THE IMPACT OF POWER STATION EMISSIONS ON SURFACE WATER QUALITY IN MPUMALANGA: THE CASE OF MAJUBA POWER STATION

BY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Study leader for his support and guidance

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TO THE LORD OUR HEAVENLY FATHER

Who has unconditionally blessed me with the strength and knowledge to complete these tasks.

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SUMMARY

The impact of air pollution by power stations on water quality, just like any other source of water pollution, is an issue of concern for all the water users since any degradation in water quality affects the water's suitability for use. The study area in which Majuba power station is located was chosen because it is in an area free of industrialisation, and is also part of the Vaal catchment. This catchment area is very important because of its water supply for Gauteng province and provides an ideal opportunity to monitor surface water pollution from atmospheric sources such as power stations.

The purpose of this research is to investigate the chemical, physical and biological quality of surface water in the vicinity (within a 31 kilometre radius) of Majuba power station. The study will determine whether this power station is causing any salinity and acidity problems at the chosen sampling sites. Salinity and acidity are water quality problems associated with atmospheric pollution.

The aim of the study is to determine whether proximity to Majuba power station has an effect on the surrounding surface water quality.

The research was conducted by means of water quality sampling, analyses and assessment. Water quality samples were taken from six sites (Majuba 1 to Majuba 6) in the vicinity of Majuba power station over a period of three years (1997 to 1999). The approach was to take four samples in a year coinciding with the four seasons of the year. Due to logistical problems only two sampling trips were undertaken, during 1997. In 1998 and 1999 the full four sampling trips were undertaken however in some instances the river was dry or was flooded hence no samples could be taken at the affected sampling sites (although a trip to the sampling site was made). The biological analyses where done on site using the biomonitoring technique while chemical analyses were performed at the laboratory at Eskom.

The biomonitoring assessment was done using the biomonitoring technique. The chemical results were assessed in terms of the suitability for use for the aquatic environment. This was done by using the water quality guidelines for the aquatic environment.

The chemical results indicated that in terms of salinity and acidity the site closest to the power station, namely Majuba 1 had the worst water quality of the six sites. Majuba 1 also had the worst results in terms of biomonitoring. Majuba 2 indicated elevated salinity levels. The other four sites, namely Majuba 3 to 6, did not indicate either salinisation or acidification. However, the biomonitoring results at these sites indicated, with the exception of Majuba 4, some deterioration in water quality. Majuba 4 had the best water quality in terms of biomonitoring. Reasons for this could not be determined.

At present it is still premature to say whether acidity in the water is a problem. This is a preliminary study and currently a more detailed multidisciplinary study that includes disciplines such as atmospheric deposition, groundwater chemistry, soil profiles and hydrology is being undertaken on the Upper Vaal catchment to comprehensively determine the impact of air pollution from power stations on the surface water quality. The proposal will be presented to the South African Water Research Commission. The ultimate aim of the multidisciplinary study is to inform decision makers in water quality management sector regarding the impact of air pollution on surface water quality, in order for them to put in place abatement technologies or strategies to mitigate surface water quality pollution.

OPSOMMING

Die impak van lugbesoedeling op waterkwaliteit, soos enige ander bron van waterbesoedeling, is bekommerenswaardig vir alle watergebruikers aangesien ‘n afname in waterkwaliteit ‘n direkte effek het op die geskiktheid van die water vir gebruik. Vir die studie is die spesifieke area gekies aangesien dit binne die Vaal opvangsgebied val wat een van die belangrikste opvangsgebiede in Suid Afrika is. Binne die opvangsgebied is daar gefokus op Majuba-kragstasie, want dit bied ‘n ideale geleentheid om die effek van lugbesoedeling op oppervlakwater te monitor in ‘n gebied wat geen ander tipe industralisasie insluit nie.

Die doel van die navorsing is om die chemiese, fisiese en biologiese kwaliteit van die oppervlakwater in die omgewing (binne ‘n 31km radius) van Majuba kragstasie te ondersoek. Daar word daar spesifiek gelet op enige abnormaliteite in die sout-inhoud of pH van die water by die verskeie toetspunte. ‘n Onnatuurlike hoë sout-inhoud of te lae pH is probleme wat normaalweg met lugbesoedeling geassosieer word.

Die studie beoog dus om te bepaal wat die invloed van Majuba kragstasie op die oppervlakswater in die omgewing is.

Vir die studie is watermonsters by bepaalde punte geneem, geanaliseer en ge-evalueer. Vir hierdie doel is ses verskillende toetspersele (Majuba 1 tot Majuba 6) in die omgewing van Majuba kragstasie gekies vir die monitering oor ‘n periode van drie jaar (1997 – 1999). Daar is jaarliks vier monsters by elke toetspunt geneem om die moontlike wisseling in waterkwaliteit vir elk van die vier seisoene te verteenwoordig. In 1998 en 1999 kon al vier besoeke gedoen word om die watermonsters in te samel, maar as gevolg van logistieke beperkinge, kon slegs twee besoeke in 1997 afgelê word. Verder is die neem van monsters by spesefieke tye gekortwiek deur of totale opdroging of oorstroming van die toetspunte, sodat geen monsters vanaf dié punte verkry kon word nie.

Die biologiese ondersoeke en evaluering is op die perseel met behulp van die Biomonitering-tegniek uitgevoer, terwyl die chemiese ondersoeke deur ‘n laboratorium by Eskom uitgevoer is. Die resultate van die chemiese ondersoeke is ge-evalueer op grond van geskiktheid vir gebruik in die akwatiese omgewing.

Die chemiese resultate dui daarop dat die die swakste waterkwaliteit in terme van soutinhoud en pH by die toetspunt naaste aan die kragstasie, naamlik Majuba 1, gevind is. Hierdie uitslag is ook deur die resultate van die biomonitoring bevestig. Geen versouting of pH-verlaging kon by die oorblywende vier punte gevind word nie. Die resultate van die biomonitering by die vier punte het egter wel ‘n afname in die waterkwaliteit getoon, met die uitsondering van Majuba 4. In terme van die biomonitering het Majuba 4 die beste waterkwaliteit getoon. Geen verduideliking vir hiedie afwyking kon bepaal word nie.

Volgens die resultate is dit egter nog te vroeg om tot die volgtrekking te kom dat ‘n verlaging in die pH van die water ‘n werklike probleem is. Hierdie is slegs ‘n voorlopige studie en daar word tans ‘n meer volledige, multidisiplinêre studie in die Vaal-opvangsgebied gedoen om die invloed van lugbesoedeling vanaf kragstasies op die oppervlakwater te bepaal. Hierdie omvattende ondersoek sluit die studie van atmosferiese neerslag, grondwater chemie, grondprofiele, en hidrologie in. Die omvattende ondersoek sal inligting oor waterbesoedeling aan die bestuurders van waterkwaliteit bied, om hulle in staat te stel om strategiee in plek te stel om waterbesoedeling te bekamp.

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CHAPTER 1: INTRODUCTION

Previous studies (Skoroszweski, 1990, Herold and Gorgens, 1991) have indicated that air pollution levels in the Mpumalanga Highveld poses potentially severe environmental hazards. These and other studies have also highlighted the need to research environmental and economic impacts of air pollution on natural resources such as vegetation, soils and water (Walmsey and Olbrich, 1989, DWA&F, 1995 (c)). Hence this research aims to establish the environmental effects of air pollution on surface waters, with particular emphasis on air pollutants arising from coal fired power stations.

This study is done in order to support some of the concepts in the Water Act, Act 36 of 1998. The concepts include the determination of the *Reserve*, the classification of catchments, the water allocations as well as the *polluter pays principle*. The *Reserve* refers to the water that have to be reserved for basic human needs and the aquatic environment before any other water use can be catered for. The *polluter pays principle* is a system where the industry, which pollutes the water, has to pay for the clean up of the water and any other associated fines. Furthermore this research is done in order to inform Eskom's strategic environmental managers regarding the installation of gas cleaning equipment in the smoke stacks.

The approach of this research is to monitor and assess the physical, chemical and biological properties of the surface water around Majuba power station, a coal-fired power station situated in Mpumalanga province. This research forms part of an overall research that will integrate the interaction between atmospheric pollution, vegetation, soil and water.

The question can be asked, do emissions from power stations have an impact on the quality of surface water in their surrounding areas? The main problem addressed by this research is to determine whether the proximity of the Majuba power station to a water resource has an impact on the surrounding water quality. The specific goals of the study are:

- To determine the biological, physical and chemical water quality in the vicinity of Majuba power station.
- To evaluate the water quality in terms of suitability for use by the aquatic environment.

Data and information regarding the surface water quality need to be known before any mitigation measures to reduce the negative impact on the environment can be undertaken (DWA&F, 1995a). This research project can be equated to the initial screening or scoping phase in the environmental impact assessment (EIA) process. The results of which can be used to initiate steps to reduce or eliminate the negative impacts of power station emissions on surface water quality.

The major water quality problems associated with power generation from coal are salinity and acidity (DWA&F,1991a). Majuba power station is located in the Vaal catchment (depicted by C11A-M and C13F-H in Figure 1). It is a catchment with increasing salinity levels and a growing dominance of sulphate (Taviv and Herold, 1990). Increasing salinity and sulphate suggest that atmospheric pollution may be a possible cause of deteriorating water quality.

The quality of surface water in a river is also determined by interactions with soil, transported solids (organics, sediments), rocks, groundwater and the atmosphere (Skoroszweski, 1990, Hodgson and Krantz, 1998). It is therefore important to describe the geology and soil of the study area in order to familiarise the reader with the study area

1.1 LOCATION OF THE STUDY AREA

Eskom's Majuba power station is a large coal-fired plant with power generating capacity of 3 900 MW. The station has been sited in a rural area some distance removed from population concentrations, the closest being the small village of Amersfoort about 10 kilometers away. This location of the study area is represented in Figure 1. Land use in the wider area consists of mixed livestock and arable farming.

1.2 GEOLOGY AND SOIL OF THE STUDY AREA

The geology of the area is relatively simple consisting predominantly of shales of the Volksrust formation (upper Ecca). The Volksrust formation also contains some sandstones and siltstones stringers, and is intruded by Karoo dolerite (DWA&F, 1995b). The widespread incidence of shale accounts for the predominance of clay loam and clay textures in the soils of the area. Under the prevailing climate, dolerite is relatively resistant to weathering and produces shallow soils in upland positions.

Shale and more particularly dolerite, release abundant quantities of divalent bases (calcium and magnesium) during weathering and consequently the soils of the area are for the most part base saturated, with bottomland soils usually containing the calcium carbonate (DWA&F, 1995b). Rainfall is insufficient to deplete the soils of bases by leaching, and acid soils do not occur on shale or dolerite in the area. Calcium and magnesium are important water quality parameters since they affect the buffering capacity of the water.

1.3 RELIEF

The landscape is typically the undulating plains types of the Transvaal Highveld. The altitude varies from 1630 metres to 2033 metres above sea level. The drainage pattern is to the north via minor streams of the Geelklipspruit and Schulpspruit (DWA&F, 1995d). Pans and vleis occur in the southeastern and western portions. The Sandspruit drainage system flows westward south of the Graskop ridge and north of Volksrust. These rivers (i.e. Sandspruit and Geelklipspruit) form part of the Vaal catchment system (indicated as C11A-M and C13F-H in Figure 1) and are some of those monitored in this study. To the east is the Usutu catchment and the Buffalo catchment to the south (DWA& F, 1997).

Figure 1: Location of Majuba power station in the Mpumalanga province

CHAPTER 2: LITERATURE REVIEW

The impact of air pollution on water quality, just like any other aspect of water pollution, is an issue of concern for all the water users since any degradation in water quality affects the water's suitability for use (DWA&F, 1996). In order for the reader to fully comprehend the research problem it is imperative to define some of the terminology used in this research. These terms are *water quality, acidic deposition, acidity* and *salinity of water, buffering capacity* and the *aquatic environment*.

2.1 TERMINOLOGY AND DEFINITIONS

2.1.1 Water Quality

The term water quality describes the biological, physical and chemical properties of water, which determines its suitability for use and its ability to maintain the health of aquatic ecosystems (DWA&F, 1998). It should be noted that water quality requirements of the different user groups are not necessarily the same. Thus water, which is ideally fit for use for one specific user group, may not ideally be suited for another. Quality is thus not an intrinsic property of water, but it is linked to the intended use of the water (DWA&F, 1997). This research assesses water quality in terms of its suitability for use for the aquatic environment.

Biological quality refers to the presence or absence of living organisms in the water (DWA&F, 1998). Since it is difficult and costly to determine all the living organisms in the water, it is generally acceptable to use biological indicators to determine the biological quality of water.

Physical quality of the water refers to those qualities that can be determined by the senses, such as odour, taste, colour and the presence of suspended particulate matter.

Chemical quality refers to the nature and concentration of dissolved substances such as salts, metals and organic chemicals.

2.1.2 Acidic Deposition

The most important anthropogenic pollutants in atmospheric deposition are sulphur dioxide, particulates and nitrous oxides (Turner, 1990). The emphasis in this study has been placed on the sulphate component of atmospheric deposition. Nitrogen compounds are largely taken up in biological processes, whereas sulphate tends to be more inert (Skoroszweski, 2000). Sulphur dioxide and nitrogen oxides are emitted during the power generation process. These emissions may be converted to sulphates and nitrates in the atmosphere and dry or wet deposited onto surfaces such as land and water - a process referred to as *acidic deposition*. Acidic deposition causes acidity of surface waters (Walmsey and Olbrich, 1989).

2.1.3 Acidity Of Surface Waters

Acidity of surface water is indicated by a number of chemical water quality parameters. These parameters include pH, sulphate and aluminium concentrations (DWA&F, 1997). A low pH value (i.e. less than 6 pH units) indicates acidification. The severity of acidification rises with a decrease in pH value. An increase in sulphate and aluminium concentrations in the water also indicates acidity.

2.1.4 Salinisation of Surface Waters

Salinisation refers to the process whereby the concentration of dissolved salts (salinity) increases or the result of this process (Williams, 1987). Salinisation is also referred to as an increase in the salinity of the water, which is depicted by the total dissolved salts (TDS) levels (DWA&F, 1996). TDS is a measure of the quantity of various inorganic salts dissolved in water. The TDS concentration is related to the electrical conductivity (EC) of the water. EC is a numerical expression of the ability of water to conduct an electric current resulting from the presence of charged species in solution (Kempster and Van Vliet, 1991). The main contributing ions to TDS are carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium (WHO, 1984).

2.1.5 Buffering Capacity

Buffering capacity is defined as the ability of a water resource to minimise or counteract the effects of acidification. The levels of cations such as magnesium and calcium as well as the total hardness and total alkalinity in the water give an indication of the buffering capacity of the water (Hart and Allanson, 1984). This means that if the buffering capacity of the water is high then the acidification impacts will be counteracted.

2.1.6 Aquatic Environment

The aquatic environment refers to animals and fish living in the water as well as plants growing in rivers and streams. The aquatic environment is part of the water resource (DWA&F, 1998).

2.2 CAUSE EFFECT RELATIONSHIP OF AIR POLLUTION ON WATER QUALITY

Air pollution is categorised as a diffuse source of water pollution (Bothma, 1998). The impacts of acidification on natural resources including water, are summarised in Figure 2. The impact of air pollution on water quality cannot be determined accurately because of the multi-factorial nature as depicted in Figure 2. However, indications of the impacts of air pollution on water quality can be given, which is what this research is aiming to do. It should be noted that this is a very wide topic

and thus the scope had to be focussed on just the highlighted part (see Figure 2). As indicated in the introduction, this research forms part of an overall research that will address some of the sections in Figure 2 such as acidification of soils, groundwater acidification and forest damage from occult precipitation.

Surface water quality may respond to atmospheric deposition by either a decrease or an increase in solute concentrations (i.e. salts dissolved in water). The most serious effects of atmospheric deposition on catchment surface water quality are those of decreased pH and alkalinity and increased sulphate and aluminium concentrations (Els, 1990, Grobler *et.al*., 1992). This process is known as acidification.

The process of acidification in a freshwater system is a gradual process that proceeds in several stages (Herold, 1996). Initially, the acidity of water draining through the soil is neutralised or buffered in the soil, with the consequent leaching of cations such as calcium and magnesium. As acidification proceeds, bicarbonate concentrations are reduced and replaced by sulphate. The sensitivity of a water body to effects of acid precipitation may therefore be predicted from alkalinity levels, which give an indication of the water's buffering capacity. Acidity is reflected by increased sulphate and aluminium concentrations and decreased pH, calcium and magnesium concentrations (Bothma, 1998).

Another air pollution impact on surface water is salinity (Herold, 1996). Increased total dissolved salts (TDS) and electrical conductivity (EC) concentrations in the water reflect salinity. The contributing ions to TDS are carbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium (Bothma, 1998). It should be noted that salinisation is commonly the result of a combination of point and diffuse source input. Diffuse as opposed to point source pollution is particularly problematic as it can go unnoticed for decades. Overseas experience suggests that serious water quality problems can be expected in the longer term from atmospheric pollution (Claire and Ehrman, 1995).

Changes in aquatic faunal community can be used as indicators of salinity and acidity (Roos, 1994). Degradation of the water resource can be detected by changes in the faunal community composition and these changes can be used to establish cause and effect relationship between air pollution and surface water quality.

In this research, aquatic fauna together with physical and chemical results are used to indicate the state of the water quality around Majuba power station. This is done in order to determine whether power station emissions have an effect on the surrounding surface water quality.

2.3 PREVIOUS RESEARCH

The possibility of negative impacts of air pollution on the environment in South Africa was first highlighted at a workshop in Pretoria in October 1987 (Walmsey and Olbrich, 1989). The workshop addressed "the air pollution situation and its implications in the Eastern Transvaal Highveld" and was attended by people from the private sector, government departments and universities. This workshop was followed by a second workshop in Pretoria in August 1988. The second workshop focussed on reviewing research and identifying future research. One of the identified research needs was to determine the impact of air pollution on surface water quality. Several studies have been done on this research topic.

Skoroszweski, (2000) did a study on the Suikerbosrand catchment, a small undisturbed catchment in the Vaal catchment, to determine the relationship between atmospheric deposition and water quality. The study indicated that sulphate was the most common chemical variable in terms of salinity. Sulphate contributed 30% to 44% of the total salt load in the catchment. The recommendations made in the study included the need for detailed study of the soil as well as the hydrology of the catchment.

A study to determine the sensitivity of the soil environment to the deposition of acidifying air pollutants has as yet not yielded conclusive results (van Tienhoven and Fey, 1998). This study is still continuing.

A study done in the Vaal Dam catchment indicated that increased runoff causes atmospherically deposited sulphate to be washed out of the soil and released into surface waters (Bosman, 1990). It was found that during dry periods atmospherically deposited sulphate is retained in the soil (Bosman, 1990). A four-year study indicated that only 36% of the atmospherically deposited sulphate was exported during dry years, but that 92% was exported during wet years (Bosman, 1990). As South Africa has more “dry years" than “wet years”, this would suggest a considerable accumulation of sulphate soils. Dry years refer to periods of low rainfall and wet years refer to periods of high rainfall.

A hydro-salinity model run for the Vaal Dam indicated that atmospheric deposition could lead to deterioration in water quality in the Vaal Dam catchment (Taviv and Herold, 1990 and DWAF, 1991b). The authors of the report acknowledge that the model contained many simplifying assumptions. The proposal from the above study was to initiate a comprehensive multi-disciplinary project to address the impact of air pollution on the salinisation of surface water.

To assess the quality of the aquatic environment, biological indicators can be used in addition to the chemical and physical water quality parameters.

2.4 BIOLOGICAL MONITORING OF SURFACE WATERS

A background on biological monitoring is given in order to familiarise the reader with this type of monitoring which has been in effect for nearly a decade in South Africa, unlike chemical monitoring which is common practice. The rationale for the choice of biological indicators used in this research is also highlighted in addition to the chemical and physical water quality parameters.

Traditionally information gathered to assist the management of water resources was predominantly non-ecological in nature (Roux, 1992). Monitoring action focussed largely on chemical and physical water quality variables. The measurement of only physical and chemical water quality variables cannot, however, provide information on the overall condition of the aquatic ecosystem (Roux, 1992). Chemical monitoring alone is insufficient to detect, for example, the cumulative and/or synergistic effects on aquatic ecosystems resulting from multiple stressors.

Many factors other than chemical water quality may have an influence on the ecological state of an ecosystem. These factors include habitat alteration, flow regulation, abstraction of water and the introduction of exotic species (Dallas and Day, 1993). Effective management of aquatic ecosystems must therefore address the effects of all these changes. In recognition of the integrated and complex nature of ecosystems, the monitoring and management has shifted to a more integrated ecosystem management approach (Roux, 1992).

Biological monitoring or biomonitoring techniques can be used to assess the overall health of, and quantifying the impacts on, aquatic ecosystems (Dallas et.al, 1999, Mcmillan and Moore, 1993). Biological monitoring is based on the assumption that measurement of the condition of aquatic communities can be used to assess the condition of the associated ecosystem (Chutter, 1992).

Aquatic biomonitoring programmes are developed for various purposes, including the following (Roux, 1992):

- Surveillance of the general ecological state of aquatic ecosystems
- Assessment of impacts (before and after or upstream and downstream of an impact, both for diffuse and point-source impacts)
- Audit of compliance with ecological objectives or regulatory standards, and

- Detection of long-term trends in the environment as a result of any number of perturbations.

In this study aquatic biomonitoring is used for assessment of impacts with the long-term aim of detecting trends (Roos, 1994).

Biological indicators commonly used for the aquatic environment are (Roux, 1992):

- Fish - being relatively long-lived and mobile, fish are good indicators of long-term influences on a river reach and the general habitat conditions within the river reach
- Invertebrates - invertebrate communities are good indicators of localised conditions in a river, especially regarding water quality, over the short-term.
- Riparian vegetation - healthy riparian zones maintain channel form and serve as important filters for light, nutrients and sediments. Changes in the structural or functional characteristics of riparian vegetation community indicate changes in the flow regime of a river, exploitation for fuel (wood), or the use of the riparian zone for grazing and ploughing.

Macro-invertebrates have been chosen to monitor the biological quality of surface water around Majuba power station since they provide a quick cost-effective method for the assessment of water quality.

There are two distinct monitoring approaches that can be followed namely: s*tressor monitoring* and *response monitoring* (Roux, 1992). The characteristics of these two monitoring approaches are summarised in Table 1 below.

Thus the aims of this research address both stressor and response assessment approaches. For example, determining the physical and chemical water quality and assessing them in terms of suitability for use by the aquatic environment addresses the stressor-oriented measurement and assessment end points. On the other hand, monitoring and assessing the changes in water quality using biological indicators addresses response-oriented measurement and assessment end points.

The two environmental management approaches namely *stressor-oriented* and *response-oriented* have been discussed and the linkages of these approaches to this research project have been demonstrated. Using both these approaches provides holistic water quality information for water quality managers.

Table 1: Characteristics of the stressor and response monitoring and assessment approaches (Roux, 1992).

	Stressor-oriented approach	**Response-oriented approach**
Monitoring focus	Causes (stressors) of pollution e.g. organic and inorganic contaminants.	Effects (responses) resulting from pollution e.g. changes in the composition or abundance of biological communities.
Management focus	Water quality regulation: controlling sources of pollution (e.g. end-of-pipe focus)	Aquatic ecosystem protection: managing the ecological health of the receiving water body (ecosystem or resource focus)
Measurement end-points	Concentration of chemical and physical water quality variables, e.g. pH, dissolved oxygen, copper.	Structural and functional attributes of biological communities, e.g. diversity and abundance of benthic invertebrates.
Assessment end-points	Compliance or non-compliance with a set criterion or discharge standards	Degree of deviation from a benchmark or desired biological condition.

This chapter gave the explanations of the terminology used as well as a detailed background on biomonitoring. Factors affecting the salinity and acidity of water have also been discussed briefly. Details of the methods used in biological and chemical water quality monitoring and assessment follow in the next chapter.

CHAPTER 3: SAMPLING AND ASSESSMENT

As discussed previously, the effect of power station emissions on surface water, was assessed by monitoring the chemical and biological quality of the surface water in the vicinity of Majuba power station. The approach involved selecting six water quality monitoring sites in the vicinity of Majuba power station. Biological and chemical water quality samples were taken from these sites and assessed in terms of suitability for use for the aquatic environment.

3.1 LOCATION OF THE MONITORING SITES

Six water quality monitoring sites in the vicinity of Majuba power station were selected to monitor whether the emissions from the power station have an effect on the surface water in its vicinity. The criteria used for the selection of these sites were (McMillan and Moore, 1993):

- Accessibility by road to enable water quality samples to be taken
- Perennial flow of the streams, since the presence of water flow is an important aspect in biological monitoring. Also, the flow determines the habitat of macro-invertebrates.
- Proximity to Majuba power station since the aim of the project is to assess air pollution impacts due to station emissions from the power station on surface water quality in the vicinity.

The site locations as well as the distance from Majuba power station are given in Table 2 below and shown spatially in Figure 3.

Table 2: Site location and distance from Majuba Power Station

Site	River	Location	Distance from Station (km)
MAJ1	Geelklipspruit	27° 03' 32" S 29° 46' 01" E	4,7
MAJ2	Witbankspruit	27° 02' 36" S 29° 48' 03" E	7,5
MAJ3	Schulpspruit	27° 08' 13" S 29° 50' 55" E	9,2
MAJ4	Watervalspruit	27° 19' 01" S 29° 46' 32" E	24,0
MAJ5	Sandspruit	27° 15' 47" S 29° 46' 51" E	18,0
MAJ6	Sandspruit	27° 14' 02" S 29° 34' 07" E	30,8

A brief description of the sampling sites is given below.

3.1.1. Majuba site 1

Majuba site 1 (MAJ1 in Table 2) is located 4,7km to the north of the power station on the Geelklipspruit river. The farming land close to the river is used primarily for grazing. The riverbed comprises of 75-80% rocks and the rest is sand and mud. The water velocity features include running water, fast riffles and pools. The water is generally silty after the rains. This is the nearest water quality monitoring site to the power station.

3.1.2. Majuba site 2

Majuba site 2 (MAJ2 in Table 2) is located 7,5km north-north-east of the station on the Witbankspruit river. The site is close to a road where the stream passes under a bridge. There are some standing pools of water. The riverbed is made up of approximately 30% sand, 30% rock and the rest, mud and bedrock. Velocity features include slow riffles, deep running water and pools. The water is only slightly discoloured. Rocks and vegetation cover approximately 80% of the banks, which include grass and reeds.

3.1.3. Majuba Site 3

Majuba site 3 (MAJ3 in Table 2) is located 9,2km east-south-east of the power station on the Schulpspruit river. The river source lies in an area approximately 11km south east south of the station. The riverbed comprises of 80% rock and the rest is sand. The velocity features include shallow water, rifles and running water. Grass and reeds cover 80% of the banks.

3.1.4. Majuba Site 4

Majuba site 4 (MAJ4 in Table 2) is located on the Watervalspruit approximately 24km to the south of the power station. The riverbed consists mainly of rocks and boulders, with 25% being mud and bedrock. Velocity features include deep and shallow running water with fast and slow riffles and pools. The banks are steep and partly covered with grass and reeds.

3.1.5. Majuba Site 5

Majuba site 5 (MAJ5 in Table 2) is located 18km south of the power station on the Sandspruit. The riverbed consists of varying degrees of rocks, sand and bedrock. Velocity features include deep running water and fast riffles. The water in Sandspruit is often brown due to the high silt loading. The banks are covered with grass, reeds and a few trees.

3.1.6. Majuba Site 6

Majuba site 6 (MAJ6 in Table 2) is located 30,8km west-south-west of the power station on the Sandspruit. The riverbed consists of varying degrees of rocks, sand and bedrock. Velocity features include deep running water and fast riffles. The water in Sandspruit is often brown due to the high silt loading. The banks are covered with grass, reeds and a few trees.

3.2 WATER SAMPLING

Chemical and biological water quality samples were taken from the six sites (namely Majuba 1 to Majuba 6). The sampling frequency was four times a year coinciding with the four seasons of the year. The results reported on are from samples taken over a three year period (i.e. 1997-1999).

Seasonal sampling was used because overseas experience suggests that the contamination of surface water with air pollutants varies seasonally, and in some areas appears to become particularly acute following spring snowmelt (Claire and Ehrman, 1995). Other areas experience peaks of acidity in autumn, probably as the onset of rains washes material deposited during summer. Many areas are subjected to highly variable acidity depending on whether the storm track included industrial or urban areas (Claire and Ehrman, 1995).

3.3 WATER QUALITY ANALYSES

The water samples were subjected to chemical and biological analyses. The biological analyses were done on site, while the chemical analyses were conducted in the laboratory at Eskom to depict acidity, salinity and buffering capacity.

The chemical parameters analysed are:

Water quality parameters depicting acidity and salinity:

- pH
- Sulphate (SO_4)
- Aluminium (Al)
- Total dissolved salts (TDS)
- Chloride (Cl)
- Electrical conductivity (EC)
- Sodium (Na)

Water quality parameters responsible for the buffering capacity:

- Total hardness (Thard)
- Total alkalinity (Talk)
- Calcium (Ca)
- Magnesium (Mg)
- Potassium (K)

Other water quality parameters analysed:

- Nitrate (NO_3)
- Ammonia (NH_3)
- Suspended solids (SS) which indicates suspended material in the water.

Biological monitoring is a recent water quality monitoring procedure and hence it is important to discuss it in much more detail than chemical monitoring which is common practice (Chutter, 1992). Biological analysis was done on-site using the South African Scoring system version 4 (SASS4) technique (Chutter, 1992). SASS4 evaluates the impact of changes in water quality, using aquatic macro-invertebrates as indicator organisms. Details on the SASS4 technique are given under the water quality assessment section.

3.4 ASSESSMENT OF WATER QUALITY

Chemical water quality was assessed in terms of the South African Water quality guidelines for the aquatic environment. Biological water quality was assessed in terms of SASS4.

3.4.1 Chemical Water Quality Assessment

In order to assess the quality of water, the guidelines of the Department of Water Affairs for the aquatic environment were used to assess the chemical water quality. Water quality guidelines for aquatic environments are represented in terms of:

- The Target water quality range (TWQR)- this is a range of concentrations within which no measurable adverse effects are expected on the health of the aquatic ecosystems, and should therefore ensure their protection.
- The Chronic effect value (CEV) - this is defined as that concentration of a parameter at which there is expected to be a significant probability of measurable chronic effects in up to 5% of the species in the aquatic community. If such chronic effects persist for some time they can lead to disappearance of sensitive species from aquatic ecosystems. This can have considerable negative consequences for the health of aquatic ecosystems, because of the interdependency among the components of the of the aquatic ecosystem.
- The Acute Effect Value (AEV) - this is defined as that concentration above which there is expected to be a significant probability of acute toxic effects in up to 5% of the species in the aquatic community. If such acute effects persist for even a short while, or occur at too high a frequency, they can quickly cause the death and disappearance of sensitive species or communities from aquatic ecosystems. This can have considerable negative consequences for the health of the aquatic ecosystems, even over a short period.

In order to summarise the water quality guidelines for the aquatic environment it can be said that the target water quality refers to a good aquatic environment, chronic effect value refers to tolerable aquatic environment with minimal impacts and acute effect value refers to significant impact on the aquatic environment.

It should be noted that most of the impacts of the water quality parameters on the aquatic environment are synergistic and depend also on the life stages of the aquatic organisms. In cases where water quality guidelines are not available an indication of whether the measured concentration of that particular water quality parameter is high or low is given. The water quality guidelines for the aquatic environment are represented in Table 3.

Table 3: Water Quality Guidelines For The Aquatic Environment. (DWA&F, 1996)

Parameter	**Target water quality range (mg/l)**	**Acute effect Value (AEV-mg/l)**	**Chronic effect value (CEV-mg/l)**
Aluminium	≤ 5	100	10
Ammonia	≤ 7 N/l	100	15 l
Arsenic	≤ 10	130	20
Residual chlorine	≤ 0.2	5	0.35
Chromium (III)	≤ 12	340	24
Chromium (VI)	≤ 7	200	14
Cyanide	≤ 1	4	110
Fluoride	≤ 750	2 540	1500
Manganese	≤ 180	1 300	370
Mercury	≤ 0.04	1.7	0.08
Zinc	≤ 2	36	3.6
pH	pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day by >0.5, of a pH unit, or by > 5%.		
TDS	TDS concentrations should not be changed by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year, and the amplitude and frequency of natural cycles in TDS concentrations should not be changed.		

Some parameters' water quality guidelines depend on the softness or hardness of the water. This is indicated in Table 4 below.

Table 4: Water Quality Guidelines for the Aquatic Environment (DWA&F, 1996).

	µg/l Copper concentration	mg/l Caco3			
		< 60 (Soft)	60-119 (Medium)	120-180 (Hard)	➢ 180 (Very Hard)
Target water quality range	Copper (µg/l)	≤ 0.3	≤ 0.8	≤ 1.2	≤ 1.4
Chronic effect value	Copper (µg/l)	0.53	1.5	2.4	2.8
Acute effect value	Copper (µg/l)	1.6	4.6	7.5	12
Target water quality range	Cadmium (µg/l)	≤ 0.15	≤ 0.25	≤ 0.35	≤ 0.40
Chronic effect value	Cadmium (µg/l)	0.3	0.5	0.7	0.8
Acute effect value	Cadmium (µg/l)	3	6	10	13

3.4.2 Biological Water Quality Assessment

The biological water quality is assessed using the South African Scoring System version 4 (SASS4), which involves the identification of macro-invertebrates in the water sample to family level and then returning the sample to the stream (Davies *et al*., 1993). In SASS4, macro-invertebrates are scored according to their sensitivity to deterioration in water quality (Davies *et al*, 1993; Mcmillan and Moore, 1993). The scores range from 0 to 15, with highly pollution-tolerant species scoring low, and intolerant/highly sensitive species score high. The SASS4 score sheet is represented in Appendix 1.

Abundance of the macro-invertebrate family at a site is also indicated by A, B, C or D on the score sheet (see Appendix 1). However the level of abundance is not incorporated into the final SASS4 score. Other categories, which are scored, include the SASS4 found at a site averaged over the total number of macro-invertebrate families (taxa) found as represented in the equation below. This average is referred to as average score per taxon (ASPT).

$$\text{ASPT} = \frac{\text{SASS4}}{\text{Number of taxa}}$$

SASS4 and ASPT are used in the biological evaluation of the water quality at a monitoring site. Guideline values for rating biological condition on the basis of the combined SASS4 and ASPT are given below. These guidelines are applicable to all rivers in South Africa except for Western Cape rivers with pH < 6 (Chutter, 1992). The biomonitoring results have been interpreted according to Table 5.

Table 5: Interpretation of Biological Monitoring Results

Scores assigned	Water quality
SASS > 100 ASPT >6	Natural water quality, habitat diversity high
SASS < 100 ASPT >6	Natural water quality, 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 extent by which SASS4 exceeds 100 and ASPT < 6.
SASS 50-100 ASPT < 6	Some deterioration in water quality
SASS < 50 ASPT variable	Major deterioration in water quality

The quality of the water obtained from the six Majuba sites monitored in the study, was assessed according to the guidelines given in Tables 3 and 4 and the interpretations given in Table 5. The results and discussion of the water quality are given in Chapter 4.

CHAPTER 4: RESULTS AND DISCUSSION

The results for the monitoring periods 1997 to 1999 for Majuba 1 to Majuba 6 are presented graphically (Figures 4 to 21). A brief discussion on the suitability of water for the aquatic environment is also given in cases where the guideline value is available. In cases where there is no guideline for the aquatic environment an indication of whether the concentration of the particular water quality parameter is high or low is given. Acidity and salinity of water are presented together since some of the parameters that affect acidity also affect salinity. Buffering capacity is also discussed since it has an effect on acidity. Buffering capacity serves to counteract the effects of acidity and might mask them.

These results are presented according to water quality parameters depicting acidity and salinity, the parameters responsible for buffering capacity, and the biological water indicators.

4.1 WATER QUALITY PARAMETERS DEPICTING ACIDITY AND SALINITY

As discussed previously, acidity is indicated by levels of pH, sulphate and aluminium, while levels of total dissolved salts and electrical conductivity in the water indicate salinity. The contributing ions to total dissolved salts are carbonate, sulphate, chloride, nitrate, calcium, magnesium and sodium (Bothma, 1998). The water quality parameters assessed are:

- Electrical conductivity
- pH
- Sodium
- Chloride
- Sulphate
- Aluminium
- Total dissolved salts

Water quality results of these parameters are represented graphically in figures 4 to 10.

4.1.1 Electrical Conductivity

Electrical conductivity (EC) is a numerical expression of the ability of water to conduct an electrical current, resulting from the presence of charged species in solution (Kempster and Van Vliet, 1991). The major contributing ions are carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium (WHO, 1984).

The electrical conductivity of water provides an indication of dissolved salts present, hence of salinity or total dissolved salts (TDS) content. High concentrations of salts can have undesirable effects in terms of aesthetic acceptability of water and economic implications through the promotion of corrosion (DWA&F, 1991(a)). It is a good indicator of possible contamination of a water source and should always be included in water quality monitoring to identify sudden changes in water quality and existing contamination.

There is no EC guideline for the aquatic environment (DWAF, 1996). However, according to Figure 4, it is noted that Majuba1 and 2 (which are sites closest to the Majuba power station) indicate high EC concentrations. This can be an indication of possible salinisation at these two sites.

4.1.2 Acidity (pH)

pH is the measure of acidity or basicity. A pH value of 7 indicates neutrality. For this study, a pH greater than 8 indicates basicity and a pH less than 6 indicates acidity of water.

The pH of all the sites is generally between 5 and 9 pH units (see Figure 5). Thus the pH does not indicate acidification of the water. However, the November 1997 sampling trip indicated pH values less than 6 but more than 5 at all the sampling sites except at Majuba 1. During this trip Majuba 1 had a pH of 6. The pH value of less than 6 at Majuba 1 was recorded during the July 1997 sampling session. Only one sampling session (November 1997), at all the sampling sites, was a pH value of less than 6 recorded. Thus no conclusion regarding acidity can be drawn from this.

4.1.3 Sodium

The levels of sodium in surface waters are generally low in areas of high rainfall and high in arid areas with low mean rainfall (DWA&F, 1991a). Industrial wastes, especially processes that give rise to brines, contain elevated concentrations of sodium. With re-use or recycling of water, the sodium concentration will tend to increase with each cycle (DWAF, 1995 a). According to Figure 6, Majuba 1 has the highest sodium concentration. The other five sites have very low sodium concentrations except for the December 1999 sampling trip at Majuba 2, which had a sodium concentration of 99.4 mg/l.

4.1.4 Chloride

Chloride, a common constituent of water, is highly soluble and once in solution tends to accumulate. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes. Chloride is of concern in water supplies because elevated concentrations accelerate the corrosion rate of metals and shorten the lifetime of equipment and structures.

The water quality guidelines are available for free residual chlorine and not chloride (DWAF, 1996). The chloride concentrations are highest for Majuba 1 and Majuba 2 and also seem to be generally higher during the dry periods (i.e. June, July and August). Chloride concentrations measured at the six sites is given in see Figure 7.

4.1.5 Sulphate

Sulphate is a common constituent of water and results from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals (DWA&F, 1996). Sulphates are discharged from acid mine wastes as well as many other industrial processes using sulphuric acid or sulphates in their processes. Atmospheric sulphur dioxide, discharged as a result of combustion of fossil fuels, can give rise to acid rain, which in turn results in the return of sulphate to surface waters in the environment (Walmsey, 1995).

Sulphate concentrations in unpolluted fresh water are typically less than 10 mg/l. Waters polluted by acid mine drainage and effluent return flows may contain as much as 500 mg/l sulphate. There is no sulphate guideline for the aquatic environment. By looking at Figure 8, it is noted that Majuba 1 has the highest sulphate concentration of all the six sites. All the other five sites have sulphate concentrations of less than 60 mg/l except for Majuba 2 with a sulphate concentration of 388 mg/l for the December 1999 sampling trip.

4.1.6 Total Dissolved Salts

The total dissolved solids (TDS) concentration is a measure of the quantity of various inorganic salts dissolved in water. The TDS of natural waters often depend on the characteristics of the geological formations that the water was, or is, in contact with. The natural processes causing TDS are enhanced through anthropogenic activities such as domestic and industrial effluents discharges (mine pump water), surface runoff from urban, industrial and cultivated areas, irrigation and other return flows. The TDS concentrations of Majuba 1 and Majuba 2 are the highest (see Figure 9). This is an indication of possible salinisation of the water.

4.1.7 Aluminium

Aluminium can be mobilised from soils and sediments by both natural weathering and accelerated acidification processes, resulting in detectable concentrations in surface waters (DWAF, 1996). Although aluminium is found in waters made naturally acidic by humic and fulvic acids, it usually adsorbs onto these and is therefore not available in soluble form in such waters, even at low pH levels. Aluminium is found in soluble forms mainly in acid mine drainage waters and is also of concern in natural waters affected by acid rain.

Aluminium is one of the principal particulates emitted from the combustion of coal (DWAF, 1996). Various species of aluminium and their salts and complexes act as buffers in very acid waters in which the carbonate/bicarbonate buffering system is no longer operational.

Aluminium concentrations measured at all the sites are above the chronic effect value of 20 ug/l for the aquatic ecosystem (see Figure 10). There are samples at all the sampling sites that exceed the acute effect value of 150 ug/l for the aquatic ecosystem. The toxic effects of aluminium are dependent on the species and life stages of the organism, the concentration of calcium in the water and pH.

Concluding remarks

A background on the parameters depicting acidity and salinity of surface water was given. From the results it is evident that salinity is higher at Majuba 1 and Majuba 2 as compared to the other water quality monitoring sites.

4.2 WATER QUALITY PARAMETERS RESPONSIBLE FOR THE BUFFERING CAPACITY

In order for a complete water quality assessment the buffering capacity of the water needs to be taken into consideration. Therefore the following section discusses the buffering capacity at the six sites monitored.

As indicated previously, the buffering capacity of the water counteracts or minimises the effects of acidification. The water quality parameters that indicate the buffering capacity are :

- Total alkalinity
- Calcium
- Magnesium
- Total hardness
- Potassium

Details on the levels of these parameters over the three-year sampling period (1997-1999) at the six monitoring sites are given below.

4.2.1 Total Alkalinity

Alkalinity is the sum of the anions (OH-, $C0_3^{2-}$ and HCO_3) of weak acids and hydroxyl ions and bicarbonate in a sample of water. The total alkalinity gives an indication of the buffering capacity of the water.

According to the results (Figure 11), all the sites have alkalinities in excess of 20 mg/l $CaCO_3$ which indicates that they have a high buffering capacity and are thus less sensitive to acidification.

4.2.2 Calcium

Calcium is one of the cations associated with the weathering of the rocks. The calcium concentration of Majuba 1 and 5 is generally less than 30 mg/l. Majuba 2 has an overall higher Ca concentration when compared to the other sites (see Figure 12).

4.2.3 Magnesium

Magnesium as well as calcium are associated with weathering of rocks. The Mg concentration patterns are similar to the Ca concentration patterns (compare Figures 12 and 13). Majuba 1, 2, 4 and 6 have higher Mg concentrations (Figure 13). Majuba 3 and 5 have lower magnesium concentrations (i.e. less than 20 mg/l).

4.4.4 Total Hardness

The total hardness is the sum of the calcium and magnesium concentrations expressed as mg/l of calcium carbonate. Temporary hardness is due to the presence of bicarbonates of calcium and magnesium and can be removed by boiling, whereas permanent hardness is attributed to other salts such as sulphate and chloride salts, which cannot be removed by boiling. An indication of the various types of water is given below:

Type of water	$CaCO_3$ in mg/l
Soft	<60
Medium	60-119
Hard	120-180
Very hard	>180

Majuba 3 and 5 have medium to hard waters (see Figure 14). Majuba 1 and 6 have medium to very hard waters while Majuba 4 has hard to very hard waters. Majuba 2 has very hard waters. According to these results the buffering capacity will be high for Majuba 2 and 4.

4.2.5 Potassium

Potassium always occurs in water in association with anions, usually chloride, but can also occur with sulphate, bicarbonate or nitrate. High concentrations of potassium may occur in runoff from irrigated lands and from fertilizer production and domestic wastes. The potassium concentration is generally low (i.e. less than 12 mg/l) at all sites except for the November 1998 sampling trip at Majuba 4 (see Figure 15). This increase is probably due to the irrigation in the area.

Concluding remarks

The buffering capacity of the six monitoring sites has been discussed. From the discussion it is evident that the sites around Majuba power station have high buffering capacity.

4.3 OTHER CHEMICAL PARAMETERS OF INTEREST

In addition to the parameters already discussed, there are other parameters that are included in the water quality analyses, and these also form part of water quality assessment.

These parameters have been included in the study because they have an impact on the aquatic environment even though they are not classified under those causing salinity and acidity or those parameters responsible for buffering capacity. The total suspended solids, nitrate and ammonia are important parameters for assessing water quality for use by the aquatic environment The rationale for inclusion of these parameters in this research is discussed below.

4.3.1 Nitrate

Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. In aquatic systems, elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms.

There is no available nitrate guideline for the aquatic environment. According to Figure 16, Majuba 1 has the highest nitrate concentration.

4.3.2 Ammonia

Natural sources of ammonia include gas exchange with the atmosphere, the chemical and biochemical transformation of nitrogenous organic and inorganic matter in the soil and water, the excretion of ammonia by living organisms, the nitrogen fixation processes whereby dissolved nitrogen gas enters the water and ground water. Ammonia, associated with clay minerals, enters the aquatic environment through soil erosion. Bacteria in root nodules of legumes fix large amounts of nitrogen in the soil and this may be leached into surrounding water. Ammonia from commercial fertilizers can be transported to the aquatic ecosystem via the atmosphere or irrigation waters. High ammonia levels are toxic to the aquatic environment.

The ammonia guideline for the aquatic environment is 7ug/l. The ammonia concentration at all the sites is far below the guideline value. Ammonia concentrations for Majuba 1 and 2 are not presented since all the values were below the laboratory detection limit of 0.1 mg/l (see Figure 17).

4.3.3 Total Suspended Solids

The total suspended solids (TSS) concentration is a measure of the amount of material suspended in water. Natural variations in rivers often result in changes in TSS, the extent of which is governed by the hydrology and geomorphology of a particular region. Suspended solids arise from erosion of land surfaces as well as land use practices such as overgrazing, removal of riparian vegetation and forestry operations.

Figure 18 indicates that the suspended solids are generally the highest at Majuba 1. The suspended solids were high at Majuba 5 during November 1997 and 1998, and also high at Majuba 6 during November 1997. The suspended solids tended to increase during the rainy periods (November to January) at all the sampling sites with the exception of Majuba 4.

<u>Concluding remarks</u>

The results indicated that the nitrate and ammonia are generally low and suspended solids seem to increase during the rainy periods at all the sites with the exception of Majuba 4.

The chemical water quality assessment was presented under three subheadings, namely those parameters responsible for acidity and salinity, those parameters responsible for buffering capacity and those parameters that form part of chemical water quality analysis. Detailed synthesis and conclusion is given in Chapter 5.

As indicated previously that chemical water quality analysis does not represent a holistic assessment of the water quality the biological quality has also been discussed in the following section.

4.4 BIOLOGICAL WATER QUALITY RESULTS

The biological assessment is done on-site by counting the number of macro-invertebrate families collected. The parameters under this section are:

- Number of families (FAMS)
- South African Scoring system version 4 (SASS4)
- Average score per taxon (ASPT).

4.4.1. FAMS

This is a representation of the number of macroinvertebrate families. The higher the number of families the better the quality of the water. According to these results (Figure 19) Majuba 6 has the lowest family score (less than 10). Majuba 1 and 5 have family scores less than 15 for all the sampling trips. The family scores for Majuba 2, 3 and 5 vary and they are in the region of 20 for some sampling trips.

4.4.2 SASS4 and ASPT

SASS4 and The average score per taxon (ASPT) results are interpreted together in Table 6 below to give an indication of water quality and habitat diversity. The graphical representation is given in Figures 20 and 21 respectively.

Table 6: A summary of the water quality based on biological indicators.

Site	Water quality
Majuba 1	There is moderate deterioration to major deterioration in water quality. Major deterioration is evident during the dry season. This improves during the rainy seasons.
Majuba 2	Moderate deterioration in water quality
Majuba 3	Moderate deterioration in water quality
Majuba 4	Borderline case between natural water quality and minor deterioration in water quality during the 1996 sampling trips. The 97 and 98 results show some deterioration in water quality.
Majuba 5	Moderate deterioration in water quality
Majuba 6	Moderate deterioration in water quality

Concluding remarks

The biological quality indicates that in general the water quality shows moderate deterioration. However major water quality deterioration is evident at Majuba 1 during the dry season (i.e. June, July, August) but improves with the rainy season (i.e. November, December, January). The best water quality in terms of biological quality is found at Majuba 4. The water quality at this site is on the borderline between natural water quality and minor water quality deterioration.

The chemical and biological water quality results have been presented graphically and discussed in this section. A synthesis of the research, conclusions that have been drawn as well as the recommendations of the research is given in the following section.

CHAPTER 5 : SYNTHESIS AND CONCLUSION

The purpose of this study was to investigate the impact of atmospheric emissions from the Majuba power stations on the surface water quality. It was envisaged that the information obtained from the study would assist Eskom management in making decisions regarding atmospheric emission abatement technologies that need to be employed in coal-fired power stations. This would contribute towards minimising the impact of atmospheric pollution on the environment.

The study investigated the possibility of occurrence of salinity and acidity problems in these waters. These water quality problems are associated with atmospheric pollution due to emissions from coal-fired power station.

The research involved assessing the water quality around Majuba power station in terms of its suitability for use by the aquatic environment. The physical, chemical and biological quality of the water was assessed at six sampling sites (Majuba 1 to 6) for a period of three years (1997-1999), with a sampling frequency of four times a year. In 1997, only two sample trips were undertaken due to logistical problems. In 1998 and 1999 four sampling trips, coinciding with the four seasons of the year, were undertaken. This was done because it was indicated previously that seasonality affects biomonitoring and acidity of the water (Bosman, 1990, Claire and Ehrman, 1995).

The current research had some limitations that are highlighted in the next section.

5.1. LIMITATIONS TO THE STUDY

The complex interactions that acidic deposition undergoes with the environment, before it can affect surface water quality, makes it very difficult to relate the cause

with the effect (Roos and Turner, 1994). The complex interactions are also subject to variations through factors such as soil types and land use.
Only one pathway, namely, atmospheric deposition of surface water quality impacts was discussed in this study. This limitation is due to the fact that this study forms part of a more comprehensive research addressing atmospheric deposition, water chemistry and soil chemistry in the upper Vaal catchment (as stated on page 1).

The weather also proved to be another limitation to this study. Due to the flooding or dryness at the sampling sites, fewer samples than intended were taken at some sampling sites. The fewer samples made water quality assessment difficult.

The lack of water quality data at the sampling sites prior to the operation of the Majuba power station also served as a limitation. The data would have provided invaluable background information for comparison purposes between the before conditions (i.e. prior to the construction of Majuba power station) and the after conditions.

The effects of atmospheric deposition on surface water usually become evident over a lag phase of several decades. The study was done over a three-year period hence it cannot make conclusive remarks regarding the impacts. Hence the investigation period of three years is also a limitation to this study. That is the reason why the water quality monitoring is continuing to date.

5.2. RESULTS

From the results, Majuba 1 has elevated sulphate concentrations as compared to the other sites. Aluminium concentration, a factor known to increase with increasing acidification, seems to indicate a seasonal variation, being highest during the rainy season (November, December and January). The sulphate and aluminium concentration can be an indication that Majuba 1, which is the site closest to the power station, is undergoing possible acidification. However, the pH is in the neutral state (6-8 pH units). This might be due to the fact that the pH decreases only after the buffering capacity has decreased. As indicated by total alkalinity and total hardness, the buffering capacity at Majuba 1 is high.

The total dissolved salts, electrical conductivity, sodium, potassium and chloride concentrations at Majuba 1 are also elevated. This is an indication that the water in this area is undergoing salinisation.

The biological monitoring results, on the other hand, indicate that the water quality shows moderate deterioration to major deterioration during the dry season. In this respect Majuba 1 has the worst water quality of all the monitoring points around the Majuba power station.

Majuba 2 does not indicate acidification of water since the sulphate, as well as aluminium concentrations, are well within acceptable levels. The total alkalinity levels indicate that Majuba 2 is the site least sensitive to acidification since the average concentration for the three years exceeds 20 mg/l $CaCO_3$. Elevated chloride, electrical conductivity and TDS indicate that there is some degree of salinisation of the water. The biological results indicate that there is moderate deterioration in water quality.

Majuba 3 has very low sulphate concentrations i.e. less than 30mg/l. The EC and TDS concentrations are also relatively low. The sulphate concentrations are relatively low and do not indicate acidification. The nitrate concentrations are also very low which is a sign that eutrophication is not occurring. The biological results indicate that there is moderate deterioration in water quality.

The physico-chemical results indicate that the water quality at Majuba 4, Majuba 5 and Majuba 6 is acceptable. However, the biological monitoring results indicate that there is moderate deterioration in water quality at Majuba 5 and 6. Majuba 4 is a borderline case between natural water quality and minor deterioration in water quality. The conclusions drawn from this synthesis follows.

5.3 CONCLUSIONS

The study investigated the impact of atmospheric emissions on the surface water quality around Majuba power station. In conclusion it can be said that emissions due to coal-fired power generation do affect the quality of surface waters. The water quality results of the six sites indicated that the two sites closest to the power station (namely Majuba 1 and Majuba 2 which are 4,7 and 7,5 kilometres respectively from Majuba power station) showed salinity problems. This is indicated by the acidity levels at Majuba 1 as represented by sulphate as well as the salinisation effects represented by total dissolved salts at both Majuba 1 and Majuba 2. The pH values at these sites do not indicate acidity. These monitoring points are within a 10 kilometre radius from the Majuba power station.

This research can be considered as an initial screening. As indicated previously, electrical power generation is probably not the only source of water pollution in the area. Other pathways such as soil and groundwater through which air pollution impacts water quality need to be investigated (Hart and Allanson, 1984). The comprehensive research will give a holistic picture of water pollution so as to lay the basis for holistic water quality management.

Recommendations to this effect have been made and a proposal to the Water Research commission will be submitted for a more detailed study.

5.4 RECOMMENDATIONS

Acidification of surface water is a long-term process and its effects only becomes evident after a lag phase of several decades, hence it is recommended that the monitoring programme should continue. The following recommendations are made in line with the motivation of the study as well as the findings of the study.

- Other pollution sources that can have an effect on the salinity and acidity of the water in the upper Vaal catchment should be investigated.
- More data should be collected in order to establish seasonal trends and an investigation of the factors causing the trends should be carried out. Several studies have mentioned seasonality as a factor associated with the acidity of the water.
- Pollution prevention and/or minimisation measures based on the findings of this investigation should be determined and implemented..
- The monitoring programme should continue to develop a detailed data set that will assist catchment management agencies in setting up classification of the rivers and determining the water allocation to different water uses in the catchment in line with the South African Water Act, Act 36 of 1998. As mentioned in the introduction, supporting the Water Act is one of the reasons for conducting this research.

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APPENDIX 1: SASS4 SCORESHEET

SASS4	Taxon	A*			Aeshnidae	8		
River	Porifera	5			Corduliidae	8		
	Coelenterarata				Libelludiae	4		
Date	Hydra sp.				Hemiptera			
	Tubellaria				Notonectidae	3		
Time	Planarians	5			Pleidae	4		
	Annelida				Naucoridae	7		
Sampling point :	Oligochaeta	1			Nepidae	3		
	Hirudunea				Belostomatidae	3		
Temp ^{0}C	Leeches	3			Corixidae	3		
	Crustacea				Gerridae	5		
pH	Amphipoda	15			Veliidae	5		
	Crabs	3			Megaloptera			
Cond (mS/m)	Shrimps	8			Corydalidae	8		
	Hydracarina				Trichoptera			
Biotopes sampled	Hydrachnellae	8			Hydropsychidae : 1 sp	4		
	Plecoptera				Or 2 spp	6		
SIC ……. (Type/time) ………..	Notonemouridae	12			Or > 2spp	12		
	Perlidae	12			Philopotamidae	10		
Marg veg… Dom so…….	Ephemeroptera				Polycentropodidae	12		
	Polymitarycidae	10			Psychomydiiae	8		
Aq veg … Dom. Spp…..	Ephemeridae	15			Ecnomidae	8		
	Baetidae 1sp	4			Hydroptilidae	6		
SOOC… Sand.. .Mud… Gravel ..	2 spp or	6			Other movable case larvae			
	> 2 spp	12			Case type score fam			
Other	Oligoneuridae	15			1 8 1	8		
	Heptgeniidae	10			2 15 1	15		
	Leptophlebiidae	13			3 20 1	20		
	Ephemerellidae	15			4 30 1	30		
PROCEDURE PROTOCOLs	Tricorythidae	9			5 40 1	40		
1. If stones in current (SIC) all kickable, sample for 2 min, otherwise for maximum of 5 min.	Prosopistomatidae	15			>5 50 1	50		
2. Gravel – ½ min	Caenidae	6			Lepidoptera			
3. Marg/Aq veg, back & forward sweep 2m	Odonata				Nymhulidae	15		
4. Stones out of current (SOOC) kick +/- 1 min.	Chlorolestidae	8			Coleoptera			
5. Samd/mud stir with feet & sweep net over disturbed area for ½ minutes	Lestidae	8			Dytiscidae	5		
6. Any other biotopes – ½ min	Protoneuridae	8			Elmidae/Dryopidae	8		
7, Complete top of form	Platycnemidae	10			Gyrinidae	5		
8. Tip net contents into tray. Remove leaves, twigs and trash.	Coenagriidae	4			Haliplidae	5		
9. Check taxa present on above list FOR THE LESSER of 15 min or % min since last taxon found	Calopterygdidae	10			Helodidae	12		

10. Estimate and record taxon abundances on scale A-1 to 10, B – 10 to 100’ C- 100 to 1000 D - >1000	Chlorocyphidae	10			Hydraenidae	8		
11. BEFORE LEAVING THE SAMPLING POINT CHECK THAT THIS FORM HAS BEEN FULLY COMPLETED!	Zygoptera juvs.	6			Hydrophilidae	5		
	Gomphidae	6			Limnichidae	8		

A* - ***score allocated to taxon.***