Potchefstroomse Universiteit
vir Christelike Hoër Onderwys

The use of biological indices to assess the water quality of the Vaal River with specific reference to the Vredefort Dome area.

A.Laas B.Sc

Dissertation submitted in partial fulfilment of the requirements for the degree Magister Scientiae in Environmental Sciences at the Potchefstroom University for Christian Higher Education.

Supervisor:	**Dr. A. Vosloo**
Co-Supervisor:	**Mr. R.F. Terblanche**

2002
Potchefstroom

TABLE OF CONTENTS

Page

Page

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

APPENDIX A:

APPENDIX B:

APPENDIX C:

Acknowledgements:

Our Heavenly Father, without Him this project would not have been possible.

My parents for their constant support, understanding and motivation during hard times.

Dr. André Vosloo, my project leader, for all the hours spent helping me with the final product, and for his confidence in me throughout the project.

Mr. Reinier Terblanche, my co- project leader, for all his help and faith in me, and for his constant motivation.

Prof. Kenné de Kock for his help with the identification of the molluscs, and for his interest in my project.

Dr. Sanet Janse van Vuuren, for all the literature and support she provided.

The managements at Uitkyk, Stone Henge, Thabela Thabeng, Elgro River Lodge, Limerick and Raaswater for allowing me to work on their property, and for their support of the project.

Mr. Johannes van der Merwe for his keen interest in the project, and his support.

The Department of Water affairs and Forestry (DWAF) for the reports, literature and information that was made available to me.

The Water Research Commission (WRC) for the reports and literature that they provided.

Abstract

Water is one of South Africa's most limited resources and the Vaal River, as one of the country's hardest working rivers, provides water to a considerable proportion of the country's agricultural, industrial and household needs.

The Vredefort Dome, one of the biggest meteorite impact sites on earth, is of great ecological significance. It maintains a unique ecosystem of biota that significantly differs from the surrounding area. The area has been proposed to receive World Heritage status, and has potential as an eco-tourism destination.

From October 2001 - August 2002 the quality of the Vaal River in the Vredefort Dome was assessed with biological indices. SASS 5, IHAS and physical-chemical analysis were conducted along the Vaal River within the Vredefort Dome.

From the results, it was evident that good to fair water quality prevailed in the Vredefort dome. The SASS and ASPT scores were in the fair to good range, and the number of taxa fell into the good to excellent range, indicating good overall river health. Seasonal patterns in the occurrence of macroinvertebrates were observed for this section of the Vaal River. Habitat scores were generally in the fair range, indicating adequate habitat conditions. The results of the physical/chemical analysis did not show any significant problems. The geomorphology of the Dome indicates a big slope between the first and last site, averaging a drop of $1.96 m.km^{-1}$. Preliminary investigations into the occurrence of freshwater molluscs in the Vredefort Dome indicated the distribution of molluscs in the area. Problems encountered in the Dome area were of aesthetical importance, resulting from a high degree of eutrophication.

More sampling is advised before any management proposals for the Dome area could be made. It is advisable that this area should be subjected to routine sampling to spot potential water quality problems as soon as possible.

Opsomming

Water is een van Suid Afrika se skaarste hulpbronne, en die Vaalrivier, een van die land se hardste werkende riviere, voorsien water aan 'n aansienlike deel van die land se landbou, indistriële en huishoudelike behoeftes.

Die Vredefortkoepel, een van die grootste meteorite-impakkraters op aarde, het aansienlike ekologiese belang. Dit onderhou 'n unieke ekosisteem van biota wat daadwerklik verskil van die omliggende omgewing. 'n Voorstel is ingedien om Wereld Erfenisstatus aan die area te verleen, en die Koepel het potensiaal tot 'n belangrike ekotoerisme bestemming.

Vanaf Oktober 2001 – Augustus 2002 is die waterkwaliteit van die Vaalrivier in die Koepel gemoniteer met behulp van biologiese indekse. SASS 5, IHAS en fisies-chemiese analises is langs die Vaalrivier in die Vredefortkoepel uitgevoer.

Die resultate toon matige tot goeie waterkwaliteit in die Koepel. Die SASS- en ASPT-tellings was in die matige tot goeie reeks, wat gesonde riviertoestande aandui. Seisoenale patrone in die voorkoms van makro-invertebrate is waargeneem in die area. Habitatwaardes was in die matige reeks wat voldoende habitat toestande aandui. Die resultate van die fisies-chemiese analises het geen beduidende probleme getoon nie. Die geomorfologie van die Koepel dui 'n groot helling tussen die eerste en laaste perseel aan, met 'n gemiddelde val van $1.96 m.km^{-1}$. Voorlopige ondersoeke na die voorkoms van varswater Mollusca in die Koepel het die verspreiding van die Mollusca in die area aangedui. Probleme wat in die Koepel waargeneem is, is van estetiese aard, en is die gevolg van 'n hoë mate van eutrofikasie.

Dit word voorgestel dat meer opnames gedoen word alvorens bestuursvoorstelle ten opsigte van die Koepel gemaak word. Dit is wenslik dat die area aan 'n roetine moniteringsprogram onderwerp word sodat potensiële waterkwaliteitprobleme so spoedig moontlik geïdentifiseer word.

List of Tables:

List of Figures:

CHAPTER 1

Introduction

Water is the essence of all forms of life on earth. Without water, life as we know it, would be impossible. All processes on earth rely on water directly or indirectly. Water can be found in solid, liquid or gaseous form, each form with its own set of characteristics.

The Hydrological cycle (Figure 1) categorizes the water environment, and describes the movement of water and the transitions from liquid to solid and gaseous form and back again. The Hydrological cycle can be defined as the continual process of transformation and redistribution of water (Davies & Day, 1998).

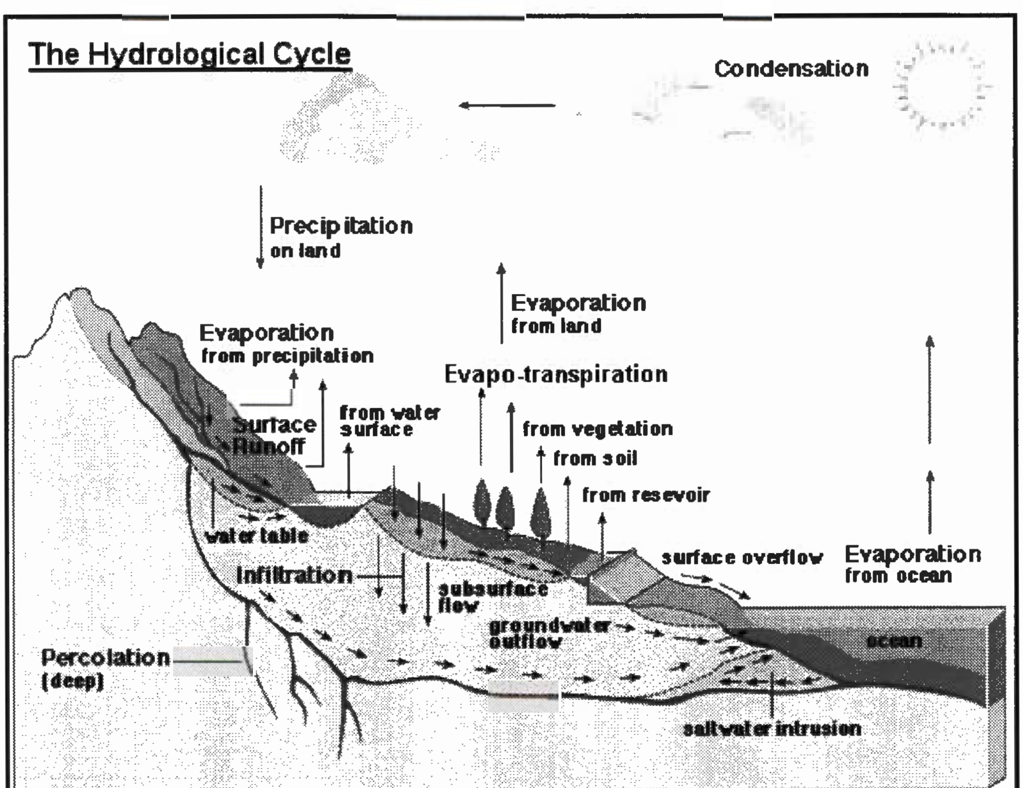

Figure 1: Graphic presentation of the Hydrological cycle (Water Facts, 2000).

The position of the landmasses and mountain ranges, as well as the cold and warm water currents of the oceans prevent the equal distribution of rain around the world so that fresh water is not only scarce, but also unevenly distributed (Davies & Day, 1998). Thus some regions are more arid than others.

Water shortages affects people all over the world. In 1999 the United Nations Environment Programme (UNEP) reported that 200 scientists in 50 countries had identified water shortage as one of the two most worrying problems for the new millennium (the other was global warming). Today, one person in five across the world has no access to safe drinking water, and one in two lacks safe sanitation. There are several reasons for the water crisis. One is the simple rise in population, and the desire for better living standards. Another is the inefficiency of the way we use much of our water, with unnecessary wastage taking place. Furthermore pollution is making more of the water that is available to us unfit for use (Anon, A. 2000).

Aquatic ecosystems provide a service to human beings, the monetary value of which has never been adequately quantified. Dead organic matter, including whole organisms, bits of organic detritus, faeces and urine, represents a source of nutrients and energy rich molecules that can provide food or a substrate for other organisms. These organisms include carrion feeders such as planarian worms, animals such as crabs, amphipods and stonefly nymphs that shred decaying leaves, and animals such as fly larvae and oligochaete worms feeding on the thick mud on the bottoms of lakes and rivers. These animals and the immeasurably more numerous microbes such as bacteria and fungi, break down the complex organic particles into simple organic molecules and ultimately into their constituent parts: carbon dioxide, water and simple inorganic substances such as nitrogen and phosphorus compounds. The carbon dioxide is released back into the water, where it can be used in photosynthesis, the nutrients such as nitrogen and phosphorus, are also taken up by plants. Denitrifying bacteria, which liberate gaseous nitrogen to the water and ultimately to the atmosphere, breaks down some nitrogenous compounds. The overall amount of inorganic nitrogen usually remains more or less constant as a result of the action of nitrifying bacteria that reverse the process, converting atmospheric nitrogen and oxygen into nitrate and nitrite ions. Phosphorus compounds cannot be made gaseous by living organisms and so they either remain in solution, or are adsorbed onto suspended or sedimented particles until plants or microorganisms take them up again. The overall process results in complex organic matter being mineralised to its inorganic constituents, which become available for re-use. Toxic wastes kill the decomposer organisms in a river, resulting in an accumulation of dead but non-rotting waste. Thus careful management of aquatic ecosystems is financially beneficial as well as being ethically appropriate (Dallas *et al.*, 1994; Davies & Day, 1998).

The conservation of natural water resources is of absolute importance for any country's economy and sound environmental management. A water resource includes not only the water, but also the structural components and biological components of the aquatic system. This resource is an ecological system, whose sustainability is dependent on the interactions between the physio-chemical attributes of the resource. Resource protection, utilization and management must therefore be based on sound ecological principles (Ashton, 2001).

In the following sections, attention will be given to specific aspects regarding water in South Africa. (1) The Vaal River as one of our most exploited rivers. (2) The Vredefort Dome as one of our most important sites of natural sites of natural heritage. (3) The River health program and it's movements towards the management and conservation of our rivers. (4) Biological monitoring as early warning system for river management. (5) The effects and importance of habitat in the riverine environment. (6) The most important physical and chemical variables in the riverine environment.

1.1. Water in South Africa as our most important natural resource

"The main conflicts in Africa during the next 25 years could be over that most precious of commodities – water" (Anon, B. 1999).

We live on a subcontinent notorious for its unpredictable rainfall (Davies & Day, 1998). South Africa is a semi-arid country, and the decline in the quality of available water is one of the biggest problems currently facing us. There are several factors that contribute to this decline and the most important being industries, agricultural practices and the population explosion.

South Africa's average annual rainfall of 500mm is only 60% of the world's average. Sixty five percent of the country receives less than 500mm of rain annually, and 21 percent receives less than 200mm. The greater part of the interior and western part of the country is arid to semi-arid. Over most of the country the average annual potential evaporation is well in excess of the annual rainfall; this greatly reduces the surface runoff in South African rivers (Heath, 1999). Prior to the change in Government in 1994, an estimated 30 to 40 percent of South Africa's population was without the minimum standard water supply. It is estimated that 15 to 20 percent of water used in some areas is wasted. The total annual consumption of water in South Africa has been estimated to be in excess of 16 billion cubic meters, and the Department of Water Affairs and Forestry (here forth referred to as DWAF) has predicted a growth of 4 to 6 percent per anum over the next few years. Water use in South Africa is still dominated by agriculture, representing 53% of the total water use, 12 % for domestic and urban use, 8% for industry, 4% for mining, 4% for power generation and 20% for nature conservation (Millard, 1999).

The shortage of water can make it impossible for the country to maintain its economical and social activities in accordance to the economic objectives. With the increase in population, the requirements for food and non-food products increase, and in both instances more water is needed. Economic development is always linked to industrial production, which increases people's life-quality. The resulting higher income is then used to buy more goods, which also increases the requirements for water (Van Rooyen, 2001).

Water management in South Africa is becoming increasingly complex. In this country water is an essential and scarce resource that is poorly distributed in terms of growing socio-economic requirements. As the population grows, the water that is available becomes scares, and its quality deteriorates. The options for water management are limited by the physiography of the country and by weather patterns that are beyond human control (Conley, 1995).

The Department of Water Affairs and Forestry is the primary agency responsible for water resources management in South Africa. With respect to water quality its mission is to ensure the health of South Africa's surface water, groundwater and coastal marine resources, for water uses and for the protection of aquatic ecosystems on a sustainable basis (Hohls, 1996). The role of the Department can be segmented into two distinct, but closely related, functional areas:

- Providing equitable access to the resource to ensure optimal economic and social development, including access to water and sanitation services for all citizens.
- Managing the resource, as well as the demands made on the resource, both to protect the resource and to ensure sustainable and equitable use by current and future generations (Ashton, 2001).

The 1994 democratic elections triggered a process of reform of South Africa's water policy and law, and an early product was the formulation of new Water Law Principles that were published in 1996. The National Water Act (NWA) (36/1998) came into effect in 1999, and heralded a major change in approach from controlled demand and management, to participatory water resource management. Under the new act the National Government remained the public trustee of the nation's water resources, but the desired transition from centralized decision making (national governance) to decentralized and participatory water resource governance (provincial and local governance) will be facilitated through the establishment of Catchment Management Agencies (CMA's). It will be the task of the CMA's to balance stakeholder interests (Roux, 2001 a).

There is an increasing public awareness of the environmental importance of water and the importance of not destroying the natural environment when water resources are developed. It is important to find a balance between water resource development and maintenance of the natural environment (Heath, 1999).

In recognition of the resilience of water resources, the Water Law Principals introduced the concept of an ecological reserve. The reserve is intended to protect the resilience of water resources, in order that basic human needs can be met and ecological functions and processes can be sustained. The reserve is defined in terms of the quality as well as the quantity and assurance of water, which are needed to protect the basic human needs and the structure and function of ecosystems so as to secure ecologically sustainable development and utilization (Roux, 2001 a).

Sustainable utilization requires achievement of a balance between an acceptable level of long-term protection of water resources and water users, and society's present requirements for economic growth and development. Pollution and the impacts of land uses cannot be prevented totally, but can be managed and regulated to achieve adequate long-term protection of water resource quality. This is the aim of the Water resource protection policy (Roux, 2001 a).

1.2. The Vaal River as "Hardest Working River" in South Africa

1.2.1. General introduction

Rivers in South Africa exemplify uncertainty. Natural river flow in semi-arid zones is characterised by variability and unpredictability both in time and space. South Africa has one of the lowest conversion ratios of rainfall to usable runoff (8.6%) of all the country's in the world, and one of the highest coefficients of variation in river flow (117%) (Uys, 2001).

Rivers continuously erode their catchments, at times transporting vast quantities of silt, clay, sand and even large boulders, depositing them where the power of the river diminishes. Rivers always borrow a great part of their characteristics form their terrestrial ecosystems - their catchments – through which they flow. In metaphorical terms they can be regarded of mirrors of the landscapes: if the landscape is badly treated, the river will magnify and mirror the abuse (Davies & Day, 1998).

Rivers are quite dynamic, their shape being constantly influenced by land types, time, seasons and rainfall (Skelton, 1993). According to Vannote *et al.* (1980), the physical variables (width, depth, velocity, flow volume, temperature and entropy gain) within a river system from headwaters to mouth present a continuous gradient of physical conditions. This gradient should elicit a series of responses within the constituent populations of plants and animals resulting in a continuum of biotic adjustments and consistent patters of loading, transport, utilization and storage of organic matter along the length of a river. Vannote *et al.* (1980) has described these characteristics as the River Continuum Concept (RCC). According to this theory rivers are open systems where energy is constantly introduced, utilized and transformed by various processes and organisms in the river, and then released downstream from the point of entry.

1.2.2. Characteristics of the Vaal Catchment

The Vaal River Catchment covers an area of 192 000 km^2 i.e. 17% of South Africa. It has some 60% of the minerals of the country, 40% of its industrial production and 30% of its agricultural production. The catchment stretches from Thaba Nchu in the South to Rustenburg in the north and from Swaziland in the east to Douglas in the west (Van Duuren, 1986).

The Vaal Bioregion encompasses the entire catchment of the Vaal River. Rainfall is fairly high in the east but low in the west. Source areas, which are spongy and sometimes associated with vlei's e.g. the Vaal Wilge and Klip Rivers, occur in the east. The rivers of this bioregion are fairly homogeneous, although the Hartz, Modder and Riet Rivers tend to be more dominated by sand bed and mud substrata than is the case with the Vaal River. A true foothill is not present, although upper stable depositing, and lower stable depositing zones can be recognized. An unstable depositing zone that can be linked to a transitional zone may also be present (Eekhout *et al.*, 1996).

The Vaal River, which is the primary tributary of the Orange River System, contributes to 8.6% of South Africa's Mean Annual Runoff (MAR) (Davies & Day, 1998). It is one of the most important river systems in Southern Africa as it stretches trough a large part of our country and supplies water to the majority of our country's industries as well as agricultural activities. The Vaal River can be seen as the "hardest working river" in the country (Van Vliet & Nel, 1983; Braune & Rogers, 1987).

The riverbed from the Vaal Barrage to Parys drops 59 meters over a distance of 53 km resulting in an average slope of 1:898. The steepest slope of 1: 227 occurs at Parys. Small rapids occur in the river from Barrage to upstream of Parys where it cuts through hard rock. Pools of water occur in-between, and in the area below the Vaal Barrage and upstream of the Parys weir, large sand and gravel deposits occur (Bruwer *et al.* 1985).

1.2.3. Land uses in the Vaal Catchment:

Agricultural land use:

The Area from Vaal Barrage to Vredefort is mainly an irrigation area. There are 5 major irrigation areas along the lower Vaal where about 62 200 ha is being irrigated. The major crops in order of importance are wheat, maize, cotton and peanuts. Other crops produced in areas under irrigation are potatoes, sunflowers, grain, sorghum, winter cereal, oats, tobacco, grapes, Lucerne, asparagus and a variety of vegetables. A number of peach growers are also present in the Parys/Vredefort area. Irrigation remains the largest user of Vaal River water. The potential for irrigation exists along the whole length of the lower Vaal River and is extended inland by the Vaalhart and Douglas Weirs (Bruwer *et al.* 1985).

Urban and industrial use:

There are several abstractors of domestic and industrial use along the Vaal. Various mining activities also occur along the Vaal River. The largest increased demands will be made by large water treatment plants for potable water and by municipalities (Bruwer *et al.* 1985).

Recreational use:

The recreational potential of the Vaal River have not been described in great detail. The Vaal is one of the major recreational assets to the local communities in the Transvaal, Free State and North Western Cape Province. There are several holiday resorts located on the banks of the river. Popular activities include fishing, camping, picnicking, swimming, hiking and bird watching (Bruwer *et al.* 1985).

1.2.4. Water quality problems in the Vaal River

There are several sources of pollution in the Vaal River, and these sources include point sources as well as diffuse sources. Diffuse sources include agricultural practices, urbanization, air pollution, natural sources and littering. Point sources include sewage works, effluents from industries, mining activities and intensive animal feeding (Oliveira, 1986).

In the middle Vaal, high sulphate loads with the contribution of total alkalinity being considerably reduced, dominate water quality. This is due to high inputs from the tributaries draining the northern section of the middle Vaal that are heavily contaminated due to intensive mining and industrial activities. The tributaries in the southern part of the Middle Vaal are low total dissolved solids (TDS), bicarbonate waters (Van Vliet & Nell, 1986).

The Vaal River and tributaries in the middle Vaal area are dominated by high TDS concentrations, and mineral water quality conditions are the worst of the Whole Vaal River Catchment. These high TDS concentrations are caused in large part by the urban, industrial and mining activities in the areas north of the Vaal River that contribute varying loads of mineral salts. Further downstream, the impact of these TDS sources is to some extend ameliorated by the inflow of lower TDS, alkaline earth-bicarbonate waters from the east (Van Vliet & Nell, 1986).

In the catchment upstream of Bloemhof Dam effluents from urban, industrial and mining activities have resulted in a marked increase in the total salinity of the Vaal River. Increasing salinity renders the water less suitable for urban and industrial use. Water users have already incurred costs associated with salinasation (Janse Van Vuuren, 1996). The effects of sediments and the associated high turbidity are being countered by the effects of increased salinity, which reduces the residence time of sediments suspended in the water column.

A greater light penetration results in extensive blooms of rooted underwater macrophytes, and can also increase the likelihood of phytoplankton blooms (Grobler *et al.* 1986).

Agriculture and industries have a noticeable effect on the quality of the water including the organism composition thereof. Especially eutrophication as a result of pollution from industries and agriculture, that releases high concentrations of normally limiting nutrients, has a big impact on the river.

Eutrophication is the process whereby high levels of nutrients (especially nitrogen and phosphorous) in water results in the excessive growth of aquatic macrophytes and algae, and thereby affects the turbidity of the water. The turbidisation of a mass of water has the effect that the depth of the eufotic zone (zone of effective light penetration) decreases (Pieterse, 2000). It is most often found in highly developed and populated areas where water-borne sewage systems and agricultural practices contribute to elevated loads of nutrients into receiving natural water systems. The nutrients promote the development of both living and decaying biological material in the receiving systems, ultimately to cause a wide array of water quality and user problems (Walmsley, 2000). Eutrophication causes the numbers of certain algae to rise, while others decline in number. This is the result of nutrients, usually limiting, becoming available in excessive amounts, upsetting the whole ecosystem of the river. This can even lead to blooms of toxic algae that have negative impacts on the water quality, and suitability for use by live stock and domestic use. Algal blooms and turbidity also causes extensive problems at water treatment works and results in high water treatment costs (Davies & Day, 1998).

The most serious aquatic macrophyte threat on the Vaal below the Barrage is caused by *Eichhornia crassipens*, commonly known as the water hyacinth. The hyacinth historically presented a problem in the Lower Vaal in the Parys area as early as 1972 (Bruwer, 1986).

Available information on primary productivity and phytoplankton concentrations in the Vaal River at Balkfontein, Stilfontein and the Vaal Barrage indicate the occurrence of algal blooms associated with the late winter and spring seasons, possibly due to favourable light conditions prevailing at these times, as well as low flow conditions, the absence of intensive turbulence and an adequate supply of inorganic nitrogen. The algae responsible for blooms are mainly blue-green, green, euglenophyte and diatom representatives. The blue-green representatives is responsible for the most of the aesthetical problems including the taste and odour of the water, and may also be responsible for the release of toxins into the water (Pieterse, 1986).

1.3. The Vredefort Dome as important site of natural heritage

The Vredefort Dome is a geological structure that is about 40 kilometres wide. The Dome was formed by a meteorite impact about 40 million years ago and is one of the three largest meteorite craters in the world. The area is situated 1300m to 1650m above sea level. The Dome Mountain Conservancy occupies 23000 ha overlapping in the Free State and Northwest Province. The vegetation type of the area is the Rocky Highveld Grassland (Bredenkamp & Van Rooyen, 1996). Vegetation in the area is mostly of the family Poaceae, but many woody plants are also present in the area. The area is mainly a summer rainfall area and between 400 and 2000 mm rain is measured annually.

In 1999 the Vredefort Dome was included in a list of 20 natural and cultural sites that was identified by the government of South Africa to be included in the list of World Heritage sites. The application for nomination as a World Heritage site is currently in progress. World Heritage is a program launched by the United Nations Educational, Scientific and Cultural Organization (UNESCO) that seeks "to protect natural and cultural properties of outstanding universal value against the threat of damage in a rapidly developing world". South Africa became a member of the World Heritage Convention in 1997 and is now eligible to put forward sites for nomination as World Heritage sites (De La Harpe, 2000). Because of its unique characteristics the Dome serves as an island-like habitat for a variety of species that does not usually occupy the area.

1.4. The River Health Programme (RHP)

The Department of Water Affairs and Forestry initiated the formal design of the RHP in 1994. The main purpose was for the programme to serve as a source of information regarding the overall ecological status of riverine ecosystems in South Africa (Roux *et al.* 1999). The RHP is essentially a national initiative to assess and monitor the ecological state of South Africa's rivers using standardized indicators to gather information on the long term environmental trends of the country's freshwater resources. The RHP rests on the foundations of the biomonitoring of aquatic ecosystems (Mangold, 2001).

There are currently seven biomonitoring indices of ecosystem health that are in various stages of development and use in RHP programmes nationwide. The primary indices, which are the most well-known and widely used are (i) The South African Scoring System (SASS) for the sampling of macroinvertebrates, which is used in conjunction with (ii) the Invertebrate Habitat Assessment System (IHAS). The secondary RHP indices are (iii) the Fish Assemblage Integrity Index (FAII), (iv) Index of Habitat Integrity (IHI) and (v) Riparian Vegetation Index (RVI) which are currently being used, but to a lesser extent. The tertiary RHP indices are (vi) the Geomorphological (GI) Index and (vii) Hydrological Index (HI), for which prototypes have recently been developed, but are not currently being applied routinely in the RHP (Mangold, 2001).

The RHP is much broader than just the biomonitoring of rivers. The River Health Programme is a people driven process that requires a team effort from committed individuals. It also requires communication, liaison, promotion, quality control, information management, reporting and management actions as key components (Mangold, 2001).

The broad objectives of the RHP are as follows:

- To measure, assess and report on the ecological state of aquatic ecosystems;
- To detect and report on spatial and temporal trends in the ecological state of aquatic ecosystems;
- To identify and report on emerging problems regarding the ecological state of aquatic ecosystems in South Africa;
- To ensure that all reports provide scientifically and managerially relevant information for national aquatic ecosystems management (Roux, 1997; Murray, 1999; Mangold, 2001).

There are two acts which are directly relevant to the RHP, namely the NWA No. 36 of 1998 and the National Environmental Management Act (NEMA) Act No. 107 of 1998. Both of these stem from Section 24 of the Constitution of South Africa (Act No. 108 of 1996) (Mangold, 2001).

1.5. Biological Monitoring

Ecological experimenting and surveys are dependent on the monitoring of animal populations and the influences of biotic and abiotic factors on these populations (Begon *et al.*, 1997).

Biological communities reflect overall ecological integrity by integrating various stressors over time and thus providing a broad measure of their synergistic impacts. Aquatic communities (e.g. fish, riparian vegetation, macro-invertebrates) can integrate and reflect the effects of chemical and physical disturbances that occur in river ecosystems over extended periods of time. These communities can provide a holistic, and integrated measure of the integrity or health of the river as a whole (Barber-James, 2001; Roux, 2001 b).

The term "water quality" is fairly vague and refers to those physical and chemical attributes of a sample of water that determine its value for a specific purpose. The physical attributes and chemical constituents of natural fresh water differ from continent to continent, and even from region to region, as a result of differences in climate, geomorphology, geology, soils, and aquatic and terrestrial biotas. Human activities affect both the quantity and quality of water in aquatic ecosystems. Since each species has natural tolerance limits for any water quality variable, and since these differ from species to species, alterations in water quality will affect different species to a greater or lesser extent. Cumulative changes in water quality may eliminate some species whilst allowing others to invade. Water quality is thus one of the major determinants of the community of organisms that lives in a particular stream (Dallas *et al.* 1994).

Because of the difficulty of chemically analysing every potential pollutant in a sample of water, and of interpreting results in terms of the severity of impact, it makes sense to turn to the sampling of aquatic biota. The main advantage of a biological approach is that it examines organisms whose exposure to water and any pollutants therein is continuous. Thus species present in riverine ecosystems reflect both the present and past history of the water quality at a particular point in the river, allowing detection of disturbances that might otherwise be missed (Eekhout *et al.*, 1996).

Biomonitoring has been defined as: " any activity in which inferences about the status and quality of the environment are drawn from structural or functional attributes of individuals, populations communities or ecosystems" (Hart, 1994 as quoted in Uys *et al.* 1996).

Indicators are considered to be those characteristics of the environment that provide quantitative or qualitative information on the condition of the ecosystem and the extent to which it is stressed by natural or human disturbances. Assessments of the ecological state of an aquatic ecosystem cannot be considered complete without evaluation of the environmental factors that affect the aquatic ecosystem. These include biotic interactions, chemical variables, flow regime, habitat structure and energy source. Biological indices act as signals of deteriorating conditions (Uys *et al.*, 1996).

Suitable indicators of ecosystems should:

- be sensitive to a range of changes/stresses and allow for the detection of trends, while being stable in response to natural variability,
- generate information which can be easily understood,
- be easy to measure,
- be founded in science,
- be representative of the overall state of the environment,
- be acknowledged by experts to measure or represent important aspects of river condition,
- be appropriate for measurement at river reach scales and over annual time periods,
- be cost effective,
- be sensitive to management intervention,
- integrate environmental effects over time and space,
- be unambiguously related to an identified issue,
- provide an early warning of widespread change,
- have a historical database and
- be capable of being measured using skills available to resource managers (Murray, 1999).

Habitat availability and diversity are major determinants of aquatic community structure. Where habitat is diverse and largely un-impacted, a healthy biological community is likely to occur. Changes in the community structure may be attributable either to deterioration in water quality, or to habitat degradation, or to both. Assessment of both the physical and of water quality parameters should thus be included in evaluation of ecological condition (Uys *et al.*, 1996).

1.6. Aquatic Invertebrates

Invertebrate communities respond relatively quickly to localized conditions in a river, especially water quality, though their existence also depends on habitat diversity. They are common, have a wide range of sensitivities and have a suitable life cycle duration that indicates short to medium term impacts on water quality (Murray, 1999).

Freshwater macroinvertebrates occur in all inland water bodies (lakes, dams, rivers an streams) capable of supporting life. This diverse group of organisms includes primitive worms (oligochaetes), flat worms (planaria), snails, crustaceans (crabs and shrimps) and insects (e.g. dragonflies, mayflies caddis flies, several families of beetles and the larvae of true flies). They can be found in a variety of habitats such as stony runs and riffles, marginal vegetation and benthic sediments, within a wide range of environmental and ecological conditions. (Barber-James, 2001; Dickens & Graham, 2002)

Macroinvertebrates are mostly primary consumers (feeding on plant material) near the base of the food chain and therefore form an important functional component of the ecosystem. Apart from serving as a food source for other animals such as fish, reptiles and birds, they play an invaluable role in removing nutrients and purifying the water they live in. Because of the great diversity of this group of organisms and the selective tolerance ranges of different species to prevailing environmental conditions, the presence or absence of certain species, decrease in species richness, or proliferation of a particular species, provides a reflection of environmental change. Therefore, resident invertebrate communities provide a long-term indication of water quantity and quality, habitat quality and other environmental conditions within an aquatic ecosystem. Macroinvertebrates are suitable for use as indicators, reflecting the current state of the environment in which they live.

The aquatic stages of macroinvertebrates extensively used in water quality monitoring because:

- they are largely sedentary, which allows for spatial analysis of pollution or disturbance effects: their presence or absence is indicative of conditions prevailing at the site sampled,
- some are found in basically any water able to support life,
- they have a wide tolerance range to environmental conditions (some species are highly sensitive while others are very tolerant of adverse environmental conditions),
- the length of their life cycle is of a suitable time period for biomonitoring purposes, i.e. long enough to observe changes within a limited time period, but short enough to observe recovery or re-colonization after an environmental perturbation such as a toxic spill or chemical contamination and
- many species are involved, resulting in a spectrum of responses to environmental stresses (Barber-James, 2001; Dickens & Graham, 2002).

However, there are a few restrictions regarding the use of macroinvertebrates in biomonitoring and water quality assessment:

- The distribution and abundance of macroinvertebrates is affected by a wide range of factors other than discernible water quality effects (e.g. flow, nature of substrate, habitat and food availability).

- They may not show responses to certain types of water quality impacts, such as some herbicides.
- Some species are naturally patchy in distribution, irrespective of suitable water quality conditions within a river system; this requires high numbers of samples to achieve reasonable estimates of population abundances if doing quantitative sampling, and if doing qualitative sampling, may result in the erroneous conclusion that such species are absent from an area.
- Regional distribution patterns of many species vary considerably depending on a number or combination of abiotic factors such as temperature, altitude and latitude.
- The faunal composition of resident macroinvertebrate communities can vary extensively longitudinally down a river with changes in flow and habitat conditions (e.g. mountain torrent streams versus lowland meandering rivers), which can lead to problems where comparisons are required.
- The presence and abundance of certain species varies seasonally.
- In lotic water species may drift downstream to areas where they do not naturally occur.
- In South Africa, the taxonomy of many groups is poorly known and understood at genus and species-level with many new species are awaiting description.
- Effective biomonitoring programmes require ecological knowledge of species involved, (which is a problem when many of the species being collected are new to science) (Barber-James, 2001).

The South African Scoring System (SASS) method has become the backbone of modern systems for monitoring rivers in South Africa. The method assesses the populations of invertebrates living in a river, to give an indication of how natural or how disturbed the river is. SASS is widely used in the National River Health Programme, and is also used in various environmental impact assessments and environmental management programmes (Graham, 2001; Dickens & Graham, 2002).

1.7. Habitat effects and importance in riverine environments

In the broadest sense, "habitat" incorporates all aspects of the physical and chemical constituents along with biotic interactions. In relation to reference conditions for invertebrates and to SASS assessments, the definition of habitat is narrowed to the quality of in-stream habitat that influences the structure and function of the riverine invertebrate community (Dallas, 2000 b).

It is considered important to assess the habitat available to invertebrates since this is likely to affect the SASS scores. The terms habitat and biotope are often used interchangeably and in relation to SASS, either one relates to the potential areas that is available for habitation by invertebrates. Since biotopes have more relevance for invertebrates, this term is used in preference to "habitat". The quality and quantity of available biotopes affects the structure and composition of invertebrate communities and the number of taxa present at a site appears to be related to the number of biotopes present. In terms of SASS scores, biotope availability influences the SASS scores, although the effect on ASPT is less pronounced (Dallas, 2000 a).

1.8. Physical and Chemical variables in the riverine environment

All surface water should be of adequate quality to support aquatic life and be aesthetically pleasing. Additionally, if needed as a source of supply, the water should be treatable by conventional processes to provide potable supply meeting drinking water standards (Viessman & Hammer, 1998).

The chemical quality of water in streams and rivers is never constant. It varies according to changes in season, in run off and in time of day and responds also to inputs of dissolved or particulate organic and inorganic matter. Water quality assessments based on the analysis of "grab" water samples need not be representative of the chemistry of the sampled river (Chutter, 1986).

A normal, healthy river system has a balance of plant and animal life represented by great species diversity. Pollution disrupts this balance resulting in a reduction in the variety of individuals and dominance of the surviving organisms (Viessman & Hammer, 1998).

Climate affects water quality in a number of ways. For instance, temperature determines the rate and extent of various chemical interactions (Davies & Day, 1998). The thermal characteristics of running water are dependant on hydrology and climate and on structural features of the catchment (Dallas *et al.*, 1994). Mean annual rainfall, and seasonal differences in rainfall determine the amount of water flowing into rivers and therefore determines the degree dilution of natural chemical constituents and of pollutants. Evaporation, on the other hand, concentrates substances in water (Dallas *et al.*, 1994; Davies & Day, 1998).

The geomorphology of the landscape determines the gradients of rivers. The greater the amount of energy imparted to water by steep gradient, the greater the degree of turbulence, and thus the greater the quantity of oxygen and other gasses that can dissolve in water (Dallas *et al.*, 1994). The steeper the gradient, the greater the erosive power of a rivers water. Particles that are brought into suspension by the friction of water on the bed also contribute to turbidity (Davies & Day, 1998).

The water chemistry is affected by the underlying geology of the catchment because rocks of different kinds vary in chemical composition (Davies & Day, 1998). Thus the rocks and the soils derived from them contribute ions in different quantities and of different proportions to the water flowing over them (Dallas *et al.*, 1994).

Various components of the aquatic biota can also affect water chemistry. The combined effects of photosynthesis and decomposition can determine both the pH and the amount of oxygen present in water (Davies & Day, 1998). During photosynthesis, carbon dioxide is removed from the water and oxygen is released into it. This process can only happen in the presence of light. If the rate of photosynthesis is great enough, the pH of the water can rise to ten or more, with consequent effects on, for instance, ammonia toxicity. At night all organisms (including plants) respire, using up oxygen and releasing carbon dioxide. Thus the amount of oxygen in the water may become limited. When organic matter is present, decomposer bacteria will use up oxygen in the process of respiration. If the rate of decomposition is greater than the rate of photosynthesis, the system may become virtually anoxic. Biological oxygen demand (BOD) is a measure of the amount of decomposition taking place (Dallas *et al.,* 1994). Terrestrial vegetation in the catchment may also produce organic compounds that, when leached into the water affect pH and inhibit microbial activity (Davies & Day, 1998). Organic materials can also complex with many toxins such as trace metals, cyanide and fluoride, and thus make the toxins unavailable to the biota (Dallas *et al.*, 1994)

Since each species thrives optimally in water with particular combinations of physical end chemical attributes, and since optimal conditions differ for each species, alterations in water quality will affect different species to a greater or lesser extent. Greater and greater changes in water quality may eliminate some species and allow others to invade, until not a single species of the original species remains (Davies & Day, 1998).

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,
- reduction in diversity as a result of very small increases in the concentrations of toxins such as trace metals and
- reduction in, and ultimately the loss of decomposers, and thus of nutrient cycling in streams.

1.8.1 Physical variables

Temperature:

For all organisms there is a temperature range, usually narrow, at which optimal growth, reproduction and fitness occur and a wider range in which they can survive. Increased water temperature reduces oxygen solubility, increases the toxicity of certain chemicals, and increases metabolic rate, including respiration and thus the amount of oxygen required by aquatic organisms (Dallas *et al.*, 1994). The rate at which chemical reactions occur increases with increased temperature. The rates of biochemical reactions usually double for every 10°C rise in water temperature, and conversely, they halve for every 10°C drop in temperature. This quotient, known as the Q_{10} of biological reactions, indicates that temperature profoundly affects the rate at which physiological reactions take place within living tissues (Davies & Day, 1998; Schmidt-Nielsen, 1998).

Since oxygen demands increase and supply decreases with increasing temperature, the biota is doubly stressed at elevated temperatures. Lowered water temperature reduces metabolic rate and thus decrease the rate at which animals can move, whilst increasing the length of time to maturity. Many life cycle characteristics, such as reproductive periods, development rates and emergence times, are cued to particular temperatures or seasonal changes in temperature (Dallas *et al.*, 1994; Davies & Day, 1998).

Suspended solids, and turbidity:

Suspended solids include silt, dead organic matter and any other small particles suspended in water. These particles have both physical and chemical effects (Dallas *et al.*, 1994).

Suspensoids, because of their small sizes may have a considerable surface area, and many of them carry an electrical charge. The result is that a variety of dissolved substances become absorbed onto the surfaces of the particles. The consequences can be significant in that absorbed substances may become unavailable, which is an advantage if they are toxic, but a disadvantage if they are nutrient molecules (Dallas *et al.*, 1994).

Turbid waters interferes with recreational use and aesthetical enjoyment (Viessman & Hammer, 1998) When water moves slowly, or not at all, the particles themselves may settle to the bottom and become part of the sediments. Settling solids damages invertebrate populations, and fill gravel spawning pools (Dallas *et al.*, 1994; Davies & Day, 1998; Viessman & Hammer, 1998). Their surfaces may be altered by chemical changes such as a decrease in pH, resulting in desorption of some of the attached molecules.

Adsorbed toxins in sediments are essentially unavailable and thus of no concern. Mobilisation of the sediments during heavy spates, or as a result of chemical alterations may result in massive releases of toxins from the sediments. Large numbers of small particles suspended in water may be visible as turbidity, causing the scattering of light. If light penetration is reduced as a result of increased turbidity primary production decreases and less food is available to organisms. Suspensoids that settle may smother and abrade riverine plants so that communities may be dominated by those organisms that are best able to cope with this alteration in habitat, whilst predators that use sight to search for their pray may be unable to find food.

Turbidity in rivers often changes seasonally, the extend of the change being governed by the hydrology and geomorphology of a region (Dallas *et al.*, 1994).

1.8.2. Inorganic chemical variables

Total dissolved solids (TDS), conductivity and salinity:

The total amount of material dissolved in water is commonly measured as TDS, conductivity or salinity. Total dissolved solids represent the total quantity of dissolved materials, organic and inorganic, ionised and un-ionised. Conductivity is a measure of the ability of a sample of water to conduct an electrical current. Total dissolved solids and conductivity usually correlate closely for a particular type of water. Salinity refers to the saltiness of water and for most purposes can be considered to be the same as TDS. Natural TDS in rivers is determined by the degree of weathering and the chemical composition of rocks and by the relative influences of precipitation and rainfall in the catchments. Anthropogenic activities such as irrigation, clear felling, and re-use of water and the release of industrial effluents, lead to increases in TDS. Information on the tolerances of riverine organisms to increased TDS is very limited. Juvenile stages are often more sensitive than adults (Dallas *et al.*, 1994; Davies & Day, 1998).

The total salinity of inland waters is usually dominated by four major cations (calcium, magnesium, sodium and potassium), and the major anions (bicarbonate, carbonate, sulphate and chloride) (Wetzel, 1983). Salinasation refers to an increased concentration of naturally occurring mineral ions, particularly those of sodium, chloride and sulphate, in water. Natural fresh water contains all of these, together with the other major ions. If these waters are subject to evaporation they will become saltier. Usually this effect is small or insignificant, except in saline pans. High concentrations of salts in water may also be caused by a number of other factors like salt in rocks and easily weathered rocks that naturally contains high concentrations of mineral ions. Certain human activities increase the TDS of water. Sewage purification, for instance, subjects the water to evaporative concentration, an unfortunate consequence of the recycling of treated effluent, particularly during dry periods. Saline industrial and mine effluents can be a costly problem. A good example is the disposal of large effluent loads into the Vaal River. Salinity in the river has increased alarmingly, particularly in the last 25 years (Davies & Day, 1998).

The effects of industrial effluents may be by far the most devastating form of salt pollution. Common to many dry-land environments is salinasation resulting from agricultural activities. Long-term irrigation results in human induced salinasation of soils and water. Rivers are characterised by increasing concentrations of salts, and pulses of particularly salty runoff after rains. Salinasation of rivers is recognised as one of the major threats to South Africa's water resources. South Africa's rivers are rapidly declining as a result of irrigation-induced salinasation. Finally human manipulation of river flow is further contributing to salinasation (Davies & Day, 1998).

pH and alkalinity:

The pH of water is a measure of the concentration of hydrogen (H^+) ions. As [H^+] increases, so the pH decreases and the solution becomes acidic and vice versa. Alkalinity is determined as "acid neutralising capacity", which in fresh waters is usually due largely to bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. Since pH is by definition log_{10} of hydrogen activity, a decrease in one pH unit means a ten-fold increase in [H^+]. The rate of pH change is determined by the buffering capacity of the water (Dallas *et al.*, 1994; Davies & Day, 1998).

The pH of natural waters is determined by geological and atmospheric influences. Most freshwaters are relatively well buffered and more or less neutral, with pH ranging between about six and eight (Dallas *et al.*, 1994; Davies & Day, 1998).

One of the main ways in which pH affects aquatic ecosystems is by determining the chemical species of many trace metals, changing the pH of water changes the concentrations of both H^+ and OH^- ions, which in turn affects the osmotic balance of aquatic organisms. Relatively small changes in pH are not normally lethal, but sub-lethal effects such as impaired growth rates and reduced fecundity may occur as a result of increased physiological stress (Dallas *et al.*, 1994; Davies & Day, 1998; Viessman & Hammer, 1998).

Eutrophication can result in a significant increase in pH, since excessive plant production consumes CO_2 and so alters the equilibrium of the CO_2/HCO_3^- buffering system. Under eutrophic conditions pH may fluctuate diurnally by two or three units, depending on the quantity of CO_2 consumed during photosynthesis relative to that produced during respiration and decomposition (Dallas *et al.*, 1994; Davies & Day, 1998).

Dissolved oxygen:

The concentration of dissolved oxygen is probably one of the most important abiotic determinants of the survival of most aquatic organisms. Under natural conditions the concentration of dissolved oxygen fluctuates diurnally, depending on the relative rates of photosynthesis and respiration. It is usually lowest at dawn, increasing during the day, peaking in the afternoon, and decreasing during the night. Various factors determine the amount of oxygen that can be dissolved in water. These include the rate of aeration from the atmosphere (dependant on turbulence, oxygen deficit and pressure), temperature, salinity and respiration by al organisms and photosynthesis by all plants. Oxygen levels decrease where organic enrichment occurs (BOD) because aerobic decomposer microorganisms require oxygen and where certain oxygen-“consuming” chemicals are present (Chemical oxygen demand - COD) (Wetzel, 1983; Dallas *et al.*, 1994; Davies & Day, 1998; Schmidt-Nielsen, 1998).

The amount of oxygen dissolved in water can be reduced by increases in temperature and salinity, by oxygen consuming chemical effluents and by high levels of organic waste, the decomposition of which consumes oxygen (Dallas *et al.*, 1994).

Aquatic organisms have physiological (e.g. a blood system to transport oxygen more rapidly than diffusion alone can provide), morphological (e.g. diffusion through the body surface, or specialised respiratory organs) and behavioural (e.g. movements to move oxygenated water over the respiration surfaces) adaptations for respiration in water (Schmidt-Nielsen, 1998).

The extent to which organisms are affected by dissolved oxygen concentrations is determined by its dependence on water as medium. Larvae of stoneflies, caddisflies and mayflies, which respire through gills or by direct cuticular exchange, are especially susceptible. Low concentrations of oxygen may cause several sub-lethal effects such as changes in behaviour, blood chemistry, growth rate and food intake, as well as lethal effects.

Nutrients:

Various elements, including carbon, oxygen, hydrogen, sulphur, potassium, nitrogen and phosphorus, are required for normal growth and reproduction in plants. Nitrogen and phosphorus are the most common limiting nutrients in that they are implicated in excessive plant growth resulting from nutrient enrichment of aquatic ecosystems (Dallas *et al.*, 1994; Davies & Day, 1998).

Phosphorus is required in numerous life processes and is an integral part of DNA. In nature, inorganic phosphorus occurs most commonly as the phosphate ion (PO_4^{3-}), which is the only directly utilisable form of soluble inorganic phosphorus (Wetzel, 1983; Dallas *et al.*, 1994; Davies & Day, 1998).

Nitrogen occurs abundantly in nature and is an essential component of many biochemical processes. It occurs as nitrate, nitrite, ammonia and many nitrogen containing organic compounds. Nitrate is seldom abundant in natural surface waters because it is incorporated into organic nitrogen in plant cells or is reduced by microbes and converted into atmospheric nitrogen. Nitrite is an intermediate in the inter-conversion of ammonia and nitrate and is toxic to aquatic organisms at large concentrations. Ammonia, either in the free un-ionised form (NH_3) or as ammonium ions (NH_4^+) is a common pollutant associated with sewage and industrial effluent. The toxicity of ammonia is directly related to the proportion of the un-ionised form , which increases in relative proportion as pH and temperature increase. High levels of nutrients may enter rivers as point-source effluents from wastewater treatment works, industry and intensive animal enterprises or diffusely as runoff from fertilised agricultural areas and urban storm water (Dallas *et al.*, 1994; Davies & Day, 1998).

1.8.3. Organic compounds

Organic compounds all contain carbon. Most of them are the normal compounds produced by living organisms and are usually not toxic (Dallas *et al.*, 1994).

Organic waste (= "oxygen-demanding waste")

Dissolved organic matter (DOM) and particulate organic matter (POM) are derived form biological activity, including the decomposition of dead material. In rivers, POM is an important source of food or energy for many benthic organisms, including detrivores and decomposer bacteria. Some of these bacteria require oxygen and when present in large quantities can entirely deplete the water of oxygen. Organic enrichment is probably the most common type of pollution in rivers. Because it results in oxygen depletion it may significantly alter community structure by encouraging the survival of hardy species and eliminating those sensitive to lack of oxygen. The main source of organic waste is effluents from domestic sewage, food processing plants and animal feedlots and abattoirs. Increases in turbidity (and hence reduced light penetration), suspended solids (and hence substrate modification) and nutrients (nitrogen, phosphorus, and hence increased potential for plant growth) combined significantly affect species richness and diversity, with community composition usually becoming much less diverse but biomass increasing many fold (Dallas *et al.*, 1994).

Toxic organic compounds

The most toxic compounds known are produced by a variety of organisms from bacteria and phytoplankton to plants and animals. Substances like these are very seldom found free in nature in toxic quantities. Toxic cyanophyte blooms are a result of human induced eutrophication. In contrast many of the exceedingly toxic synthetic organic compounds enter aquatic ecosystems in industrial or agricultural effluents and often persist in the environment. Some of these chemicals are produced specifically as biocides (toxic chemical produced specifically to kill pest organisms and are thus particularly effective as environmental toxins), while others are only incidentally toxic (Dallas *et al.*, 1994).

Although each variable may affect aquatic organisms either beneficially or detrimentally, the effects of combinations of variables may be greater or less than the effect of each on its own. When variables interact to produce a magnified effect, it is known as synergism. On the other hand, the toxicity of some substances is decreased in the presence of others, and this is called antagonism (Dallas *et al.*, 1994).

1.9. Project Aims

It is clear that water is one of our most important assets and that it should be thoroughly managed. There is very little information on the water quality and general health of the Vaal River water below the Barrage, making management of the area difficult if not impossible. Furthermore the Vredefort Dome is an important landmark for South Africa, and has recently been nominated to receive World Heritage status.

Taking the above into account, the research aims of the project can be summarised as follows:

1. Providing a baseline set of data on the water quality and macroinvertebrate diversity of the Vaal River in the Vredefort Dome.
2. Preliminary investigation using SASS 5 (the most recent version of the South African Scoring System) to identify possible problem areas and influences on the water quality of the Vaal River in the Vredefort Dome.
3. Preliminary investigation on the effects of seasonal variance of the riverine environment.

4. Identification of research priorities for a largely neglected area of great importance by:
    a. conducting a thorough literature study,
    b. using SASS 5 as an indicator of biological water quality and river health,
    c. assessing habitat diversity on the Vaal River in the Vredefort Dome, and its effects on the aquatic macroinvertebrates,
    d. assessing some of the most important physical and chemical variables in the riverine environment,
    e. assessing the effects of seasonal variation on the macroinvertebrate communities of the Vaal River in the Vredefort Dome and
    f. prioritising management possibilities and needs.

CHAPTER 2

Materials and Methods

2.1. Sampling sites:

During the pilot study, six sampling sites were identified in and around the Vredefort Dome.

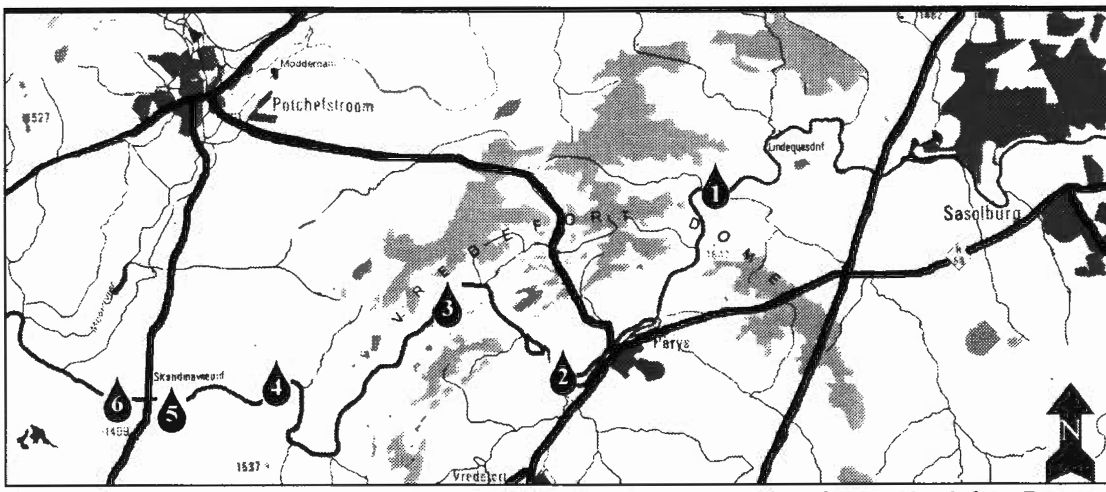

Figure 2: Map indicating the sampling sites along the Vaal River in the Vredefort Dome

1	**Site 1** **Uitkyk**	26°47.004′S 27°30.739′E 1422M	4	**Site 4** **Elgro**	26°55.431′S 27°10.588′E 1325M
2	**Site 2** **Stone Henge**	26°54.098′S 27°23.392′E 1365M	5	**Site 5** **Limerick**	26°56.237′S 27°04.054′E 1320M
3	**Site 3** **Thabela Thabeng**	26°51.828′S 27°17.765′E 1352M	6	**Site 6** **Raaswater**	26°55.971′S 27°04.251′E 1302M

Site 1 and is situated below the Barrage, on the edge of the Vredefort Dome. Site 2, 3 and 4 is situated downstream of Site 1, within the Dome. Site 5 and 6 are the last two sites, and is again situated at the edge of the Dome. Site 1 gives an indication of the quality of the water coming into the Dome from the Barrage. Site 2 is situated downstream of Parys, and could give an indication of the effects of a town on the water quality. Sites 3 and 4 should give an indication of the changes in water quality as the water flows through the dome. Sites 4 and 5 is situated in the vicinity of an animal feeding lot and could give an indication of the effects of intensive agricultural practices on the water quality and river health.

The sites were selected on grounds of their position in the dome, accessibility, and habitats available. The sites were named according to the name of the resort at which the site was located. One of the major problems encountered during the search for suitable sites, was that most of the land in this area is privately owned, and the owners are usually only available on weekends. Some of the other areas were inaccessible due to heavy riparian growth and lack of access roads. The chosen sites, though, gives a good representation of the general characteristics of this part of the river. Descriptions of the conditions at the different sites are given in Table 1.

Table 1: Descriptions of the habitat conditions at the six sampling sites along the Vaal River in the Vredefort dome.

Site no and name	Land Use[1]	Vegetation		River make-up[4]	Estimated river width	Water Depth		Islands	Substrates[5]	River Banks
		Terrestrial[2]	Aquatic[3]			Runs & Riffles	Deepwater			
1. Uitkyk	RR.	Gr, Fo, Tr	Wg, Hy, Fa, Wl	Ru, Ra, Ri, Dw	50 – 200 m	20 – 500 cm	500 cm – 2 m	10 – 20	Pe, Ro, Bo, Gra, Sa.	Impacted
2. Stone Henge	RR.	Gr	Wg, Hy, Fa	Ra, Ri	40 – 400 m	20 – 100 cm	200 – 600 cm	20 - 30	Br, Gr, Sa	Impacted
3. Thabela Thabeng	RR.	Gr, Re, Tr, Fo	Wg, Hy, Fa	Ru, Ri, Ra, Dw	50 – 200 m	20 – 500 cm	500 cm – 2 m	2 – 5	Pe, Ro, Bo, Gr, Sa, St, Mu	Lightly impacted
4. Elgro Lodge	RR & GP.	Gr, Re, Tr, Fo.	Wg. Hy	Ra, Ru, Ri	100 – 200 m	10 – 500 cm	500 cm – 1m	2 – 5	Pe, Ro, Bo, Gra, Sa, Mu	Un-impacted
5. Limerick	RR.	Gr, Re, Fo	Wg, Hy, Fa, Wl.	Ra, Ru, Ri	50 – 100 m	20 – 500 cm	500 cm – 1 m	1 – 2	Ro, Bo, St, Gra, Sa, Mu	Fairly Un-impacted
6. Raaswater	RR.	Gr, Re	Wg, Hy, Fa.	Ru, Ra, Ri, Dw	50 – 200 m	10 – 500 cm	500 cm – 2 m	5 – 10	Ro, Bo, Gra, Sa, Mu	Lightly impacted

1 **GP = Game park; RR = Recreational resort.**

2 **Fo = Forbs; Gr = Grasses; Re = Reeds; Tr = Trees**

3 **Fa = Filamentous algae; Hy = Hyacinths; Wg = Water grass; Wl = Water lilies**

4 **Dw = Deepwater; Ra = Rapids; Ru = Runs; Ri = Riffles**

5 **Bo = Boulders Br; = Bedrock; Gra = Gravel; Mu = Mud; Pe = pebbles; Ro = Rocks; Sa = Sand; St = Stones**

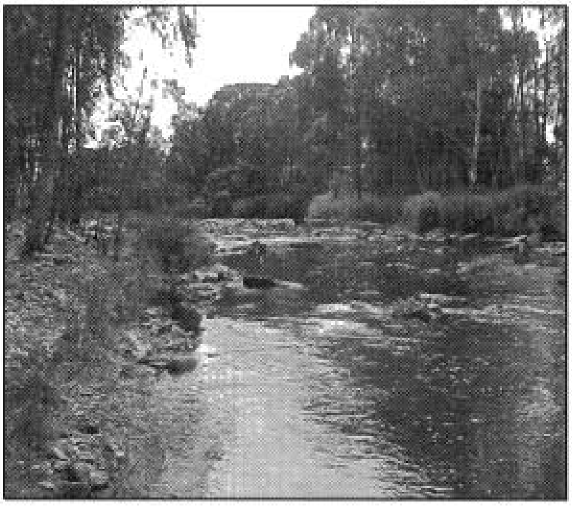

Figure 3: Plate of the upstream view at Site 1 (Uitkyk)

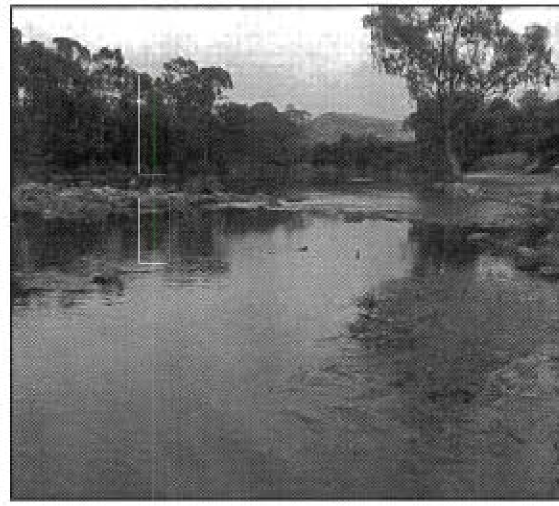

Figure 4: Plate of the downstream view at Site 1 (Uitkyk)

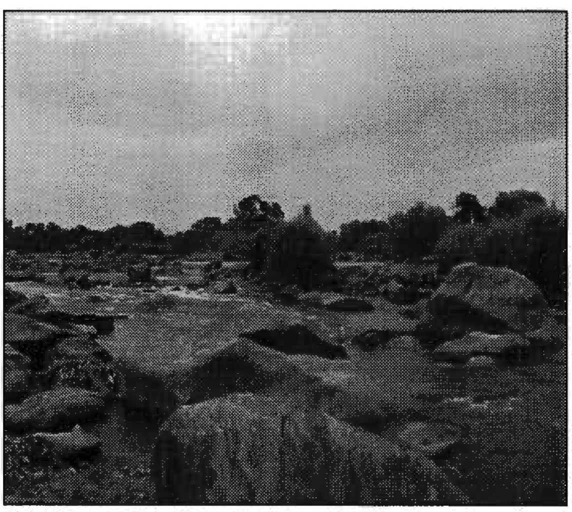

Figure 5: Plate of the upstream view at Site 2 (Stone Henge)

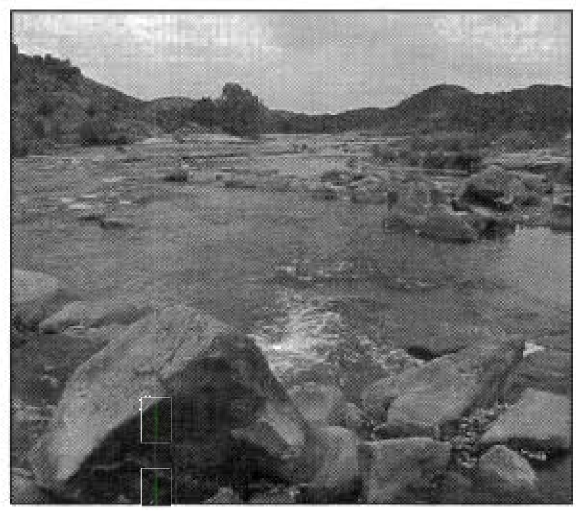

Figure 6: Plate of the downstream view at Site 2 (Stone Henge)

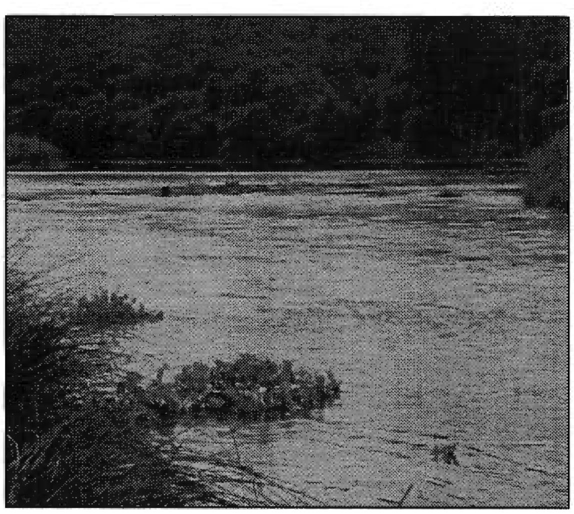

Figure 7: Plate of the upstream view at Site 3 (Thabela Thabeng)

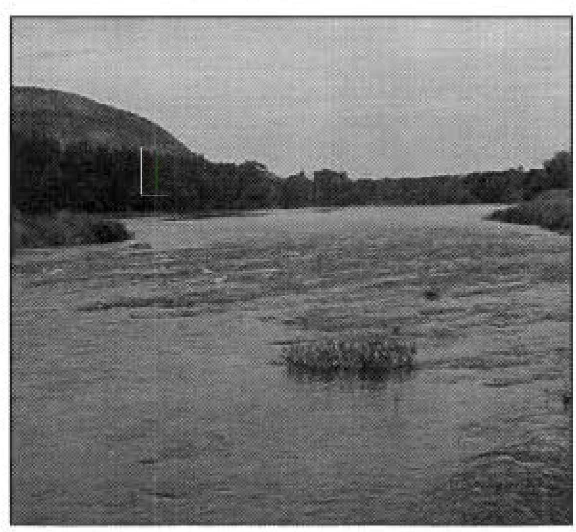

Figure 8: Plate of the downstream view at Site 3 (Thabela Thabeng)

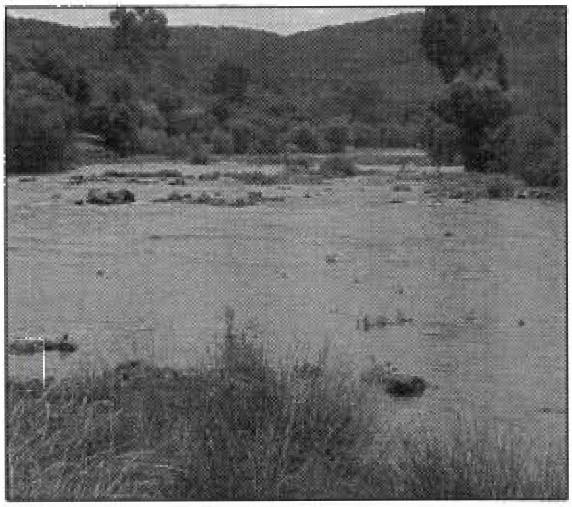

Figure 9: Plate of the upstream view at Site 4 (Elgro)

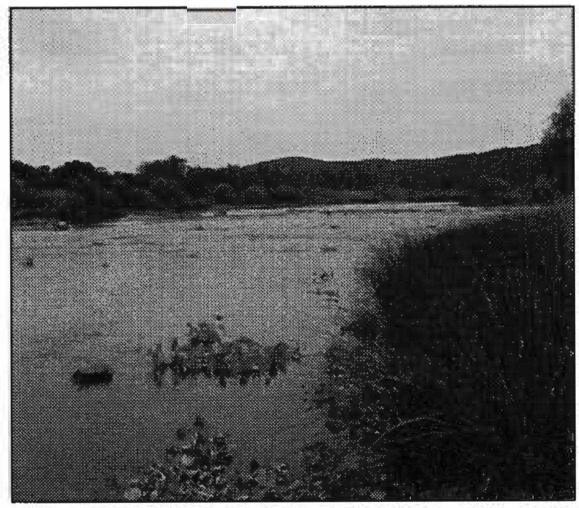

Figure 10: Plate of the downstream view at Site 4 (Elgro)

Figure 11: Plate of the upstream view at Site 5 (Limerick)

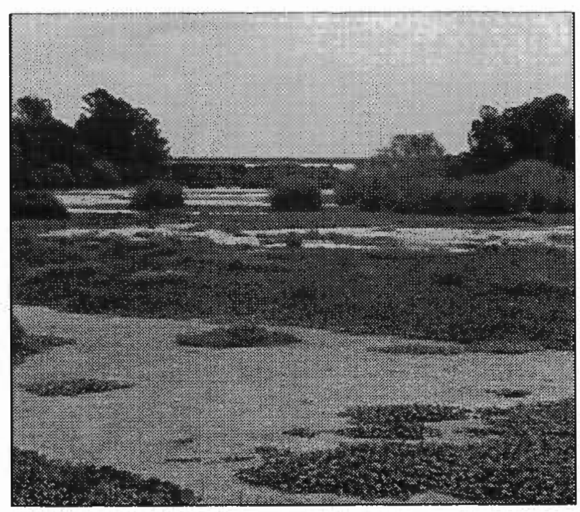

Figure 12: Plate of the downstream view at Site 6 (Limerick)

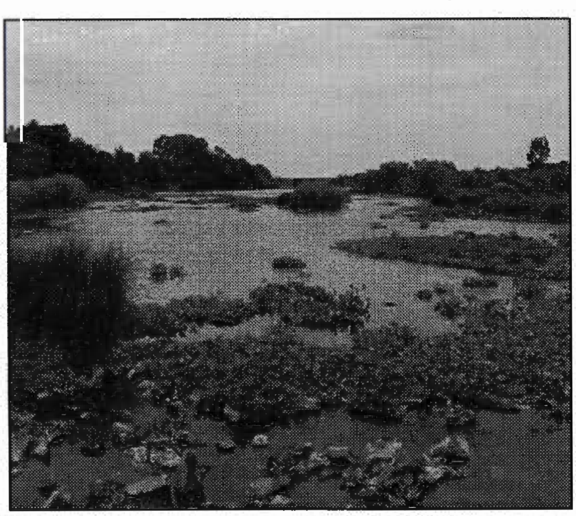

Figure 13: Plate of the upstream view at Site 6 (Raaswater)

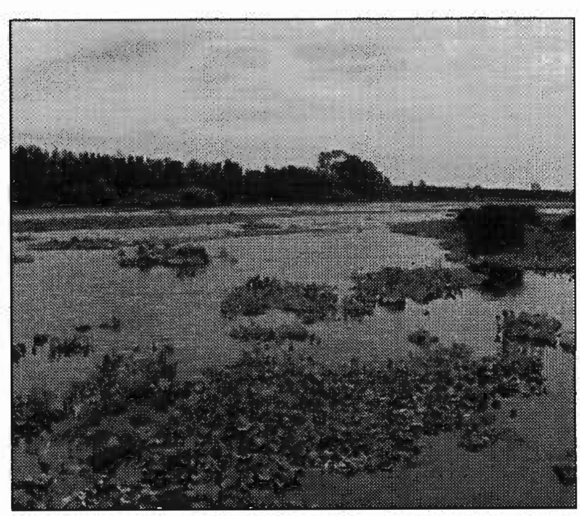

Figure 14: Plate of the downstream view at Site 6 (Raaswater)

2.2. Macroinvertebrate sampling: The South African Scoring System (SASS) version 5

The field procedures of the SASS method are based on the British Biological Monitoring Working Party (BMWP) method. Collections of invertebrates are made from streams and rivers using a standardized net following defined methods. At the streamside water is placed in a photographic or other large tray and the collected invertebrates are tipped into the tray. The types of invertebrates found are recorded on a score sheet (see Appendix A, Figure 34) (Chutter, 1998).

The score sheet consists of space to record when and where the sample was collected, instructions for collecting the sample and analysing it and a list of invertebrate groups, mainly at the family level, and a number between 1 and 15 opposite each name. These numbers have been allocated to each family according to its perceived sensitivity to water quality change, the most tolerant families being scored 1 and the most sensitive 15 (Chutter, 1998).

The families present at a sampling site are marked on the score sheet and the results are given in the form of:

1. The SASS score,
2. The number of taxa recorded and
3. The Average Score Per Taxon (ASPT),

All sampling was done with a standard net with a square frame of 300 mm x 300 mm, onto which a net with a pore size of 1mm was mounted. The net had a handle of about 1 m long.

Sampling was done according to the following protocol (Chutter, 1998):

Stones (S):

Stones in current (SIC):

Movable stones with a diameter between 3 and 20 cm in the flowing sections of the river

Stones and bedrock was kick-sampled for at least two minutes, where all stones are easily moveable, with a maximum of 5 minutes. The net was held in position downstream of the part being sampled and the rocks was kicked over and against another, thereby dislodging organisms and allowing the current to sweep them into the net.

Stones out of current (SOOC):

Stones that are located in the still parts of the river, such as behind sand banks and in backwaters.

Stones and bedrock of an area of approximately 1m^2 was kick-sampled. The rocks were kicked to dislodge organisms, and the net was continuously swept over the agitated area to collect any organisms that has been dislodged from the stones being kicked.

Vegetation (VG):

Marginal Vegetation (MV):

All bank-side vegetation including bushes and reeds, as well as overhanging leaves and grasses.

Marginal vegetation was sampled by sweeping the net under and through the vegetation, from side to side, for a total area of 2m.

Aquatic Vegetation (AV):

All plants that is rooted and / or submerged in the water, as well as floating water plants.

Aquatic vegetation was sampled by sweeping the net over and through the submerged vegetation from side to side for a total area of 2m.

Gravel, Sand Mud (GSM):

Sand includes all sandbanks as well as isolated clumps of sand in hollows and between rocks; Gravel includes of course material with a diameter of between 2mm and 3cm; Mud includes all the finer particles and sediment.

These habitats was sampled by stirring and agitating the GSM for half a minute, while sweeping the net over the agitated area to collect the dislodged organisms.

The resulting content of the net was tipped into a photographic tray and all obvious twigs, leaves and other trash was removed. The taxa present were checked for the lesser of 15 minutes, or until 5 minutes after the last taxa have been seen.

For the purposes of more detailed analysis the organisms in the trays were collected and preserved in 70% ethanol for later laboratory identification and verification.

Estimated abundance values was allocated according to the following scale:

A: 1 – 10; B: 11 – 100; C: 101 – 1000; D: > 1000

Statistical analysis was done on the SASS data to investigate possible seasonal differences in the scores. Three seasons were sampled (summer, autumn and winter) and was analysed accordingly. Statistical analysis was included for SASS, ASPT and Number of taxa. A description of the statistical tests that were conducted is given in chapter 2.6.3.

2.3. Habitat Assessments: Invertebrate Habitat Assessment System (IHAS)

The IHAS is designed to limit the bias of the individual so that different samplers should get the same habitat score.

The IHAS scoresheet (see Appendix A, Figure 35) is a series of specific questions, to which the answer box along side the question with the correct statistic should be marked. Each of the boxes has a value between zero and five, generally, the higher the value, the better the habitat. These values are totalled to give final habitat scores. The total IHAS is out of 100 points or percent.

There are two main sections in the IHAS scoresheet: sampling habitat and stream characteristics, each division having a maximum of 55 and 45 points respectively. The sampling habitat section is divided into three sub-sections: stones in current (20 pts), vegetation (15 pts), and other habitat / general (20 pts).

Although the sub-sections under sampling habitat have a maximum score of 20/15/20, it is possible to score higher than these values if there is a particular good habitat available. In such cases the scores are reduced to the maximum values. A further calculation in each of these sub-sections is needed: an adjustment value to equal the maximum. Thus each sub-section needs three scores: the actual total value of the marked boxes; an adjustment value which would make the total equal to 20/25/20; and a final "usable" total which is the lower of the actual total or the maximum.

The second section simply records the physical aspects and conditions of the stream, and man-made or other impacts along its banks. This score has a maximum of 45 points and needs no adjustments.

e g.: For SIC (max 20): actual total (14), adjustment (+6), final total = 14;

For vegetation (max 15) - actual total (17), adjustment (-2), final total = 15;

For other habitat (max 20) - actual total (11), adjustment (+9), final total =11.

This gives:

Total adjustment: (+6 –2 +9) = +13

Total habitat value: 40 out of 55

The second section simply records the physical aspects and conditions of the stream, and man-made or other impacts along its banks. This score has a maximum of 45 points and needs no adjustments. To continue the above example:

Total physical characteristics value: 38 out of 45

Total IHAS score: 78% (40+38)

It is presently thought that a total score of over 75% represents good habitat conditions, and over 65% indicates adequate habitat conditions (McMillan, 1998).

2.4. Water Chemistry

Limited Chemical Analysis was conducted. Variables that were sampled included: pH, dissolved oxygen, conductivity and temperature. The variables were measured using a WTW multiline P4 SET water tester.

2.5. Freshwater Molluscs

From May to August all molluscs that were found in the sorting trays were collected and preserved in 70% ethanol for identification purposes. Professor Kenné de Kock, from the School of Environmental Science and Development of the Potchefstroom University, did the identification of the molluscs (Walker, 1932; Kuiper, 1964; Brown, 1994 and Appleton, 1996).

The collected molluscs were included in the National Snail Collection held by the School of Environmental Science and Development at the Potchefstroom University.

2.6. Data Analysis

2.6.1. SASS

The SASS score is calculated by summing the numbers against each taxon present. The data was interpreted according to the following guidelines set out by Chutter (1998) (Table 2).

Table 2: Chutter's guidelines for interpreting SASS results for alkaline (hard) waters (Chutter, 1998)

SASS Score	ASPT	Description
SASS > 100	ASPT > 6	Water quality natural, Habitat diversity high.
SASS < 100	ASPT > 6	Water quality natural, Habitat diversity reduced.
SASS > 100	ASPT < 6	Borderline case between water quality natural and some deterioration in water quality, interpretation should be based on the extend by which SASS exceeds 100 and ASPT is < 6.
SASS 50 - 100	ASPT < 6	Some deterioration in water quality
SASS < 50	ASPT variable	Major deterioration in water quality.

2.6.2. ASPT

The ASPT is calculated by dividing the SASS score by the number of taxa (Chutter, 1998).

2.6.3. Statistical Analysis:

Statistical analysis was conducted using Statistica version 6.0 from StatSoft Inc.

The first step in each analysis was to determine if the data was normally distributed. To determine normality, the Shapiro-wilk W test was used (StatSoft, Inc. 2001). If the *W statistic* was significant ($p < 0.05$), then the hypothesis that the respective distribution is normal was rejected.

For parametric data (data with a normal distribution), break down and one-way ANOVA was used, and the categorised box and whisker plots were constructed. Post-hoc analysis was done using the Tukey Honest

Significant Difference (HSD) test to investigate statistically significant differences among the sites.

For non-parametric data (data that is not normally distributed), non-parametric statistics was used for comparing multiple independent samples (groups), and a box and whisker plot was constructed. Kruskal-Wallis ANOVA and median test were done for testing significance.

CHAPTER 3

Results & Discussion

3.1. SASS

Table 3: The SASS scores from all the sampling sites on the Vaal River in the Vredefort Dome from October 2001 to August 2002 (N.S. = not sampled)

SASS	Oct-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Site 1	132	124	128	120	144	130	98	92	92
Site 2	104	93	N.S	118	117	N.S.	103	100	97
Site 3	111	130	125	107	123	105	109	104	96
Site 4	126	N.S	151	115	131	136	125	123	103
Site 5	N.S.	117	109	114	134	116	125	127	103
Site 6	105	139	129	129	129	134	103	109	101

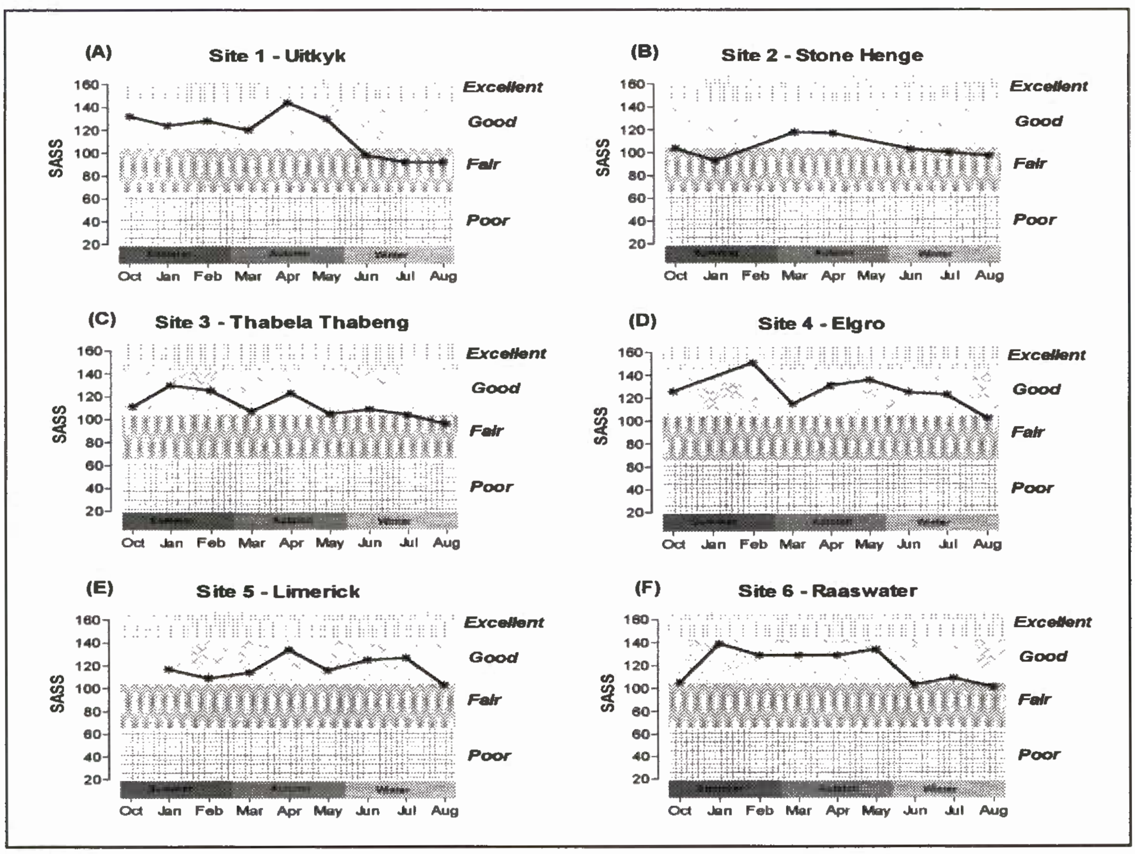

Figure 15: SASS scores for all the study sites on the Vaal River in the Vredefort Dome where each point indicates a single score. Classification based on Chutters (1998) classification svstem for SASS 4 data.

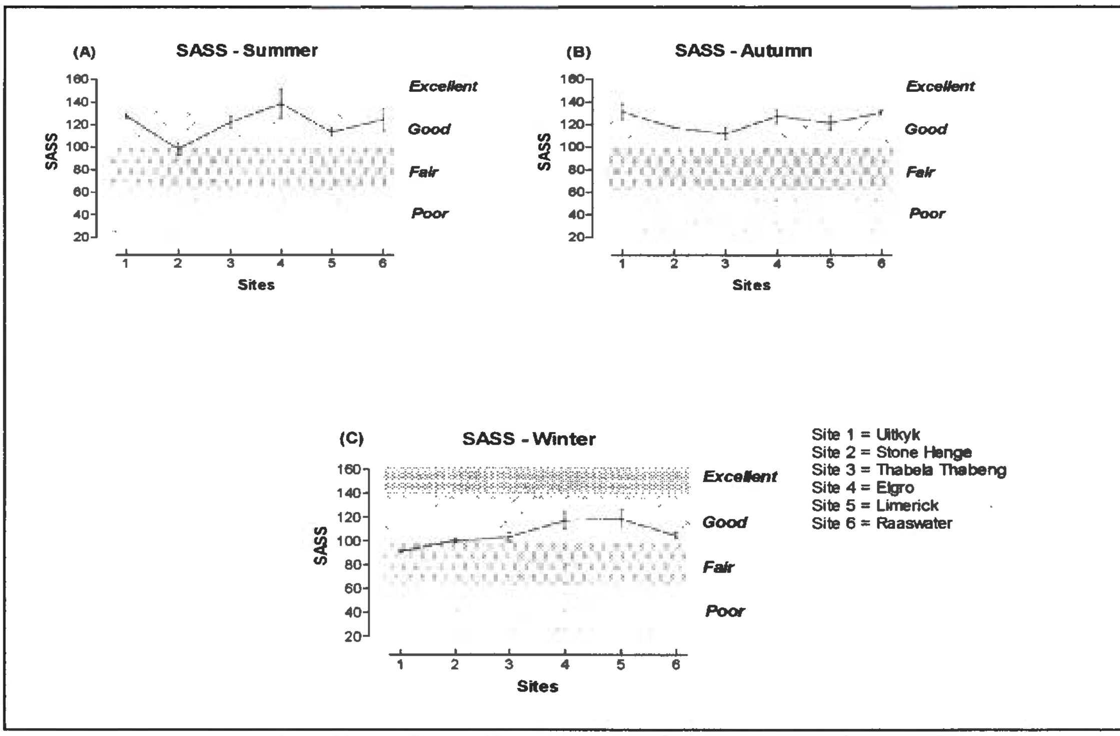

Figure 16: Seasonal SASS scores for all the study sites on the Vaal River in the Vredefort Dome where each point indicates the average scores for the three months of each season sampled (Summer = Oct – Feb; Autumn = Mar – May; Winter = Jun - Aug)

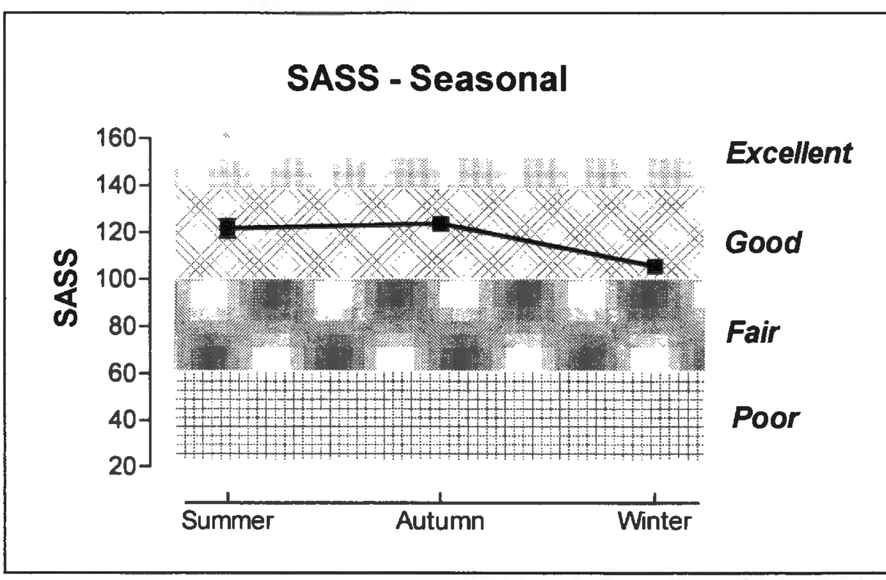

Figure 17: Seasonal SASS scores for all of the study sites on the Vaal River in the Vredefort Dome where each point indicates the average scores of the six sites of the three-months for each season (Summer = Oct – Feb; Autumn = Mar – May; Winter = Jun - Aug)

The SASS score should generally be higher in an area with a variety of habitats since invertebrates have specialized habitat requirements, and the greater the number of habitats, the more different groups of invertebrates can occupy the area (Chutter, 1998; Barbour *et. al.*, 1999; Barber-James, 2001; Dickens & Graham, 2002; Lepono *et al.*, 2001; WRC, 2001). The SASS, NT, and ASPT values was based on the sum of all of the biotopes sampled at each site.

The overall impression from the SASS values is that for all of the sites, over the whole period of sampling, the water quality is in the fair to good range (see Figure 15). This is an indication that the water quality of the Vaal River in the Vredefort Dome is quite adequate to sustain a viable community of aquatic invertebrates. The highest SASS score (144) was obtained at Site 1 during April 2002, and the lowest SASS scores (92) was also obtained at Site 1 during June and July 2002 (Table 3). There is, however, a clear indication of a reduction in water quality over the winter sampling period, with the SASS values for August on the edge of fair water quality. These reduction coincides with the low flow conditions that prevail during winter months. Palmer (1997), though, found that the highest average scores of SASS, NT and ASPT in the Middle Orange River were obtained during conditions of low flow. Chutter (1998) also indicated that the information obtained in the summer rainy season was often poor. A more plausible explanation then could be that these lower values could be an indication of a negative influence coming from a point upstream of Site 1.

The IHAS values (Figure 29) for the last three months stayed in the fair range, and did not show any significant decrease in the last three months. Since habitat availability influences the SASS scores (Dallas, 2000 b), and there were no significant changes in habitat scores, habitat was adequate and could not have an impact on the invertebrate communities. Thus the impact noticed over the last three months is either caused by some anthropogenic source or natural occurrence.

There is a decrease in the SASS values between Site 1 and Site 2 (Figure 15 A & B), which reflects a decrease in water quality. Parys is situated between these two sites, and this could be an indication of the effects that a town could have on the water quality of the River. During February and May sampling could not be conducted at both these two sites (due to inaccessibility of Site 2), and the effect could not be indicated. During March the SASS values did not show any change in water quality between the two sites. The reason for this is unclear, but it is possible that there was a reduction of effluents from the town, or that the effluents during that period was diluted by water from the previous 2 months of elevated flows. From June to August, there is a change in the pattern, in that the SASS values show a slight increase between these sites during those months. This could be linked to the influence that was described for these three months, and could be an indication that the water quality above Site 1 was already being reduced, to a point lower than that was caused by the town. Something that needs to be kept in mind is that the habitat conditions at Site 2 (Figure 29 B) differs somewhat from the rest of the sites in terms of the types and availability of biotopes (Figure 29), and this could also have an impact on the SASS score at this site.

Between Site 5 and Site 6 (Figure 15 E & F), a cattle feeding lot is situated that could give an indication of the effects of high intensity agricultural practices. It is apparent that there is an effect on the water quality during most of the months. During January, February, March and May there was an increase in the water quality between these two sites. During April and August there was a minimal impact. During June and July, there is a marked decrease in water quality between these two sites. Increases in water quality could be due to the fact that somewhat more phosphate and nitrogen nutrients may enter the water from the feeding lot, resulting in unnaturally good conditions, with a lot of available nutrients making the water mesotrophic, promoting the development of both living and decaying biological material (Walmsley, 2000). Decreases could be caused when too much nutrients enter the water, turning the water eutrophic, causing blooms of algae that can lead to further eutrophication and toxic levels of nutrients in the water (Walmsley, 2000). To find a more accurate cause for the patterns observed between these two sites, more detailed chemical analysis of the nutrients would have to be done. Observations made at the these sites indicated that there was much denser algal populations in the vicinity of the feeding lot that at any other site that was sampled, and this could be an indication that nutrient enrichment is taking place in the area.

A summary of the SASS data for the summer months (Oct - Feb) at the different sites is given in Figure 16 A. Site 2's scores are lower than the rest, and Site 2 differed from the other sites in terms of the habitat conditions, and it was expected that this site would have a lower average than the rest. The other sites do not differ a lot from each other for the summer months. Except for Site 2, the summer data for the sites shows that the average summer scores was in the good water quality class. Site 2 falls into the fair class for most of the summer months, most probably due to poorer habitat conditions at this site.

The SASS data for the autumn months (Mar - May) all fall within the good range of water quality (Figure 16 B). There is some variability in the data, but no significant differences were found. Site 3 differed somewhat from the rest of the sites for the autumn months, the reason for this is unclear, and it could be indicative of a minor disturbance of anthropogenic origin. The difference is not statistically significant, and the score is still in the good range, so this is not a threatening impact. If the autumn SASS data is compared to that of the summer, it is apparent that the average autumn scores are confined to a narrower range: between about 110 and 135 for the autumn vs. between about 90 and 140 for summer.

Figure 16 C indicates a large variation in the average winter (Jun - Aug) SASS data. The lowest scores were encountered at Site 1 followed by a systematic increase through Sites 2 to 5, and thereafter a slight decrease in scores at Site 6.

The average scores for the winter are somewhat lower compared to that of the summer and autumn, and the scores vary to a greater degree. A possible reason for this might be that the winter is known for low flow conditions, and that any impacts that occur during this season is concentrated, and has a more pronounced effect on the SASS scores. It should be taken into account that even though the scores were on average lower for the winter months, most of the sites still scored in the good range, with only Site 1 and 2 scoring in the fair range.

The categorised plot in Figure 17 indicates the distribution of the average seasonal SASS values. From this graph it is clearly evident that the highest average SASS values was obtained for the autumn months, followed by the summer months. The winter months clearly had the lowest scores, showing statistically significant decreases compared to the summer and autumn values ($p = 0.002608$ between summer and winter; $p = 0.000481$ between autumn and winter)

3.2. Number of taxa

Table 4: The Number of taxa collected from the study sites on Vaal River in the Vredefort Dome from October 2001 to August 2002 (N.S. = not sampled)

Number of taxa	Sept/Okt-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Site 1	23	21	23	19	28	25	21	19	21
Site 2	20	17	N.S	20	22	N.S.	20	20	20
Site 3	19	21	19	18	21	20	19	21	20
Site 4	23	N.S	23	19	24	23	22	23	20
Site 5	N.S.	19	18	18	24	23	22	25	22
Site 6	21	25	22	22	24	26	21	21	20

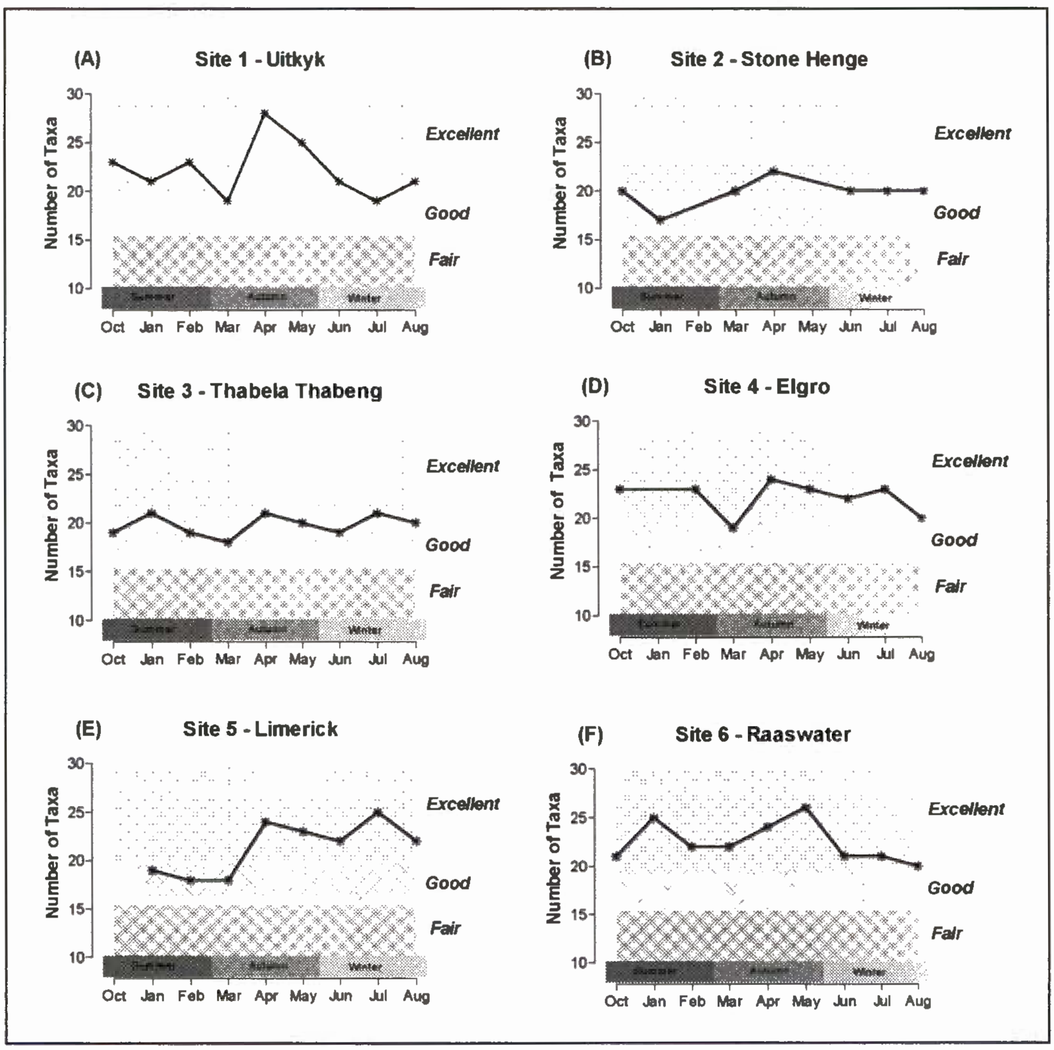

Figure 18: The spatial results for the Number of taxa that was recorded from the study sites on the Vaal River in the Vredefort Dome, each point indicating a single value.

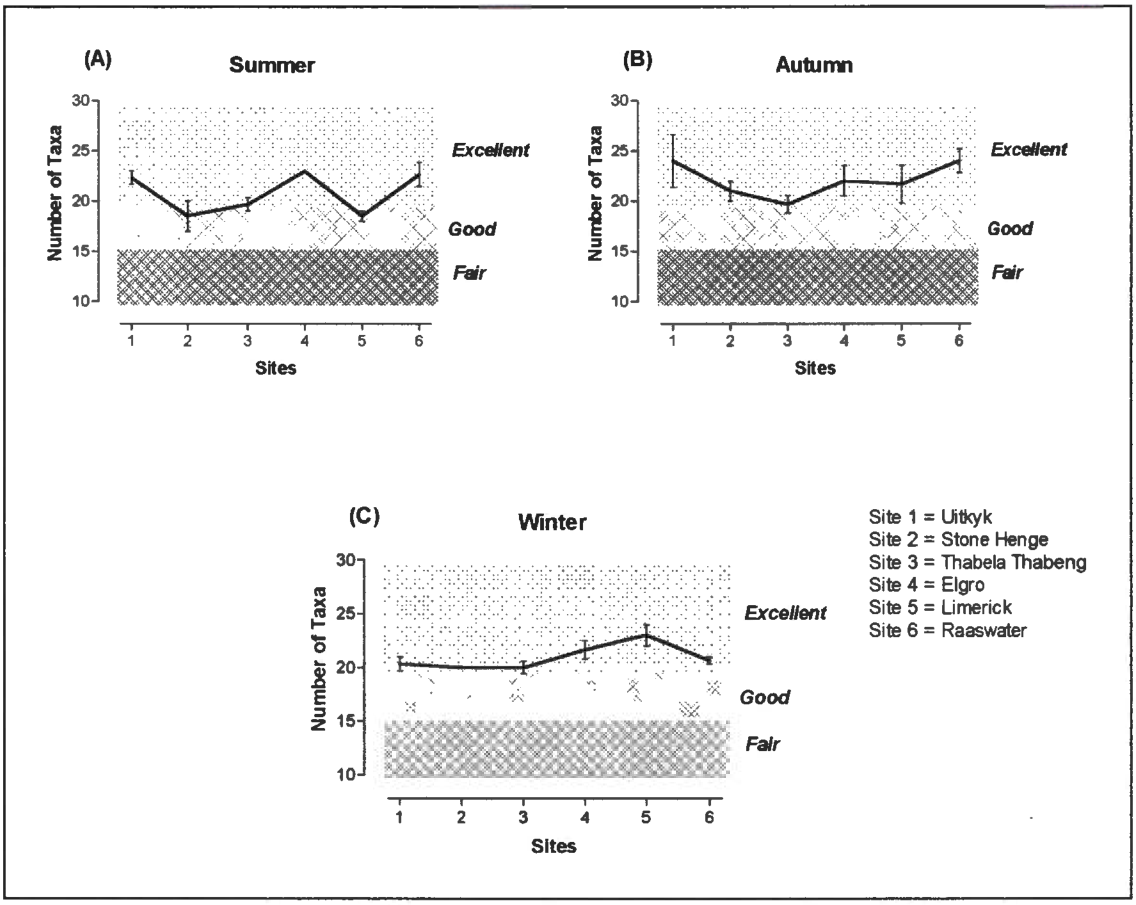

Figure 19: Seasonal Number of taxa values for the study sites on the Vaal River in the Vredefort Dome, each data point indicating the average Number of taxa for the three months of each season sampled.

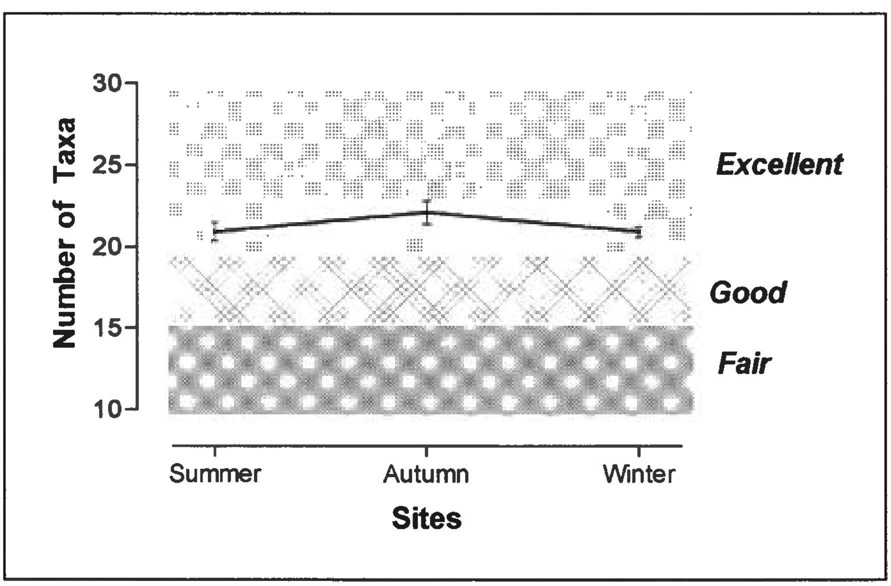

Figure 20: Seasonal Number of taxa values for the study sites on the Vaal River in the Vredefort Dome, each data point indicating the average values for the six sites for the three months of each season sampled

The NT is a measure of biodiversity at a site (Davies & Day, 1998). From Figure 18 it is clear that values for the NT that were collected all fall into the good to excellent range. This is an indication that there are a number of macroinvertebrate families occurring at the various sites and thus the water and habitat quality is adequate to support a diversity of organisms. The highest NT (28 taxa) was found at Site 1 during April 2002, and the lowest number (17 taxa) was found at Site 2 during January 2002 (Figure 18 A & B).

During the winter, NT was on average slightly lower than usual, and this follows the same general pattern that was observed for the SASS score over the winter months. Since one of the key objectives is to establish the degree to which a site has been impacted, it is important to reduce the potential influence of temporal or seasonal variability. The lowered SASS score could be due to a reduction in the diversity of families over that period, and the lower diversity of families may be linked to the effect of seasonal change in the structure and composition of the invertebrate communities. The effects of seasonal variability cannot be used in this discussion since the data generated here is baseline data, and there is no previous data for the study area to which the data can be compared. The lower NT during the winter could also be linked to some impact that was coming from upstream of Site 1, and that systematically spread through the rest of the Dome.

It is noticeable that Site 2 shows the lowest NT in general over all of the months. This could be caused by one of two factors. The first is that the habitat conditions at this site differs from the rest, in that some of the biotopes at this site is less abundant than at other sites. The absence of certain biotopes (habitat availability) could result in a lower NT and SASS scores (Dallas, 2000a). The reason for the decrease in habitat availability is that the Vaal River in this area runs through a granite outcrop, and the main substrate is bedrock, with limited amounts of movable stones and gravel, and aquatic vegetation is also less abundant. Thus there may be a lack of suitable habitats at this site as is evident from the IHAS values for this site (Figure 29 B). Another possibility for the lowered scores is that the town of Parys is situated just upstream of Site 2, and the effluent from this town might have negative effects on the water quality.

From Figure 19 A, it is clear that all of the NT values for the summer months (Oct - Feb) fall within the good class. The biggest difference was between Sites 2, 5 and 4. Sites 2, 3 and 5 fell in the good range whilst Sites 1, 4 and 6 fell within the excellent range.

From Figure 19 B it is evident that the autumn months (Mar - May) had the highest NT. With exception of Site 3, all of the sites fell within the excellent class. The data is also more closely grouped than for the summer months.

From the plot for the NT values for the winter months (Jun - Aug) in Figure 19 C it is apparent that all of the values falls within the excellent range of water quality. All the values are quite closely grouped, which differs from what was observed from the winter data for SASS and ASPT.

From Figure 20 it is again clear that the best average values of NT was recorded during the autumn months. In this case, however, the average values for the summer and winter months are about the same.

3.3. ASPT

Table 5: The ASPT values for the study sites on the Vaal River in the Vredefort Dome for October 2001 to August 2002 (N.S. = not sampled)

ASPT	Okt-2001	Jan-2002	Feb-2002	Mar-2002	Apr-2002	May-2002	Jun-2002	Jul-2002	Aug-2002
Site 1	5.73	5.63	5.57	6.31	5.10	5.20	4.67	4.84	4.38
Site 2	5.20	5.47	N.S	5.90	5.32	N.S.	5.40	5.00	4.85
Site 3	5.84	6.19	6.58	5.90	5.86	5.25	5.74	4.95	4.80
Site 4	5.45	N.S	6.57	6.05	5.46	5.91	5.68	5.59	5.15
Site 5	N.S.	6.15	6.10	6.33	5.58	5.04	5.68	5.08	4.68
Site 6	5.00	5.56	5.86	5.86	5.38	5.15	4.90	5.19	5.05
Average	5.44	5.80	6.14	6.06	5.45	5.31	5.35	5.11	4.82

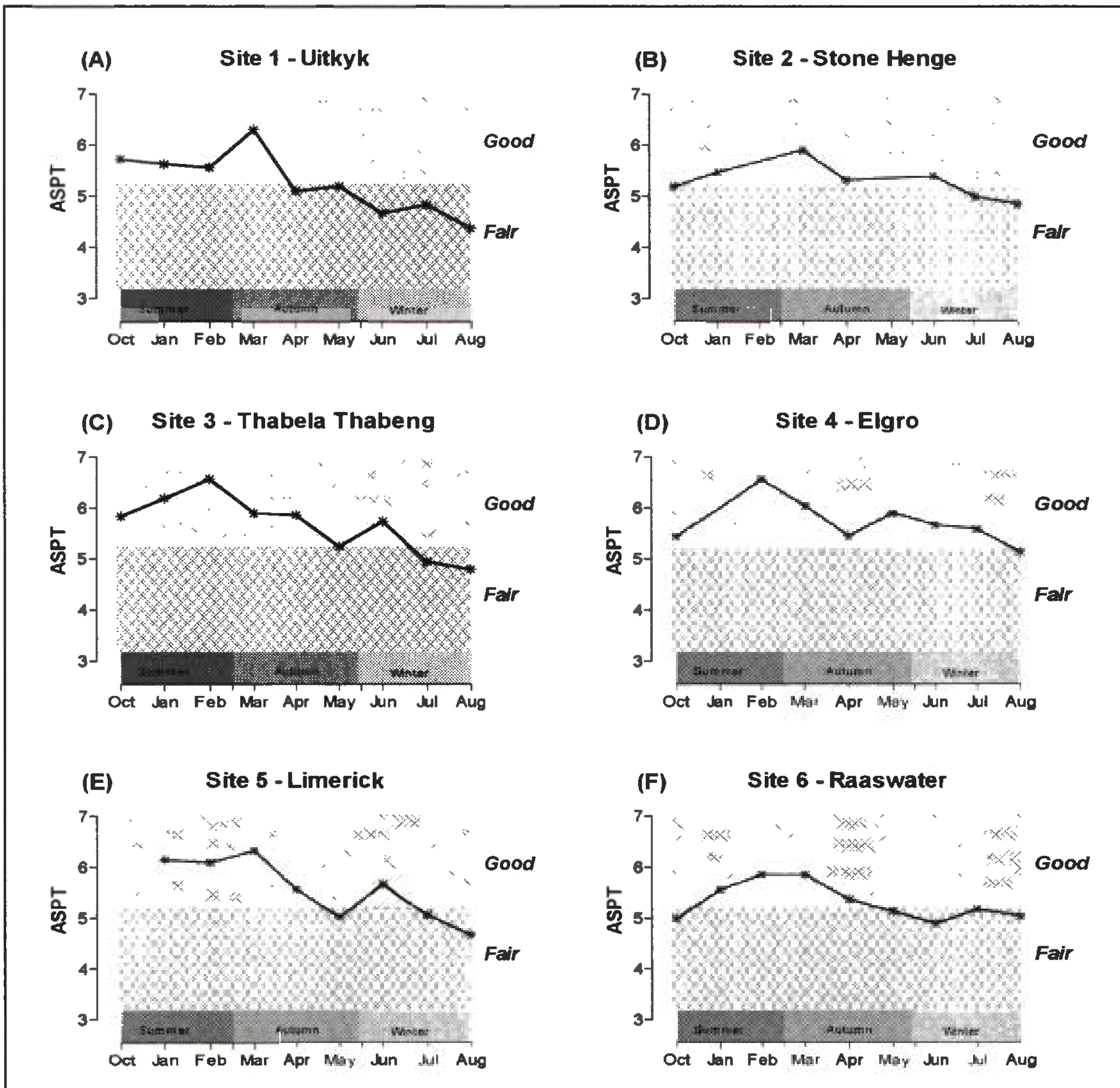

Figure 21: The ASPT values for the study sites on the Vaal River in the Vredefort Dome, each data point indicating a single value

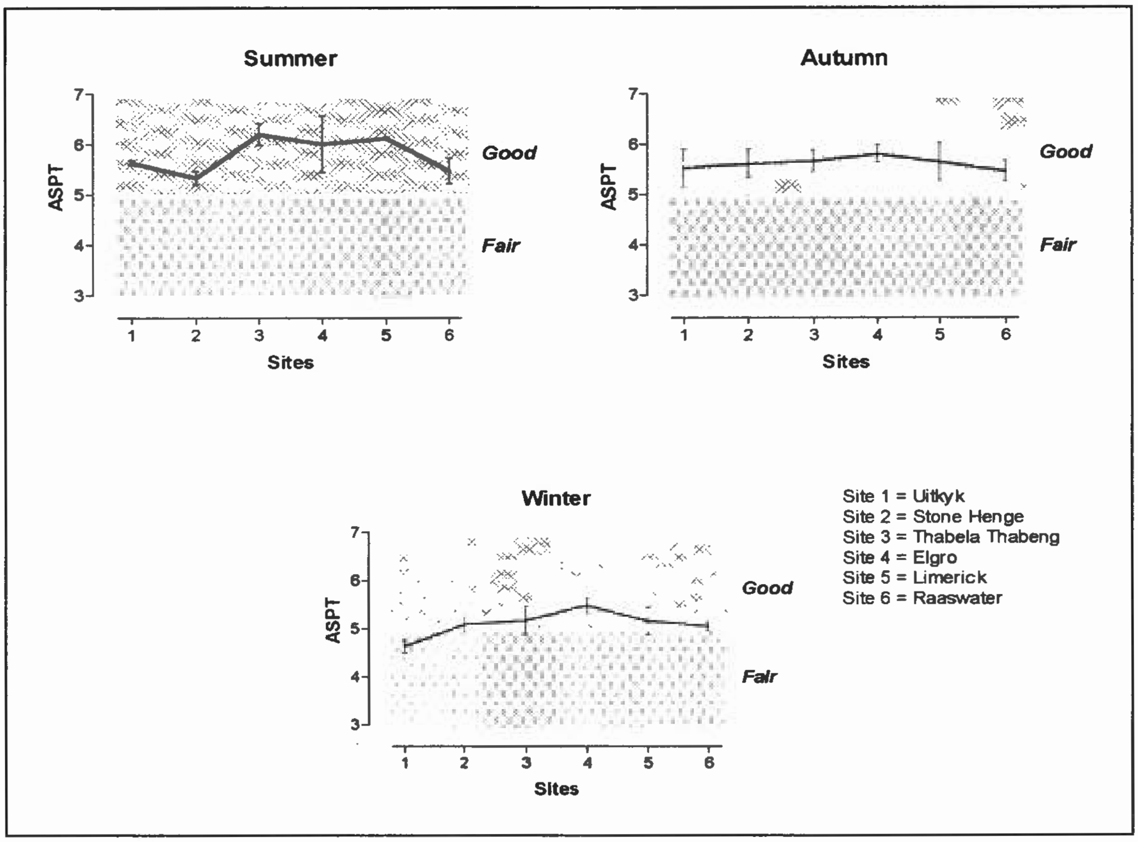

Figure 22: Seasonal ASPT values for the study sites on the Vaal River in the Vredefort Dome, each data point indicating the values for the three months of each season sampled.

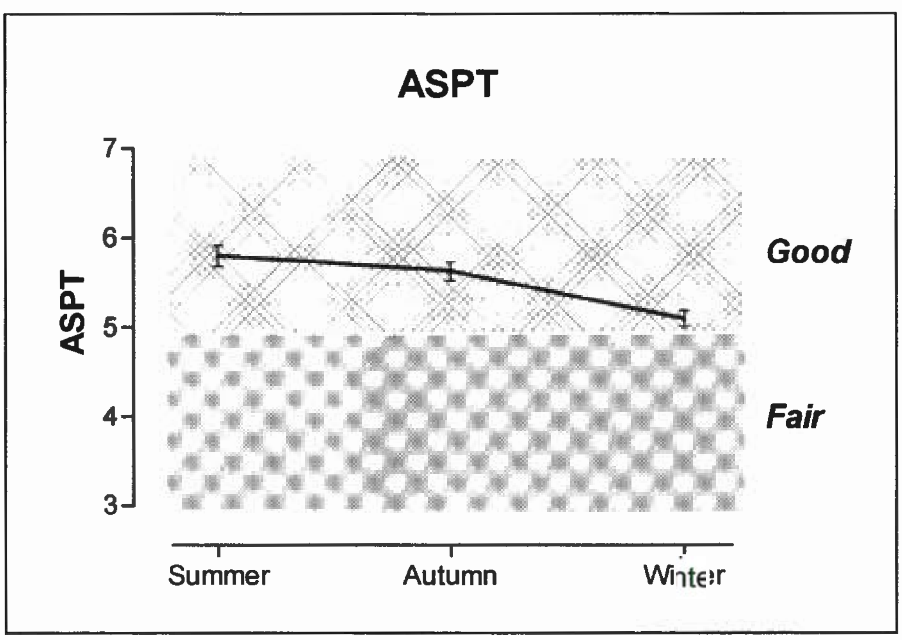

Figure 23: Seasonal ASPT values for the study sites on the Vaal River in the Vredefort Dome, each data point indicating the average values for the six sites for the three months of each season sampled

Significant variation in the ASPT both in space and time is indicative of changes in water quality, and or environmental conditions (Barber-James, 2001). Thus un-impacted sites would have a higher SASS and ASPT scores than would impact sites. There is a correlation between the SASS and ASPT scores (Chutter, 1998; Dallas, 2000a; Barber-James, 2001). The main difference between the SASS and ASPT scores is that SASS is a function only of the tolerance scores for the taxa found present (Murray, 1999), and gives more of an indication of the diversity of organisms at a site, while ASPT gives an indication of the sensitivity of the organisms at the sites. Thus the ASPT gives a better indication of the actual prevailing water quality (Davies & Day, 1998).

The highest ASPT value (6.58) was obtained at Site 3 during February 2002, and the lowest ASPT score (4.38) was obtained at Site 1 during August 2002 (Figure 21 C & A). The average ASPT shows an increase every month from October 2001 to March 2002, and from there a gradual decrease from April 2002 to August 2002, with the lowest average ASPT occurring during August.

All of the ASPT scores (Figure 21) are in the fair to good range for water quality, which again gives an indication that the water quality in the Dome area is quite adequate. The same pattern that was observed in the SASS data can be seen in Figure 15 in that there is a gradual decrease in water quality over the winter months. The gradual decrease has started in April 2002 and has shown some degree of recovery during June 2002, but during July and August 2002, the decrease reaches its lowest values. The decrease in ASPT could be linked to seasonal changes in the invertebrate communities, or it could indicate that some of the less pollution tolerant species have been removed from the system, and this should act as an early warning sign that there is a possible problem arising somewhere higher up in the river.

Figure 22 A shows that the ASPT for the summer months (Oct - Feb) falls within the fair to good range with Sites 1, 2 and 6 in the fair range, and sites 3, 4 and 5 in the good range. The ASPT values do not differ significantly form each other, and all fall within a very narrow range. Site 2 again proves to have a lower average value compared to the rest of the sites.

Figure 22 B shows that the average ASPT values for the autumn (Mar - May) months are all in the good range, and that they are very little differences in the data for the different months. The average ASPT values are somewhat higher than was the case for the summer months. This shows that there is a degree of correlation between the ASPT and SASS scores. The ASPT smoothes out the SASS score to some extent, which is clearly evident if Figure 15 and 21 are compared. In general, ASPT gives a better indication of water quality than the SASS score, whilst the SASS score gives a better idea of the diversity of macroinvertebrates at the sites.

From Figure 22 C it is clear that there are some variation in the data for the winter months (Jun - Aug) compared to that for the summer and autumn months. The biggest variation is between Sites 1 and 4, which was also evident from the ANOVA Tukey HSD test ($p = 0.04$). Even though there is more variability, only Sites 1 and 5 scored in the fair category, the rest of the sites still scoring in the good range. The average winter scores were generally somewhat lower than for the other seasons, as was the case with the SASS scores.

From Figure 23 it is clear that the best average values were recorded in the summer and autumn months, and the lowest values was recorded for the winter months. This indicates that even though the best diversity was found during the autumn months, the best overall water quality was recorded during the summer months. It was interesting to note that the lowest average values for diversity and water quality were recorded for the winter months.

Table 6: Summary of the overall results form the biomonitoring of the Vaal River in the Vredefort Dome (N.S. = not sampled).

	Oct - 2001		Jan - 2002		Feb - 2002	
	SASS	ASPT	SASS	ASPT	SASS	ASPT
Site 1	132	5.73	124	5.63	128	5.57
Site 2	104	5.20	93	5.47	N.S	N.S
Site 3	111	5.84	130	6.19	125	6.58
Site 4	126	5.45	N.S	N.S	151	6.57
Site 5	N.S.	N.S.	117	6.15	109	6.10
Site 6	105	5.00	139	5.56	129	5.86
	Mar - 2002		Apr - 2002		May - 2002	
	SASS	ASPT	SASS	ASPT	SASS	ASPT
Site 1	120	6.31	144	5.10	130	5.20
Site 2	118	5.90	117	5.32	N.S.	N.S.
Site 3	107	5.90	123	5.86	105	5.25
Site 4	115	6.05	131	5.46	136	5.91
Site 5	114	6.33	134	5.58	116	5.04
Site 6	129	5.86	129	5.38	134	5.15
	Jun - 2002		Jul - 2002		Aug - 2002	
	SASS	ASPT	SASS	ASPT	SASS	ASPT
Site 1	98	4.67	92	4.84	92	4.38
Site 2	103	5.40	100	5.00	97	4.85
Site 3	109	5.74	104	4.95	96	4.80
Site 4	125	5.68	123	5.59	103	5.15
Site 5	125	5.68	127	5.08	103	4.68
Site 6	103	4.90	109	5.19	101	5.05

Key:	
(dark)	Some deterioration in water quality
(grey)	Borderline case between water quality natural and some deterioration in water quality.
(white)	Water quality natural, Habitat diversity high.

The data as presented in Table 12 gives a good indication of the water quality classes as set out by Chutter's guidelines (1998). From this data, it is clear that the water quality was for most of the sites and months in the class of borderline case between natural water quality and some deterioration in water quality. The extent by which SASS exceeds 100 and ASPT is < 6 is for most of sites is marginal, indicating a lesser degree in deterioration in water quality.

For January to March 2002, it is clear that good water quality circumstances prevailed, and according to Chutter's guidelines (1998) fell into the class water quality natural and high habitat diversity.

For the months from June to August 2002, there was a definite reduction in the water quality. These are the winter months of reduced flow, and one of the reasons for the decline might be ascribed to the seasonal shift in the invertebrate communities. It is also possible that any toxic substances in the water are concentrated during this period of time since no rainwater enters the system, and water levels are at their lowest.

Water quality data was limited and thus the SASS data was not related mathematically or statistically to water quality variables.

An invertebrate community is more likely to respond to maximum concentrations than to mean concentrations and the duration of exposure to high concentration will be likely to be as important as the actual concentration. In attempting to relate a surrogate measure (biological property) of water quality with actual water quality, there are two facts that prevent the use of mathematical analysis such as correlation and regression. The first is the period represented by biological (weeks, possibly months) and chemical (possibly hours) samples. Theoretically, this should be overcome by the very frequent measurement of chemical variables over long periods, but this is impractical. The second fact is that there are many chemical variables that have deleterious effects on river biology. No one has yet been able to derive a scale of water quality embracing all the chemical variables so that comparisons between water and biological quality have been based on picking out single or very few variables at a time (Chutter, 1994).

3.4. Seasonal Macroinvertebrate occurrences

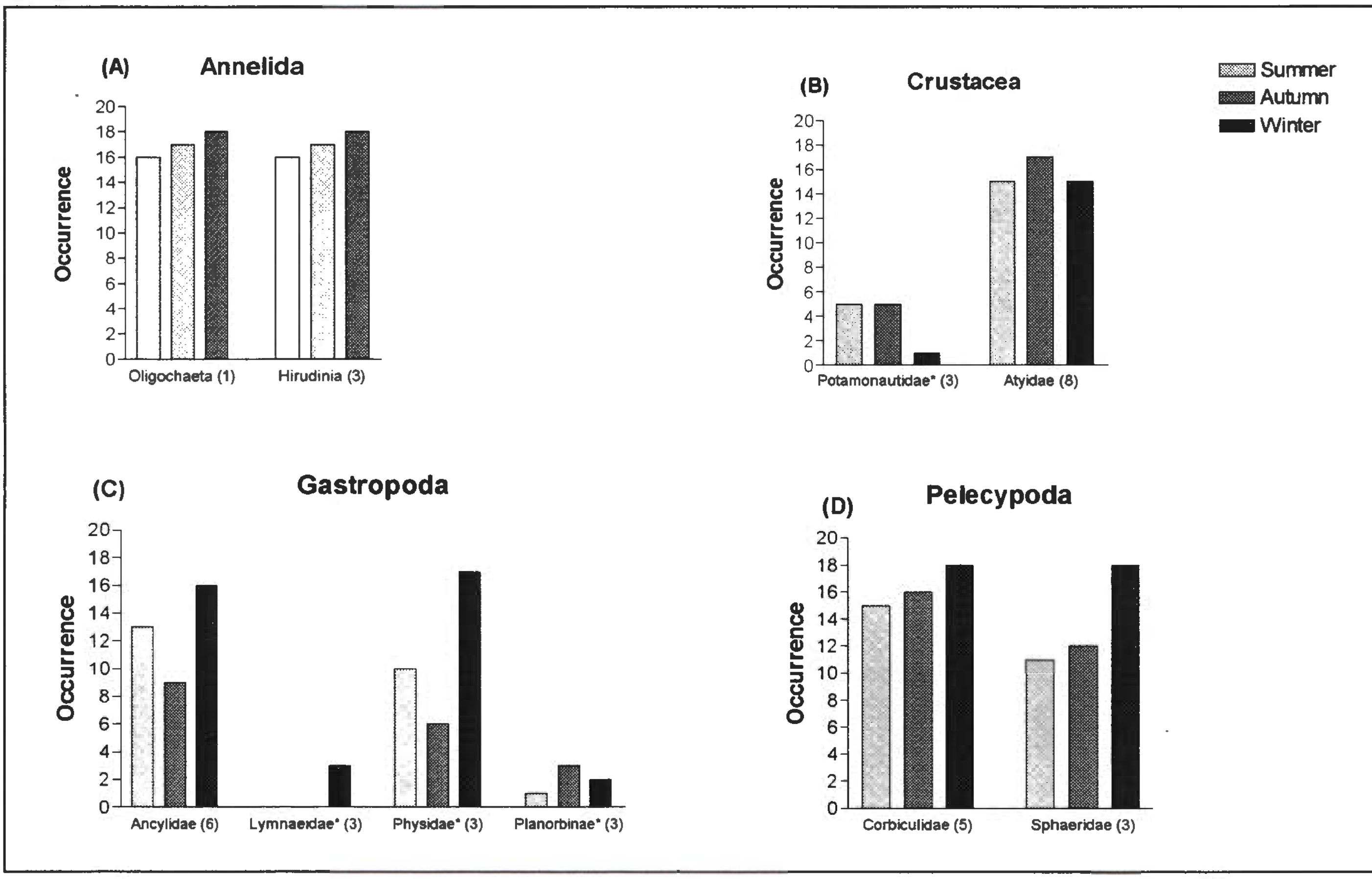

Figure 24: Seasonal occurrences of Annelida, Crustacea, Gastropoda and Pelecypoda at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxons SASS weight. (Occurance was measured by the number of animals present)

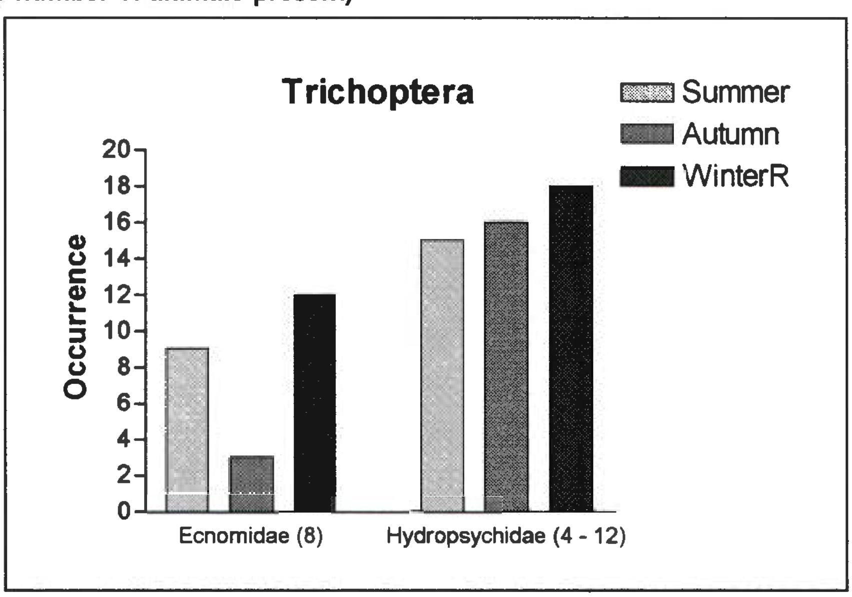

Figure 25: Seasonal occurrences of Trichoptera at the sampling sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxons SASS weight. (Occurance was measured by the number of animals present)

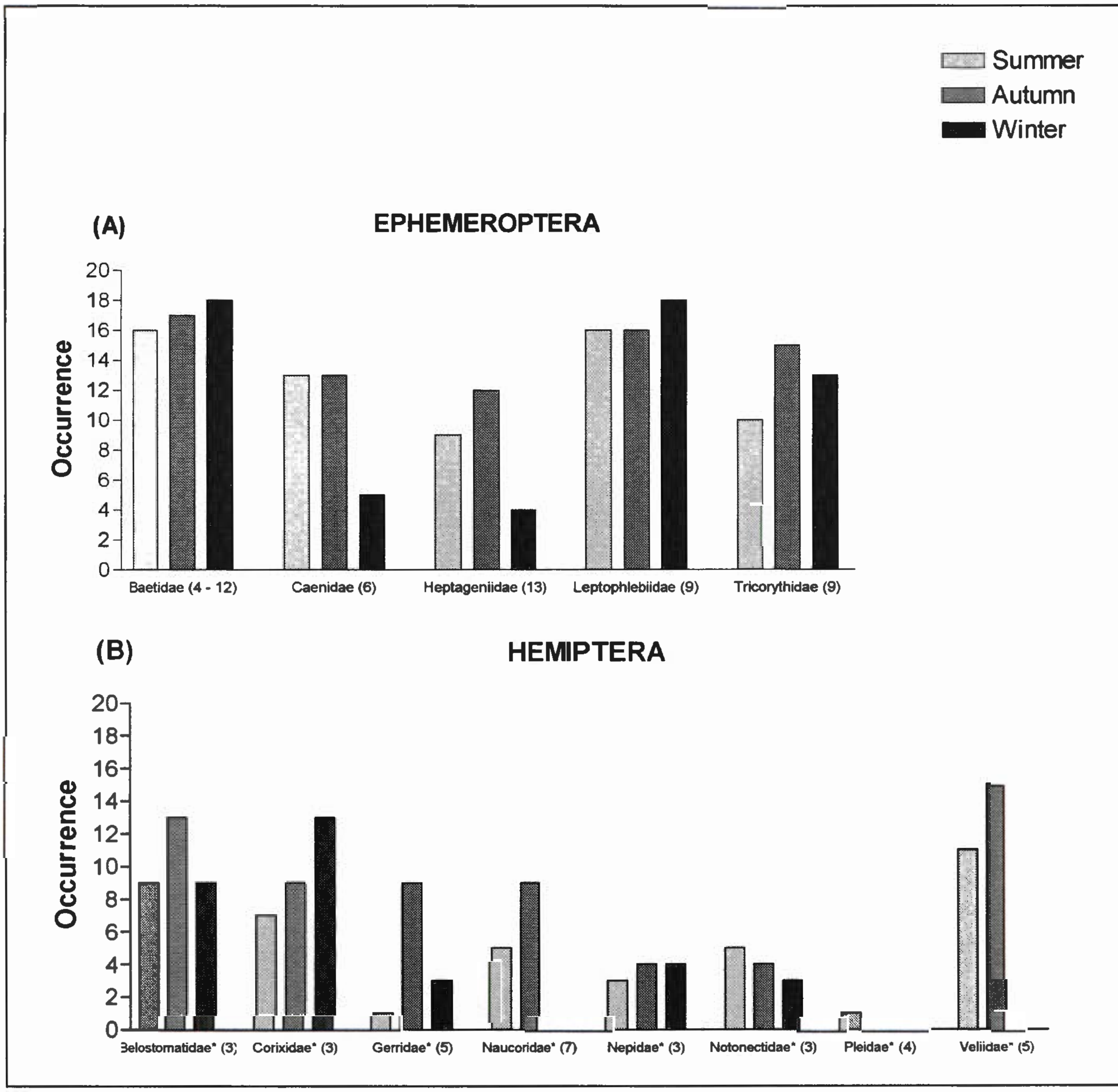

Figure 26: Seasonal occurrences of Ephemeroptera and Hemiptera at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxons SASS weight. (Occurance was measured by the number of animals present)

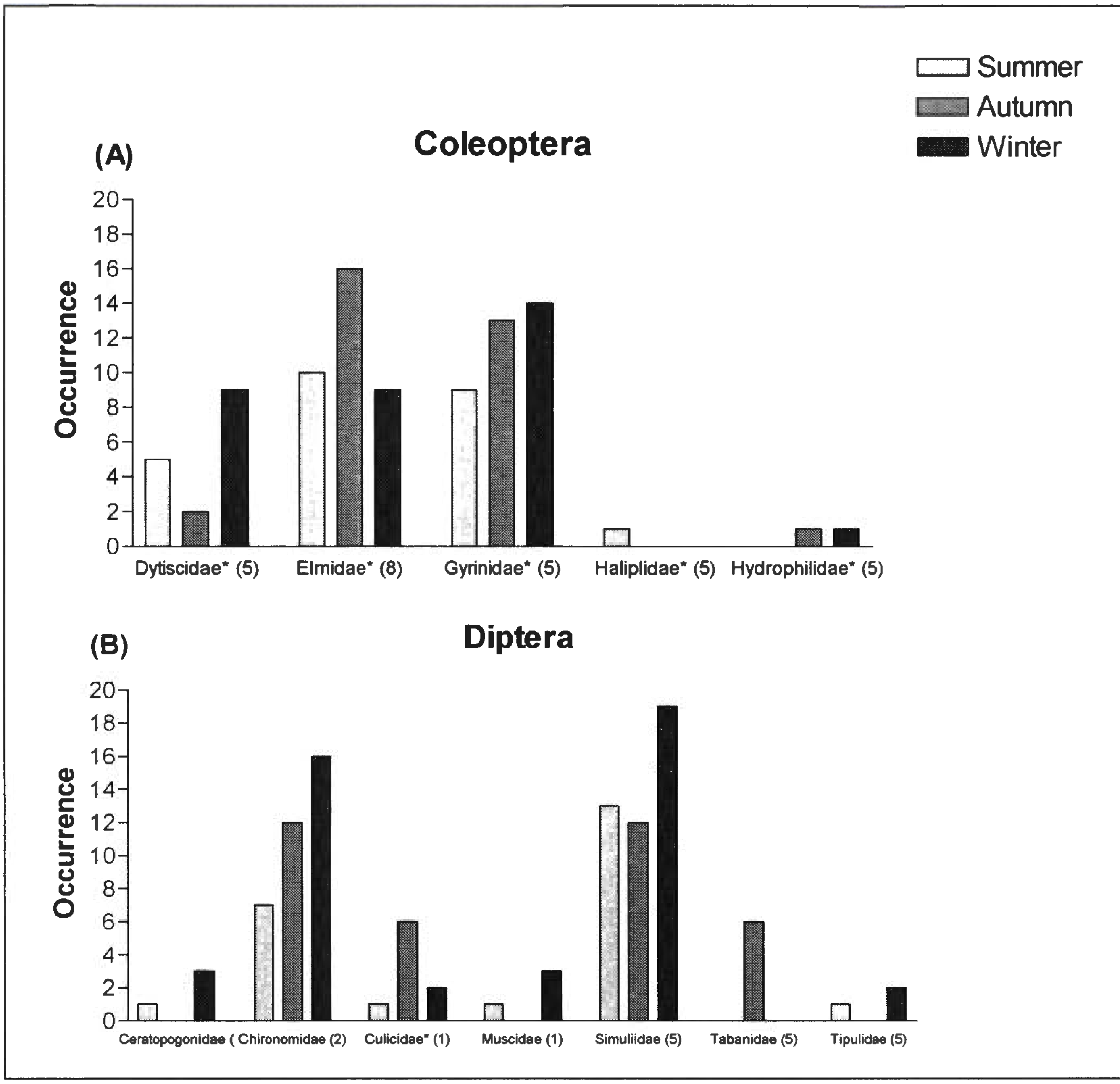

Figure 27: Seasonal occurrences of Coleoptera and Diptera at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxons SASS weight. (Occurance was measured by the number of animals present)

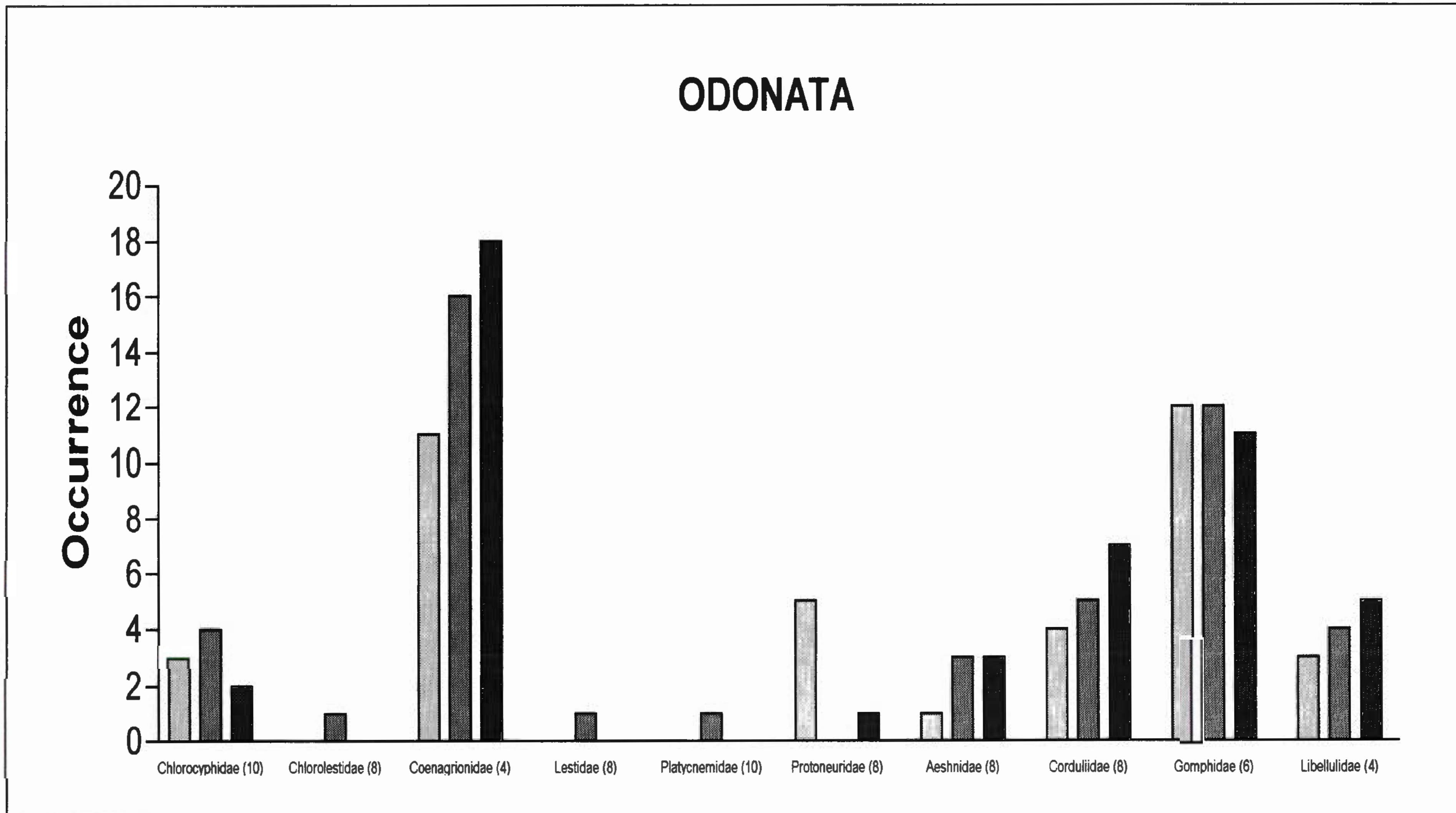

Figure 28: Seasonal occurrences of Odonata at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxons SASS weight. (Occurance was measured by the number of animals present).

Figures 24 to 28 gives a summary of the seasonal occurrences of macroinvertebrates at the study sites along the Vaal River in the Vredefort Dome.

For the Annelida (Figure 24 A) it is clear that both the Oligochaeta and Hirudinea showed the same seasonal pattern, where it were most abundant during the winter months, less abundant for the autumn months and least abundant during the summer months.

For the Crustacea (Figure 24 B), the Atyidae were most abundant during the autumn months, and about equally abundant during the summer and winter months. The Potamonautidae were clearly less abundant than the Atyidae. The summer and autumn abundance of the Potamonautidae were the highest, with a very low occurrence during winter.

For the Gastropoda (Figure 24 C), it is clear that the greatest occurrences occurred during the winter months, followed by the summer months, and the autumn months indicated the lowest occurrences. This was the case with exception of the Planorbinae, where the greatest abundance occurred during the autumn, followed by the winter and the summer months indicated the lowest abundance. The Lymnaeidae were only found in the winter months.

The Pelecypoda (Figure 24 D) shows a similar seasonal occurrence as the Annelida, with the greatest occurrences during the winter followed by the autumn, and finally the summer months. A full description of the occurrence of the different molluscs is given in section 3.10.

For the Trichoptera, Figure 25 indicates that the Hydropsychidae had the same seasonal occurrence pattern as the Annelida and Pelecypoda (Figure 24). The Echnomidae were most abundant during the winter months, followed by the summer months, and were least abundant during the autumn months.

The seasonal occurrence of Ephemeroptera (Figure 26 A) showed great variation among the different taxa. The Beatidae were comparable to the Annelida, Pelecypoda and Hydropsychidae. The Leptophlebiidae were most abundant during the winter months followed by equal occurrences during the autumn and summer. The Caenidae were most abundant during the summer and autumn months, with a very low winter occurrence. The Heptageniidae were most abundant during the autumn months, followed by summer, and with a low winter occurrence. The Trichorythidae were most abundant during autumn, followed by winter and finally summer.

Figure 26 B indicates that there were again great variations in the occurrence of Hemipteran taxa. The Belostomatidae occurred more frequently during the autumn, and had equal occurrences during summer and winter. The Corixidae were most abundant during winter, followed by the autumn and summer months when it were less abundant. The Gerridae were clearly most abundant during autumn, followed by low occurrences during summer and winter. The Naucoridae were most abundant during autumn, followed by summer, being absent during the winter. The Nepidae were most abundant during autumn and winter, and only marginally less abundant during summer. The Notonectidae were most abundant during the summer, with lower occurrences during the autumn and winter months. The Pleidae occurred only once during the summer. The Veliidae were the most abundant Hemipteran taxon, and were most abundant during autumn, followed by summer and being absent during the winter.
Figure 27 A indicates the occurrences of the Coleopteran taxa. The Dytiscidae occurred most frequently during winter, followed by summer and then autumn. The Elmidae were the most abundant Coleopteran during the autumn, followed by summer and then winter. The Gyrinidae were most abundant during winter, followed by autumn and then summer. The Halipidae occurred only once during the summer, and the Hydrophilihae occurred once in each of autumn and winter.

The occurrences of Dipteran taxa are depicted in Figure 27 B. The Ceratopogonidae 3 times in winter, once in summer and were absent during the autumn. The Chironomidae were most abundant during the winter, followed by autumn and then summer. The Culicidae were most abundant during autumn followed by winter and finally summer. The Muscidae occurred 3 times in winter, once in summer and were absent during the autumn. The Simuliidae were the most abundant Dipteran taxa during the winter, followed by summer and then autumn. The Tabanidae occurred only in autumn. The Tipulidae occurred twice during winter, once during summer and were absent during autumn.

Figure 28 shows the occurrences of the Odonata taxa. The Chlorocyphidae were most abundant during autumn, followed by summer and then winter. The Chlorolestidae, Lestidae and Platycnemidae all occurred only once during autumn. The Coenagrionidae were the most abundant Odonate taxon, with highest occurrences during winter, followed by autumn and then summer. The Protoneuridae were most abundant during summer, occurred once during winter and were absent during autumn. The Aeshnidae were equally abundant during autumn and winter, followed by summer. The Corduliidae and Libellulidae had the same occurrence pattern, being most abundant during winter followed by autumn and then summer. The Corduliidae were overall more abundant than the Libellulidae. The Gomphidae were most abundant during summer and autumn, followed by winter.

It is clear that there appears to be patterns in the occurrence of invertebrates during the different seasons. To explain these seasonal occurrences of invertebrates is impossible without a good knowledge and understanding of the biology and ecology of aquatic invertebrates, as well as knowledge of seasonal processes and changes in the riverine ecosystem.

Several factors influence the presence and absence of macroinvertebrate families at a specific place and time. The structure of the benthic invertebrate community changes in response to changing water conditions (Chutter, 1998; Dickens & Graham, 2002). When invertebrates are used for biomonitoring, temporal variation may influence judgment as to whether or not a site is disturbed. Consistent differences can occur in the NT and biotic indexes between winter and summer samples (Dallas, 2000a). Dallas (2000a) recommended that at least two, and preferably three seasons be sampled, excluding the high rainfall period. Sampling of reference sites should continue until an understanding is gained on the influence of season on the interpretation of biomonitoring data (Dallas, 2000b).

In South Africa, summer is the high rainfall period, and sampling should thus be avoided during this period. Due to time constraints, sampling for this project had to be initiated in summer in order to sample three seasons within the available time. Since sampling was only conducted for a one-year period, care should be taken when interpreting any seasonal changes in the invertebrate community structure. It is possible that some taxa were missed during one or more of the seasons, and conditions that prevail during a particular season may vary annually to some degree. Although long-term cycles may be relatively predictive, short term and annual cycles are far from being so (Davies *et al.*, 1993).

Temperature is an important factor that can govern the occurrence of animals (Schmidt-Nielsen, 1998). The water temperature of the Vaal River changed to some extent with the seasons. It is thus possible that some of the invertebrates were less active in the colder winter months, and that they could have been missed during winter sampling. It is also possible that some of the larval stages were absent during some of the seasons.

Most species of invertebrates cannot survive year round but tend to occur either in summer and autumn, or in winter and spring. Thus seasonal communities replace each other in an endless cycle, with the missing set of animals 'waiting in the wings', as eggs, larva or nymphs, for the change in season that will trigger their next appearance (Davies & Day, 1998).

3.5. IHAS

Table 7: The IHAS values for the study sites on the Vaal River in the Vredefort Dome for October 2001 to August 2002 (N.S. = not sampled)

IHAS	Sept/Okt-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Site 1	77%	67%	71%	70%	64%	72%	64%	70%	73%
Site 2	64%	59%	N.S	61%	61%	N.S.	65%	62%	67%
Site 3	75%	67%	70%	69%	65%	72%	68%	72%	68%
Site 4	69%	N.S	69%	69%	65%	64%	71%	63%	68%
Site 5	N.S.	80%	66%	74%	58%	65%	69%	67%	64%
Site 6	85%	83%	74%	74%	73%	61%	68%	65%	67%

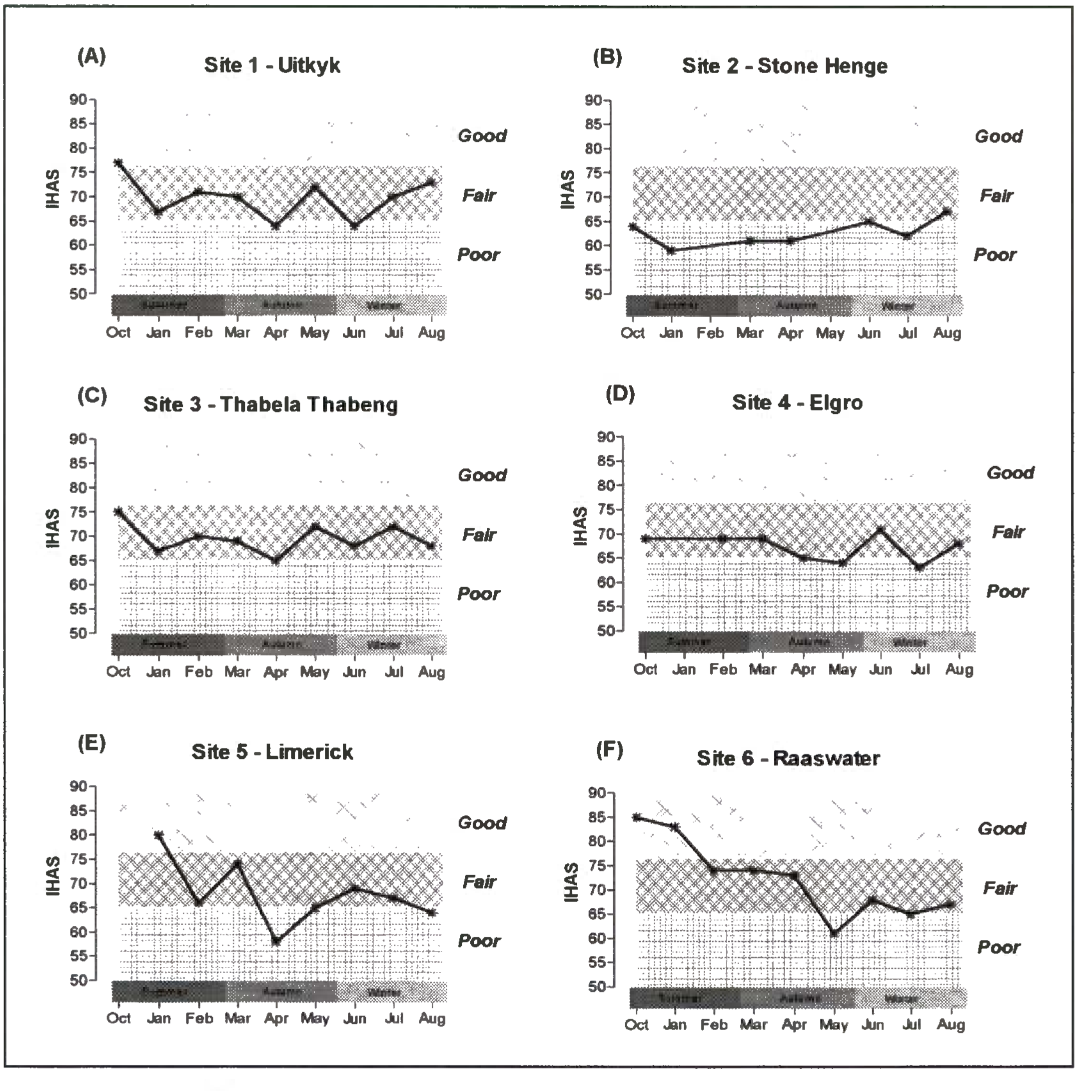

Figure 29: The IHAS values for the study sites on the Vaal River in the Vredefort dome, each data point indicating a single value

IHAS was designed for use with SASS 4 and gives an indication of the quality and availability of habitats for the aquatic macroinvertebrates (McMillan, 1998). Although IHAS was developed for SASS 4, it can still provide valuable, and relevant, habitat information.

Figure 29 shows that the instream riverine habitat is constantly changing over time and space, and this could have an influence on the SASS score. For the Vaal river In the Vredefort Dome, the habitat scores varies from poor to good, with the bigger part of the scores being in the fair habitat quality spectrum. This shows that in general, there are adequate habitat quality and quantity to sustain a viable invertebrate diversity, but that habitat could possibly have some effects on the SASS scores for some of the sites, and for some of the months.

The main cause for the varying habitat conditions may be the fact that the water and flow levels of the Vaal River is quite variable over time. This is especially true for the rainy season, where inflow from the catchments various streams and vlei's can cause great fluctuation in the water level. One of the effects of variable flow levels is that many of the biotopes are constantly changing, and could become unavailable at times. This was the case for November and December when no sampling could be conducted due to flood conditions in the river. It is noticeable, though, that the invertebrate communities show a fast recovery time when suitable habitat conditions return. After the November/December 2001 floods, the IHAS scores for January 2002 were all in the Fair region, and the SASS, NT and ASPT scores showed that the water quality was fair to good for January 2002 (see Figures 29, 15, 18 and 21).

Although conditions of high flow have a marked effect on the IHAS and invertebrate scores, the negative effect seems to be only temporal, and could not cause long-term effects on the invertebrate water quality.

The invertebrates occurring in the river have many adaptations for life in different parts of the riverine habitat (Davies & Day, 1998). Invertebrates that live on and around the rocks of the rapids and riffles have been well adapted to cope with the conditions of high flows. Some have bodies that are shaped to give the least resistance to water drag (typical of the Ephemeroptera, with bodies that are rounded at the top and flat at the bottom). Some of the other families in the fast flowing parts of the river build resistant cases in which they can hide during unfavourable flow conditions. The organisms that live in association with the aquatic vegetation have legs that are adapted to hold on to vegetation, and these organisms can move up along the banks as the water level rises, utilizing riparian vegetation to anchor themselves during periods of high flow. Most of the open water invertebrates are strong swimmers that possess strong legs and streamlined bodies to aid them with swimming.

Thus, the invertebrates have several adaptations that could help them to withstand unfavourable flow conditions.

For most of the months that sampling was done at both Sites 1 and 2, it is clear that there is a marked spatial decrease in the habitat quality between the two sites, followed by an increase in habitat quality. The reason for the poor habitat conditions at Site 2 is that the Vaal River in this part flows through a granite rich substrate consisting mainly of bedrock, and that some of the biotopes available at the other sites are less plentiful at this site. Thus, the quantity of suitable biotopes in this area could have an impact on the diversity of macroinvertebrates at this site, and could be a reason for the lower SASS, NT and ASPT scores at this site.

During April 2002 the lowest average IHAS scores was recorded over all of the sites. It was noted that during April very low flow conditions prevailed, and it is possible that some of the biotopes were exposed during that month, and was thus unavailable for the invertebrate communities. The SASS, NT and ASPT values for April is quite good which indicates that the invertebrates were still present even though some of the biotopes were unavailable.

3.6. Dissolved oxygen

Table 8: The values of dissolved oxygen (mg.l^{-1}) for the study sites on the Vaal River in the Vredefort Dome for February to August 2002 (N.S. = not sampled)

DO_2 (mg.l^{-1})	Feb-02	Mar-02	Apr-02	Jun-02	Jul-02	Aug-02
Site 1	7.4	7.79	11.62	14.1	11.24	10.95
Site 2	N.S	7.65	10.87	11.5	9.61	10.01
Site 3	8.49	7.13	9.78	11.99	11.3	10.57
Site 4	10.01	7.25	10.94	11.88	10.25	10.35
Site 5	6.54	10.14	11.33	11.4	10.3	9.46
Site 6	7.92	7.92	8.31	8.3	9.14	8.6

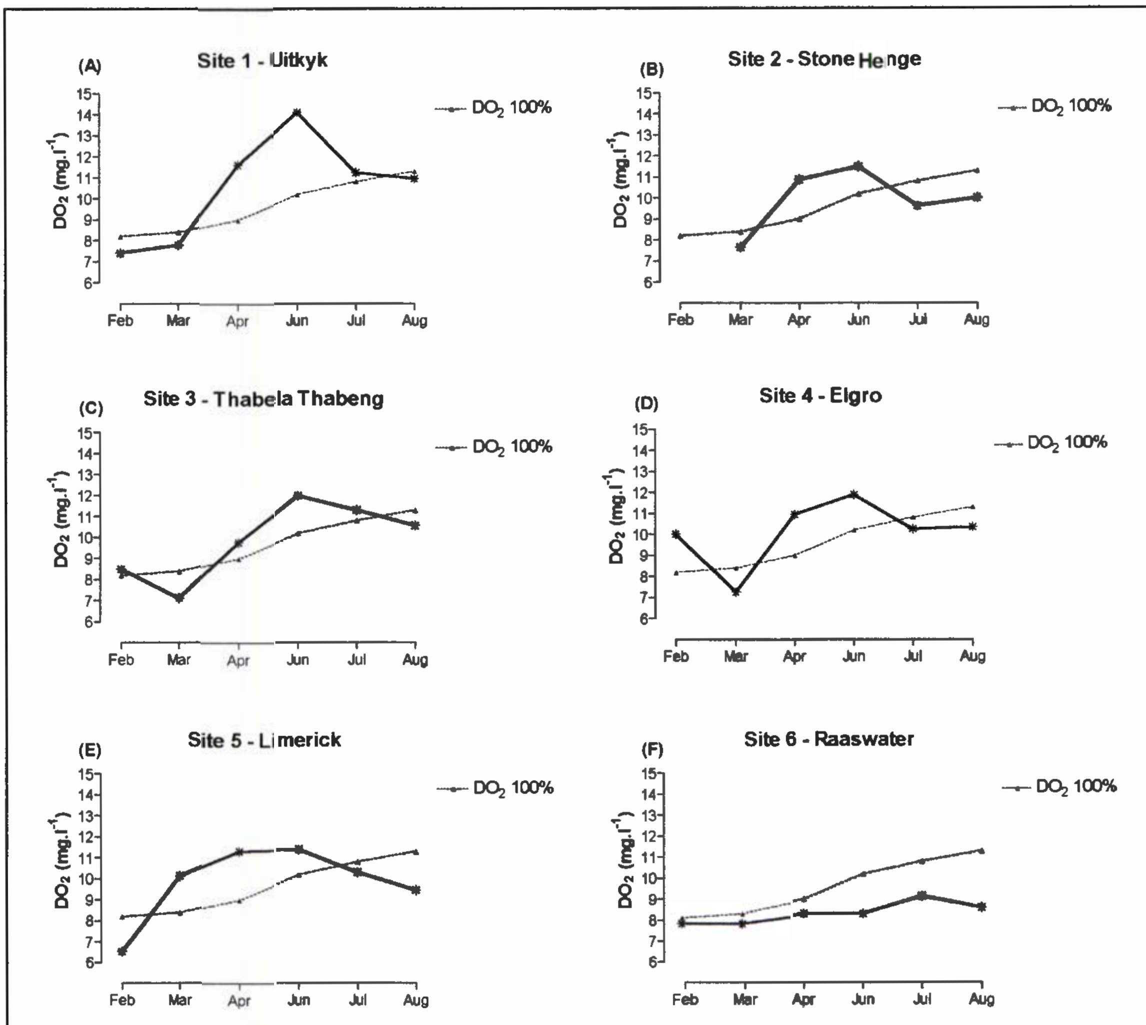

Figure 30: The values of dissolved oxygen (DO_2) for the study sites on the Vaal River in the Vredefort Dome, each data point indicating a single value. (Dotted line indicates values for DO2 at 100% saturation)

When discussing the DO_2 data, it should be taken into account that the sites were sampled during different times of the day. The DO_2 levels in rivers vary both in time and space (Dallas *et al.*, 1994; Davies & Day, 1998). Sampling for a particular site was conducted at the same time of day each month, and care was taken to sample it in the same kind of flow conditions at each of the sites, and for each month. Thus DO_2 levels for each site is comparable, even though it may not be comparable between sites.

The plots in Figure 30 shows that there was a great variation in the levels of dissolved oxygen both over time and space. The lowest DO_2 level (6.54 $mg.l^{-1}$) was recorded at Site 5 during February 2002, and the highest level (11.99 $mg.l^{-1}$) at Site 3 during June 2002.

DO_2 levels also change spatially in that not all parts of the river get evenly aerated. Thus there would be more available DO_2 in the white water rapids and riffles, than would be in the slower parts of the river. Thus both the time of day and the part of the river where DO_2 was sampled plays a role in the levels that will be detected (Dallas *et al.*, 1994).

In Figure 30 the average temperature for the sites was calculated, and the approximate amount of DO_2 at 100% saturation was calculated for each month at each site. This data was used to indicate whether the water was under or over saturated with O_2.
For most of the sites, the Do_2 levels are higher during the cooler months, correlating well with the fact that more oxygen can dissolve in colder water (Schmidt-Nielsen, 1998).

Site 6 is the only site that differs substantially from the other sites. The DO_2 levels for this site are much lower than for the rest, and the water at this site was always under-saturated with oxygen. Site 6 was always sampled early in the morning and it could be possible that the oxygen levels could be reduced by respiration during the night, but Site 1 has also been sampled early mornings, and shows a different picture than Site 6. A more plausible explanation could be the effects of the cattle feeding-lot upstream of Site 6. Eutrophication as a result of increased nutrient inputs from the feeding lot could cause a remarkable increase in the amount of respiration that takes place, and could also be responsible for the low DO_2 levels (Dallas *et al.*, 1994; Walmsley, 2000).

3.7. pH

Table 9: The pH values for the study sites on the Vaal River in the Vredefort Dome for February to August 2002 (N.S. = not sampled)

pH	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Site 1	7.8	8.38	8.58	8.38	9.09	9.4	9.22
Site 2	N.S	8.41	8.66	N.S.	9.36	9.38	8.96
Site 3	8.41	8.17	8.21	8.9	9.12	9.59	8.82
Site 4	8.44	8.09	9.2	8.88	9.27	9.52	8.91
Site 5	7.83	8.25	8.64	8.6	9.2	9.51	8.82
Site 6	8.1	8.1	8.44	8.54	9.33	9.35	8.76

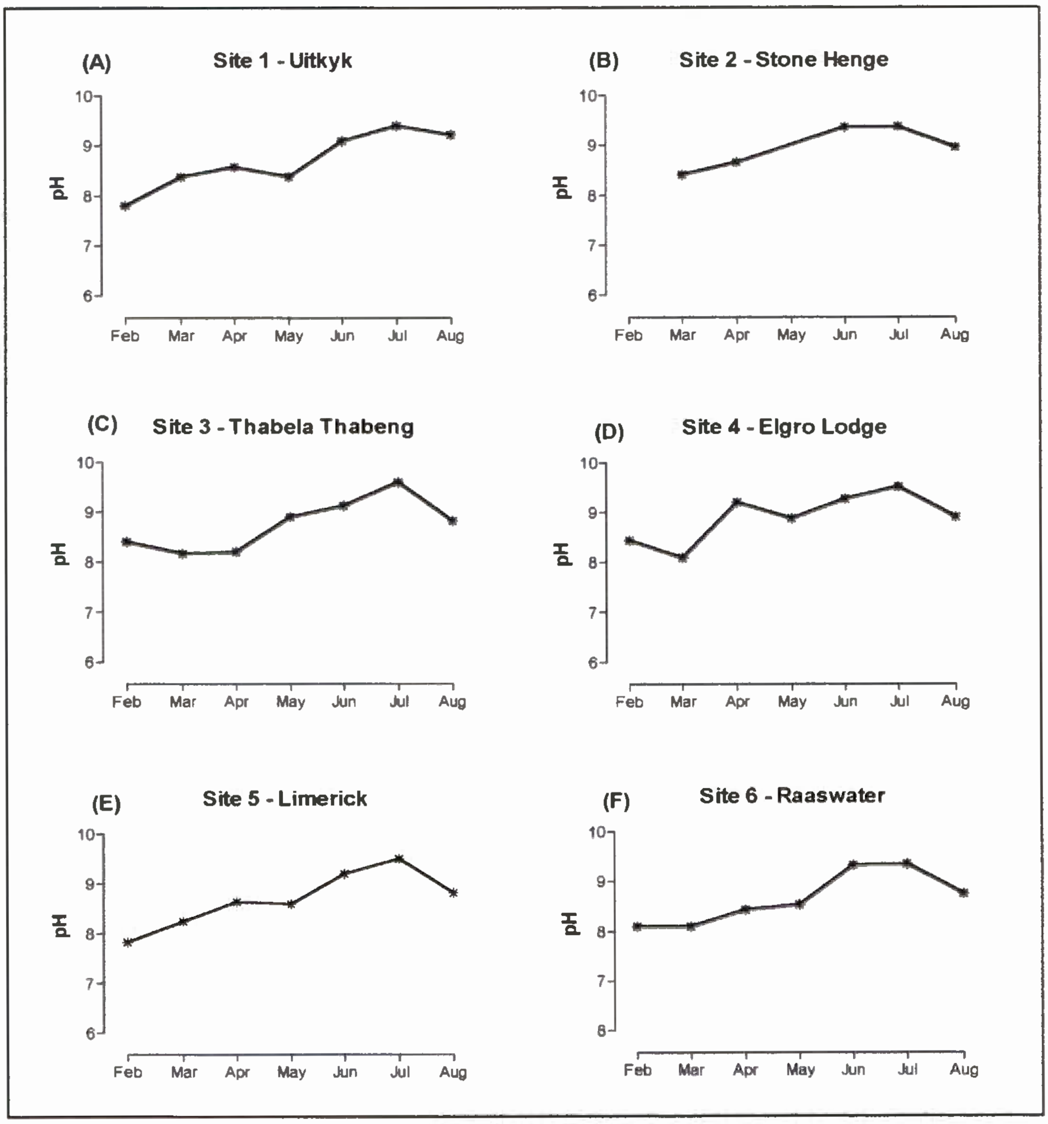

Figure 31: The pH values for the study sites on the Vaal River in the Vredefort dome, each data point indicating a single value

In Figure 31 it is clear that the pH values show a steady increase over time until June/July where it reaches a maximum from where it starts a decline. This could be due to seasonal change that takes place in the water environment. The increase in pH can be the result of excessive plant production that consumes CO_2 and so alters the equilibrium of the CO_2 / HCO_3^- buffering system (Dallas *et al.*, 1994). The decline between July and August could be the result of the die-off period of algae after the autumn bloom, when the respiration increases as a result of the decomposing of the algae (Walmsley, 2000). Excessive respiration causes an increase in the levels of inorganic CO_2 and a decrease in DO_2 levels, that results in a decrease of pH (Dallas *et al.*, 1994).

pH plays an important role in the mobilization of certain substances in water, and this is usually associated with decreases in pH. Increases in pH could have an influence on the ionic balance of organisms in the aquatic environment (Davies & Day, 1998).

3.8. Conductivity

Table 10: The conductivity values (in µS.cm^{-1}) for the study sites on the Vaal River in the Vredefort Dome for February to August 2002 (N.S. = not sampled)

Conductivity	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Site 1	543	372	595	663	780	864	767
Site 2	N.S	333	570	N.S.	790	853	796
Site 3	478	324	529	677	781	850	779
Site 4	568	327	595	690	755	830	801
Site 5	319	583	465	714	754	818	819
Site 6	435	435	461	724	743	816	830

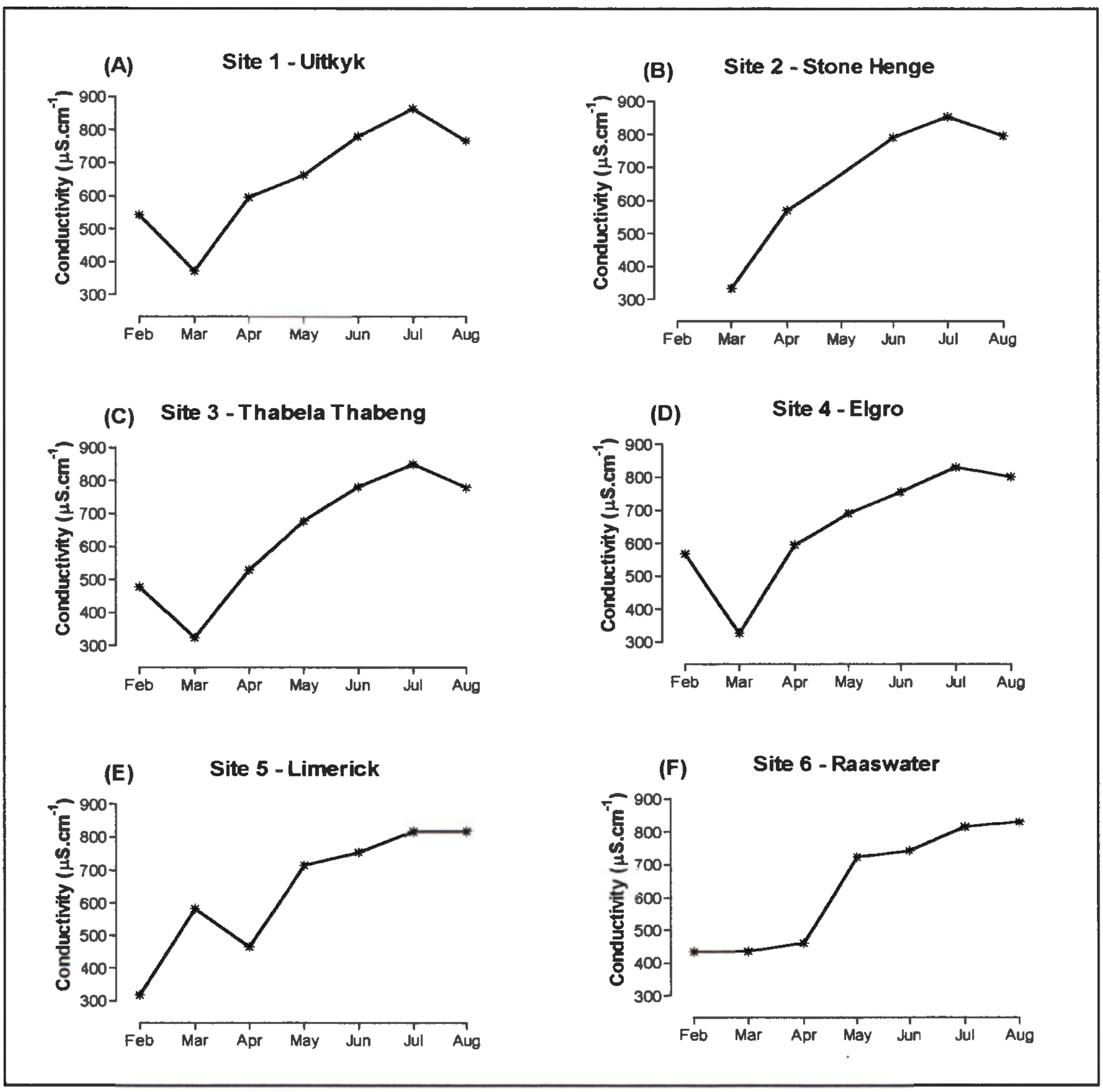

Figure 32: The conductivity values for the study sites on the Vaal River in the Vredefort dome, each data point indicating a single value

Conductivity gives an indication of the amount of dissolved solids that is present in the river system (Dallas *et al.*, 1994; Davies & Day, 1998). The lowest levels conductivity (319 $\mu S.cm^{-1}$) was recorded for Site 5 during February and the highest levels (864 $\mu S.cm^{-1}$) for Site 1 during July (see Figure 32 E & A).

Figure 32 show that the conductivity increased over time. From April, where the increase starts, the river was at low flow conditions typical of the dry winter season. Thus the low flow conditions and evaporation from the surface could have had a concentrating effect on the amount of dissolved substances in the river (Davies & Day, 1998).

For February and March the lowest conductivity levels were measured. During November and December there were floods in the Vaal system, and these lower levels could be due to the influx of rainwater with lower levels of dissolved substances.

3.9. Geomorphology

Table 11: Gradients between the study sites along the Vaal River in the Vredefort Dome.

	Gradient ($m.km^{-1}$)
Site 1 – Site 2	2.71
Site 2 – Site 3	0.59
Site 3 – Site 4	0.92
Site 4 – Site 5	0.43
Site 5 – Site 6	5.14
Average	1.96

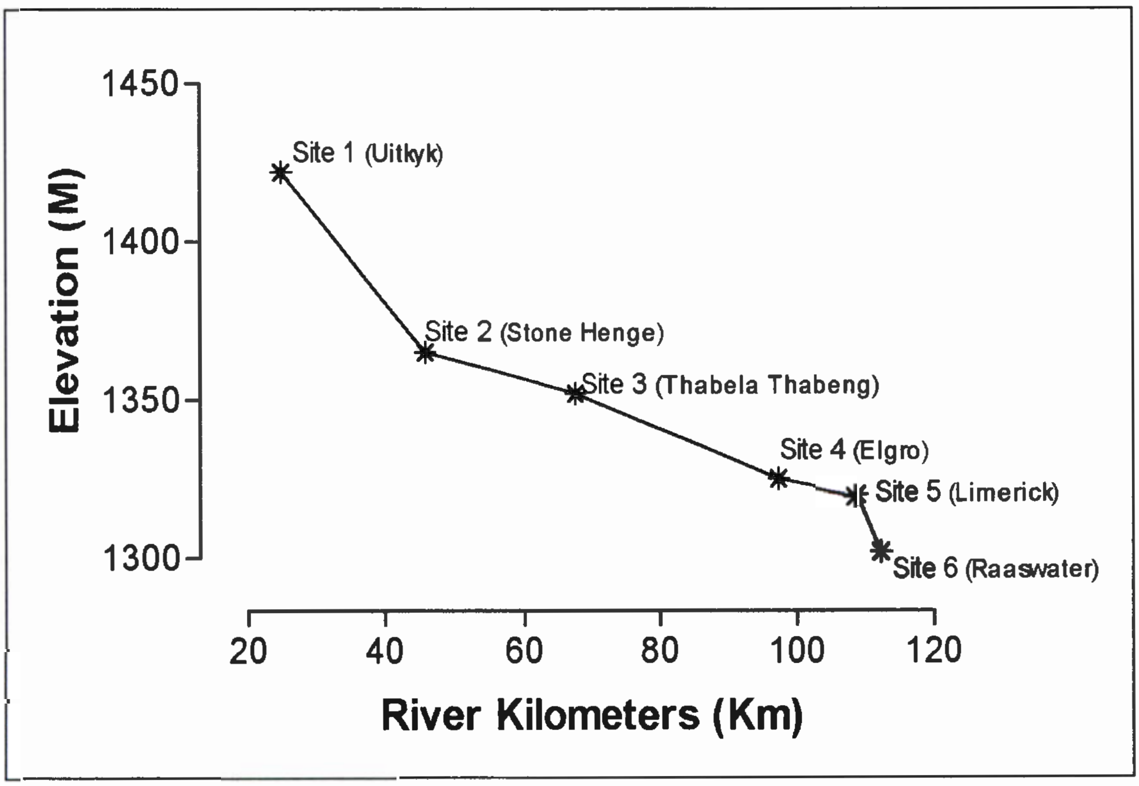

Figure 33: Graph indicating the geomorphological gradient and distribution of the study sites at the Vaal River in the Vredefort Dome

Figure 33 is a graph of the elevation of the sites against the River kilometres. The River kilometres were calculated using the Vaal Barrage as starting point (0 km) and measuring the length of river from the Barrage to each of the sites. This graph gives a clear indication of the position of the sites relative to one another, and of the gradient between them. There is quite big gradient between Site 1 and 2 with an average drop of 2.71 m/km. The gradient between Site 2 and 3, between 3 & 4 and between 4 & 5 is less steep (0.59; 0.92 and 0.43 m/km respectively). The biggest gradient was between Sites 5 & 6 with an average drop of 5.14 m/km (Table 10). Steep gradients such as these can have a discernible effect on the riverine environment. The greater the gradient, the more potential energy there is for the water. This gradient can increase the flow rate, which could have secondary effects such as better potential for gasses to dissolve in the water, but it also enhances the effects of scouring and thus could have a contribution to the degree of turbidity in the water (Dallas *et al.*, 1994).

3.10. Freshwater Molluscs

Table 12: Results of the freshwater molluscs that were collected in the SASS nets from the study sites along the Vaal River in the Vredefort Dome

		Uitkyk				Stone H			Thabela			Elgro				Limerick				Raaswater			
Families	**Species**	May	Jun	Jul	Aug	Jun	Jul	Aug	May	Jun	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Physidae	*Physa acuta*	X	X	X	X	X	X	X			X		X	X	X	X	X	X	X	X	X	X	X
Ancylidae	*Burnupia cf. mooiensis*	X	X	X	X					X	X				X			X	X	X		X	X
	Burnupia cf. transvaalensis				X	X	X	X				X	X	X			X			X			
	Ferrissia cf. cawstoni		X																				
Lymnaeidae	*Lymnaea columella*		X	X	X													X					
	Lymnaea natalensis															X			X		X		
Planorbidae	*Gyraulus connollyi*	X	X		X																		
Corbiculidae	*Corbicula fluminalis*	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X
Sphaeriidae	*Pisidium costulosum*			X	X						X			X	X							X	X
	Pisidium viridarium				X		X	X	X		X			X	X		X	X		X		X	X

From Table 11 it is evident that the occurrence of mollusc species varies from site to site and from month to month. Ten mollusc species from six families were collected over the sampling period. The molluscs that were most commonly found in the Dome area were *Physa acuta, Corbicula fluminalis, Pisidium viridarium and Burnupia mooiensis.*

Physa acuta occurred at all of the sites. It has been given the nickname "the sewage snail" because it is frequently found in organically polluted, oxygen poor water and is sometimes the only species of mollusc found under such conditions. *Physa* is a North American species that has become invasive in many river systems in South Africa and is tolerant to polluted waters where it may occur in great numbers (Appleton, 1996). It is common in stagnant and flowing waters in or near towns (Brown, 1994). The occurrence of this snail in the Vaal River system could be an indication of organic pollution resulting from the land use practices in the area.

Lymnaea columella and *L. natalensis* occurred at four of the sites, but were less abundant than most of the other molluscs. *L. columella* is susceptible to both *Fasciola hepatica and F. gigantica* (Liver flukes), and *L. natalensis* serves as major intermediate for the giant liver fluke, *Fasciola gigantica*. Both *Lymnaea* species frequently occur in permanent streams and water impoundments. Moderate pollution may be favourable (Brown, 1994; Appleton, 1996).

The other molluscs that were collected at the various sites are common species in the Vaal River, and are of no medical or veterinary importance (Brown, 1994, Appleton, 1996).

CHAPTER 4

Conclusions

Fresh water is one of South Africa's most important, but also most endangered resources. There are several problems associated with our natural freshwater resources. One of the biggest single problems is eutrophication resulting from malpractices in industrial and agricultural activities (Walmsley, 2000). The Vaal River is one of the South African interior's most important sources of fresh water, and this river is already severely threatened by increases in salinity and eutrophication (Van Vliet & Nel, 1983; Van Duuren, 1986; Van Vliet, 1986; Braune & Rogers, 1987; Walmsley, 2000).

The outputs of a biomonitoring study should give a general description of the health of a river, and should be able to identify areas that could be of concern. Biomonitoring should be used as a routine monitoring and early warning tool. Biomonitoring cannot replace thorough chemical analysis, but it can be used as an tool to indicate when complete chemical analyses may be necessary.

There were some complications during the planning and execution of this project. One of the major problems that became known during the planning phase was that accessibility to the river was difficult. The land is privately owned, and the owners could not always be located for permission to enter their land. Another problem that hampered accessibility was the fact that for great parts of the Dome, the riparian vegetation was almost impenetrable and there were few access roads to the river, and thus sampling had to be conducted at recreational resorts where access to the water was possible.

During the duration of the study, there were several changes in the flow of the river, and the river was in flood during November & December, which made sampling impossible at those times. There were great differences in the flow conditions of summer compared to winter, which could have had an effect on the results of the investigation. The flow of the Vaal River in this area is governed by precipitation in the catchment, and by the amount of water released by the Vaal Barrage, and is thus regulated to some extent.

One of the main aims of this biomonitoring study was to provide a baseline set of data on the water quality and macroinvertebrate diversity of the Vaal River in the Vredefort Dome. This objective was met, and data on a variety of river-related aspects was generated. Data provided by this study included biomonitoring data (SASS, ASPT and Number of taxa), some baseline physical-chemical data (pH, Dissolved oxygen and Conductivity), data on habitat conditions (IHAS) limited geomorphologic data, data on the occurrence of freshwater molluscs in the Dome and finally data on the seasonal occurrences of aquatic macroinvertebrates in this stretch of the Vaal River.

The South African Scoring System (SASS) has proven to be a very successful biomonitoring tool that uses riverine macroinvertebrate communities to assess the health of rivers in South Africa. SASS does not give an explanation of all water quality aspects, and it is possible to obtain high SASS, ASPT and Number of taxa values, whilst there may still be water quality related aspects overseen for instance aesthetical problems, and herbicide impacts.

From the SASS results it is evident that the Vaal River in the Vredefort Dome sustains healthy macro-invertebrate communities, and that the quality of the water is in the fair to good range. Even though there was some variation in the water quality, the variations were generally small, and could be ascribed to the dynamic nature of riverine ecosystems.

Since there is such a magnitude of natural variables that influences the ecology of riverine systems, care should be taken to consider all influences when interpreting the results of biomonitoring studies. One of the problems in the interpretation of the data that was obtained in this investigation was that there were no previous studies to which the data could be compared. Thus, it was difficult to distinguish between natural impacts and those of anthropogenic nature. Assumptions cannot be made from the results before a thorough investigation have been launched into the nature and extent of the possible anthropogenic influences. Such anthropogenic influences can be studied in the framework of land use activities in the area.

It was expected that the town, Parys. Situated between Site 1 and Site 2 would have a marked impact on the water quality. The SASS results indicated a lower score for Site 2, but this site was also characterised by poor habitat availability, and the hypothesis that the town had a negative influence on the water quality could not be proved.

It was also suspected that the animal feeding lot between Site 5 and Site 6 could have a negative effect on the water quality, but clear evidence for this could not be seen in the results. What was noticed though was that there was a greater presence of algae and macrophytes at Site 6 compared to Site 5, and it is possible that this increase in productivity is brought about by the release of nutrients from the animal feeding lot. To prove this, chemical analysis of the nutrient levels in the area need to be conducted, in conjunction with analysis of the algal community structure.

The habitat conditions in the Dome varied to some extent, changing seasonally and with natural occurrences such as flooding. This has a definite effect on the SASS score since the riverine macroinvertebrates is quite sensitive to the quality and availability of suitable habitats. Habitat conditions varied between poor and good, with the majority of the habitats falling in the fair range for most of the sampling period. Thus habitat conditions were not natural, and this could have lowered the overall macroinvertebrate diversity to some extent, which can have an effect on the results of SASS.

From the results, it became evident that there were differences in the occurrences of macroinvertebrate taxa over the different seasons (see Table 14). Some taxa only occurred during one or two of the seasons, and some taxa were less abundant during certain seasons. During both summer and autumn, 27 different taxa were observed, whilst only 23 taxa were observed during the winter (see Table 14). Differences in the composition of the invertebrate communities were also observed for the different seasons, and Table 15 gives an indication of the taxa that was absent from the study sites during the different seasons.

Although patterns have been observed in the analysis of the data in terms of seasonal variation, care should be taken not to make too many assumptions from the seasonal data and statistics. Before any conclusions can be made regarding seasonal patterns, sampling should be conducted for at least two more years, so that there is seasonal data for at least three years.

It was hypothesised that the Vredefort Dome with its unique structure and characteristics could have a dilution, and/or purification effect on the water of the Vaal River. Because of the Dome's geology and topography, it was thought that it could concentrate precipitation runoff into the Vaal River. It was also thought that this relatively pristine area could give the river's natural redundancy a chance to enhance the water quality of the river.

From the results there seems to be some spatial enhancement in the water quality of the Vaal River. This improvement in the water quality was relatively small though, and there was no firm proof that the Dome's structure and functioning was accountable for the improvement. One of the factors that made the dilution effect difficult to prove is that there was good precipitation in the upper reaches of the Vaal River, and more water than usual entered the Dome from the upper catchments. Thus, water from the catchment above the Vredefort Dome could have diluted the water that entered the Dome, and could be the reason for the improvements in water quality. It is suggested that sampling be conducted for a few more seasons to investigate the dilution effect, if any, of the Dome.

One way in which the Dome could have an effect on the water quality of the Vaal River is by means of its geomorphology. The gradient in the Vaal River in the Dome was quite steep at places, which could have an effect on the amelioration of possible impacts in the Dome. Where the gradient is steep, the water flows faster, better aeration takes place and impacts on the water quality of the river is distributed downstream relatively fast. This could provide a plausible explanation for the fact that there were no significant changes in water quality below the animal feeding lot between Site 5 and 6. The gradient between these two sites were particularly high ($5.14 m.km^{-1}$) and thus the effluent from the feeding lot may well be distributed downstream at a high rate, and the direct effects thus being reduced.

The substratum of the Vaal River in the Dome is also dependant on the unique geology of the Dome, and thus habitat structure in the Dome may be different from other parts of the Vaal River. This could have an effect on the structure of macroinvertebrate communities in the Dome compared to other areas of the Vaal River.

From the literature study, it became evident that until recent years, very little literature was available on biological monitoring of Southern African rivers. There were much more literature available on biomonitoring in foreign countries, especially America, Australia and Britain. Conditions in South Africa are unique, and cannot be compared to environmental conditions in other countries, so that that literature is valuable to develop a background knowledge and understanding of biomonitoring, but techniques had to be adapted to local conditions. Recent years have seen a radical increase in the numbers of publications on the monitoring and management of rivers and streams in South Africa. The literature available is largely limited to technical reports on the available indexes for monitoring, and where literature is available on rivers and streams, it is limited to very few rivers and streams in one or two regions e.g. State of the Rivers Report: Crocodile, Sabie-sand and Olifants Rivers Systems (WRC, 2001).

There is a great need towards information on the conditions in the Vaal River below the Barrage. In all literature studied, very little information is available on this section of the Vaal river, and efforts should be made to do an in-depth study of this section, to attain information on both site specific and regional conditions.

Since the Vaal River is one of South Africa's most important water resources, this River should be closely monitored, over a much wider area than is currently surveyed. Reference conditions should be derived for periphyton, riverine macroinvertebrates, fish and riparian vegetation.

Management of river catchments is a people driven process, and advances should be made to improve public participation and awareness. Tertiary educational institutions could make a big contribution in terms of training personnel for sampling and monitoring of riverine biotas, and in terms of further research to improve knowledge on the ecology of our rivers. Further research need to be done in terms of management methods for different river systems, and for areas of great ecological significance such as the Vredefort Dome.

For the effective management of the Vaal Catchment, it would be feasible to initiate a CMA to monitor the river system. One of the first steps that need to be taken is to do additional studies to develop a set of reference conditions to witch further monitoring results can be compared. To do this it is recommended that for a period of 2 to 3 years, sampling of biological as well as chemical variables should be conducted monthly and over a wider range of sites (All possible influences during this period should be taken into account). After that period, sampling frequency can be reduced to three sampling sessions per year in the spring, autumn and winter. The summer period (rainy season with fluctuations in flow) should be avoided because of the inconsistent data that would be generated (Dallas, 2000).

It is also advisable that a larger scope of sampling should be used for the setting of reference conditions, and routine sampling. One of the most important aspects that should be included into such a sampling programme would be the monitoring of some of the major nutrients like N and P, and also the algal community should receive more attention since algae play an important role in a nutrient rich river system like the Vaal. Riparian vegetation should also be monitored, and the effect of the removal of riparian vegetation at recreational resorts could deserve some attention.

Another important aspect facing the environmental manager is to gain information on the land uses in the catchment. There are a variety of land uses in the Vredefort Dome, and this may have a substantial influence on the overall quality of the water. A thorough study into the geomorphology and geology would also help a great deal in the understanding of the River environment in the Dome, and to understand the kinds, and quantities of dissolved substances in the water.

CHAPTER 5

References

ANON, A. 2000. Dawn of a thirsty Century, BBC-News. [Web: http://news.bbc.co.uk/hi/english/sci/tech/newsid_755000/755497.stm] [Date of access: 24/05/02]

ANON, B. 1999. Africa's potential water wars. BBC-News. [Web: http://news.bbc.co.uk/hi/english/world/africa/newsid_454000/454926.stm] [Date of access: 24/05/02]

APPLETON, C.C. 1996. Freshwater Molluscs of Southern Africa. University of Natal Press, Scottsville, South Africa.

ASHTON, P. 2001. Integrated Catchment Management: Balancing Resource Utilization and Conservation. Course notes, Aquatic Biomonitoring, Grahamstown.

BARBER-JAMES, H.M. 2001. Freshwater Biomonitoring Using Benthic Macroinvertebrates. Short course on biomonitoring. Grahamstown.

BARBOUR, M.T., J. GERRITSEN, B.D. SNYDER, and J.B. STRIBLING. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

BEGON, M., HARPER, J.L. & TOWNSEND, C.R. 1996. Ecology: Individuals, Populations and Communities. Marston Book Services Ltd., Oxon.

BRAUNE, E. & ROGERS, K.H. 1987. The Vaal River Catchment: Problems and Research needs, South African National Research Programmes Report no 143, Foundation for Research Development, Counsel for Scientific and Industrial Research, Pretoria.

BREDENKAMP, G.J. & Van ROOYEN, N. 1996. Rocky Highveld Grassland. (*In* LOW, A.B. & REBELO, A.G. 1996. Vegetation of South Africa, Lesotho & Swaziland. 1996. Pretoria: Department of Environmental affairs & Tourism.

BROWN, D. 1994. Freshwater Snails of Africa and their Medical Importance. Revised 2nd edition. Taylor and Francis ltd. London.

BRUWER, C. 1986. Macrophytes in the Vaal River in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, Pretoria.

BRUWER, C.A., VAN VLIET, H.R., SARTORY, P.L. & KEMPSTER, P.L. 1985. An Assessment of Water Related Problems of the Vaal River between Barrage and Douglas Weir. Technical report TR 121. Department of Water Affairs, Pretoria.

CHUTTER, F.M. 1986. Biotic Indices and Water Quality in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, Pretoria.

CHUTTER F.M. 1998. Research on the Rapid Biological Assessment of Water Quality Impacts in Streams and Rivers. WRC report no 422/1/98. Water Research Commission, Pretoria.

CONLEY, A. 1995. Water: Can South Africa Prosper without a strong conservation ethic? Department of Water Affairs and Forestry. EPPIC'S World Environment Day Symposium.

DALLAS, H.F. 2000 a. Ecological reference condition project: Field Manual. Volume 1: General information, catchment condition, invertebrates and water chemistry. Southern Waters Research and Consulting cc. Freshwater Research Unit. University of Cape Town.

DALLAS, H.F. 2000 b. The derivation of ecological reference conditions for riverine macroinvertebrates. NAEBP Report series No 12. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

DALLAS, H.F. DAY, J.A. REINOLDS, E.G. 1994. The Effects of Water Quality Variables on Riverine Biotas. Report to the Water Research Commission. WRC Report 351/1/94.

DAVIES, B.R. O'Keeffe, J.H. Snaddon, C.D. 1993. A Synthesis of Ecological Functioning, Conservation and Management of South African River Ecosystems. WRC Report No. TT62/93. Water Research Commission, Pretoria.

DAVIES, B. & DAY, J. 1998. Vanishing Waters. University of Cape Town Press. University of Cape Town. Rondebosch. Cape Town.

DE LA HARPE, H. 2000. Potchefstroom in 2000. Volume 1. September 2000

DICKENS, C. & GRAHAM, M. 2002. The South African Scoring System (SASS) Version 5 Rapid bio-assessment Method For Rivers. Hydrobiology, Umgeni Water, Pietermaritzburg, South Africa.

EEKHOUT, S., BROWN, C.A. & KING, J.M. 1996. National Biomonitoring Programme for Riverine Ecosystems: Technical Considerations and Protocol for the Selection of Reference and Monitoring Sites. NBP Report Series No.3. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria. South Africa.

GRAHAM, M. 2001. Accreditation of the SASS Method. River Health. Newsletter of the National Aquatic Ecosystem Biomonitoring Programme. No. 8. RHP communications office. Manyaka Greyling, Meiring (Pty) Ltd, Pretoria.

GROBLER, D.C., TOERIEN, D.F. & ROSSOUW, J.N. 1986. Effects of Sediment on /water Quality in the Vaal River System in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, Pretoria.

HEATH, R.G.M. 1999. A Catchment-Based Assessment of the Metal and Pesticide levels of Fish from the Crocodile River, Mpumalanga. Thesis represented in fulfilment of the requirements for the degree Philosophiae Doctor in Zoology. Faculty of Natural Sciences at the Rand Afrikaans University.

HOHLS, D.R. 1996. National Biomonitoring Programme for Riverine Ecosystems: Framework document for the programme. NBP Report Series No 1. Institute for water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

JANSE VAN VUUREN, M.S. 1996. Environmental variables, abundance and seasonal succession of phytoplankton populations in the Vaal River at Balkfontein. Unpublished M.Sc. Thesis, PU for CHE, Potchefstroom.

KLEYNHANS, C.J. River Habitat: Assessment of Habitat Integrity. Short course on biomonitoring. Grahamstown.

KUIPER, J.G.J. 1964. Contribution to the knowledge of the South African species of the genus *Pisidium.* (Lamellibranchiata). Annals of the South African Museum, Cape Town. The Rustica Press Pty. Ltd. Wynberg, Cape Town.

LEPONO, T. KOTZE, P. NIEHAUS, B. DU PREEZ, H. 2001. Ecological Effects of Release of Water from the LHWP Dams into the Ash/Liebenbergsvlei System. Report no. Potch/01/Hons. Potchefstroom University for CHE. Potchefstroom.

LOW, A.B. & REBELLO, A.G. *eds.* 1996. Vegetation of South Africa, Lesotho and Swaziland. Pretoria. Department of Environmental Affairs & Tourism.

MANGOLD, S. 2001. National Aquatic Ecosystem Biomonitoring Programme: An Implementation Manual For the River Health Programme – a hitchhiker's guide to putting the RHP into action. NAEBP Report Series No 15. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

McMILLAN, P.H. 1998. An Integrated Habitat assessment System (IHAS v2), for the Rapid Biological Assessment of Rivers and Streams. A CSIR research project, number ENV-P-I 98132 for the water Resources Management Programme, CSIR.

MILLARD, A. 1999. Water management. Tradeport U.S. & Foreign Commercial Service and U.S. Department of State. [Web:] http://www.tradeport.org/ts/countries/safrica/isa/isar0008.html [Date of access: 10/08/2001]

MURRAY, K. 1999. National Aquatic Ecosystem Biomonitoring Programme: National Implementation Assessment. NAEBP Report No. 8. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

OLIVEIRA, M.P., 1986. Sources of water pollution in the Vaal River in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, PO Box 395, Pretoria, 0001.

PALMER, R.W. 1997. Changes in the abundance of invertebrates in the stones-in-current biotope in the Middle Orange River over five years. WRC Report No. KV130/00. Water Research Commission, Po Box 824, Pretoria, 001, South Africa.

PIETERSE, A.J.H. 1986. Aspects of the Ecology and Significance of Algal populations of the Vaal River in

PIETERSE, A.J.H. PLK321: Plantekologie, Die Ekologie van binnelandse waters (Limnologie), Skool vir Omgewingswetenskappe en ontwikkeling, Afdeling Plantkunde, PU vir CHO, 2000

ROUX, D.J. 1997. National Aquatic Biomonitoring Programme: Overview of the design process and guidelines for implementation. NAEBP Report Series no. 6. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

ROUX, D.J. 2001 a. Resource directed measures and river classification. CSIR Environmentek. Short Course on Aquatic Biomonitoring. Grahamstown.

ROUX, D.J. 2001 b. Biomonitoring of Rivers. CSIR Environmentek. Short course on biomonitoring. Grahamstown.

ROUX, D.J. KLEYNHANS, C.J. HILL, L. ENGELBRECHT, J.S. DEACON, A.R. KEMPER, N.P. 1999. Adaptive Assessment and Management of Riverine Ecosystems: The Crocodile/Elands River case study. Water SA. Vol. 25 No. 4. : 501 - 511

SCHMIDT-NIELSEN, K. 1998. Animal Physiology, Adaptations and Environment. Fifth Edition. Cambridge University Press, Cambridge, United Kingdom.

SCIENCE JUNCTION, 2000. Water What-ifs. Comparison of adult and larval stages of mayfly, stonefly, beetle, caddisfly, dragonfly and fly. NC State University.
[WEB: http://www.ncsu.edu/sciencejunction/depot/experiments/water/lessons/macro/macrolarva.html] [Date of access: 22/09/02]

SKELTON, P. H. 1993. 'n Volledige gids tot die Varswater Visse van Suider Afrika. Southern Boekuitgewers (Edms) Bpk.. Halfweghuis.

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

StatSoft, Inc. (2001). *STATISTICA* for Windows [Computer program manual]. Tulsa, OK: StatSoft, Inc., 2300 East 14th Street, Tulsa, OK, 74104-4442, (918) 749-1119, fax: (918) 749-2217, e-mail: info@statsoft.com, WEB: http://www.statsoft.com.

UYS, M.C., GOETCH, P-A. & O'KEEFFE, J.H. 1996. National Aquatic Biomonitoring Programme: Ecological indicators, a review and recommendations. NBP Report Series No. 4. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

UYS, M.C. 2001. Ecological goals for rivers. Laughing waters. Short course on biomonitoring. Grahamstown.

VAN DUUREN, F. 1986. The Role of the Vaal River Catchment Association in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, Pretoria.

VANNOTE, R.L. MINSHALL, K.W. CUMMINS, J.R. SEDEL, J.R. & Cushing, E. 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37: 130 – 137.

VAN ROOYEN, C. 2001. Kommer Oor Skaars Water. Landbou Weekblad. No. 1227, 30 November 2001.

VAN VLIET, H.R. 1986. General Chemical quality of the Vaal River in The Vaal River Ecosystem: Status and Problems. Occasional report no. 5. Foundation for Research Development. Council for Scientific and Industrial Research, Pretoria.

VAN VLIET, H.R. & NELL, U. 1983. Surface water quality of South Africa. The Vaal River catchment: 1979 to 1983. Technical report TR 131. Department of Water Affairs. Pretoria,

VIESSMAAN, W. & HAMMER, J. 1998. Water Supply and Pollution Control. Sixth Edition. Addison Wesley Longman, Inc. California.

WALKER, B. 1923. The Ancylidae of South Africa. Written and published in Great Brittan.

WALMSLEY, R.D. 2000. Perspectives on Eutrophication of Surface Waters: Policy/Research Needs in South Africa. A review and discussion document. Final report to the Water Research Commission on the Consultancy Development of a Framework for Research Programme on Eutrophication in South Africa. WRC Report No. KV129/00. Water Research Commission, Pretoria.

WATER FACTS, 2000. Water Basics. The Water Page. Water Policy International Ltd. [WEB: http://www.thewaterpage.com/waterbasics.htm]
[Date of access: 02/10/02]

WETZEL, R.G. 1983. Limnology. Second edition. Saunders College Publishing, Orlando, Florida..

WRC. 2001. State of the Rivers Report: Crocodile, Sabie-sand and Olifants Rivers Systems. WRC report No TT 147/01. Water Research Commission. Pretoria.

Appendix A:

Scoresheets

River Health Programme - SASS 5 Score Sheet

May 2001

Date: / /200__

Grid References:
S: ° ' , "
E: ° ' , "
WGS-84 | Cape datum

Site code:……………………

River:……………………………………

Site description:……………………………

Weather Condition:…………………………

Temp:……………°C pH:………………

DO:……………mg/l Cond:………mS/m

Biotopes sampled:

SIC ………… Time……… ……minutes
SOOC…………
Bedrock…………
Aquatic veg'n……… Dom. sp……………
MvegIC………… Dom. sp……………
MvegOOC……… Dom. sp……………
Gravel………… Sand……………
Mud……………
Hand picking/Visual observation……………

Flow: Low/Medium/High/Flood
Turbidity: Low/Medium/High
Riparian land use:

Disturbance in the river: eg. sandwinning, cattle drinking point, floods etc.

Signs of pollution: eg. smell and colour of water, petroleum, dead fish, etc.

Other observations:

Taxon		S	VG	GSM	TOT
PORIFERA	5				
COELENTERATA	1				
TURBELLARIA	3				
ANNELIDA					
Oligochaeta	1				
Leeches	3				
CRUSTACEA					
Amphipoda	13				
Potamonautidae*	3				
Atyidae	8				
Palaemonidae	10				
HYDRACARINA	8				
PLECOPTERA					
Notonemouridae	14				
Perlidae	12				
EPHEMEROPTERA					
Baetidae 1sp	4				
Baetidae 2 sp	6				
Baetidae > 2 sp	12				
Caenidae	6				
Ephemeridae	15				
Heptageniidae	13				
Leptophlebiidae	9				
Oligoneuridae	15				
Polymitarcyidae	10				
Prosopistomatidae	15				
Teloganodidae SWC	12				
Tricorythidae	9				
ODONATA					
Calopterygidae ST,T	10				
Chlorocyphidae	10				
Chlorolestidae	8				
Coenagrionidae	4				
Lestidae	8				
Platycnemidae	10				
Protoneuridae	8				
Zygoptera juvs.	6				
Aeshnidae	8				
Corduliidae	8				
Gomphidae	6				
Libellulidae	4				
LEPIDOPTERA					
Pyralidae	12				

Taxon		S	VG	GSM	TOT
HEMIPTERA					
Belostomatidae*	3				
Corixidae*	3				
Gerridae*	5				
Hydrometridae*	6				
Naucoridae*	7				
Nepidae*	3				
Notonectidae*	3				
Pleidae*	4				
Veliidae/M...veliidae*	5				
MEGALOPTERA					
Corydalidae	8				
Sialidae	6				
TRICHOPTERA					
Dipseudopsidae	10				
Ecnomidae	8				
Hydropsychidae 1 sp	4				
Hydropsychidae 2 sp	6				
Hydropsychidae > 2 sp	12				
Philopotamidae	10				
Polycentropodidae	12				
Psychomyiidae/Xiphocentronidae	8				
Cased caddis:					
Barbarochthonidae SWC	13				
Calamoceratidae ST	11				
Glossosomatidae SWC	11				
Hydroptilidae	6				
Hydrosalpingidae SWC	15				
Lepidostomatidae	10				
Leptoceridae	6				
Petrothrincidae SWC	11				
Pisuliidae	10				
Sericostomatidae SWC	13				
COLEOPTERA					
Dytiscidae*	5				
Elmidae/Dryopidae*	8				
Gyrinidae*	5				
Haliplidae*	5				
Helodidae	12				
Hydraenidae*	8				
Hydrophilidae*	5				
Limnichidae	10				
Psephenidae	10				

Taxon		S	VG	GSM	TOT
DIPTERA					
Athericidae	10				
Blephariceridae	15				
Ceratopogonidae	5				
Chironomidae	2				
Culicidae*	1				
Dixidae*	10				
Empididae	6				
Ephydridae	3				
Muscidae	1				
Psychodidae	1				
Simuliidae	5				
Syrphidae*	1				
Tabanidae	5				
Tipulidae	5				
GASTROPODA					
Ancylidae	6				
Bulininae*	3				
Hydrobiidae*	3				
Lymnaeidae*	3				
Physidae*	3				
Planorbinae*	3				
Thiaridae*	3				
Viviparidae* ST	5				
PELECYPODA					
Corbiculidae	5				
Sphaeriidae	3				
Unionidae	6				
Sass score					
No. of taxa					
ASPT					

IHAS

Other biota:

Comments:

Procedure: Kick stones in current & bedrock for 2 mins, max. 5 mins. Kick SOOC & bedrock +/- 1m2. Sweep vegetation (IC & OOC) for 2m total. Stir & sweep gravel, sand, mud for 30 secs total. * = airbreathers

Hand picking & visual observation for 1 min - record in biotope where found. Tip net contents into tray. Remove leaves, twigs & biota. Check taxa present for 15 mins and stop if no new taxa seen after 5 mins

Estimate abundances: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000   S = Stone and rock; VG = All vegetation; GSM = Gravel, sand, mud   SWC = South Western Cape, T = Tropical, ST = Sub-tropical

Rate invertebrate biotope sampled: 1 - very poor (i.e. limited diversity), 5 - highly suitable (i.e. wide diversity)

Figure 34: Example of the SASS 5 Scoresheet that was used during the study (Dickens & Graham, 2002)

SAMPLING HABITAT — Boxes score:	0	1	2	3	4	5
Stones-in-current (SIC)						
Total length (m) of broken water (riffles or rapids)	none	0-1	>1-2	>2-3	>3-5	>5
Total length (m) of submerged stones in current (run)	none	0-2	>2-5	>5-10	>10	
Number of separate SIC areas kicked	0	1	2-3	4-5	6+	
Average size (cm) of stones kicked (gravel <2, bedrock >20)	none	<2, >20	2-10	11-20	2-20	
Amount of stone surface clear (of algae, sediment, silt etc)*	n/a	0-25	26-50	51-75	>75	
Protocol: time (mins) spent actually kicking SIC (grvl/bedr=0)	0	<1	>1-2	2	>2-3	>3
SIC Scores: (A= SIC boxes total; B=adjustment to equal 20; C= final total) *Note: up to 25% of stone is usually embedded in stream bottom.*	actual	A	adj.	B	max. 20	C
Vegetation						
Length (m) of fringing vegetation sampled (banks)	none	0-½	>½-1	>1-2	2	>2
Amount (m^2) of aquatic vegetation / algae sampled	none	0-½	>½-1	>1		
Fringing vegetation sampled in: (none; pool or still only; run only; mixture of both)	none		run	pool		mix
Type of veg (% leafy vegetation vs stems/shoots) (aqv only =49)	none	0	1-25	26-50	51-75	>75
Veg Scores: (D= Veg boxes total; E=adjustment to equal 15; F= final total)	actual	D	adj	E	max. 15	F
Other Habitat						
Stones-out-of-current (SOOC) sampled: (protocol = 1 m^2)	none	0-½	>½-1	1	>1	
Sand sampled: (protocol = 1 min) (present, but only below stones)	none	below	0-½	>½-1	1	>1
Mud sampled: (protocol = ½min) (present, but only below stones)	none	below	0-½	½	>½	
Gravel sampled: (protocol = ½min) (if all, SIC stone size=<2)**	none	0-½	½	>½*		
Bedrock sampled (*all* = no SIC, sand, gravel) (if all, SIC stone size >20)**	none	some			All**	
Algae present (1-2m^2=algal bed, rocks=on rocks, isol=isolated clumps)	>2m^2	rocks	1-2m^2	<1m^2	isol.	none
Tray identification (using time as per protocol)		under		Correct		over
Other habitat Scores: (G= O.H/G boxes total; H=adjustment to equal 15; I= final total)	actual	G	adj.	H	max. 20	I
HABITAT TOTALS						
J=Total adjustment (B+E+H); K=Total habitat (C+F+I)			adj	J	max. 55	K
STREAM CHARACTERISTICS						
Physical						
River make-up (pool = pool/dam only; run only; rapid/riffle only; 2mix = 2 types etc.)	pool		run	Rapid/ riffle	2mix	3mix
Average stream width (m)		>10	5-10	<1	1-2	>2-5
Average stream depth (m)	>2	>1-2	1	>½-1	½	<½
Approximate stream velocity (slow = <½m/s; fast = >1 m/s)	still	slow	fast	med.		mix
Water colour (disc.= discoloured with visible colour but still clearish)	silty	opaque		disc.		clear
Recent disturbances due to: (constr. = construction)***	flood	fire	Constr.	other		none
Bank/riparian vegetation is: grass=includes reeds; shrubs=includes trees)	none		grass	shrubs		mix
Surrounding impacts: (erosn=erosion/shear bare banks; farm=farmland/settlements)***	erosn.	farm	trees	other		open
Left bank cover (%) (rocks and vegetation; shear = 0%)	0-50	51-80	81-95	>95		
Right bank cover (%) (rocks and vegetation; shear = 0%)	0-50	51-80	81-95	>95		
Stream characteristics total (L=physical boxes final total) *** Note: if more than one option, choose lowest					max. 50	L
TOTAL IHAS SCORE (K+L)		%	M			

Figure 35: Example of the IHAS scoresheet that was used during the study (McMillan, 1998)

Appendix B:

Glossary of Terms:

Aquatic ecosystems:	Ecosystems that provide a medium for habitation by aquatic organisms. And sustain aquatic ecological processes.
Anthropogenic:	Resulting from the presence or activities of humans
Benthos:	Living on the bottom substrata (sediments, debris, logs, cobbles, etc.) of aquatic biotopes.
Bioassessment:	Assessment of (usually) water quality by examining some aspect of the biota.
Biomonitoring:	The gathering of biological information in both the laboratory and the field for the purpose of making an assessment or decision or in determining whether quality objectives are being met.
Biodiversity:	The array of life from gene to species to communities and associated habitats. Biodiversity comprises composition, structure and function. Composition is the identity and variety of elements in a collection, and includes species lists and measures of species diversity and genetic diversity. Structure is the physical organization or pattern of a system, from habitat complexity as measured within communities to the pattern of patches and other elements at a landscape scale. Function involves ecological and evolutionary processes, including gene flow, disturbances, and nutrient cycling.
Biota:	Living organisms, including plants, animals and microorganisms.
Biotic Integrity:	The ability to support and maintain a balanced, integrated, adaptive community of organisms having a full range of elements (genes, species and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics and meta-population processes) expected in the natural habitat of the region.
Biotope:	A homogeneous environment that satisfies the habitat requirements of a biotic community (e.g. riffle, pool or sandbank).

Catchment: The area from which any rainfall will drain into a watercourse through surface flow.

Ecological Indicator: Measurable attribute of a high-level ecosystem component (biological, chemical or physical). A high-level biological component would typically be fish, invertebrates or riparian vegetation. (For example, one measurable attribute of fish is frequency of occurrence at a series of sites.) A high-level non-biological component might be habitat, water quality or geomorphology. (One measurable attribute of geomorphology is bank stability.)

Ecological Integrity: The ability of an ecosystem to support and maintain a balanced, integrated composition of physicochemical habitat characteristics, as well as biotic components, on a temporal and spatial scale, that are comparable to the natural (i.e. unimpaired) characteristics of such an ecosystem. (High ecological integrity implies that the structure and functioning of an ecosystem are unimpaired by anthropogenic stresses.)

Ecosystem: Any unit that includes all of the organisms (i.e. the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biodiversity and material cycles (i.e. exchange of material between living and non-living parts) within the system.

Habitat Integrity: The maintenance of a balanced, integrated composition of physicochemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats of the region.

Invertebrate: An animal lacking backbone and internal skeleton.

Macro-invertebrates: Invertebrates retained by mesh size 200 um.

Natural Environment: Aquatic ecosystems and those ecosystems dependant on them, thus including not only the underwater ecosystems of rivers themselves but also riparian belts and floodplains and the organisms such as wildlife that depend on rivers for drinking water and on riparian vegetation for shelter.

Monitoring Sites: Sites selected to assess the condition of available physical habitat, water quality and biological parameters for a river, relative to the expected un-impacted condition.

Pool: A feature with slow through-flow of water (low or zero velocity,) generally deep relative to river size.

Reference Site: A site that has been exposed to relatively little or no anthropogenic impact that can be used to define the physical habitat, water quality and biological parameters for a particular kind of river. These sites represent the best condition that can be achieved in a particular kind of river, against which the conditions found at the monitoring sites in the kind of river can be assessed.

Resource: Any natural raw material, either living or non-living, renewable or non-renewable

Riffle: A shallow, fast-flowing reach of a river with turbulent flow and broken water.

Riparian: Living or located on the banks of streams or rivers.

Run: An area of transition between a pool/rapid and riffle. Depth is variable and velocity is generally moderate.

Runoff: Water that does not filter into soil but flows over the surface and into natural surface waters.

Stressor: Any physical, chemical or biological entity or process that can induce adverse effects on individuals, populations, communities or ecosystems.

Surface Water: Water above the ground surface in lakes, dams, rivers and pans.

Sustainable Development: Integrating social, economic and environmental considerations into planning, implementation and decision-making to ensure that development meets the needs of the present without compromising the ability of future generations to meet their needs.

Turbidity: A measure of the light-scattering ability of water. It indicates the concentration of suspended solids in the water

Watercourse: A river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows.

Water Resource: Includes the physical or structural aquatic habitats (both instream and riparian), the water, the aquatic biota, and the physical, chemical and ecological processes which link habitats, water and biota.

The glossary of terms was compiled from the following references:
Dallas *et al.*, 1994 & Eekhout *et al.,* 1996

Appendix C:

Seasonal macroinvertebrate occurrences

Table 13: Seasonal occurrences of macroinvertebrates at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicate the taxon SASS weight.

Taxon	Summer	Autumn	Winter
ANNELIDA			
Oligochaeta (1)	16	17	18
Hirudinea (3)	16	17	18
CRUSTACEA			
Potamonautidae (3)	5	5	1
Atyidae (8)	15	17	15
EPHEMEROPTERA			
Baetidae (4 – 12)	16	17	18
Caenidae (6)	13	13	5
Heptageniidae (13)	9	12	4
Leptophlebiidae (9)	16	16	18
Tricorythidae (9)	10	15	13
ODONATA			
Chlorocyphidae (10)	3	4	2
Chlorolestidae (8)	0	1	0
Coenagrionidae (4)	11	16	18
Lestidae (8)	0	1	0
Platycnemidae (10)	0	1	0
Protoneuridae (8)	5	0	1
Aeshnidae (8)	1	3	3
Corduliidae (8)	4	5	7
Gomphidae (6)	12	12	11
Libellulidae (4)	3	4	5
HEMIPTERA			
Belostomatidae (3)	9	13	9
Corixidae (3)	7	9	13
Gerridae (5)	1	9	3
Naucoridae (7)	5	9	0
Nepidae (3)	3	4	4
Notonectidae (3)	5	4	3
Pleidae (4)	1	0	0
Veliidae (5)	11	15	0

Table 13: Continued

Taxon	Summer	Autumn	Winter
MEGALOPTERA			
Corydalidae (8)	5	0	0
TRICHOPTERA			
Ecnomidae (8)	9	3	12
Hydropsychidae (4 - 12)	15	16	18
COLEOPTERA			
Dytiscidae (5)	5	2	9
Elmidae (8)	10	16	9
Gyrinidae (5)	9	13	14
Haliplidae (5)	1	0	0
Hydrophilidae (5)	0	1	1
DIPTERA			
Ceratopogonidae (5)	1	0	3
Chironomidae (2)	7	12	16
Culicidae (1)	1	6	2
Muscidae (1)	1	0	3
Simuliidae (5)	13	12	19
Tabanidae (5)	0	6	0
Tipulidae (5)	1	0	2
GASTROPODA			
Ancylidae (6)	13	9	16
Lymnaeidae (3)	0	0	3
Physidae (3)	10	6	17
Planorbinae (3)	1	3	2
PELECYPODA			
Corbiculidae (5)	15	16	18
Sphaeriidae (3)	11	12	18

Table 14: Summary of the Number of taxa and community composition of invertebrates observed during the different seasons of sampling at the study sites along the Vaal River in the Vredefort Dome. The values in brackets indicates the wheight value of each taxon.

Summer Taxa		Autumn Taxa		Winter Taxa	
No	**Taxon**	**No**	**Taxon**	**No**	**Taxon**
1	Oligochaeta (1)	1	Oligochaeta (1)	1	Oligochaeta (1)
2	Hirudinea (3)	2	Hirudinea (3)	2	Hirudinea (3)
3	Potamonautidae (3)	3	Potamonautidae (3)	3	Potamonautidae (3)
4	Atyidae (8)	4	Atyidae (8)	4	Atyidae (8)
5	Baetidae (4 - 12)	5	Baetidae (4 – 12)	5	Baetidae (4 – 12)
6	Caenidae (6)	6	Caenidae (6)	6	Caenidae (6)
7	Heptageniidae (13)	7	Heptageniidae (13)	7	Heptageniidae (13)
8	Leptophlebiidae (9)	8	Leptophlebiidae (9)	8	Leptophlebiidae (9)
9	Tricorythidae (9)	9	Tricorythidae (9)	9	Tricorythidae (9)
10	Chlorocyphidae (10)	10	Chlorocyphidae (10)	10	Chlorocyphidae (10)
11	Coenagrionidae (4)	11	Chlorolestidae (8)	11	Coenagrionidae (4)
12	Protoneuridae (8)	12	Coenagrionidae (4)	12	Protoneuridae (8)
13	Aeshnidae (8)	13	Lestidae (8)	13	Aeshnidae (8)
14	Corduliidae (8)	14	Platycnemidae (10)	14	Corduliidae (8)
15	Gomphidae (6)	15	Aeshnidae (8)	15	Gomphidae (6)
16	Libellulidae (4)	16	Corduliidae (8)	16	Libellulidae (4)
17	Belostomatidae (3)	17	Gomphidae (6)	17	Belostomatidae (3)
18	Corixidae (3)	18	Libellulidae (4)	18	Corixidae (3)
19	Gerridae (5)	19	Belostomatidae (3)	19	Gerridae (5)
20	Naucoridae (7)	20	Corixidae (3)	20	Nepidae (3)
21	Nepidae (3)	21	Gerridae (5)	21	Notonectidae (3)
22	Notonectidae (3)	22	Naucoridae (7)	22	Ecnomidae (8)
23	Pleidae (4)	23	Nepidae (3)	23	Hydropsychidae (4 - 12)
24	Veliidae (5)	24	Notonectidae (3)		
25	Corydalidae (8)	25	Veliidae (5)		
26	Ecnomidae (8)	26	Ecnomidae (8)		
27	Hydropsychidae (4 - 12)	27	Hydropsychidae (4 - 12)		

Table 15: An indication of the taxa that were absent from the study sites along the Vaal River in the Vredefort Dome during the different seasons

Taxa absent during summer:	
No	Taxon
1.00	Chlorolestidae (8)
2.00	Lestidae (8)
3.00	Platycnemidae (10)
Taxa absent during autumn:	
No	Taxon
1.00	Protoneuridae (8)
2.00	Pleidae (4)
3.00	Corydalidae (8)
Taxa absent during winter:	
No	Taxon
1.00	Chlorolestidae (8)
2.00	Lestidae (8)
3.00	Platycnemidae (10)
4.00	Naucoridae (7)
5.00	Pleidae (4)
6.00	Veliidae (5)
7.00	Corydalidae (8)