	0.32	0.21	0.26	Not available	0.2 – 0.4
Sodium	50.25	152.00	177.50	135.75	Not available	70 – 100
Sulphate	115.75	150.00	458.75	411.25	Not available	150 - 300

Source: Rand Water (2002) & DWAF (1996)

When comparing the variables of the elements sampled at sample points B4, B5, B16 and B15 with the Water Quality Standard for Aquatic Ecosystems as in Table 4, it is clear that the water quality of the Blesbokspruit river system does not comply with the water quality standards for aquatic ecosystems, as set by the Department of Water Affairs and Forestry, 1996. When comparing the information in Table 4 it is also clear that, although the system is not healthy by comparison, the river health declines, regarding certain elements, at sample point B16 which is the first sample point downstream of the point of discharge of the treated mine water. The motivation of this study is thus to determine the extent of damage this action of pumping water from Grootvlei Mine has on the population of the benthic fauna in a portion of the Blesbokspruit Ramsar Site on the East Rand between point B5 and B15 as indicated in Figure 1.

3. BENTHIC FAUNA AS BIOLOGICAL INDICATORS OF THE HEALTH OF AQUATIC ECOSYSTEMS

3.1 Benthic Macro-invertebrates

Benthic fauna live on the bottom of rivers and are for most of their lives immersed in water. The quality of this water will have a direct impact on their health and survival. Owing to the differing sensitivities of the organisms (some tolerant, others sensitive) the composition of the communities present can be used as an indicator of the water quality and the general river health at that site (Dallas & Day, 1993; Davies, O'Keefe & Snaddon, 1993; Dickens & Graham, 2001 and Barton & Boston, 2001)

Williams & Feltmate reported in 1992 that the time required for benthic fauna to return to their natural state, following disturbances such as point source industrial pollutants, can be in the order of up to 10 years for streams and decades for lakes. They also concluded that the recovery of benthic fauna populations, following cessation of mining activities, even combined with terrestrial rehabilitation, is very slow. The same will apply to wetlands as the benthic fauna will rely on the same resources and conditions.

3.2 Types of Benthic Communities

Benthic organisms may live either within the sediments or upon the sediments.

- The animals that live in the sediments are called **infuanal.** They obtain their food and dissolved oxygen primarily from interstitial water held between the sediment particles. Some even engulf sediment, utilize the food that is taken in with it and then excrete or eliminate the indigestible sand particles.
- Benthic organisms that live on top of the sediment, rocks, logs or plants are called **epibenthos**. The substrate to which the organisms are attached can be identified as a suffix in the term.
  - **Epifauna** are those organisms attached to animals (e.g. crustaceans or snails)
  - Organisms that live attached to rocks are called **epilithic.**
  - Those on plants are known as **epiphytic**.
  - Those living upon mud or sand are known as **episammic** organisms.
- The microscopic assemblage of organisms (mostly algae, bacteria, fungi and molds) that grow freely upon or attached to surfaces of submerged objects are called **periphyton.** Since the periphyton include both planktonic and benthic forms, it is sometimes difficult to determine to which group they belong. Periphyton is common in both lakes and streams.
- **Lake Benthos** is often also classified according to the zone that they live in.
  - **Littoral benthos** and **sublittoral benthos** are characterised by body appendages that allow the organisms to cling to plant stems and leaves.
  - **Profundal benthos** is adapted for gathering or filter feeding the fine organic particles that typify the profundal zone.
    - With the lack of coarse particulate organic matter, shredding invertebrates are absent.
    - Likewise, since there is no light in the profundal zone, grazing (or scraping) animals are absent.

- ☐ In fact, the only functional feeding groups in the profundal zone are:
  - ☐ Gatherers (e.g. worms),
  - ☐ Filter feeders (e.g. fingernail clams), and
  - ☐ Predators (e.g. midge flies).
  - ☐ Occasionally a fourth group, the **abyssal benthos**, is present. But the abyssal zone is present only in very deep lakes (>500 m) and many of the benthic species are blind.
- ☐ **In streams**, the benthic assemblage in the **riffle areas** (rapids) is very different from that in the **pools**, or back eddies. The benthos of pools is often very similar in form, habits and species composition to those found in ponds and lakes. In general, the benthic communities of rivers, are composites of assemblages from their tributaries, truly riverine species and cosmopolitan species that occur virtually everywhere.
- ☐ **In wetlands,** the benthic assemblage are largely filter feeders, deposit feeders, detritivores and small predatory invertebrates. The benthos of wetlands is often very similar to lake benthos except for the abyssal or deep water benthos.

3.3 Biological Assessment of the Health of Aquatic Ecosystems

Biological assessment (bio-assessment) refers to the use of living organisms for assessing various aspects of the biological integrity (health) of ecosystems. Bio-assessment is based on the premise that living organisms, especially the more sedentary ones, reflect the conditions of their environment during their lives (Adendorff, 1997; Chutter, 1998 and Davies & Day, 1998). The organisms most commonly used in water quality monitoring are periphyton, fish and macro-invertebrates because of their abundance and relative easiness to collect.

According to the National River Health Programme (De Wet, 1999 and Roux, 1997 as cited by Dickens & Graham, 2001) bio-monitoring may be used to:

- ♦ Assess the ecological state of aquatic ecosystems;
- ♦ Assess the spatial and temporal trends in ecological state;
- ♦ Assess emerging problems;
- ♦ Set objectives for rivers;
- ♦ Assess the impact of developments,
- ♦ Predict changes in the ecosystem due to developments;
- ♦ Determine changes in the biotic size spectrum;
- ♦ Determine changes in specie diversity; and
- ♦ Determine reduced population stability.

3.3.1 Advantages of bio-assessments

The major advantages of incorporating bio-assessment in determining water quality are the following:

- ♦ Biological communities reflect overall ecological integrity (i.e. chemical, physical and biological);

- Biological communities integrate the effects of different pollutant stresses and thus provide a holistic measure of their aggregate impact;
- Routine monitoring of biological communities is relatively inexpensive compared to the cost of chemically or toxicity tests;
- Where criteria for specific ambient impacts do not exist (e.g. non-point source impacts) biological communities may be the only practical means of evaluation;
- Invertebrates are largely non mobile and are thus representative of the location being sampled;
- Bio-assessments offer long term analysis of both regular and intermittent discharges;
- Sampling is easy, require few people and inexpensive gear and has no detrimental affect on the resident biota;
- Benthic macro-invertebrates are abundant in most streams (Dallas, Day & Reynolds, 1994; Davies & Day, 1998 and De Wet, 1999)

3.3.2 Disadvantages of bio-assessment

The major disadvantages of bio-assessment in determining water quality are the following:

- The uncertainty of taxonomic status associated with certain groups of invertebrates makes taxonomic resolution difficult;
- Invertebrates may not be sensitive to all pollutants;
- The distribution and abundance of benthic macro-invertebrates can be affected by factors other than water quality;
- Misidentification of families is always a possibility;
- Invertebrate biota is not spread uniformly across a river, even within a single biotope. (Dallas, Day & Reynolds, 1994 and Dickens & Graham, 2001).

3.4 Biological Indicators of the Health of Aquatic Ecosystems

According to Dallas & Day (1993) the assessments of the effects of water quality on aquatic ecosystems, and their inhabitants, is a relatively new skill in South Africa as it was only developed in 1979. In South Africa biotas are adapted to a wide variety of conditions across the country and very little knowledge about the response of any of them to deterioration in water quality is known (Davies & Day, 1998).

Since the communities of organisms in any ecosystem are made up of individual species, it is reasonable to suppose that determining the responses of some of these species will provide an accurate reflection of the effect of changes in water quality on the ecosystems in which they live. For the same reason, it is possible to use measures of the structure of the biological communities of an ecosystem. Lastly, since the interactions within ecosystems result in processes such as decomposition, measures of these processes are also measures of ecosystem functioning and hence of ecosystem "health". The question arises as to which of these numerous indicators can be used to predict or avoid the effects of reductions in water quality.

Some of the major biological indicators of benthic fauna are listed in Table 5 (Dallas & Day, 1993). Numerous attributes of individual species, biotic communities and natural processes can be used to assess the biological integrity of an aquatic ecosystem. Biological integrity is defined as the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition diversity and functional organisation comparable to that of the natural habitats within a region (Dallas, Day & Reynolds, 1994). Each of these attributes may be considered a biological indicator. Historically the term "biological indicator" has been associated with a particular "indicator organism", but in the current context its application is much broader and incorporates structural and functional attributes of individual organisms within a community, and whole communities.

Table 5: *Some biotic indicators that can be used to estimate the effects of reduced water quality on ecosystems and their biotas (Dallas & Day, 1993).*

ATTRIBUTES OF	BIOLOGICAL INDICATOR
Individual Species	Behaviour Growth rate Metabolic rate Sensitivity to pathogens Condition Fecundity Age to maturity Survival rate Abundance Biomass Recruitment and turnover
Biotic Communities	Species composition **Biodiversity (e.g. number of species)** Complexity of interrelationships Community succession Alteration in key species Resilience to change Sensitivity to change Rate of species colonisation and emigration Rate of re-establishment of equilibrium densities
Natural Processes	Rate of photosynthesis Rate of nutrient cycling Rate of decomposition

For the purpose of this study the biological indicator will be the **biodiversity** (number of species) above and below the point of discharge of treated polluted underground water to determine the impact of the polluted underground water pumped by the mine.

3.4.1 Sensitivity scales to pollution of aquatic ecosystems

The sensitivity scales were derived from the tolerances to pollution as used in the South African Scoring System 4 (Dickens & Graham, 2001).

A broad explanation of the sensitivity scales will be as follows:

1 – 5 Highly tolerant to pollution (i.e. Family Baetidae, score: 4)

6 – 10 Moderately tolerant to pollution (i.e. Family Ecnomidae, score : 8)

11 – 15 Very low tolerances to pollution (i.e. Family Heptageniidae, score : 13)

3.5 The Value of Wetlands as Habitat

From the following discussion on wetlands it will become clear that the value of a wetland will vary with the nature of the wetland, its position in the landscape and the needs of the population interacting with it. The value of a wetland is not site specific but transgresses regional, political and in some cases, international borders. With the location of the Blesbokspruit and the aforementioned definition of a wetland as directives, the value of wetlands to society should be evaluated in terms of the resources and services that accrue from the functions in the landscape. Although certain values of wetlands, for example fertile soils, have been recognised for millennia, many others, particularly those deriving from the manner in which wetlands function as a habitat, have only recently been recognised and accepted. This is because of the relatively recent expression of problems such as pollution, erosion and increased run-off, on scales that have potentially disastrous consequences for mankind as described by Huntley (1991) The value of the wetlands to society can therefore be evaluated in the contexts of available resources and services accruing from the way a system functions, as described in Table 6.

Table 6: *A generalised depiction of resource and values of wetlands, their conservation concern and the predominant geographical scales over which society benefits (Adapted from Huntley, 1991 and Kupchella & Hyland, 1993)*

	CONSERVATION CONCERN	GEOGRAPHICAL SCALE		
		Local	Regional	Global
Water	Fill or dredging of wetlands reduces their flood storage capacity. Pollution reduces their water consumption possibilities and biodiversity			
Soil	Removal of vegetation increases erosion and reduces capacity to moderate wave intensity and reduces biodiversity. Furthermore, destruction of wetland topographic contours or vegetation decreases wetland capacity to filter surface runoff and act as sediment traps. This increases water turbidity and siltation of downstream reservoirs, storm drains, and stream channels.			
Plants	Certain plants are dependent on the wetland functions for reproduction. Plants also play an important role in the overall function of the system. The disappearance of one or more species could lead to the collapse of the system or an income for users.			
Animals	Fills, dredging, damming, pollution and other alterations destroy and damage flora and fauna and decrease productivity. It could also impede on the movements of mammals, fish and birds.			
Energy	The loss of a wetland and its associated energy resource could lead to the collapse of the system as well as the rural community dependant on it.			
Flood attenuation	If the natural vegetation is lost or if flood flows are blocked by fills, dikes or other structures, increased flood heights and velocities result, causing damage to adjacent upstream and downstream areas.			
Aquifer recharge	Fills or drainage may destroy wetland aquifer recharge capability, thereby reducing base flows to streams and groundwater supplied for domestic, commercial, or other uses.			
Pollution control	Destruction of wetland contours or vegetation decreases natural pollution control capability, resulting in lowered water quality of downstream lakes, streams and other waters.			
Social attributes	Fill, dredging or other interference with wetlands causes loss of area for boating, swimming, bird watching, hunting, fishing and aesthetics			

Studies in the United States by Hodges-Copple (1989) as cited by Kupchella & Hyland (1993), have estimated that the function provided by an acre (0.405 ha) of healthy wetland is worth $US 10 000 to $US 30 000 a year. In current terms it meant R100,000 to R300,000 per hectare. The extent of wetlands in South Africa is poorly documented. What is known is that an estimated 58% of the wetlands in the 10 000 km² catchment of the Mfolozi River in Kwa-Zulu Natal have been lost through erosion and a variety of man induced factors like dredging, dam building and forestry (Preston-White, 1990). The functions and values of wetlands are only just being recognised in South Africa but there is no yardstick available at present by which the resources and services provided by wetlands can be reliably evaluated. Much needs to be accomplished before their attributes are translated into policy, regulations and management plans.

3.6 The Significance of the Blesbokspruit Wetland; International Importance

The Blesbokspruit Wetland, as one of the larger wetlands in the Highveld region of Gauteng in Southern Africa, became a high conservation priority because it forms an important component of one of the tributaries of the Vaal River, which provides water to the highly industrialised and densely populated Gauteng Province. The value of this system lies in its ability to purify industrial and domestic effluent discharged into the system from local industries, water care works and mines, thereby reducing pollutant loads downstream on entering the Vaal River. In addition, the wetland acts as an important refuge for many water bird species, particularly in the context of the highly industrialised urban environment of the Far East Rand, where most of the wetland habitats have been lost.

The Blesbokspruit supports significant numbers of waterfowl, including yellowbilled duck, *Anas undulata*, and spurwinged goose, *Plectropterus gambensis*, especially in the dry season, when water levels are artificially maintained. The nutrient-rich water provides food for greater flamingo, *Phoenicopterus ruber*, lesser flamingo, *Phoenicopterus minor*, and goliath heron *Ardea goliath*, all of which are South African Red Data Book species. Other notable birds include avocet, *Recurvirostra avosetta*, purple heron, *Ardea purpurea*, African spoonbill, *Platalea alba*, glossy ibis, *Plegadis falcinellus* and yellowbilled stork, *Mycteria ibis*. The African marsh harrier, *Circus ranivorus*, which has been displaced from much of its range, maintains a strong population here. (Madden, 2002) In one way or the other the benthic faunal assemblages support these birds as a food source.

In February 1971, the International Union for the Conservation of Nature (IUCN) and the International Waterfowl Research Bureau held a conference in Ramsar, Iran. At this conference delegates decided that countries should be encouraged to identify those wetlands that are most valuable as bird habitats, and to designate them as Wetlands of International Importance. These wetlands have since become known as Ramsar Sites (Davies & Day, 1998). South Africa became the fifth contracting member on 12 March 1975. Member countries have the obligation to include sites in the list and to formulate and implement their planning so as to preserve the ecological character of their listed sites. Criteria have been developed for determining which wetlands should be considered "internationally important" based upon their ecological and hydrological values and their importance for conserving biological diversity, so as to include them in the Ramsar list. Blesbokspruit was the fourth wetland in 1986 to be designated a Ramsar Site in South Africa (Compaan, 1992). Table 7 is a summary of the designated Ramsar Sites in South Africa.

Table 7*: A summary of the Ramsar Sites in South Africa*

Ramsar Site	**Province**	**Designation Date**
Barbers Pan	North West	1975
De Hoop Vlei	Western Cape	1975
St Lucia System	Kwa-Zulu Natal	1986
Blesbokspruit	Gauteng	1986
Tongaland Turtle Beaches	Kwa-Zulu Natal	1986
De Mond/Heuningnes Estuary	Western Cape	1986
Langebaan Lagoon	Western Cape	1988
Kosi-estuarine System	Kwa-Zulu Natal	1991
Lake Sibaya	Kwa-Zulu Natal	1991
Orange River Mouth	Northern Cape	1991
Verloren Vlei	Western Cape	1991
Wilderness Lakes	Western Cape	1991
Natal Drakensberg Park	Kwa-Zulu Natal	1997
Usutu/Pongola Floodplain, Ndumu Game Reserve	Kwa-Zulu Natal	1997
Seekoeivlei	Free State	1997
Nylsvlei	Northern Province	1998

3.6.1 Montreux record

Ramsar Sites that are degraded in one way or another, are listed in what is known as the Montreux Record. The Blesbokspruit was listed on the Montreux Record of the Convention in 1996 in response to a decline in the ecological character of the site, brought about primarily by the discharge of large volumes of polluted underground water from the adjacent Grootvlei Gold Mine. As a result of this and other impacts a large portion of the Ramsar Site does not at present meet all of the criteria under which it was designated to the List of Wetlands of International Importance. Processes are underway to restore the site and manage it towards a desired future state by the Department of Environmental Affairs and Tourism as well as Ekurhuleni Metropolitan Municipality. (Marshall, 2002).

Although South Africa is a signatory of the Ramsar Convention there has, according to Breen and Begg (1999) as cited by Huntley (1991), until comparatively recently, been little interest in the conservation of wetlands. Neither have South African Wetlands been formally classified or inventorised but plans are currently being put in place by the Department of Environmental Affairs and Tourism to inventorise South African wetlands (Dini, 2002).

4. WATER POLLUTION AND ITS IMPACT ON THE BENTHIC FAUNA

To address and analyse the problem and extent of water pollution and to understand its impact on the environment and the benthic fauna specifically, it is important to take note of the various sources and interpretations of pollution.

4.1 Defining Pollution

There are many definitions for pollution depending on the specific situation, contaminants or materials, environmental components and quality norms involved. Pollution could generally be defined as energy or matter in the wrong location at the wrong time. The National Water Act, 1998 (Act 36 of 1998) defines pollution as:"*… the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it-*

(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or

(b) harmful or potentially harmful:

(aa) to the welfare, health or safety of human beings;

(bb) ***to any aquatic*** *or non-aquatic organisms;*

(cc) to the resource quality; or

(dd) to property."

From these two definitions it could be concluded that pollution is always relative to a certain reference value. The impact that the pollution may have then depends on the extent of quality deterioration relative to the established norm. Pollution becomes obvious when man's activities result in exceedence of the natural capacity of an ecosystem, thereby causing an imbalance in the system, which requires an enormous input of energy to rectify. Water and air are components of our environment where pollution becomes more apparent. Polluted water has different impacts on different families of benthic fauna such as the *Athericidae*, which will only occur in unpolluted water, compared to the *Chironomidae* which can occur in heavily polluted water.

According to Fuggle & Rabie (1994, p.285) the quality of many water sources in South Africa is declining. This is primarily as a result of salination, eutrophication and pollution by trace metals and micro pollutants. Many rivers in South Africa are naturally high in dissolved salts. However, increased urbanisation, industrialisation, irrigation, stock farming, erosion and the spread of alien vegetation have markedly reduced the potential usefulness of many rivers and water bodies in South Africa. The solving of water pollution problems must therefore be integrated with air pollution, energy, land use and population policies.

4.2 The Causes and Problems of Water Pollution

The causes of water pollution can be due to two main reasons, namely natural water pollution and pollution caused by man and his activities and both these causes have a negative impact on the benthic faunal assemblage.

4.2.1 Natural water pollution

The water quality of a specific source (e.g. a pristine river) can change continuously. From the origin, rains, springs, etc., it dissolves chemical substances on its way to the ocean. As it filters through the soil, more substances are dissolved from the substrata. In the various regions of the country the chemical composition of the underground water is affected differently owing to geological factors (Davies & Day, 1998). The most important inorganic salts which dissolve in water are carbonates, bicarbonates, chlorides, sulphates, nitrates as well as trace elements such as barium and phosphorous. However, the phenomena of water pollution through the natural processes is beyond man's resolve, but the introduction of other pollutants by man could cause an imbalance in the ecosystem.

4.2.2 Water pollution caused by man

This type of pollution is as old as man himself and gathered momentum through the development of agriculture, industrialisation, the increase in population and urbanisation. Man made water pollution is classified into two different types, namely pollution originating from:

- Point source; and
- Diffuse or non-point source.

The variety and types of pollution from these two sources are indicated in Figure 5 which indicates man's impact on the aquatic environment and which is self-explanatory.

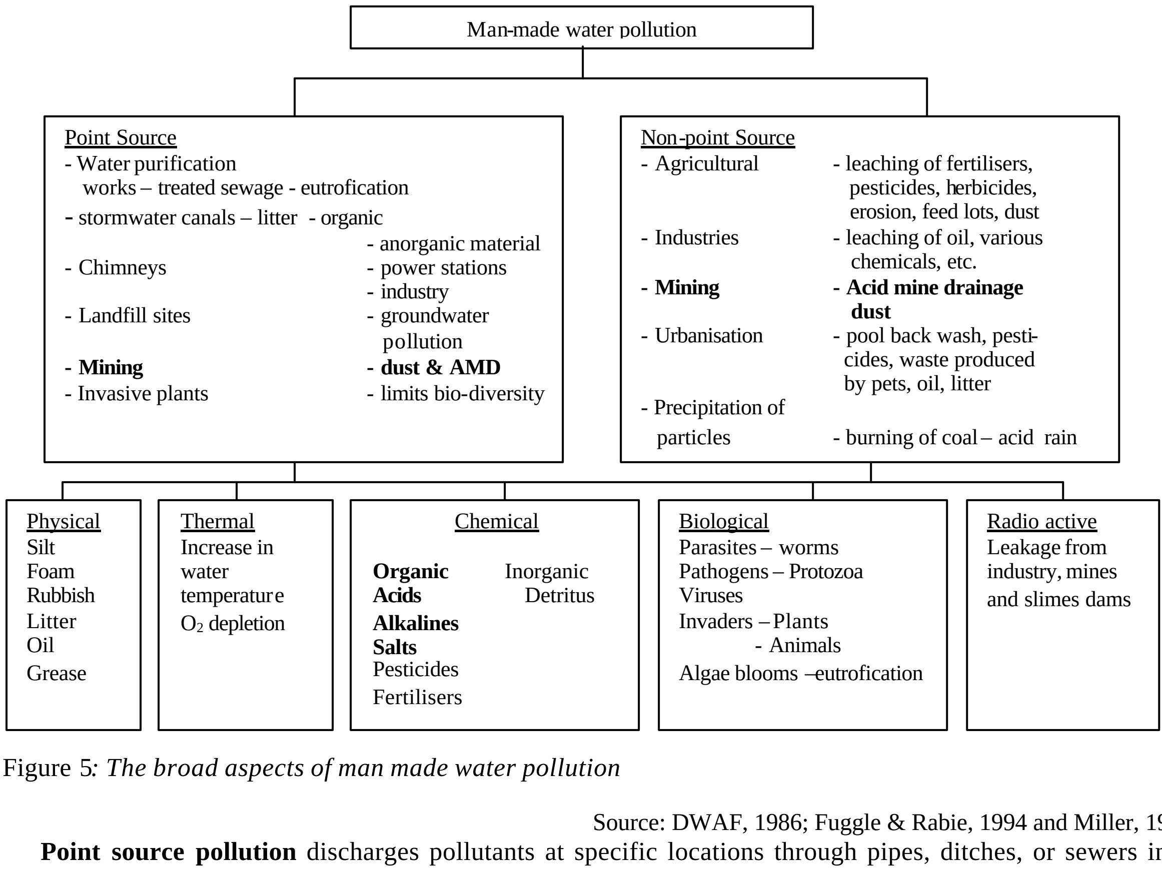

Figure 5*: The broad aspects of man made water pollution*

Source: DWAF, 1986; Fuggle & Rabie, 1994 and Miller, 1994

Point source pollution discharges pollutants at specific locations through pipes, ditches, or sewers into bodies of surface water. Examples include factories, sewage treatment plants (which remove some but not all pollutants), active and abandoned underground mines, etc. Because point sources are at specific places (mostly in urban areas), they are fairly easy to identify, monitor and regulate.

Non point pollution sources are sources that cannot be traced to any single site of discharge. They are usually large, poorly defined areas that pollute water by runoff, sub-surface flow, or deposition from the atmosphere. Examples include runoff of chemicals into surface water (including stormwater) and seepage into the ground from croplands, livestock feedlots, logged forests, streets, lawns, septic tanks, construction sites, parking lots and roadways.

4.3 Types of Water Pollution and the Resultant Impact on the Benthic Fauna

4.3.1 Stream pollution

Flowing streams – including rivers – recover rapidly from degradable, oxygen-demanding wastes and excess heat by a combination of dilution and bacterial decay. This natural recovery process works as long as streams are not overloaded with these pollutants, and as long as their flow is not reduced by drought, damming, or diversion for agriculture and industry. Slowly degradable and non-degradable pollutants are not eliminated by these natural dilution and degradation processes. This breakdown of degradable wastes by bacteria depletes dissolved oxygen, which reduces or eliminates populations of organisms with high oxygen requirements until the stream is cleansed. The depth and width of the resulting oxygen sag curve (Figure 6) and thus the time and distance required for a stream to recover, depends on the stream's volume, flow rate, temperature, and pH level, as well as the volume of incoming degradable wastes.

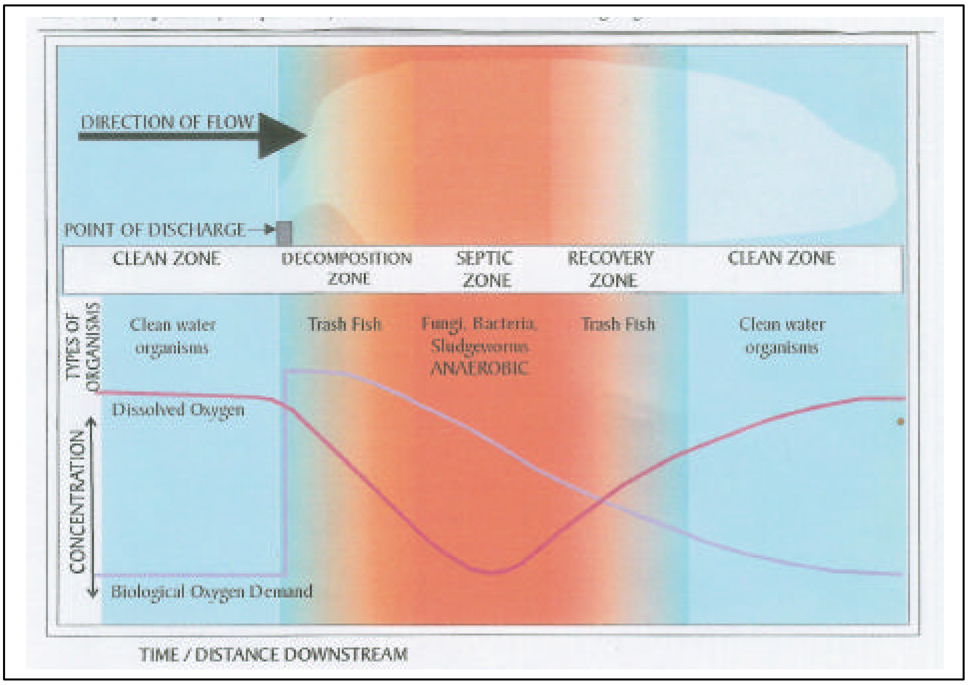

Figure 6: *Dilution and decay of degradable, oxygen demanding wastes and heat, showing the oxygen sag curve and the curve of oxygen demand*

Source: Miller, 1996, p.595

4.3.2 Groundwater pollution

Groundwater often surfaces as springs which feed a wetland. When groundwater becomes contaminated, it cannot cleanse itself of degradable wastes, as surface water can if it is not overloaded. Because groundwater flows are slow and are not turbulent, contaminants are not effectively diluted and dispersed. Groundwater also has much smaller populations of decomposing bacteria than do surface water systems, and its cold temperature slows down decomposition reactions.

Groundwater can be contaminated from a number of sources, including underground storage tanks, landfills, abandoned hazardous-waste dumps, deep wells used to dispose of liquid hazardous wastes, mines and industrial-waste storage lagoons located above or near aquafers. When this polluted ground water surfaces it will have a negative impact on the benthic fauna as discussed under 4.1.

4.3.3 Wetlands and reservoir pollution

In lakes, reservoirs and wetlands dilution is often less effective than in streams as these water bodies frequently contain stratified layers that undergo little vertical mixing. Stratification also reduces levels of dissolved oxygen, especially in the bottom layer because the water is in little or no motion. In addition, lakes and reservoirs, have little flow, further reducing dilution and replenishment of dissolved oxygen. The flushing and changing of water in lakes and large artificial reservoirs can take from 1 to 100 years, compared with several days to several weeks for streams (Miller, 1996, p.483). Lakes, reservoirs and wetlands, are more vulnerable than streams to contamination by plant nutrients, oil, pesticides, and toxic substances such as iron, lead and mercury, that can destroy both benthic life and fish and birds that feed on contaminated aquatic organisms.

4.3.4 Other types of Pollution

Near urban or agricultural areas the input of nutrients to a wetland can be greatly accelerated by human activities, which results in a process known as cultural eutrophication. Such a change is caused mostly by nitrate- and phosphate-containing effluents from sewage treatment plants, runoff of fertilizers and animal wastes, and accelerated erosion of nutrient-rich topsoil.

During hot weather or drought, this nutrient overload produces dense growths of organisms such as algae, cyonobacteria (Hartebeespoortdam 2001) and water hyacinths (Loskopdam 1974). Dissolved oxygen in both the surface layer of water near the shore and in the bottom layer is depleted when large masses of algae die, fall to the bottom, and are decomposed by aerobic bacteria. This oxygen depletion can kill fish and other aquatic animals such as the benthic fauna.

Another class of water pollutants is sediment, or suspended matter – insoluble particles of soil and other solids that become suspended in water, mostly when soil is eroded from the land. By weight this is by far the biggest water pollutant. Sediment clouds water and reduces photosynthesis; it also disrupts aquatic food webs and carries pesticides, bacteria, and other harmful substances which can wipe out benthic faunal assemblages. Sediment that settles out destroys feeding and spawning grounds of fish, and it clogs and fills lakes, wetlands, artificial reservoirs, stream channels, and harbours.

Water can also be polluted by a variety of organic chemicals, which include oil, fuel, plastics, pesticides, cleaning solvents, detergents, and many other chemicals. They threaten human health and harm fish and other aquatic life. Water can also be polluted by water-soluble radioactive isotopes, e.g. from slimes dams, which are capable of being concentrated in various tissues and organs of aquatic species as they pass through food chains and webs. Ionising radiation from such isotopes can cause birth defects, cancer, and genetic damage.

Heat absorbed by water used to cool industrial and power plants can lower water quality. The resulting rise in water temperature – thermal pollution – lowers dissolved oxygen and makes aquatic organisms more vulnerable to disease, parasites, and toxic chemicals.

Another form of water pollution, called genetic pollution, occurs when aquatic systems are disrupted by the deliberate or accidental introduction of non-native species. Introduced species spread through canals linking bodies of water and by deliberate introduction to enhance fishery production and, according to Fuggle & Rabie (1994, p.292) all major South African rivers are inhabited by alien animals such as trout, bass and carp as well as insects e.g. *Limnophyes pusillus* (midge fly) and *Cyrtobagous salviniae* (a weevil). These invasive species have a major detrimental impact on indigenous species and communities through competition for food and space, predation, hybridisation, the introduction of parasites and disease, disruption of breeding behaviour of other fishes and habitat alteration.

Alien plants, of which four species are relevant, *Eichornia crassipes, Salvinia molesta, Azolla filiculoides* and *Myriophyllum aquaticum*, have a marked impact on Southern African fresh water ecosystems (Fuggle & Rabie (1994, p.292)). *Azolla* and *Myriophyllum* have been noted on the Blesbokspruit. These invasive plants alter water flow patterns, decrease oxygenation from the atmosphere and reduce light intensities in the water with the resultant impact on water organisms.

4.4 Water Pollution Monitoring in the Study Area

Rand Water monitors the rivers draining the catchment areas of both the Vaal Dam and the Vaal River Barrage Reservoir. The Barrage Reservoir is fed from the Vaal Dam and the Suikerbosrand and Klip River but the water quality from this catchment has suffered through the explosion of both formal and informal urbanisation and intense industrial activity to such an extent that Rand Water no longer draws water for drinking purposes from the Barrage Reservoir but from the Vaal Dam (Rand Water, 2001)

Industries use water as a solvent, a coolant, a dust settler and a cleanser and as a means of transport (Davies & Day, 1998, p.318) and in the process the water gets polluted. Some mining processes produce acids and heavy metals together with cyanides. Steel mills can deliver mixtures of toxic material such as cadmium, arsenic, tin, lead, copper, antimony as well as acids and phenols (Davies & Day, 1998) . Mining activities not only pollute the underground water through their physical and chemical underground processes but also surface water with acid mine drainage and metals such as copper, lead, cadmium, arsenic, cobalt, nickel and chrome. Table 8 shows the results of water monitoring undertaken by Rand Water on the Blesbokspruit at various points upstream and down stream of the area of investigation.

Table 8*: Pollutant concentrations of the Blesbokspruit at the inflow & outflow of the area of investigation (March 2002), as indicated in Figure 1, compared to the objectives as set by Rand Water*

	Pollutant Concentrations (mg/1)											
	E.coli		Chemical Oxygen Demand As 0		Conductivity		Phosphate		Sodium		Sulphate	
	Mea-sured	Ob-jective	Mea-sured	Ob-jective	Mea-sured	Ob-jective	Mea-sured	Ob-jective	Mea-sured	Ob-jective	Mea-sured	Ob-jective
Inflow	-	<10	56	<20	99.33	<45	0.37	<0.2	115.83	<70	104.33	<150
Out-flow	-	<10	20.67	<20	173.33	<45	0.33	<0.2	147.50	<70	497.50	<150

Source: Springs Service Delivery Centre (2002)
Rand Water (2002)

4.5 Water quality: Aquatic ecosystems

The term "water quality" was coined with reference to the quality of water required for human use: "good quality" water is "pure" and unpolluted and suitable for drinking as well as for agricultural and industrial purposes. It is critically important to acknowledge however, that this is entirely a human perspective since each species thrives optimally in water with particular combinations of physical and chemical attributes. Since optimal conditions differ for each species, alterations in water quality will affect different species to a greater or lesser extent. Changes in water quality may eliminate some species and allow others to invade, until not a single species of the original assemblage remains.

The effects of altered water quality on aquatic communities include:

- A shift in the physical position of a community of riverine organisms;
- The introduction or loss of key species (for instance, the massive growth of benthic algae in eutrophic waters may result in a "population explosion" of snails and the loss of mayfly and stonefly nymphs);
- Reduction in diversity as a result of very small increases in the concentrations of toxins such as trace metals;
- Reduction in, and ultimately loss of, decomposers and thus of nutrient cycling in streams and lakes.

4.6 Water quality management in South Africa

Until 1989 water quality in South Africa was managed on the basis of uniform effluent standards. Despite the enforcement of these standards, the quality of South Africa's water sources continued to deteriorate (DWAF, 1993). To counter this deterioration a set of water quality guidelines which describe water guidelines in terms of requirements of various recognised users were developed. The guidelines also explain the effect of changes in water quality on a specific water use, as well as the norms determining fitness for use.

The water quality requirements of the different water user groups are not necessarily the same and thus five main water uses for inland surface water are recognised and addressed in these guidelines:

- Domestic
- Recreational
- Industrial
- Agricultural
- Natural environment – (benthic fauna)

These different guidelines imply that water, which would ideally be fit for use for one specific user group, may not be ideally suited for another. In addition, water seldom becomes totally unfit for use when the quality deteriorates. Quality is thus an intrinsic property of water, but is linked to the use made of the water. The region where the study of the benthic fauna is to take place will now be discussed.

5. THE STUDY AREA

5.1 Historical Background

Before mining operations commenced in the early 1900's the study area was typical flat Highveld terrain of grassland and probably crop farming. The Blesbokspruit ran unrestricted through the area, fed by various springs, with little or no reedbeds along its banks. With the discovery of coal and gold and together with the establishment of the town of Springs a number of embankments were built across the Blesbokspruit for roads, railway lines and pipelines. These caused a certain amount of flooding and vast stretches of shallow water were formed, creating one of the few permanent wetlands in the then Transvaal. The mining operations from the early 1900's to the 1960's, the rock dumps, slime dams and residential development changed the character of the area from rural highveld to industrial – residential (Compaan, 1992; Scott, 1995 and University of Pretoria, 1999). Polluted effluent from these developments will have a negative impact on the benthic fauna assemblage.

5.2 Delimitation of the study area

The study area is in Gauteng Province on the East Rand in the Ekurhuleni Metropolitan Municipality about 3 km east of Springs. The investigation area is defined by 26°15' – 26°18'S and 28°29' – 28°30'E and is approximately 1585 m above sea level. (Figure 1, p.5) The size of the study area is approximately 290 ha including the adjacent grassveld. The northern border is the R555, Welgedacht Road and the southern border the R28, Ermelo Road. The eastern side of the study area is bordered by slimes dams and overgrazed land with sink holes from an old coal mine as well as agricultural small holdings. The western side is bordered by residential area, Grootvlei Mine, a slimes dam and agricultural small holdings.

5.3 Geology and Geomorphology with relation to the water in the Blesbokspruit and the concomitant Benthic Fauna

According to Compaan's report (1992) the geology of the area is fairly simple with flat lying sedimentary rocks of Karoo and Transvaal sequence overlying older formations of gold bearing Witwatersrand Supergroup sediments. Important factors to note from the geology with relation to the water in the system and the concomitant benthic fauna are:

- The distribution of dolomite, which is an important aquifer in the area and supplies much of the water which seeps into the underground workings and feed the stream. Dolomite also has a neutralising or buffering effect on surface and groundwater, thus maintaining a high pH;
- The outcrop areas of Black Reef sediments (the base of the dolomites), which are regions of surface exploration, trenching and open mining activity which might contribute to the inflow of water into the mine which needs to be pumped out as polluted water;
- The distribution of Karoo sediments. The lowermost sequences consist of Diamictite, a very fine grained sediment of glacial origin, which could form a confining layer preventing groundwater from passing through the Karoo sediments.

5.4 Topography and Surface Hydrology as a factor in the Benthic Faunal Assemblages

The Blesbokspruit forms part of the Vaal River Barrage catchment and covers some 1427 km^2 of the catchment. According to the geological map, the spruit flows over alluvium covered dolomite for much of its course to where it flows into the Suikerbosrand River. The Blesbokspruit flows almost north south and the elevation distance is only a 0.92 m fall over 4900 m distance through the area of interest. Because of this low gradient the river is swampy and choked with reeds as depicted in Figure 7 and rich in bio-diversity supported by the benthic fauna assemblages

Figure 7: *An aerial photo of the area of interest indicating the reed beds*

The most prominent topographic features in the study area are man made. Residential areas, of which Bakerton suburb is on the 1:100 year floodline, slimes dams and headgear from Grootvlei Mine and farming activities are some of these man made features which can be observed east of the study area.

5.5 Climate as a food producing and bio-diversity enhancing factor

The climate in this area is temperate, highveld with a short cold winter. Frost occurs on average on 43.3 days per year with the highest of 88 days per year in 1988 and the lowest of 24 days in 2001. The average minimum temperature being 1.2° C and the lowest -5° C measured 30 June 1994. The maximum average temperature is 28.96° C and the highest 36° C measured 8 January 1993. Rainfall occurs in summer predominantly during thunder storms experienced from October to April. The average precipitation is 906.89 mm per year.

These records were obtained from an accredited weather station at the Division of Parks & Recreation of the Springs Service Delivery Centre which have records since 1920. This weather station is about 5 km west of the area of interest. All the above averages were calculated over a period of 11 years from 1991 – 2001 unless otherwise indicated.

As the frost kills off the plants the plant rests become an important food source for zoo-plankton and benthic invertebrates. The seasonal fluctuation of the wetland with the dry and wet seasons invite different bird species like waders and flamingo's which, inter alia, feed on the benthic fauna.

5.6 Land Use and its impact on the Benthic Fauna

The study area lies within 10 km of the industrial area of Springs, adjacent to Grootvlei Mine and within one kilometre of urban and suburban developments. East of the study area is agricultural land – mainly cattle farming. Three slimes dams are within 500 m of the study area. Figures 8(a) and 8(b) depict the proximity of one of the slimes dams and leachate from the same slimes dam. Polluted effluent and dust impacts negatively on the water quality of the spruit with the concomitant negative impact on the benthic fauna as discussed in 4.3.4.

Figure 8(a): *The proximity of one of the slimes dams to the Blesbokspruit*

Figure 8(b): *Leachate from the slimes dam above with the other slimes dam in the background*

6. DATA COLLECTION AND ANALYSIS

6.1 Methods of data collection for Biological Monitoring

Numerous methods have been developed for bio-assessment of the integrity of aquatic systems. Some of these are based on some aspect or other of a single species (the bio-accumulation of heavy metals on a particular species of crabs or fish for instance, (De Wet, 1990 and Adendorff, 1997), but most are based on attributes of whole assemblages of organisms such as fish, algae or invertebrates. Davis and Day (1998) state that bio-monitoring has only recently become a routine tool in the management of inland waters. In South Africa the development in the field of bio-assessment was enhanced by the development of the South African Scoring System (SASS) by Dr Mark Chutter which will be discussed in 6.1

6.1.1 The Development of Methods for Bio-assessment

Biotic indices are generally used to quantify the degree of pollution in an aquatic system by assigning scores based on organism sensitivity or tolerance to pollution (some indices also score abundance.) These scores are summed to provide a value which is an indication of the pollution status of a particular site. Cook (1976) as cited by Dallas, Day & Reynolds (1994) stated that the ideal biotic index should have the following attributes:

- Be sensitive to the effects of pollution;
- Have general application to different types of streams;
- Provide a continuous assessment from polluted to unpolluted sites;
- Be independent of sample size; and
- Have relatively simple data gathering and index calculations.

Numerous biotic indices and score systems have been developed. The following provides a brief overview of the biotic indices that have been developed by various groups.

✪ Trent Biotic Index (TBI)

This index was originally developed by the Trent River Authority in the United Kingdom for use in the Trent River area. It is based on the presence or absence of six key groups of benthic fauna and their relative tolerance to pollution. These tolerances facilitated the calculation of an index value between 15 (“clean” streams) and 0 (gross pollution and absence of life). Over a fifteen year period this index was modified to form many subsequent indices such as Chandler’s Score (CBS), Biological Monitoring Working Party Score (BMWP), the modified BMWP score and the Belgium Biotic Index.

✪ Chandler’s Score System (CBS)

This score system is based on the TBI but it also incorporates an abundance factor in the final calculation of index score.

- ✪ Biological Monitoring Working Party (BMWP) Scoring System

  This system is a simplification of CBS. The abundance factor was, however, eliminated because it was time consuming and had only a small effect on score value. Pollution intolerant families were given a high score (10), whereas pollution tolerant families were given a low score (2). The SASS was loosely based on this system and adapted for South African conditions.

- ✪ Indice Biotique and the Indice Biologique Global (IB and IBG)

  These indices were developed in France and requires the sampling of eight different biotopes, which are defined on the basis of substrate and velocity conditions.

- ✪ Belgian Biotic Index (BBI)

  This index combines the scoring procedures of IB and TBI.

- ✪ Chutter's Biotic Index (CBI)

  This index is restricted to fauna associated with the stones-in-current biotope and to the assessment of waters subject to organic pollution. This index has been fairly widely used in South Africa e.g. Damelin & Alexander (2000) and Dallas, Day & Reynolds, (1994) and has been modified for use internationally.

- ✪ Hilsenhoff's Biotic Index (HBI)

  This index was modified from CBI by changing tolerance value for local fauna (Wisconsin, USA) and excluding selected invertebrate taxa. Approximately 400 species or genera have been assigned scores.

- ✪ Invertebrate Community Index (ICI, Iowa, USA 1987)

  This index is derived from the Index of Biotic Integrity which is based on the attributes of fish communities.

- ✪ Australian Rapid Biological Assessment Method

  This procedure involves the standardised collection of 100 animals from defined habitats (riffles, stream edges, rocks in pools and submerged wood) within a water body and scored to the Signal Biotic Index (similar to BMWP).

- ✪ Macro-invertebrate Community Index (MCI)

  This method was developed for use in New Zealand's stony streams and is based on the BMWP method. Scores are however allocated on the generic level.

✪ South African Scoring System (SASS)

This method of rapid biological assessment was developed for use in South African rivers and streams and is based on benthic macro-invertebrates and is specifically aimed at assessing the impairment of water quality. (Dallas, Day & Reynolds, 1994). This scoring system is derived from the MBWP system although scores have been modified for local taxa and the range of scores expanded so that a tolerant taxon is allocated a score of one whereas a sensitive taxon is allocated a score of 15. The total score per site is calculated by summing the taxon scores and the average score per taxon (ASPT) is calculated by dividing this total score by the number of taxa. Both scores are considered when determining water quality impairment. Chutter (1998) suggests the following guidelines for the interpretation of SASS4 scores:

SASS4 > 100, ASPT > 6: Water quality natural, habitat diversity high;
SASS4 < 100, ASPT > 6: Water quality natural, habitat diversity reduced;
SASS4 > 100, ASPT < 6: Borderline case between water quality natural and some deterioration in water quality;
SASS4 50 – 100, ASPT < 6: Some deterioration in water quality;
SASS4 <50, ASPT variable: major deterioration in water quality.

The South African Scoring System (SASS4) is the rapid bio-assessment scoring method that was used in the present study as it was developed for use in South African and is specifically aimed at assessing the impairment of water quality. (Score sheet attached as annexure A).

6.2 Data required from the benthic faunal assemblages to assess the impact of the polluted water pumped by Grootvlei Mine

Numerous methods have been developed for bio-assessment of the integrity of aquatic systems but according to Davies & Day (1998), bio-monitoring has only recently (1979) become a routine tool in the management of inland waters. In the field of bio-assessment the South African Scoring System (SASS) is a technique that uses invertebrates as tools in the rapid bio-assessment of water quality in river systems. Because SASS is a relatively simple tool that provides useful information about water quality the present version, SASS4, was used in this study. A copy of a SASS4 sheet is attached as Annexure A.

Two premises underpin SASS. The first is that some invertebrate taxa are much more sensitive to chemical pollutants than others. The second premise is that the invertebrate faunal assemblage, at any site, at any time, is dependent not only on the water quality sampled, but also on the conditions that have pertained at that site over the entire life span of the assemblage. **The data thus needed to make meaningful deductions about the health of the system is:**

i) the benthic fauna diversity and quantity upstream from the point of discharge of the polluted water;
ii) the benthic fauna diversity and quantity at the point of discharge;

iii) the benthic fauna diversity and quantity downstream from the point of discharge of the polluted water; and

iv) the physical attributes (depth of water, temperature, flowing tempo, depth of the mud and vicinity of reeds) of the sample points. This was needed to identify homogenous sample points. These sample points are indicate in Figure 1, p.5.

The following steps were taken in the data collection process:

(i) Site identification for homogeneous sample points.
(ii) Construction and placing of the artific ial substrates at the identified sample points.
(iii) Collection of the artificial substrates after eight weeks and the collection of any benthic fauna specimens as per proven method from the substrates in marked plastic containers.
(iv) Identification of the benthic fauna families and counting of the individual animals.
(v) Transferring the information to the South African Scoring System 4 card and determining the scores.
(vi) Interpretation of the scores.

6.3 Collection of SASS4 samples in the field

Invertebrates were collected with a “kick-net”, a rectangular scoop-net on a stick as depicted in Figure 9. The sides of the frame are 300 x 400 mm, the mesh no larger than 1 mm and the bag deep enough (at least 400 mm) so that the sampled material is not easily washed out. The material on the bed of the river was literally kick-sampled. The net was held downstream of the area to be sampled, the substratum was vigorously turned over with a gumboot so that the disturbed particles, including leaves, twigs, sediments and animals, were washed into the net by the flow of the water.

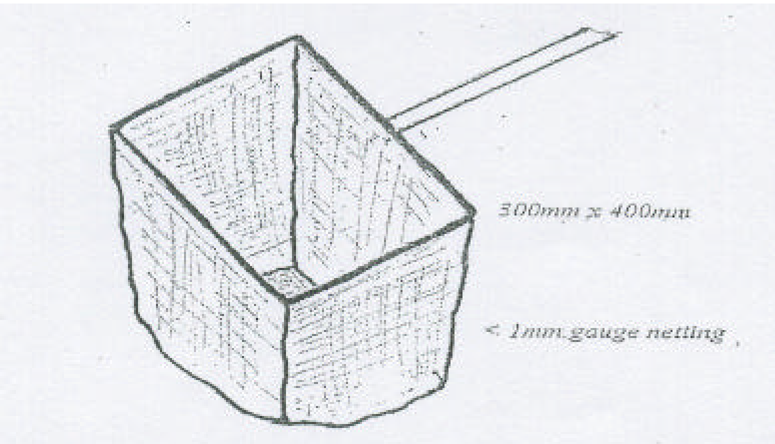

Figure 9: *A depiction of a kick -net as used in this study*

As the streamflow in the wetland was not fast enough, virtually at a standstill at four of the six sampling points, this method of sample collection was discarded as being unsuccessful.

Following this unsuccessful sample collection the sampling of macro-invertebrates from soft (mud & silt) bottom sub strata was performed by employing a Birge-Eckman grab (grab capacity = 4500 ml) as depicted in Figure 10. The sample was poured into a close-grained gauze net (mesh size = 225/cm^2) and rinsed in the water at the locality to rid the sample of excess mud. This method was previously successfully applied by authors such as De Wet, (1990) and Adendorff (1997). However, owing to the huge amount of large particles of organic material in the wetland, this method was not as successful as originally assumed. The core-tube method was also discarded because of the substance of the mud.

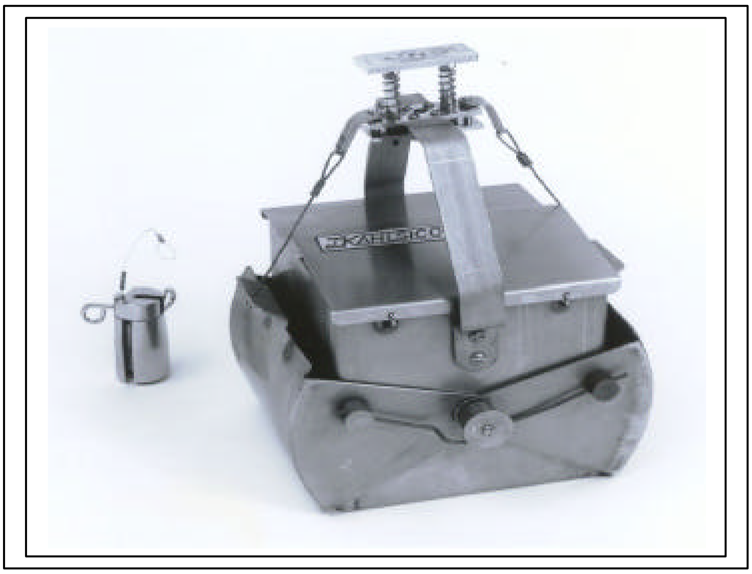

Figure 10: *A depiction of a Birge-Eckman grab as used in this study;*

6.3.1 Artificial Substrates – A new bio-monitoring protocol for benthic fauna

As the study area is a lentic eutrophic wetland, the biotopes used for the SASS cannot be used and an alternative suitable biotope needed to be investigated. Thirion (1999) in her studies used the method described by De Pauw et al (1994), in Belgium, with great success. Their results indicated that artificial substrates can replace the usual handnet samples and provide a correct assessment (De Pauw et al 1994 as cited by Thirion , 1999). This method of data collection was also used in this study.

One of the major advantages of using artificial substrates is that the effect of habitat is eliminated. The biological quality of the water body can thus be assessed independently of the natural substrative. Sampling the natural substrates gives an indication of the resident biota and is impacted by the available habitat, whereas artificial substrates measures the colonisation potential and is indicative of the water quality but not of the natural invertebrate fauna.

6.4 Delimination of the sampling points for the data collection

For the purpose of this study it was important that the immediate surrounds at the different sample points in the wetland corresponded. The six artificial substrates to collect invertebrates were therefore placed in open water ($\geq$ 50 m²) in the reed beds where there is virtually no streamflow as depicted in Figure 11.

Figure 11*: A photographic presentation of one of the sampling points*

The water depth at the sample points ranges from 300 mm to 650 mm and the mud depth from 100 mm to 700 mm. The mud consists mainly of organic material in suspension. The water temperature ranged from 19° C to 22° C on the date of placing the samples to 11° C to 14° C on the date when the samples were removed. The sample area is bordered on the east by the Bakerton suburb, Grootvlei Mine and a slimes dam and on the western bank by two slimes dams, grassveld and agricultural small holdings as indicated in Figure 1.

All the sample points were $\geq$ 20 m from the edge of the wetland where there should be no external impacts from the land adjacent to the wetland on the substrates. Sample point 1 is the furthest upstream from the point source of pollution, sample point 4 is the downstream point closest to the point source of pollution and sample point 6 is the furthest downstream from the point of pollution. Sample points 3 and 4 might be influenced by acid mine drainage as point 3 is between two slimes dams and point 4 is the first downstream point after the slimes dams (Figure 1 shows sampling points). Two artificial substrates to collect the invertebrates were placed at each sample point of which one was removed at point 1 and 3 a week prior to the final investigation to determine the invertebrates families. Table 9 is a descriptive summary of the six sample points indicating the position, temperature, water and mud depth, altitude and the distance between each sample point. Sample point 4 is the closest downstream from the point of discharge of the treated mine water.

Table 9: *Summary of the six sampling points*

SAMPLING POINT	POSITION	TEMPERATURE		WATER DEPTH	MUD DEPTH	ALTITUDE	DISTANCE
		27.04.2002	19.06.2002				
1	S 26°13'14"	22°C	14°C	300mm	500mm	1584.96m	Point 1 – 2
	E 28°28'28"						1150m
2	S 26°13'843"	20°C	12°C	350mm	400mm	1584.96m	Point 2 – 3
	E 28°29'136"						950m
3	S 26°14'25"	20°C	11°C	500mm	600mm	1584.35	Point 3 – 4
	E 28°29'391"						1150m
4	S 26°15'111"	22°C	14°C	300mm	<100mm	1584.35	Point 4 – 5
	E 28°29'558"						900m
5	S 26°15'346"	19°C	14°C	350mm	700mm	1584.25	Point 5 – 6
	E 28°29'868"						750m
6	S 26°15'849"	19.5°C	13°C	650mm	450mm	1584.04	
	E 28°30'230"				Total distance points 1 – 6:		4900m

6.5 Construction and placing of the artificial substrates at the sample points: method followed

Artificial substrates, similar to the Belgian substrate (De Pauw et al. 1994 as cited by Thirion, 1999) were used. Bags with a 10 mm mesh netting were filled with approximately 35 stones with a diameter of between four and eight cm. The six bags were filled with stones and each corresponded to the volume of approximately 3 litres as depicted in Figure 12. No comparison of the natural substrate could be sampled as a similar substrate to the artificial substrate does not occur in the wetland.

Figure 12: *A photographic presentation of the artificial substrate*

La Point and Fairchild (1992) as cited by Thirion (1999) recommend the colonisation period from 10 days to eight weeks. Thirion (1999) suggests that colonisation much beyond two months would not greatly enhance the community. The test substrates were left in place above the mud for a period of eight weeks.

6.6 Collection of the artificial substrates and identification of the colonised benthic fauna

At the end of the colonisation period the artificial substrates were retrieved. A net (mesh size < 1 mm) was held underneath the substrates as it was retrieved to prevent the more mobile invertebrates from escaping. Both netting and substrates were placed in a plastic container filled with approximately eight litres of water from the collection point. The netting was rinsed in the container and all lingering specimens were brushed off with a soft brush. The stones were rinsed in the water and brushed clean using a soft brush and checked for attached specimens. Each complete sample was washed through a fine sieve (mesh size 0.5 mm) to remove most of the fine suspended matter and placed in a five liter plastic bucket and taken to the laboratories at the Water Quality Science Institute in Pretoria to identify the macro-invertebrates. At the laboratories each sample was washed through a sieve (mesh size 1mm) to remove more of the suspended matter. Each sample was then returned to a shallow white tray (400 mm x 350 mm) with clean water and the invertebrate taxa identified and recorded on the SASS form (a copy is attached as Annexure A).

6.7 Application of the South African Scoring System (SASS4)

Each taxon (usually each family) of invertebrates from South African rivers has been allocated a score, ranging from 1, for those taxa most tolerant of pollutants, to 15 for those most sensitive to pollutants. The combined scores for all of the taxa at a particular site will be high if the taxa are mostly pollution-sensitive, and low if they are mostly pollution –tolerant. Thus the highest total scores are to be expected in the clean waters of upper rivers. And the lowest scores in severely polluted rivers. To complete the SASS exercise, the scores for all the taxa in the sample were added (the Total Score), the number of taxa were also counted and recorded. The total score was then divided by the number of taxa to get the Average Score Per Taxon or ASPT (Davies & Day, 1998).

7. DISCUSSION OF THE RESULTS OBTAINED FROM THE STUDY

7.1 Water quality results

During the study period the Blesbokspruit Wetland was rich in nutrients (eutrophic) as a result of McComb Water Care Works discharging into the system upstream from the sampling points. Table 10 gives the results of water samples taken at each sampling point and analysed at the water care laboratory of the Springs Service Delivery Centre, compared with Rand Water's water quality objectives for the Blesbokspruit.

Table 10: *Water analysis at the six sampling points for macro invertebrate fauna in the Blesbokspruit Wetland (Date analysed: 20 June 2002)*

Sample Point	1	Rand Water Objective	2	Rand Water Objective	3	Rand Water Objective	4	Rand Water Objective	5	Rand Water Objective	6	Rand Water Objective
PH	7.1	Ideal	6.8	Ideal	7.5	Ideal	7.6	Ideal	7.6	Ideal	7.8	Ideal
Electrical Conducti-vity @ 25°C (mS/M) (EC)	92	Tolerable	93	Tolerable	96	Tolerable	248	Unaccep-table	162	Unaccep-table	162	Unaccep-table

As no specific standards for electrical conductivity (EC) and pH for aquatic ecosystems have been determined in the South African Water Quality Guidelines: Aquatic Ecosystems (Department of Water Affairs and Forestry, 1996), objectives set by Rand Water were used for comparison. From Table 10 it is clear that the water at all six sampling points comply to the pH objectives. However, the objectives set for EC by Rand Water, especially at the point of pollution (sample point 4) and downstream (sample points 5 & 6) are exceeded to unacceptable proportions as set by Rand Water standards. The pH levels in the study area fluctuate between pH 6.8 (point 2) to pH 7.8 (point 6) and is well within the ideal range. Conductivity is a measure of the total quantity of salts dissolved in a sample of water. The ions that form the bulk of total dissolved solids (TDS) are sodium ($Na+$), potassium ($K+$), calcium (Ca^2+), Magnesium (Mg^2+) cations and the chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) anions. These major ions are not toxic *per se* and are indeed needed in certain quantities by the biota. The pH values of most fresh water systems in South Africa range between about 6 and 8. Levels below 7 indicate acidic and above 7, alkaline levels. Low pH levels will mobilise the toxic substances such as the aqua-Al^{3+} ion as well as zinc (Zn^{3+}).

The bar diagram, Figure 13, is a comparison between the electrical conductivity of the water sampled at the six sampling points and the water standards set for the Blesbokspruit by Rand Water. It illustrates the results of the electrical conductivity at 25 °C measured in milli siemens per meter (mS/M). The bars clearly indicate that site 4, which is $\leq$ 20 m downstream of the point where the treated polluted water is discharged into the Blesbokspruit, is the most impacted upon and that the following two points, point 5 and 6, are also severely affected.

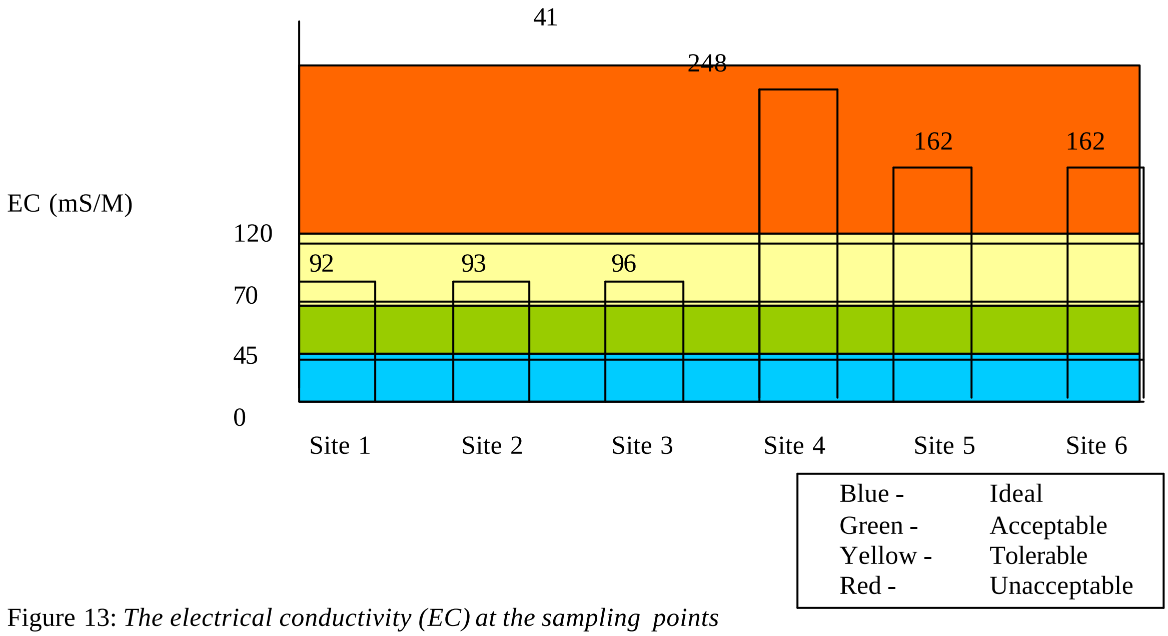

Figure 13: *The electrical conductivity (EC) at the sampling points compared to the standards set by Rand Water*

7.2 The effects of the altered water quality of the Blesbokspruit on the benthic fauna

Since each specie of benthic fauna thrives optimally in water with particular combinations of physical and chemical attributes, and since optimal conditions differ for each species, alterations in water quality will affect different species to a greater or lesser extent. Changes in water quality will eliminate some species and allow others to invade until not a single species of the original assemblage remains. Changes in water quality will also lead to a loss or reduction of bio-diversity as indicated in this study.

Davies & Day (1998) stated that in a pristine wetland system, a large variety of benthic fauna occur because of the absence of any pollutants which might impact on the cycle of the benthic fauna. Because the original balance between rainfall and runoff, erosion and sediment transport and the plants and animals in a stream, has probably been permanently damaged in the urban environment, it is, according to Davies & Day (1998), necessary to recognise that urban streams cannot be pristine. This was accepted in this study but, because of the apparent superficial “health” of the system, the benthic fauna counts, as well as the family diversity, was expected to be much higher than was accounted for.

7.3 Results of the data collected

7.3.1 Interpretation of SASS4 results

The South African Scoring System, version 4, (SASS4), as discussed in Chapter 6, sec. 6.2, has been used in this study to determine the health of the wetland. In summary, SASS uses the presence or absence of aquatic invertebrate fauna as a means of estimating the degree of pollution of the water in a natural water body. Each taxon (usually each family) of invertebrates from South African rivers has been allocated a score ranging from 1, for those taxa most tolerant of pollutants, to 15 for those most sensitive to pollutants. (A score sheet is attached as Annexure A). The combined scores for all the taxa at a particular site will be high if the water is pollution free and the lowest scores will be in severely polluted water. To complete the SASS exercise the scores for all the taxa in the sample are added to give the Total Score. The number of the taxa is recorded. The Total Score is divided by the number of taxa to get the Average Score Per Taxon (ASPT). Table 11 summarises the SASS4 results of the benthic invertebrate survey on the Blesbokspruit.

Table 11: *Summary of the SASS results of the benthic invertebrate survey of the Blesbokspruit Wetland*

Sample points	pH	EC (a) 25°C (mS/M)	Temp °C	# Animals	# Families	Total score as per SASS 4	Average score per taxon (ASPT)	Other Families present
1	7.1	92	14	20	3	9	3	Ostracod x 63 Cladocera x 2 Unidentified x 1
2	6.8	93	12	121	4	11	2.75	Ostracod x 7
3	7.5	96	11	142	5	16	3.2	None
4	7.6	248	14	2 dead	0	0	0	None
5	7.6	162	14	40	4	11	2.75	None
6	7.8	162	13	155	6	26	4.33	Ostracod x 4 Cladocera x 7

As the number of families in Table 11 is a measure of the biodiversity at a site, and the habitat at all six sites is exactly the same, the presumption is that the Families, Total Score and Average Score Per Taxon (ASPT) should also be the same. However, from Table 11 above it is clear that this is not the case. From the aforementioned it was also clear that the two premises which underpin SASS4 prevail, viz: that some invertebrate taxa are more sensitive to pollution than others; and, that the invertebrate assemblage at any site, at any time, is dependent not only on the water quality at the time of sampling, but also on the conditions that have pertained at that site over the entire life span of the assemblage. The discussions for the interpretation of the SASS4 scores above also indicate that there is major deterioration in water quality in the area of interest in the Blesbokspruit Wetland because of the very low Average Score Per Taxon which further deteriorates to 0 at sample point 4. Table 12 is a summary of the results of the benthic invertebrate survey of a portion of the Blesbokspruit Wetland.

As each family of invertebrates from South African rivers has been allocated a score, ranging from 1 for those taxa most tolerant of pollutants to 15 for those most sensitive to pollutants, an analysis of Tables 11 and 12 indicate that the Blesbokspruit, at the area of investigation, was polluted and under stress at the time of the investigation. This is supported by:

- The small specie diversity accounted for;
- The low score per family ranging from 1 to 6 which indicate that only organisms tolerant to pollution is present; and
- The low average score per taxon (ASPT) which range from 0 to 4.33.

Table 12: *Summary of the benthic invertebrate survey of the Blesbokspruit Wetland*

Site	Families Accounted	# Animals	SASS4 Score per Taxon	Average Score per Taxon
1	Oligochaeta	12	1	
	Chironomidae	7	2	
	*Ancylidae	1	6	
	Ostracod	63	-	
	Cladocera	2	-	
	Unidentified	1	-	
	TOTAL	86		3
2	*Planaria	9	5	
	Oligochaeta	62	1	
	Hirudinea	3	3	
	Chironomidae	47	2	
	Ostracod	7	-	
	TOTAL	128		2.75
3	* Planaria	4	5	
	Coligochaeta	31	1	
	Hirudinea	82	3	
	Hydrophilidae	1	5	
	Chironomidae	24	2	
	TOTAL	142		3.2
4	-	-	-	
5	* Planaria	3	5	
	Oligochaeta	9	1	
	Hirudinea	7	3	
	Chironomidae	21	2	
	TOTAL	40		2.75
6	* Planaria	1	5	
	Oligochaeta	29	1	
	Hirudinea	4	3	
	Pleidae	8	4	
	* Hydrophilidae	3	5	
	Chironomidae	108	2	
	*Ancylidae	2	6	
	Ostracoda	4	-	
	Cladocera	7	-	
	TOTAL	155		4.33

Table 13 is a summary of the families associated with the SASS which were identified at the six sampling points in the Blesbokspruit, indicating their score per taxon as well as the total number of animals collected.

Table 13: *The families identified at the six sampling points in the survey indicating their score per taxon as well as the total number of animals collected*

Family	Score per Taxon	Number of Animals	Percentage of total Number of Animals
Oligochaeta	1	143	29.92%
Chironimidae	2	207	43.30%
Hirudinea	3	96	20.0%
Pleidae	4	8	1.78%
Planaria	5	17	3.51%
Hydriphilidae	5	4	0.84%
Ancylidae	6	3	0.63%

The analysis of Table 13 indicates that as the score per taxon increased from 1 to 6, the number of animals drastically decreased by 98%. This affirms the finding that the Blesbokspruit, at the area and time of investigation, was under pollution stress.

The bar diagram (Figure 13) illustrates the results of the impact of the pumped underground water on the macro invertebrate fauna of the Blesbokspruit where point 4 is immediately (<20 m) downstream of the pollution point source as indicated on Figure 1.

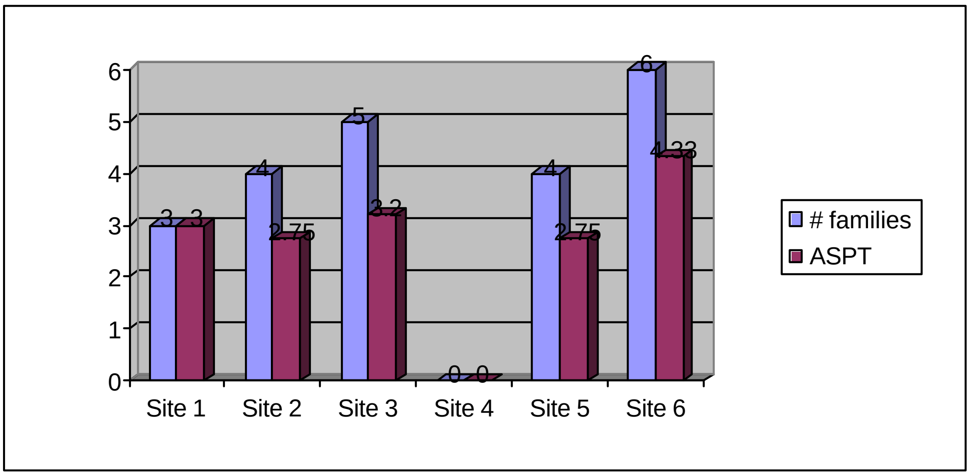

Figure 13: *The impact of the pumped underground water on the macro invertebrate fauna of the Blesbokspruit. Sample point 4 is immediately down stream of the point of discharge of the mine water*

The bars clearly indicate that site 4, as the point which is the most impacted upon with no benthic fauna recorded, and the recovery of the benthic fauna at sites 5 and 6 downstream of the point of pollution (site 4). This bar-graph compares well with Figure 6, page 24 which depicts the dilution and decay of degradable, oxygen demanding wastes and heat which shows the oxygen sag curve and the curve of oxygen demand.

The low specie diversity (3) and Average Score Per Taxon (3) at site one can be attributed to a sewage spill ten days prior to the artificial substrates being taken from the spruit. This spill happened approximately 200 m upstream from where the sample was taken. The appearance of Ostracod (630 animals) at this point is, according to Thirion (2002), indicative of sewage pollution as Ostracods survive and thrive in faecal polluted water.

8. CONCLUSION

The biotic assessment of the benthic fauna confirmed the expected rapid decline of species up to 20 m downstream of the point of discharge of treated polluted underground water by Grootvlei Mine (Table 11). This rapid decline of species is further emphasised by the chemical analysis of the water pumped (Table 2) and the chemical analysis of the water at each sampling point (Table 4). This rapid decline in species is clearly depicted in Figure 14 which depicts the number of animals, the variety of species and the total score as per the SASS4, where the total score is a fixed score allocated to a taxon at each sampling point.

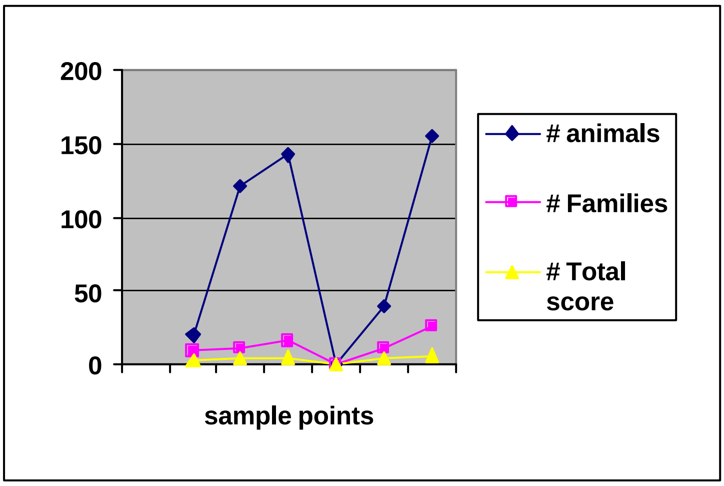

Figure 14: *The impact of the water, pumped by the mine at sampling point 4, on the benthic fauna of the Blesbokspruit*

It is therefore concluded that:

i. the water quality of the Blesbokspruit sample area (Table 10) as well as the water quality discharged by the mine into the spruit (Table 2) both exceed the standards set by DWAF (Table 4) and the water quality objectives set by Rand Water (Table 4 and Figure 10), in some cases considerably. From this it is concluded that the water discharged into the Blesbokspruit Wetland system, by the mine, is contributing to the integrity of an already stressed system and concomitant benthic faunal assemblages.

ii. the sampling sites on the Blesbokspruit indicate that the capacity of this aquatic ecosystem is under pressure as indicated by the low specie diversity and low average score per taxon (ASPT) as indicated in Tables 12 and 13 and in Figure 14 and could further be reduced (perhaps irreversibly altered) downstream of the point of pollution, due to the long term impacts of the treated underground water pumped from the mine. The long term effect of this action is unknown and further studies in this regard is essential. Radical management plans should be implemented if this valuable natural resource is to be preserved for future generations. This also concurs with the guidelines of the interpretation of SASS4 as suggested by Chutter (1998) and discussed under 6.1.1.

iii. this study concurs with previous laboratory studies done by Haigh & Davies-Coleman (1997) and Damelin & Alexander (2000) as well as field studies done by Chutter (1988) and Thirion (1999) who determined that benthic fauna are impoverished with an increase in pollution. Field investigations of benthic invertebrate communities is therefore important as these communities are indicative of long term exposure effects of pollutants in an aquatic ecosystem, as was also indicated in this study.

iv. the use of artificial substrates proved to be a successful way to collect benthic faunal assemblages in a wetland and shows potential for use elsewhere.

v. faecal pollution has a negative impact on the benthic fauna as indicated by the low specie diversity at sample point 1 as well as the high count of Ostracods.

vi. the precipitation of flocculent observed on the river bed at sample point 4 and the concomitant encrustedness of the reeds with what appeared to be lime flock was not clarified as to whether the observed mortality of the benthic fauna was due to physical as opposed to chemical factors as it did not form part of this study. It could therefore be concluded that a combination of factors including the flocculent, rather than one or the other, caused mortality.

vii. with (vi) in mind, remediating options for the Blesbokspruit Wetland, which include neutralising the effluent entering the spruit, may not be the answer to eradicate the stream toxicity, as the flocculent will contribute to the lagging of the toxic effects behind the remediative effect. This needs further research, specifically on the Blesbokspruit as Klopper & Schultze (1995), quoted by Hill (1997), remarked that chemical neutralisation has only limited potential to be successful because of the strong buffering of acidified waters.

9. RECOMMENDATION

An aquatic ecosystem is a complex system comprising interacting physiochemical and biological components whose dynamics are often integrated. South Africa, with its biological diversity, is a dry county and it will be at the water's edge that the sustainability of its diverse ecosystems and human populous will be fought.

The availability of contaminants to aquatic organisms is dependant on numerous sediment and water characteristics and the organisms exposure via contact and feeding. Since aquatic ecosystems are holistic systems it is naïve to assume their components can be separated into individual, non-interacting compartments. Each individual organism is dependent on the next one for survival. Contaminated water therefore has to be recognised as a significant problem contributing to environmental degradation. It is clear that although various uncertainties exist regarding water pollution assessment, pollution can no longer be ignored and not only chemical analysis, but also biological monitoring, which was successfully proved in this research, should form an integral part of water quality monitoring programmes in South Africa.

According to Fuggle & Rabie (1999) water pollution control is based on the following principles:

- The water environment has a capacity to assimilate a certain, usually quantifiable, amount of pollutants without detriment to predetermined quality objectives;
- Water quality management objectives are primarily determined by the present and intended uses of the water resources;
- The assimilative capacity of a water body is part of the water resource and, as such, must be managed judiciously and shared in an equitable manner among all the water users;
- For those pollutants which, because of their toxicity, extent of bio-accumulation and persistence, pose the greatest threat to the environment, a precautionary approach aimed at minimising or preventing impacts to the water environment must be followed.

Following the above principles it is therefore recommended that:

i. More tests be done during various times of the year, with different natural environmental impacts to obtain a clearer picture of the ecosystem health as the interpretation of the SASS4 scores show low Average Score Per Taxon counts at all the test points. This could be due to the low water temperature as the analysis was done in the winter.

ii. As the use of artificial substrates to sample, and SASS4 to evaluate the macro invertebrate colonisation potential in wetlands showed potential; it does not provide a final answer as a large number of wetlands are naturally and intentionally turbid because of decomposed organic matter in suspension. A separate study should focus on these turbid water bodies so that their biotic integrity can also be evaluated and established. Separate studies should also be conducted to test and adapt the SASS4 scoring system in other water bodies such as wetlands and shallow impoundments with little or no water movement.

iii. As the evaluation of the artificial substrates was not done because it does not fall within the scope of this study it is thus recommended that the artificial substrates be evaluated at different lentic water bodies for sampling macro benthic invertebrates.

iv. As artificial substrates measure the colonisation potential and is indicative of the water quality, and not of the natural fauna (Thirion: 2000) a separate study should test (and adapt) the protocol for measuring biotic diversity in turbid water bodies with limited natural habitats such as ponds and wetlands.

v. As this study confirmed the treated polluted underground water pumped by Grootvlei Mine has a negative impact on the already stressed benthic fauna families of the Blesbokspruit. The extent of the pollution plume caused by the pumping of the treated underground water, as well as the recovery distance of the benthic fauna should be determined by further studies.

vi All forms of faecal pollution in the Blesbokspruit must be eliminated as it impacts on the biodiversity of the benthic fauna.

vii. From an environmental management point of view, decisions concerning optimal management of the discharge of polluted underground water from mines, and the effect thereof on aquatic environments, must be made. Environmental damage is an inevitable result of economic growth under existing patterns of technology and consumer preference. However, efforts and costs of remediating the environmental damage done to these resources, (at no cost to the polluter), from which man is dependent for his well-being, are excessive. Questions that come to mind is whether the economic growth versus remediation costs of the resultant damaged environment is always justifiable and, also in the case where the polluter-pays-principle does not apply, should the industry which make use of natural resources to disperse effluent not pay a transport charge or dispersement charge?

viii. As artificial substrates tend to be selective for certain taxa (Thirion: 2000) such as *Chironomidae* and *Hydroptilidae* (Thirion: 2000), and the fact that most of the sensitive (high scoring) taxa are characteristic of riffle areas in streams, an ASPT for wetlands needs to be determined in further studies.

To resolve the Blesbokspruit management dilemmas the following is also recommended:

- An evaluation of the current situation with regards to the resource base, its requirements and its management should be undertaken;
- Development of a policy to deal with local, provincial, national and international interests is imperative;
- Setting of objectives for co-ordinative management of the wetland and developing an implementation plan to ensure that these objectives are met are urgently needed; and
- Developing a co-ordinated institutional framework with budgets to ensure the effective implementation of the programme should take place as soon as possible.

Based on the legislated and functional responsibilities it is proposed that this programme be facilitated and co-ordinated by the Department of Environmental Affairs and Tourism, supported by Gauteng Department of Agriculture, Conservation, Environment and Land and the Ekurhuleni Metropolitan Municipalty.

REFERENCES

Adendorf, A. 1997: Effects of mining activities on selected aquatic organisms. Unpublished Ph.D. Thesis: Rand Afrikaans University, Johannesburg

Allanson, B.R. 1961: Investigations into the ecology of polluted inland water in the Transvaal. Hydrobiologia, 18: 1-76

Anon. 1999: Die stand van besoedeling in verskeie boorgate in die Springs Munisipale gebied. Ongepubliseerde verslag in die Departement van die Stadsingenieur. Stadsraad van Springs: Gauteng Provinsie

Anon. 2000: Most states ignore leading causes of water pollution. International Wildlife, Vol. 30, No. 4, pp. 6-7

Anon. 2002: Resolution V.4 on the Montreux Record http://www.ccwr.ac.za/wetlands/montreux_rep.htm

Barton, D.R. &. Boston, C.M. 2001: Laurel Creek Watershed monitoring pilot study: Benthic Invertebrate Water quality Component. http://www.adm.uwaterloo.ca/inforwast/watgree/laurelcreek/14.thml.

Buckle, H. 2001: Forget 2025…. Gauteng has already ran out of water. Government Digest March 2001, Auckland Park: Malnor

Chutter, F.M. 1998: Research on the rapid biological assessment of water quality impacts in streams and rivers. Water Research Commission, Report No. 422/1/99. Pretoria.

Compaan, P.C. 1992: Blesbokspruit Ramsar Data. Internal Report of Transvaal Directorate of Nature and Environmental Conservation: Pretoria.

Cowling, R.M., D.M. Richardson & S.M. Pierce. 1997: Vegetation of Southern Africa. Cambridge: University Press.

Dallas, H. F. & Day, J.A. 1993: The effect of Water Quality Variables on Riverine Ecosystems: A Review report to the Water Research Commission, Report No. TT61/93. Pretoria.

Dallas, H.J., J.A. Day & E.G. Reynolds. 1994: The Effects of Water Quality Variables on Riverine Biotas. Report to the Water Research Commission, Report No. 351/1/94. Pretoria.

Dallas, H. F., J.A. Day, D.E. Musibona & E.G. Day. 1998: Water quality for aquatic ecosystems: Tools for evaluating. Regional Guidelines. Report to the Water Research Commission, Report No. 626/1/98. Pretoria.

Damelin, L.H. & Alexander, J.J. 2000: Rapid quantitative evaluation of water quality using a modified biological test. Report to the Water Research Commission, Report No. 784/1/00. Pretoria.

Darkey, D. & Donaldson, S.E. 2000: Water Pollution and community perceptions in Mamelodi, Pretoria. Paper presented at the WISA 2000 Biennial Conference, Sun City, 28 May – 1 June 2000.

Davies, B. & Day, J. 1998: Vanishing Waters. Cape Town: UCT Press.

Davies, B.R., J.H. O'Keefe & C.D. Snaddon. 1993: A synthesis of Ecological functioning, conservation and Management of South African River Ecosystems. Report to the Water Research Commission, Report No. TT 62/93. Pretoria.

Day, J.A., B.A. Stewart, I.J. de Moor & A.E. Louw. 2001: Freshwater invertebrates of Southern Africa. (Vol. 2 & 4) Report No. TT 141/01 to the Water Research Commission, Pretoria.

De Fontaine, M. 2002: Kliprivier, Gauteng. Personal Communication.

Department of Environmental Affairs and Tourism (DEAT). 1997: White Paper on the Conservation and Sustainable use of South African Biological Diversity. Notice 1095 of 1997. Pretoria: Government Printer.

Department of Environmental Affairs and Tourism (DEAT). 1998: A National Strategy for Integrated Environmental Management in South Africa. Pretoria: Government Printer.

Department of Water Affairs. 1986: Management of the Water Resources of The Republic of South Africa. Pretoria: Department of Water Affairs.

Department of Water Affairs and Forestry (DWAF). 1993: South African Water Quality Guidelines, Vol. 1, 2, 3 & 4. Pretoria: Government Printer.

Department of Water Affairs and Forestry (DWAF). 1996: South African Water Quality Guidelines, Volume 7: Aquatic Ecosystems, Pretoria: Government Printer.

De Wet, L.M. 1990: Akkumulering van Swaar Metale in 'n Myn- en Nywerheidsbesoedelde Meer-ekosisteem. Ongepubliseer MSc Script in the Faculty of Natural Science, Rand Afrikaans University, Johannesburg.

De Wet, L.P.D. 1996: The occurrence and bio-accumulation of selected metals and radionuclides in aquatic and terrestrial ecosystems on the Witwatersrand. Unpublished Ph.D. Thesis in the Faculty of Natural Science, Rand Afrikaans University, Johannesburg.

De Wet, L.P.D. 1999: Biomonitoring. A General guide to biomonitoring of aquatic ecosystems. Waterlab Research. Pretoria

Dickens, C. & Graham, M. 2001: South African Scoring System (SASS) Version 5. Rapid Bioassessment Method for rivers. Pietermaritzburg: Umgeni Water.

Dini, J. 2002: Department of Environmental Affairs and Tourism, Pretoria. Personal communication.

Du Plessis, P. 2002: Director Civil Engineering & Planning. Springs SDC, Ekurhuleni Metropolitan Municipality, Gauteng Province. Personal communication.

Eichstadt, L.A. 2000: Contamination of soil and groundwater of industrial sites: A regulatory perspective on specific case studies. Paper presented at the WISA 2000 Biennial Conference, Sun City, 29 May – 1 June 2000.

Etherington, J.R. 1983: Wetland Ecology. London: Edward Arnold.

Fitzgerald, P., A. McIennan & B. Munslow (eds) 1995: Managing sustainable development in South Africa: Cape Town: Oxford.

Frost, S., M.T.L. Chiu & M. Pugh-Thomas. 1976: Seasonal Changes in invertebrate populations in the polluted river Medlock. Environmental Pollution, 11: 223-240.

Fuggle, R.F. & Rabie, M.A. 1994: Environmental Management in South Africa. Cape Town: Juta.

Fuggle, R.F. & Rabie, M.A. 1999: Environmental Management in South Africa. Cape Town: Juta.

Gerber, A. & Gabriel, M.J.M. 2002: Aquatic invertebrates of South African Rivers. Institute for Water Quality Studies. DWAF. Pretoria.

Grootvlei Mine. 2002: Prinsloo, J. & Nel, P. Personal communication.

Haigh, E.H. & Davies-Coleman, H. 1997: Standard Laboratory Organisms for Water Quality Studies Programme. Report to the Water Research Commission, Report No. 545/1/97. Pretoria

Harmse, J.T. 2001. Rand Afrikaans University. Johannesburg. Personal communication.

Hill, L. 1997: Assessment of the biotic hazard of the acid mine drainage impacted Blesbokspruit near Witbank, Mpumalanga. Unpublished M. Sc.-script. Rand Afrikaans University: Faculty of Science.

Huntley, B.J. 1991: Biotic Diversity in South Africa. Oxford: Oxford University Press.

Jenkins, J.A., E. Shields & L. Johnson, 1997: Pollution prevention plan for the National Wetlands Research Centre: Lafayette, LA, U.S. Geological survey. National Wetlands Research Centre. http://eeirc.wwrc.gov/RIS/RISWEB.ISA

Kempe, J.O. 1983: Review of Water Pollution Problems and Control Strategies in the South African Mining Industry. Water Science Technology, 15: 27-58.

Kuhn, A.L., S.N. Venter, G van Ginkel, E. Vermaak & L. Zingitwa. 2000: Identification of areas with faecally polluted water sources in South Africa. Paper presented at the WISA 2000 Biennial Conference, Sun City, 28 May – 1 June 2000.

Kuphchella, C.E. & Hyland, M.C. 1993: Environmental Science: Living with the system on nature (3^{rd} Ed.) Engelwood Cliffs, N.J.: Prentice-Hall.

Laing, M. 1990: Jekyll-and-Hyde herbicides,: in Preston-Whyte, R. (ed.) 1990: Rotating the Cube: Environmental Strategies for the 1990's. Durban: University of Natal.

Leitman, J. 1995: Environmental Management, Approaches and tools for a rapidly urbanising world. Proceedings of the World Bank Workshop: Environmental Assessment in Africa. June 1995, Durban, South Africa.

Madden, S. 2001: Counts of waterbirds made on the Blesbokspruit as part of South African Co-ordinated Waterbird Counts. Unpublished reports: 1995 – 2001.

Madikizela, B.R., Dye, A.H. & O'Keefe, J.H. 2001: Water Quality and Faunal Studies in the Umzimvubu Catchment, Eastern Cape, with particular emphasis on Species as indicators of Environmental Change. Report to the Water Research Commission, Report No. 716/1/01. Pretoria.

Marais, M., N. Armitage & S. Pithey. 2000: Proposed catchment management strategies to reduce litter loadings in S.A. urban drainage systems. Paper presented at the WISA 2000 Biennial Conference. Sun City 28 May – 21 June 2000.

Marshall, E.A. 2002: Director Community Services. Springs Service Delivery Centre, Ekurhuleni Metropolitan Municipality, Gauteng Province. Personal communication.

Meglitsch, P.A. 1967: Invertebrate Zoology. New York: Oxford University Press.

Miller, G.T. 1994: Living in the environment (8^{th} Ed.) Belmont: Wadsworth.

Miller, G.T. 1996: Living in the environment (9^{th} Ed.) Belmont: Wadsworth.

Preston-White, R. (Ed.) 1990: Rotating the cube: Environmental strategies for the 1990's. Durban: University of Natal.

Ramsar Convention Bureau. 2002: e-mail: ramsar@ramsar.org.

Rand Water, 2001. Potable water – Quality criteria. Johannesburg: Rand Water

Rand Water 2002: Water analysis reports for the Blesbokspruit: Johannesburg: Rand Water.

Republic of South Africa, 1996: The Constitution of the Republic of South Africa, Act 108 of 1996. Pretoria: Government Printer.

Republic of South Africa, 1998: National Environmental Management Act, No. 107 of 1998. Pretoria: Government Printer.

Republic of South Africa, 1998: National Water Act, No. 36 of 1998. Pretoria: Government Printer.

Schoonbee, H.J., A. Adendorff, L.M. de Wet, L.P.D. de Wet, C.L. Fleischer, C.G. van der Merwe, P.H. van Eden & A.J.A. Venter. 1995: The occurrence and accumulation of selected heavy metals in fresh water ecosystems affected by mine and industrial polluted effluent. Report to the Water Research Commission, WRC report No. 312/1/96. Johannesburg: Rand Afrikaans University.

Scott, R. 1995: Flooding of Central and East Rand Gold Mines. Report to the Water Research Commission, Report No. 486/1/95. Pretoria.

Smuts, G.L. 1987: Harvesting and managing waterfowl on the Blesbokspruit. South African Journal of Wildlife Management, Suppl. 1: 126-135.

Spinoza, B. 2001: Ethics. Hertfordshire: Wordsworth.

Steffen, Robertson & Kirsten Consulting Engineers. 1996: Monitoring of the Blesbokspruit: Impacts of treated mine effluents from Grootvlei Mine. Report No. 229511 for Grootvlei Proprietary Mines. September 1996.

Steffen, Robertson & Kirsten Consulting Engineers. 1996: Institutional Responsibilities for the management of the Blesbokspruit Wetland. Report No. 232023 for Grootvlei Proprietary Mines. October 1996.

Thirion, C. 1999: A new biomonitoring protocol to determine the ecological health of impoundments using artificial substrates. African Journal of Aquatic Science 2000. 25: 124-133.

Thirion, C. 2002: Institute of Water Quality Studies. Department of Water Affairs and Forestry (DWAF). Personal Communication.

Turner, K. & Jones, T. 1991: Wetlands: Market and intervention failures. London: Earthscan.

University of Pretoria. 1999: A Management Plan for the Blesbokspruit Ramsar Site. Report done for Gauteng Department of Agriculture, Conservation and Environment, Directorate: Nature Conservation. Pretoria: University of Pretoria.

Vermaak, J.F. 1972: 'n Ekologiese studie van die Germiston meer met spesiale verwysing na besoedelingstoestande en die effek daarvan op die akwatiese makro invertibraat fauna. MSc.-verhandeling Randse Afrikaanse Universiteit. Johannesburg.

Walmsley Environmental. 1995: A preliminary assessment of the environmental, social economic and financial implications of dewatering the East Rand Basis into the Blesbokspruit or alternatively, allowing it to flood. Vol. 1 Report No. W 147. Department of Mineral and Energy Affairs.

Weaver, A. 1990: 2020, Running and empty. in Preston-Whyte, R. 1990: Rotating the cube: Environmental Strategies for the 1990's. Durban: University of Natal.

Wessels, H.J. 1974: 'n Ondersoek na die bentiese fauna van die mineraalbesoedelde Blesbokspruit sisteem in die Vaalrivier opvang gebied. Unpublished M.Sc Thesis. Rand Afrikaans University, Johannesburg.

Wichers, H.N.S., M.J. Freemand & M.R. Howard. 1996: The Management of Urban Impoundments in South Africa, Volume 142. Report to the Water Research Commission, Report No. TT77/96. Pretoria.

Williams, D.D. & Feltmate, B.W. 1992: Chemical Disturbances – Mine Waste. http://www.chebucto.ns.ca/science/SWCS/ZOOBENTH/BENTHOS/ii.html

GLOSSARY

Aquatic	referring to water
Benthic	referring to the bottom of an aquatic systems
Bio-assessment	the use of living organisms to assess conditions
Bio-diversity	the diversity of life from a taxonomic, ecological and genetic point of view
Biological Monitoring	monitoring of living organisms as indicator of habitat integrity
Biotic	pertaining to living organisms (as opposed to abiotic)
Conductivity	the ability of water to conduct an electrical current, also a measure of the total quantity of salts dissolved in a sample of water
DWAF	the South African State Department of Water Affairs and Forestry
Ecosystem	the combination of all factors, biotic and abiotic, that make up a particular environment and its organisms
Environment	all the physical, chemical and biological factors and conditions that influence an object
Eutrophic	rich in nutrients and therefore in plant lifes
Fauna	collective term for the animals living in a particular area
Floc	the coalescence of fine particles into a coarser precipitate
Lentic	of standing water (ponds, lakes, etc.)
Littoral	pertaining to the shores of lakes or the sea
Lotic	of running waters (rivers, streams, etc)
Monomictic	of lakes, those that overturn or mix only one a year
pH	a measure of the acidity in a solution
point source	a single identifiable point at which an effluent enters a water body
pollution	the degradation of natural systems by the addition of harmful substances
Ramsar Convention	the convention whereby wetlands are declared of special value as waterbird habitats
Recovery distance	the distance downstream from a disturbance at which the effects of the disturbance are no longer seen
Saprophytic	living on liquid food
TDS	total dissolved solids: a measure of the total number of material dissolved in water

ANNEXURE A
A copy of a completed SASS form

(6)

SASS4

River: Blesbokspot .... Date: 19/06 Time: 15:00

Sampling point: (6) S26°15'849" E28°30'23"

Temp °C: 13 .. pH: 7.8 .. Cond mSm⁻¹: 162

Dissolved oxygen: ....

Alt. 5196ft 1583.04 m.a.s.

Biotopes sampled:

SIC .... /Type/tim: Artificial substrate

Marg Veg: T. capensis/Dom. sp.: Phragmites australis

Aq Veg .... Spp ....

SOOC .... Sand .... Mud: X ... Gravel ....

Other: Deep water

Procedure Protocols:

1. If stones-in-current (SIC) all kickable, sample for 2 min, otherwise for a maximum of 5 min.
2. Gravel 1/2 min.
3. Marg/Aq veg, back and forward sweep 2m.
4. Stones out of current (SOOC) kick +/- 1m².
4. Sand/mud stir with feet and sweep net over disturbed area for 1/2 minute.
5. Any other biotopes 1/2 min.
6. Complete top of form.
7. Tip net contents into tray. Remove leaves, twigs and trash.
8. Check taxa present on above list for the lesser of 15 minutes or 5 minutes since the last taxon was found.
9. Estimate abundances on scale:
   A: 1 to 10; B: 10 to 100;
   C: 100 to 1000; D: > 1000
10. Before leaving the sampling point check that this form has been fully completed.

A': score allocated to taxon.

TAXON	A'	
Porifera	5	
Coelenterata		
Hydra sp.	1	
Turbellaria		
Planaria	5	1
Annelida		
Oligochaeta erdwurm	1	29
Hirudinea bloedsuier	3	4
Crustacea		
Amphipoda	15	
Decapoda	3	
shrimps	8	
Hydracarina		
Hydrachnellae	8	
Plecoptera		
Notonemouridae	12	
Perlidae	12	
Ephemerellidae		
Polymitarcyidae	10	
Ephemeridae	15	
Baetidae 1 sp. or	4	
2 spp or	6	
> 2 spp	12	
Oligoneuridae	15	
Heptageniidae	10	
Leptophlebiidae	13	
Ephemerellidae	15	
Tricorythidae	9	
Prosopistomatidae	15	
Caenidae	6	
Odonata		
Chlorolestidae	8	
Lestidae	8	
Protoneuridae	8	
Platycnemidae	10	
Coenagriidae	4	
Calopterygidae	10	
Chlorocyphidae	10	
Zygoptera juvs.	6	

Gomphidae	6	
Aeshnidae	8	
Corduliidae	8	
Libellulidae	4	
Hemiptera		
Notonectidae	3	
Pleidae backswimmer	4	8
Naucoridae	7	
Nepidae	3	
Belostomatidae	3	
Corixidae	3	
Gerridae	5	
Veliidae	5	
Megaloptera		
Corydalidae	8	
Trichoptera		
Hydropsychidae		
1 sp or	4	
2 spp or	6	
> 2 spp	12	
Philopotamidae	10	
Polycentropodidae	12	
Psychomyiidae	8	
Ecnomidae	8	
Hydroptilidae	6	
Other movable cased larvae:		
Number of case types		
1 type or	8	
2 types or	15	
3 or more types	20	
Lepidoptera		
Nymphulidae	15	
Coleoptera		
Dytiscidae	5	
Elmidae/Dryopidae	8	
Gyrinidae	5	
Haliplidae	5	
Helodidae	12	
Hydraenidae	8	
Hydrophilidae	5	3
Limnichidae	8	
Psephenidae	10	

Diptera		
Blepharoceridae	15	
Tipulidae	5	
Psychodidae	1	
Culicidae	1	
Dixidae	13	
Simuliidae	5	
Chironomidae	2	108 (mooi)
Ceratopogonidae	5	
Tabanidae	5	
Syrphidae	1	
Athericidae	13	
Empididae	6	
Ephydridae	3	
Muscidae	1	
Gastropoda		
Lymnaeidae	3	
Melaniidae	3	
Planorbidae	3	
Physidae	3	
Ancylidae slakke.	6	2
Hydrobiidae	3	
Pelecypoda		
Sphaeriidae	3	
Unionidae	6	
Total Score	26	155
Number of families	6	
Average Score per taxon (ASPT)	4.33	

Other families present

Crustacea
class. Ostracoda (seed shrimps) x 4
Order: Cladocera (water fleas) x 7

Val 0.92 m van punt 1-6.