SEASONAL RAINFALL INFLUENCES ON MAIN POLLUTANTS IN THE VAAL RIVER BARRAGE RESERVOIR: A TEMPORAL-SPATIAL PERSPECTIVE

By

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MINOR DISSERTATION

Submitted in partial fulfilment of the requirements for the degree

MAGISTER ARTIUM

In

ENVIRONMENTAL MANAGEMENT

In the

FACULTY OF HUMANITIES

at the

UNIVERSITY OF JOHANNESBURG

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2007
ACKNOWLEDGEMENTS

I would like to thank the following persons for their help and encouragement:

- My husband Stefan for his patience and tremendous help during the whole process;

- My mother for her ongoing support;

- Prof. Harmse for his guidance; and

- Mr. F. van Wyk, Head: Catchment Management of Rand Water for providing the water quality monitoring data.
ABSTRACT

South Africa is situated within a semi-arid part of the world which is characterised by high seasonal variability in terms of rainfall and runoff, with high evaporation rates. This causes streamflow to be relatively low for most of the year, with seasonal sporadic high flows. Further stress is applied to the water resource through population growth, increased urbanisation and industrial activities.

The study area is considered to be the most populated of the Upper Vaal Water Management Area (WMA), which is the most important WMA in terms of economic productivity in South Africa. This research report focused on assessing the temporal and spatial variations of pollution between four different sampling points located in the Vaal Barrage Reservoir, which is located in the heart of the Upper Vaal WMA. The Vaal River Barrage Reservoir forms a 64 kilometres long water body with an estimated total storage capacity of 63 million litres of water. The four sampling points are V2 (Vaal River at Engelbrechts Drift Weir); VRB 24 (Vaal River Barrage at 24 km); VRB 37 (Vaal River Barrage at 37 km) and V17 (Vaal Barrage Reservoir Outlet).

The aim of this research is to determine the type of physical and chemical pollutants within the Vaal River Barrage which currently poses the biggest problem to river health. The spatial and temporal differences of the pollutant loads are established and discussed. In addition, it is determined what the seasonal influence of rainfall has on the water quality measured at the four different sampling points.

Chemical pollutants which currently pose the biggest threat in terms of water quality for the Vaal Barrage Reservoir are Phosphates, Electrical Conductivity and Sulphates. These three water quality variables do not comply with the minimum standards as set by Rand Water. The occurrence of these pollutants in the Vaal River can be explained by the vast inputs of return flow water from sewage treatment plants, underground mine water and discharge from industries. Microbiological factors were not taken into consideration for this dissertation, due to the unavailability of the data for most of the sampling sites for the majority of the study period.
It was found that there are seasonal variations in terms of water quality at three sampling points: VRB24, VRB37 and V17. Sample point V17 had the highest inverse correlation for the three pollutants which pose the biggest threat to the health of the Vaal Barrage Reservoir water body. This implies that high seasonal variability occurs in the pollutant load at this sampling point.

Sample point V2 had extremely low inverse correlation figures, which implies that rainfall has little or no impact on the level/concentration of a pollutant. This can be explained by two factors. Firstly the dilution effect which water released from the Vaal Dam has due to the close proximity to V2. Secondly because urban, mining and industrial activities are much less evident at this point, and subsequently return flows are less.
# ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGIS</td>
<td>Agricultural Geographic Information System</td>
</tr>
<tr>
<td>CIWEN</td>
<td>Chartered Institute for Water and Environmental Management</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
</tr>
<tr>
<td>DEAT</td>
<td>Department of Environmental Affairs and Tourism</td>
</tr>
<tr>
<td>DWAF</td>
<td>Department of Water Affairs and Forestry</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical Conductivity</td>
</tr>
<tr>
<td>NO₃</td>
<td>Nitrate</td>
</tr>
<tr>
<td>PO₄</td>
<td>Phosphate</td>
</tr>
<tr>
<td>SO₄</td>
<td>Sulphate</td>
</tr>
<tr>
<td>VBCEC</td>
<td>Vaal Barrage Catchment Executive Committee</td>
</tr>
</tbody>
</table>
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Appendix A: Averaged Monthly Graphs for Water Quality Variables

Appendix B: Averaged Yearly Graphs for Water Quality Variables
1. INTRODUCTION

According to Boyd (2000) human settlements develop in areas with dependable supplies of water. Johannesburg is one of the very few cities in the world that developed and continues to grow despite not having an adequate supply of water close by. Although the availability of water is important, the quality thereof is of even more importance to humans (Clarke, 2002).

South Africa is also situated within a semi arid part of the world which is characterised by high seasonal variability with rainfall and runoff, with high evaporation rates. This causes streamflow to be relatively low for most of the year, with seasonal sporadic high flows (DWAF, 2003).

Most of the available surface water in this country occurs in the Eastern and South Eastern parts, while the greatest demand occurs in the central region. In the Vaal River catchment, the demand for water already exceeds the available resource potential (Thompson, 2006).

The Vaal River supply area is the most important water supply region in South Africa (DWAF, 2002) because it supplies water to the largest concentration of urban population in the country, as well as the largest economic sector (supplying industries, power stations and agricultural production).

In 1923 Rand Water dammed the Vaal River to form the Vaal River Barrage Reservoir. The water levels are controlled by barrage gates and inflow from the tributaries (Suikerbosrant River, Klip River, Blesbok Spruit, Taabosch Spruit & Riet Spruit) and the Vaal Dam (Stephenson, 2002). This reservoir used to supply water to the Witwatersrand but no longer does so because of deteriorating water quality (Rand Water, 2005a). In 1938 the Vaal Dam was built upstream of the Vaal River Barrage Reservoir, which is now the main source of water and point of water extraction for Rand Water.

The Vaal River Barrage Reservoir forms a 64 kilometres long body of water upstream with an estimated total storage capacity of 63 million litres. The surface area of the Vaal River
Barrage is estimated at 168,35 km² with an average depth of 4,5 metres (Van Wyk, 2001). The rivers that feed into the Vaal River Barrage Reservoir (Suikerbosrant, Klip, Blesbok, Taaibos & Riet) flow through industrial and heavily populated areas such as Johannesburg, Vereeniging and Sasolburg.

In areas with a waterborne sewage system, waste water is transported by sewerage pipes to waste water treatment works. The waste water is treated to a standard set by the Department of Water Affairs and Forestry (DWAF), and then released into the closest river (Rand Water, 2005b). Inflow water quality standards (chemical, biological and bacteriological composition) are extremely important, as each waste water treatment plant is designed to treat a certain capacity and quality of effluent (Roodt, 2002).

Rapid and unplanned urbanization has surpassed the capacity of the existing waste water treatment infrastructure, leading to problems with pollution of storm-water and faecal pollution from urban runoff (De Kock, 2005).

As the water demand rises, the volume of effluents returned to the river also increases. Effluents will therefore increasingly affect water quality (Grobler et al., 1987). One of the main factors that would negatively impact on the recreational activities (camping, canoeing, boating, picnicking, bird watching, water-skiing and fishing) and the sustainable use of the reservoir is the deterioration in water quality. The deterioration in the water quality in the Barrage can be attributed to the deterioration in the water quality of some of the rivers (Klip, Blesbok, Taaibos, Riet, and, Suikerbosrant) feeding into the Vaal River Barrage Reservoir (De Kock, 2005).

South Africa’s environmental law is considered to be extremely progressive. At the very top level, in the Constitution of the Republic of South Africa, it is stated that: “...everyone has a right to an environment which is safe and not harmful to one’s health...” (Constitution of South Africa, 1996). The National Water Act (1998) of South Africa’s main purpose is to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled by taking into consideration factors such as:
According to Thompson (2006) some of the above mentioned factors are in direct conflict with each other in certain catchments. This allows for situations where trade-offs take place between the above mentioned factors, according to which factor is considered as more important. Relating his statement to the study area, it is clear that item (v) and (vi) are in conflict with items (vii) and (viii).

Water in the Upper Vaal Water Management Area (WMA) is in great demand due to population growth and subsequent increase in water demand for domestic, industrial and agricultural use. The greater the demand for water becomes, the greater the increases that are expected in terms of pollution load, catchment destruction and a decrease in water quality (Rand Water, 2005b).
2. RESEARCH PROBLEM

This research will make use of the water quality data obtained for four sampling points situated within the Vaal River Barrage Reservoir: V2 (Vaal River at Engelbrechts Drift Weir); VRB 24 (Vaal River at 24 km); VRB 37 (Vaal River at 37 km) and V17 (Vaal Barrage Reservoir Outlet). All these sampling points are situated within the Upper Vaal Water Management Area.

The aim of this research is to determine the type of pollutants within the Vaal River Barrage which currently poses the biggest problem to river health. The spatial and temporal differences to the pollutant loads will be established and discussed. In addition, it will be determined what the seasonal influence of rainfall has (if any) on the water quality measured at the four different sampling points.

The water quality of the Vaal Barrage Reservoir has been affected by mining, industrial and agricultural processes and more recently by urbanisation and subsequent anthropogenic influences over the past few years.

This study will examine the spatial and temporal variations of certain important water quality parameters in the Vaal Barrage Reservoir. These parameters will be compared with the water quality guidelines developed by DWAF (with specific reference to the guidelines for Aquatic systems, Domestic use, and Recreational use) as well as the Vaal River Barrage in stream water quality criteria as determined by Rand Water.

To achieve the above mentioned goals of this study, the research procedure will be conducted in two phases. The first phase will involve the following actions to be followed:

- Water quality data, taken at four sample sites in the Vaal Barrage Reservoir from 1992 - 2006 will be obtained from Rand Water;

- The data will be analysed in terms of certain selected physical and chemical parameters;
- The results will be compared with the Water Quality Guidelines of DWAF for Aquatic systems, Domestic use and Recreational use as well as with the in-stream water quality criteria for the Vaal River Barrage Reservoir (as determined by Rand Water); and
- The parameters will be discussed with special emphasis on those exceeding the Water Quality Guidelines.

Once phase one has been accomplished, phase two of the research will be undertaken, *i.e.* to determine the influence of rainfall on each of the water quality parameters used. This will be done in order to determine whether or not there is a seasonal influence (in terms of rainfall) on the pollutants to the Vaal Barrage Reservoir.
3. METHODOLOGY

This minor dissertation has been divided into four sections to present a logical sequence. Refer to Figure 3-1 for the schematic flow chart of this.

Figure 3-1: Schematic flow chart
4. BACKGROUND TO STUDY AREA

This chapter will provide background to water and catchment management in South Africa, and in the Vaal River Barrage in particular. The physical and socio-economic characteristics of the area surrounding the Vaal River Barrage Reservoir will be discussed thereafter. This is done in order to give more information regarding the activities which puts stress on the water resource.

4.1. Water Management Areas in South Africa

South Africa was divided into 19 Water Management Areas (WMA’s) in October 1999. The boundaries of the WMA’s do not correlate with administrative boundaries. Dividing South Africa into these 19 WMA’s took into consideration the following factors:

- Institutional efficiency;
  - The creation of a large number of catchment management agencies, responsible for a small area
- Financial self sufficiency from water use charges;
- Location of centres of economic activity;
- Social development patterns;
- Centres of water related expertise for future assistance; and
- Distribution of water resources infrastructure.

(DWAF, 2004b)

The Vaal Barrage Reservoir falls within the Upper Vaal WMA (WMA number 8) as depicted in Figure 4-1. The natural conditions (topography, geology, soils, vegetation and land use) of the study area will now be discussed using information from this WMA.
Figure 4-1: Water Management Areas of South Africa
Adapted from (DWAF: 2004c)
4.1.1. Vaal Barrage Reservoir Catchment area

The Orange/Vaal river system is one of the most important river systems in South Africa, because it sustains nearly half the economic production and a large proportion of the population of the country. The study area falls within the North-Western section of the Upper Vaal WMA, as can be seen in Figure 4-2. This area is referred to as the area downstream of the Vaal Dam to the Vaal Barrage.

The Barrage area falls mainly within secondary C2 catchment, and more specifically tertiary catchment C22 which is heavily urbanised. Table 4-1 depicts the different quaternary catchments areas which relates to the Vaal River Barrage Reservoir. The quaternary catchments are important because water use permits, licences and authorisations are awarded by DWAF based on this information.

Table 4-1: Quaternary Catchment Areas and Descriptions for the Vaal River Barrage Reservoir

<table>
<thead>
<tr>
<th>Key Area Name</th>
<th>Catchment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaal Dam to Vaal Barrage</td>
<td>C22F</td>
<td>Vaal River Barrage Catchment</td>
</tr>
<tr>
<td></td>
<td>C22G</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C22H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C22I</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C22J</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C22K</td>
<td></td>
</tr>
<tr>
<td>Vaal Barrage to Mooi</td>
<td>C23A</td>
<td>Remaining Vaal River Catchment in the Upper Vaal WMA</td>
</tr>
<tr>
<td></td>
<td>C23B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C23C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C23L</td>
<td></td>
</tr>
</tbody>
</table>

Some of the highest concentrations of domestic and industrial water users in South Africa are found within these catchments. The Vaal River Barrage Reservoir area is characterised by a large number of mining, industrial and urban activities which impact significantly on the
hydrology of the catchment. The influence of these activities will be discussed in more detail in section 8.

Table 4-2: Dimensions of Vaal Barrage Reservoir
Adapted from (Van Wyk, 2001)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>64.36 km</td>
</tr>
<tr>
<td>Greatest Width</td>
<td>1 220 m</td>
</tr>
<tr>
<td>Submerged Area</td>
<td>16.83 km²</td>
</tr>
<tr>
<td>Depth of Water: At Barrage</td>
<td>7.65 m</td>
</tr>
<tr>
<td>At River Intake Pumping Station, Vereeniging</td>
<td>5.185 m</td>
</tr>
<tr>
<td>Vaal Barrage Full supply gross storage capacity</td>
<td>$10^6$ m³ 53.710</td>
</tr>
<tr>
<td>Full supply surface area</td>
<td>13.04 km²</td>
</tr>
</tbody>
</table>

According to DWAF (2003), the Vaal Barrage Reservoir represents 4.5% of the total Vaal River Catchment and contributes 7.8% of total Mean Average Runoff (MAR). Refer to Table 4-3 for the annual inputs and outputs to the Vaal Barrage Reservoir.

Table 4-3: Annual Inputs and Outputs to the Vaal River Barrage
Adapted from (Van Wyk, 2001)

<table>
<thead>
<tr>
<th>Input and Output of Vaal River Barrage</th>
<th>Amount of Water (in Ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receives:</td>
<td>1 296 000</td>
</tr>
<tr>
<td>Abstracted:</td>
<td>845 000</td>
</tr>
<tr>
<td>Released:</td>
<td>450 000</td>
</tr>
<tr>
<td>Irrigation &amp; other abstractions:</td>
<td>432 000</td>
</tr>
</tbody>
</table>

According to DWAF (2004c) return flows to the Upper Vaal WMA (and specifically the Vaal Barrage Area) represents a significant portion of the total yield. The return flows are predominantly made up from the urban sector (discharges from sewage treatment plants) and the mining sector (due to mine dewatering).
Figure 4-2: Location of Sub-Areas and Sub-Catchments of the Upper Vaal WMA of South Africa
Adapted from (DWAF: 2004c)
Here follows a description of the physical and socio-economic environment of the study area.

**4.1.2. Location and sample point positions**

The Vaal Barrage Reservoir is situated within the Upper Vaal Water Management Area (herewith referred to us Upper Vaal WMA), which is situated within parts of Gauteng, Mpumalanga, Free State and North West Provinces (Figure 4-3).

![Regional Setting: Vaal River Barrage Sampling Points](image)

**Figure 4-3: Vaal Barrage Reservoir Catchment Area**

Map adapted from (AGIS, 2007) ¹

1. All AGIS maps were edited to the best quality for the software
Sample point V2 is situated to the South West of the study area, downstream of the Vaal Dam and close to Deneysville. The nearest towns to sample point VRB 24 is Vanderbijlpark and Vereeniging, closest to sampling point VRB 37.

### 4.1.3. Topography

In the vicinity of the Vaal Barrage the average height above sea level is 1450m, some steep areas do occur in the area of offspring of the Wilgespruit (DWAF, 2004c). The whole study area can be categorised as undulating plains.

### 4.1.4. Geology and Soils

Sedimentary rocks from the Karoo Sequence underlie the greater part of the Upper Vaal WMA. The geology to the north of the Vaal River can be described as andesitic lava of the Hekpoort Formation of the Pretoria Group, Transvaal Sequence; dolerite; sandstone, grit and shale of the Ecca Group, and the Karoo Sequence (AGIS, 2007). There are dolomitic exposures in the central areas (in the Catchment of the Mooi tributary) of the study area. The predominant mineable minerals that are found in the area are gold, uranium, base metals, semi precious stones and industrial minerals, uranium and coal (DWAF, 2002). All four sampling points are underlaid by Paleozoic rocks.

Soil types are largely dependent on the underlying geology. In the Upper Vaal WMA there are three main soil types (DWAF, 2002):

- Sandy Loam;
- Clayey Loam; and
- Clay Soil.

### 4.1.5. Climate

The position of the different weather stations in the Vaal River Barrage Area is depicted in Figure 4-4. Weather stations which measure all weather variables are indicated in green.
The weather station in Vereeniging is close to sampling point VRB 37, and this was used for the compilation of average minimum and maximum temperatures as is depicted in Figure 4-5.

![Weather Stations: Vaal River Barrage Sample Points](image)

**Figure 4-4: Weather Stations near the Vaal River Barrage Reservoir**

Map adapted from (AGIS, 2007)

The daily minimum and maximum temperatures were measured at Vereeniging by the South African Weather Services (station number 04387311 for 1985-1992 & station number 04387843 for 1993-2006). This data displayed in Figure 4.5.

On average, the months with the highest maximum temperatures are January, February and March and October. The lowest minimum temperatures are observed in June and July.

---

2 All AGIS maps were edited to the best quality for the software
Figure 4-5: Average Minimum and Maximum Temperatures

See Figure 4-6 for the average monthly rainfall for the Vaal Barrage area as measured at Deneysville (station number 0439203 9), Vanderbijlpark (station number 0438551 X) and Vereeniging (station number 0438731 1 for 1985 – 1992 and station number 0438784 3 for 1993 – 2006).

Figure 4-6: Average Monthly Rainfall for the Vaal Barrage Area
As is clear from Figure 4-6, the rainfall measured in Deneysville, Vereeniging and Vanderbijlpark share similar characteristics. November, December and January are considered as the months with the highest rainfall, with June, July and August with the lowest. For standardising the rainfall comparison undertaken in section 8, the same rainfall data will be used for analysis on all four sampling points.

4.1.6. Vegetation

Acocks Veld Types for South Africa is classified within 11 broad categories, or simplified veld type. These 11 categories are further subdivide into 70 different veld types. All four sampling points, and their surrounds fall within one simplified veld type namely Pure Grassveld, and specific veld type namely Cymbopogon – Themeda Veld (Acocks Veld Type Number 48). Please refer to Figure 4-7.

![Veld Types: Vaal River Barrage Sampling Points](image)

**Figure 4-7: Veld Type of the Study Area**

*Map adapted from (AGIS, 2007)*

---

\(^3\) All AGIS maps were edited to the best quality for the software
The occurrence of alien vegetation is a problem along the riparian zones, due to the fact that the vegetation is not only reliant on rainfall, but has year round access to water due to the proximity to the river or streams. Table 4-4 depicts the extent of alien vegetation as it occurs in the study area.

The predominant species of alien vegetation in the Upper Vaal WMA include (but is not limited to) Acacias, Pines, Eucalyptus, prosopis species and melia azedarachs (DWAF, 2002).

### Table 4-4: Extent of Alien Vegetation in the Study Area

<table>
<thead>
<tr>
<th>Catchment Description</th>
<th>Condensed Area of Alien Vegetation (km²)</th>
<th>Average Reduction in Runoff (10⁶ m³/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaal Dam to Vaal Barrage</td>
<td>72,4</td>
<td>4,3</td>
</tr>
<tr>
<td>Barrage to Mooi River</td>
<td>6,0</td>
<td>0,3</td>
</tr>
</tbody>
</table>

#### 4.1.7. Land use

The land use in the area includes agriculture (dryland, livestock and game farming), gold and coal mining, power generation, industrial activities and urban development and related activities.

### Table 4-5: Land Use per Catchment Area

<table>
<thead>
<tr>
<th>Catchment Description</th>
<th>Urban (km²)</th>
<th>Irrigation (km²)</th>
<th>Other (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaal Dam to Vaal Barrage</td>
<td>119,9</td>
<td>29,2</td>
<td>2 606,5</td>
</tr>
<tr>
<td>Barrage to Mooi River</td>
<td>0</td>
<td>25,1</td>
<td>3 207,9</td>
</tr>
</tbody>
</table>

Figure 4-8 depicts the Internal Strategic Perspective of the Upper Vaal WMA, i.e. the sewage treatment works, mines and industry as well as urban areas in the study area.

---

4 Land use information used as given by DWAF, 2002.
Figure 4-8: Internal Strategic Perspective for the Upper Vaal WMA
Adapted from (DWAF: 2004c)
**Industrial**

The industrial activities include mineral processing plants, steel industry, petrochemical industries, fertiliser manufacture, pulp and paper and light industry (DWAF, 2004c). According to Rand Water (2005b), industries produce waste which may affect various water quality parameters such as pH, colour, eutrophication, and salinity.

Industries in the Upper Vaal Water Management area include Sasol (near Sasolburg and Secunda), Sappi and Mittal (formerly known as Iscor which is located near Vanderbijlpark).

Pollution pressures on the Vaal Barrage Reservoir include the effluent of 33 water care works (treating domestic and commercial effluents) which is discharged at an average volume of 859 ML/d⁻¹ (DEAT, 1999).

**Mining**

Mining activities in the Upper Vaal WMA ranges from gold mining to quarrying (DWAF, 2002). Gold mining occurs mostly to the north-west of the Upper Vaal WMA, although the reserves are nearly depleted, unmined gold reserves are still present in the far West Rand near Westonaria, Carltonville and Randfontein (DWAF, 2003). It is not expected that growth in the gold mining sector will occur, mostly due to the fact that the depth of the ore makes it less financially viable to mine. According to DWAF (2004c) there is still potential for coal mining in the Vereeniging area downstream of the Vaal Dam.

According to DEAT (1999) there are fifteen operating gold mines, and 29 closed mines are distributed on the North side of the Vaal River Barrage catchment.

**Domestic**

The study area is heavily urbanised, especially near sampling points VRB 24, VRB 37 & VRB 17. The main urban areas are: Vereeniging, Vanderbijlpark and Sasolburg. Rand Water does supply potable water to the population in this area. According to DWAF (2003)
more than 80% of the population in the Upper Vaal WA reside in the area downstream of the Vaal Dam, of which 97% live in an urban environment. Although approximately 90% of the population in the Upper Vaal WMA are classified as urban (and thus 10% classified as rural), the possibility does exist that some people in the WMA use the available surface water for domestic purposes. For this reason the DWAF guidelines for domestic use will be included in the data analysis in section 8.

The trend in the Johannesburg-Vanderbijlpark-Vereeniging area leans toward concentration of economic development which means increased urbanisation with a subsequent strong demand for water (DWAF, 2003).

**Agriculture**

Less than 3% of the sectoral contribution of the Upper Vaal WMA to the national economy is attributed to agriculture. Although agriculture does have an influence on the water quality of the Vaal River Barrage Reservoir (mainly due to rainfall wash off of fertilisers, and soil) the amount of water abstracted for agricultural processes are considered to be minor in comparison with other abstractions and therefore were not included for the data analysis in section 8.

**Recreation**

The Vaal River Barrage Reservoir is heavily utilised as a recreational area. Numerous activities such as boating, fishing, skiing and rowing take place in the study area. The DWAF water quality guidelines for recreational use will be used for discussion purposes in section 8.

**4.1.8. Economic Activity**

According to DWAF (2004c), the Vaal WMA is recognised as the economic engine of South Africa. The Upper Vaal WMA contributes approximately 20% of the Gross Domestic Product (GDP) to South Africa, and has the second largest contribution to the national wealth
amongst the 19 water management areas (DWAF, 2003). The largest economic sectors to the economy are manufacturing, trade, financial services and mining (refer to Figure 4-9).

![Sectoral Contribution to the Economy](image)

**Figure 4-9: Sectoral Contribution of the Upper Vaal WMA to the Economy**
*Adapted from (DWAF, 2003)*

### 4.2. History of Vaal River Barrage Reservoir

In 1923 Rand Water dammed the Vaal River to form the Vaal River Barrage Reservoir. The water levels are controlled by barrage gates and inflow from the tributaries (Suikerbosrant, Klip River, Blesbok Spruit, Taaibos Spruit & Riet Spruit) and the Vaal Dam (Stephenson, 2002). The Vaal River Barrage Reservoir is 64 kilometres long and has a total storage capacity of 63 million litres, a surface area of 168,35 km² with an average depth of 4.5 metres (Rand Water, 2005a).
The rivers (Suikerbosrant, Klipriver, Blesbokspruit, Taaibosspruit & Rietspruit) that feed into the Vaal River Barrage Reservoir flow through industrial and heavily populated areas such as Johannesburg, Vereeniging and Sasolburg. This reservoir was used to supply water to the Witwatersrand but no longer does because of deteriorating water quality (Rand Water, 2005a). In 1938 the Vaal Dam was built upstream of the Vaal River Barrage Reservoir, which is now the main source of water for Rand Water – the main supplier of water to the greater Johannesburg area.
5. Water Availability

South Africa’s water resources are scarce and limited compared to global figures (Thompson; 2006). As can be seen from Figure 5-1, only 2.59% of the world’s water resources are classified as fresh water, and only 0.014% are classified as accessible fresh water, the rest of the world’s fresh water resources are either found in groundwater resources, or in ice caps and glaciers. Of the 149 countries in the world (for which data is available), South Africa was classified as the 26th most water stressed country and already has less water per person available than both Botswana and Namibia (Thompson, 2006).

The availability of water is not only dependent on the available quantity, but also reliant on the quality thereof (Thorius, 2004).
5.1. Water availability in the Upper Vaal Water Management Area

The Upper Vaal WMA is greatly dependant on transfers and releases on other water management areas (DWAF, 2003). The flow of the Vaal Barrage Reservoir in particular is greatly dependent on return flow and releases from the Vaal Dam due to highly seasonal rainfall.

This means that the water quality in the Vaal Barrage Reservoir is determined by the water quality from upstream, as well as the activities within the sub catchment. The Barrage receives water inputs from the Suikerbosrand/Blesbokspruit, Klip River and sub catchments upstream of the Vaal Dam.

Inputs to the Vaal Barrage upstream of the Vaal Dam, which incorporates the activities in the Riet spruit and Taibosspruit catchments. These activities include irrigation, sewage treatment plant discharges, mining and urban developments (DWAF, 2004c), all of which produces water quality issues in terms of eutrophication (due to elevated nutrients) and increased salinity.

Figure 5-2 depicts the major areas responsible for return flow to the Upper Vaal WMA. Urban return flows (which includes water discharged from sewage treatment plants and storm water) accounts for the majority of the water at 71,8%. Water releases from dewatering due to mining activities accounts for 21,7%.
5.1. Water quality

Water quality is defined as the fitness of use it possesses by describing its physical, chemical, biological and aesthetic properties (DWAF, 1996a). DWAF has compiled several guides in respect of water quality based on specific uses. The water quality of the study area will be compared to the DWAF guidelines for water quality for domestic, recreational and aquatic use in section 8 of this report.

According to Thompson (2006) the quality of South Africa’s surface water resources are compromised by the following:

- Soil erosion;
- Urban and industrial effluent discharges;
- Informal settlements;
- Seepage from landfills and mine related tailings, and
Underground mine water discharge (to ensure safe and workable conditions for the mining of minerals and miners).

Vaux (2001) explains that there is a worldwide decline in water quality which has implications in terms of food security as well as ecosystem and human health. According to Ntegwe (2006), polluted water is not able to achieve a balanced ecosystem, thereby eliminating the symbioses between living organisms and their environment.

The Department of Water Affairs and Forestry (1996a), determines water quality by considering the following:

- Water quality problems associated with a particular water use;
- The effects of poor water quality on the use;
- The norms commonly used as a yardstick to measure the quality of the water used;
- Water quality constituents generally of concern; and
- Specific characteristics of the water used which may influence its quality requirements.

5.2. Sources of water pollution

Davies & Day (1998) define pollution as water which is offensive to human, animal or plant life. According to Ellis et al. (1989) water pollution can be attributed to either diffuse or point source pollutants. Although these two sources of pollution represent the majority of pollution to water resources, cognisance should be taken of other sources of pollution which does not relate to either category. According to Beck (2005), surface water quality is vulnerable to events from accidents, faults, failures and runoff associated with the specific urban areas functioning. These different views will be discussed next.

5.2.1. Point Source Pollutants:

Point source pollutants are relatively easy to identify, as it is added to the water body from a specific point, and can be managed by means of issuing of licences and permits.
**5.2.2. Diffuse Pollutants**

Diffuse pollution is much harder to determine than point sources, because they originate from a variety of sources which is hard to determine. Unlike point source pollution, diffuse pollution cannot be controlled by issuing licences, because the origin thereof can’t be pinpointed. The scale and nature of the pollution is dependent on the soil type, rainfall and occurrence of storms. Poor *et al.* (2006) state that water pollution is closely linked to runoff from impervious surfaces, especially from run off from urban areas.

According to the Chartered Institute for Water and Environmental Management (CIWEN) (2003), diffuse pollution can affect water quality and can be attributed to the use of land for agriculture, forestry, industry and urban activities.

According to the UK Environmental Protection Agency (CIWEN, 2003), the main sources of diffuse pollution can be listed as the following:

- Nutrients such as nitrogen and phosphorus from overuse of fertilisers and manure;
- Faecal pollution from overloaded or badly connected sewage systems;
- Pathogens and soil from livestock;
- Urban areas and construction and demolition sites;
- Pesticides, poor storage and handling, and run-off;
- Organic wastes (slurries, surplus crops, sewage sludge) that are poorly stored or disposed of;
- Oil and hydrocarbons from vehicle maintenance, spills from storage and handling as well as road and industrial run-off;
- Solvents from industrial areas; and
- Metals and chemicals from atmospheric deposition, abandoned mines and industrial processes.

Industrial activities may deliver diffuse pollution to a water body by means of conducting activities on areas drained by surface water sewers which drains into rivers. This may release oils, hydrocarbons, sediment, phosphorus, iron, acidifying pollutants and solvents to the water body (CIWEN, 2003).
Agriculture contributes to diffuse pollution through contamination associated with organic wastes. The demand for higher agricultural productivity has been associated with more use of fertilizers, pesticides. According to CIWEN (2003) most incidents of diffuse pollution of drinking water supplies can be attributed to agricultural sources. The rate, location and timing of inputs of inorganic fertilisers (such as slurry and manure) and pesticides are also important factors. The type of agricultural cultivation and local drainage will affect the risk that the substances (and soil) will have on the watercourses they drain to. Diffuse pollution presents itself in the form of nutrient leaching to surface and ground waters. Both nitrate and phosphate can enrich the water body (eutrophication) and cause changes to the local ecology. Nitrate has a potential impact on health and standards have been imposed for drinking water.

Recreational activities (golf, sports field management, boating, camping) contribute to pesticides, suspended solids, faecal pathogens and nutrients.

### 5.2.3. Other Sources of Pollution

According to Thompson (2006), other sources of pollution which may influence water quality can be classified as:

- The chemical reaction of exposed geological formations;
- Air emissions from burning substances which falls to the earth and causes contamination; and
- Disposal of material which may impact on a water resource.

Accidental water pollution is another cause which can arise from many sources; such as burst pipes and tanks, major leaks, fires, oil spills (Rand Water, 2005b).

### 5.3. Water pollution monitoring in the Vaal River Barrage Reservoir

Water monitoring in the Vaal River Barrage Reservoir is conducted on a weekly basis. A range of water quality criteria are monitored.
6. WATER QUALITY ASSESSMENT CRITERIA

As discussed in the previous section, water quality can be defined as the fitness of use it possesses by describing its physical, chemical, biological and aesthetic properties (DWAF, 1996a). This section will discuss the water quality variables used for assessing water quality in the Vaal Barrage Reservoir for the purposes of this research report.

The specific physical, chemical and biological water quality variables were chosen after discussion with Van Wyk (2006) from Rand Water. The online water quality reports of the Vaal Barrage Reservoir were looked at (Rand Water, 2006) to determine the properties which poses the highest threat to the water body.

The expected quality of water differs, depending on the intended use thereof. For each of the properties mentioned in this section, a table will be provided to specify the acceptable range of the water quality in terms of domestic, aquatic and recreational use, as determined by DWAF, as well as the different in stream water quality guidelines for the Vaal Barrage Reservoir, as determined by the Vaal Barrage Catchment Executive Committee (VBCEC).

6.1. Physical Properties

Different physical properties of water will be discussed next. The physical characteristics of water may potentially impact on aquatic life, recreational use or the treatment of water to be suitable for other uses (DWAF, 2004c). For the purposes of this study, the following water quality parameters are discussed in this section: Chemical Oxygen Demand, Electrical Conductivity and pH.
6.1.1. Chemical Oxygen Demand (COD)

The chemical oxygen demand serves as an indication of the presence of organic matter in a water body. COD can be defined as “the amount of oxygen required to oxidise all the organic matter that is susceptible to oxidation by a strong chemical oxidant” (DWAF, 1996c, 27). Refer to Table 6-1 for the water quality guidelines for COD.

The COD gives therefore an estimate of the presence of organic matter in a water body. Two forms of organic matter exist, namely autochthonous organic matter, which arises in a water body through the growth and death of aquatic organisms, and allochthonous organic matter, which originates outside the water body. Most organic compounds can be oxidized to between 95%-100% of their theoretic value (DWAF, 1996c).

Table 6-1: COD - Water Quality Guidelines

<table>
<thead>
<tr>
<th></th>
<th>DWAF Water Quality Guidelines (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Use</td>
<td>No Guideline Exists</td>
</tr>
<tr>
<td>Aquatic Ecosystems</td>
<td>No Guideline Exists</td>
</tr>
<tr>
<td>Recreational</td>
<td>No Guideline Exists</td>
</tr>
</tbody>
</table>

Vaal Barrage Reservoir In-Stream Guidelines (mg/l)

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Acceptable</th>
<th>Tolerable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 (mg/l)</td>
<td>10 – 20 (mg/l)</td>
<td>20 – 30 (mg/l)</td>
<td>&gt; 30 (mg/l)</td>
</tr>
</tbody>
</table>

6.1.2. Electrical Conductivity

DWAF (1996a, p.150) concludes that the total dissolved solids (TDS) concentration is directly proportional to the electrical conductivity (EC) of water. EC is much easier to measure than the TDS and is therefore an estimate of the total dissolved solid concentration. Refer to Table 6-2 for the water quality guidelines for EC.
Kempster & Van Vliet (1991) state that electrical conductivity is used to measure the ability of a water sample to conduct an electrical current. Inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium, iron and aluminium all affect the waters electrical conductivity levels (DWAF, 1996a). When a sample contains dissolved solids or salts, they get separated into positively charged (cations) and negatively charged (anions) particles. Water containing ions will conduct electricity, and the concentration of dissolved ions in a sample determines conductivity (DWAF, 1996d).

The TDS concentration also depends on physical processes such as evaporation and rainfall as TDS concentrations are generally low in rainwater, less than 1 mg/l and low in water in contact with granite, siliceous sand and well-leached soils, less than 30 mg/l (DWAF, 1996a). The underlying geology of an area also has the potential to affect conductivity levels. Streams that run through areas with granite bedrock tend to have lower conductivity because granite rock is composed of materials that do not ionize in water. Streams that receive large amounts of runoff containing clay particles generally have higher conductivity because of the presence of minerals in clay that ionize more readily in water The concentrations are much higher in water in contact with Precambrian shield areas and in water in contact with Palaeozoic and Mesozoic sedimentary rock formations (DWAF, 1996a).

<table>
<thead>
<tr>
<th>Table 6-2: Electrical Conductivity - Water Quality Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DWAF Water Quality Guidelines (mS/m)</strong></td>
</tr>
<tr>
<td>Domestic Use</td>
</tr>
<tr>
<td>Aquatic Ecosystems</td>
</tr>
<tr>
<td>Recreational</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vaal Barrage Reservoir In-Stream Guidelines (mS/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ideal</strong></td>
</tr>
<tr>
<td>&lt; 18 (mS/m)</td>
</tr>
</tbody>
</table>
**Implications on Aquatic Ecosystems**

Individual ions which make up the TDS exerts physiological effects on aquatic organisms. The changes in the concentration of the TDS can affect these organisms on three levels: effects on the adaptations of individual species, the effects on community structure and on microbial and ecological processes which include rates of metabolism and nutrient cycling (DWAF, 1996d).

The rate of change in TDS concentrations and the duration of change are more important than absolute changes in TDS concentrations, particularly in systems where the organisms may not be adapted to fluctuating levels of TDS (DWAF; 1996d). Seasonal fluctuations in TDS may have affects on the water temperature and effects community composition and functioning.

**Implications on Human Health**

The health effects related to TDS are minimal at below 2000-3000mg/l TDS whereas higher concentrations of salts have an unpleasant taste to water and may also adversely affect the kidneys (DWAF, 1996a). Some of the physiological effects, which may be directly related to high concentrations of dissolved salts, include:

- **Laxative effects, from mainly sodium sulphate and magnesium sulphate**;
- **Adverse effects of sodium on certain cardiac patients and hypertension sufferers**;
- **Effects of sodium on women with toxemia associated with pregnancy**;
- **Some effects on kidney function**.

(DWAF, 1996a, p152).

Excessive skin dryness and discomfort may result when water with very high concentrations of TDS is used for bathing and washing purposes. Saline water affect animal health and performance due to the palatability of the water. The taste is also influenced by the types of salts present in the water as well as the level of salinity. Certain salts, such as magnesium sulphate, is more harmful than sodium chloride or sodium sulphate.
6.1.3. pH

Alkalinity in water represents the ability to neutralise strong acids (Ellis et al, 1989) also known as ‘buffering capacity’ – the ability of the water system to resist changes in pH. Refer to Table 6-3 for the water quality guidelines for pH.

Table 6-3: pH - Water Quality Guidelines

<table>
<thead>
<tr>
<th>Domestic Use</th>
<th>6 – 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Ecosystems</td>
<td>No Guideline Exists</td>
</tr>
<tr>
<td>Recreational</td>
<td>6.5 – 8.5</td>
</tr>
</tbody>
</table>

Vaal Barrage Reservoir In-Stream Guidelines

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Acceptable</th>
<th>Tolerable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0 – 8.4</td>
<td>6.5 – 7.0; and 8.4 - 8.5</td>
<td>6.0 – 6.5; and 8.5 - 9.0</td>
<td>&lt; 6.0; and &gt; 9.0</td>
</tr>
</tbody>
</table>

The power of hydrogen (pH) scale ranges from 0 - 14, and is a measure of the concentration of hydrogen ions in a solution and is used to measure the acidity/alkalinity of a solution. If the value of the measurement is less than 7,0 the solution is acidic (high concentration of positive hydrogen ions - strongly acidic). If the value is greater than 7,0 the solution is alkaline, more commonly known as basic (high concentration of negative hydroxide ions - strongly basic). DWAF (1996a) summarises that at a pH of less than seven for water is acidic, while at a pH of greater than seven, water is alkaline.

According to Palmer et al. (2004) pH of natural occurring water is determined by the underlying geology as well as atmospheric conditions.

The DWAF Target Water Quality Range (TWQR) is between 6,0 and 8,0 (DWAF; 1996a). The pH of pure water (that is water containing no solutes) at a temperature of 24°C is 7,0 the number of H+ and OH- ions are equal and the water is therefore electrochemically neutral. As the concentration of hydrogen ions (H+) increases, pH decreases and the solution
becomes more acid. As H+ decreases, pH increases and the solution becomes more basic (DWAF, 1996 a).

**Implications to Aquatic Ecosystems**

The buffering capacity affects the rate of change of pH in aquatic systems. In poorly buffered waters, pH can change quickly, which in turn may have severe effects on the aquatic biota (DWAF, 1996d). The significance of pH changes to aquatic biota depends on the extent, duration and timing of thereof. Small changes in pH often cause large changes in the concentration of available metallic complexes and can lead to significant increases in the availability and toxicity of most metals.

**Implications to Human Health**

The taste of water, its corrosive effects (acidity), chlorinating efficiency and the solubility of metal ions are influenced by pH. At a low pH water may taste sour, while high pH causes water to have a soapy taste (Kempster & Van Vliet, 1991). According to DWAF (1996d), people attaining water from a body which is exposed to acid rain tend to have a deficiency in selenium (due to solubility of elements as a result of the lowering of pH in water).

### 6.2. Chemical Properties

According to Neal *et al.* (2005), the chemical water quality of a water body is extremely important to ecological status thereof. Phosphates and nitrates are good indicators of the level of domestic pollution in surface waters (DEAT, 1999).

**6.2.1. Nitrate**

DWAF (1996a) reports that nitrates are the end products of the oxidation of ammonia or nitrite. According to DWAF (1996a) nitrates result from the natural decomposition by micro-organisms of organic nitrogenous matter, which is present in excreta principally in the form of urea. Nitrate found in surface water does not only have its origin from human
sewage, but also from run-off from agricultural land containing excessive fertiliser (Ellis et al. 1989).

DWAF (1996a) states that the conversion of nitrite (NO₂) to nitrate (NO₃) under oxidising conditions the most stable positive oxidation state of nitrogen and is far more common in the aquatic environment. Refer to Table 6-4 for the water quality guidelines for nitrate.

Table 6-4: Nitrate - - Water Quality Guidelines

<table>
<thead>
<tr>
<th>DWAF Water Quality Guidelines (mg/l)</th>
<th>Domestic Use</th>
<th>Aquatic Ecosystems</th>
<th>Recreational</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;6 (mg/l)</td>
<td>&lt;0.5 (mg/l)</td>
<td>No Guideline Exists</td>
</tr>
</tbody>
</table>

Vaal Barrage Reservoir In-Stream Guidelines (mg/l)

<table>
<thead>
<tr>
<th>Ideal</th>
<th>Acceptable</th>
<th>Tolerable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.5 (mg/l)</td>
<td>0.5 – 3.0 (mg/l)</td>
<td>3.0 – 6.0 (mg/l)</td>
<td>&gt; 6.0 (mg/l)</td>
</tr>
</tbody>
</table>

**Implications to Aquatic Ecosystems**

Nitrates are highly water-soluble and substantial quantities are found in soil, water and plants. A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement. Nitrates along with phosphates cause nutrient enrichment to the water body which stimulates the growth of algae. Algal blooms may cause problems associated with bad odours and taste (DWAF, 1996a). Algae also prevents penetration of sunlight, and may cause oxygen deficiencies in the water.

**Implications to Human Health**

Nitrate has no aesthetic implications, but has the potential to cause tiredness chronic in nature. In extreme cases cyanosis and difficulty to breath in bottle fed infants may occur (DWAF, 1996a). Nitrate oxidises haemoglobin (red blood cells) to methaemoglobin, which is unable to transport oxygen through the body. Poisoning result in suffocation due to a lack of oxygen in the tissue (DWAF, 1996a).
6.2.2. Phosphate

According to Ellis et al. (1989), phosphorous is usually present as phosphate which is an important aspect in surface water quality. Due to the discharge of waste water treatment works, high levels of phosphate are released to the receiving water body. These phosphates are derived from domestic detergent powders, agricultural runoff and animal waste. Refer to Table 6-5 for the water quality guidelines for phosphate. Phosphate is a basic component of living tissues, during decomposition of organic matter the phosphate levels tend to increase. Significant amounts of phosphate are found in animal and human excreta and consequently in sewage and farm effluent. Large quantities of phosphate are applied as fertilizers in agriculture, and runoff from these areas often contains high concentrations of phosphate.

Table 6-5: Phosphate - Water Quality Guidelines

<table>
<thead>
<tr>
<th></th>
<th>DWAF Water Quality Guidelines (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Use</td>
<td>No Guideline Exists</td>
</tr>
<tr>
<td>Aquatic Ecosystems</td>
<td>&lt;0.5 (mg/l)</td>
</tr>
<tr>
<td>Recreational</td>
<td>No Guideline Exists</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Vaal Barrage Reservoir In-Stream Guidelines (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal</td>
<td>&lt; 0.03 (mg/l)</td>
</tr>
<tr>
<td>Acceptable</td>
<td>0.03 – 0.05 (mg/l)</td>
</tr>
<tr>
<td>Tolerable</td>
<td>&gt; 0.05 (mg/l)</td>
</tr>
<tr>
<td>Unacceptable</td>
<td></td>
</tr>
</tbody>
</table>

Implications to Aquatic Health

Phosphorus is necessary for plant and animal growth. Phosphates stimulate the growth of biota which provides food for fish. This may increase the fish population and improve the water body’s quality of life. However, when too much phosphate is present, algae and waterweeds grow at an accelerated speed which has implications to the use and availability of oxygen (DWAF, 1996a). Jarvie et al. (2006) are of the opinion that phosphorous is a key nutrient to the eutrophication of rivers.
6.2.3. Sulphate

Refer to Table 6-6 for the water quality guidelines for sulphate. DWAF (1996a, p.143) states “Sulphate is the oxy-anion of sulphur in the +VI oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium”. Sulphates tend to accumulate and give rise to progressively increasing concentration since most sulphates are highly soluble in water.

Sulphate concentrations in unpolluted fresh water are typically less than 10 mg/l. Atmospheric sulphur dioxide, discharged on combustion of fossil fuels, can give rise to sulphuric acid in rainwater (acid rain) and as such, this results in the return of sulphate to surface waters in the environment (DWAF, 1996b). The associated cations, usually magnesium and sodium govern the interactions of sulphate.

Concentrations of several hundred milligrams of sulphate per litre may occur when acid mine drainage takes place (DWAF, 1996c). Acid mine waste, and many other industrial processes such as tanneries, textile mills and other processes using sulphuric acid or sulphates discharge sulphates (Kruger, 2004).

Table 6-6: Sulphate - Water Quality Guidelines

<table>
<thead>
<tr>
<th></th>
<th>DWAF Water Quality Guidelines (mg/l)</th>
<th>Vaal Barrage Reservoir In-Stream Guidelines (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Use</td>
<td>&lt;200 (mg/l)</td>
<td>Ideal: &lt; 20 (mg/l)</td>
</tr>
<tr>
<td>Aquatic Ecosystems</td>
<td>No Guideline Exists</td>
<td>Acceptable: 20 – 100 (mg/l)</td>
</tr>
<tr>
<td>Recreational</td>
<td>No Guideline Exists</td>
<td>Tolerable: 100 – 200 (mg/l)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vaal Barrage Reservoir In-Stream Guidelines (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal: &lt; 20 (mg/l)</td>
</tr>
<tr>
<td>Acceptable: 20 – 100 (mg/l)</td>
</tr>
<tr>
<td>Tolerable: 100 – 200 (mg/l)</td>
</tr>
<tr>
<td>Unacceptable: &gt; 200 (mg/l)</td>
</tr>
</tbody>
</table>
***Implications to Aquatic Health***

Typical concentrations of sulphate in surface water is 5 mg/l, although concentrations of several hundred mg/l may occur where dissolution of sulphate minerals or discharge of sulphate-rich effluents from acid mine drainage takes place (DWAF, 1996b).

***Implications to Human Health***

Sulphate affects the palatability of water by imparting a salty or bitter taste (DWAF, 1996b). Acute health effects (diarrhoea) are caused by ingesting water with a high concentration of sulphate.

**6.2.4. Faecal coliforms**

Faecal coliform bacteria are a collection of relatively harmless micro-organisms that live in large numbers in the intestines of humans and other warm-blooded animals. They aid in the digestion of food. *Eschericia coli* is the most common member of this group. These organisms have the ability to grow at elevated temperatures and are associated only with the faecal material of warm-blooded animals. The Faecal Coliform group is “used to evaluate the quality of wastewater effluents, river water, raw water for drinking water supply, treated drinking water, water used for irrigation and aquaculture and recreational water” (DWAF, 1996a, p78).

<table>
<thead>
<tr>
<th>Table 6-7: Faecal Coliforms - Water Quality Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DWAF Water Quality Guidelines (counts/100ml)</strong></td>
</tr>
<tr>
<td>Domestic Use</td>
</tr>
<tr>
<td>Aquatic Ecosystems</td>
</tr>
<tr>
<td>Recreational</td>
</tr>
<tr>
<td><strong>Vaal Barrage Reservoir In-Stream Guidelines</strong></td>
</tr>
<tr>
<td>Ideal</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>Tolerable</td>
</tr>
<tr>
<td>Unacceptable</td>
</tr>
</tbody>
</table>
Implication to Aquatic Health

Kureya (2003) states that human waste is a major cause of water pollution in southern Africa, because it contains bacteria and parasites that may cause disease. When human wastes end up in rivers, nutrients fertilize and stimulate growth of algae and other biota. The oxygen in the water is used up and plants and fish end up dead, which contributes to eutrophication of the water body.

Implication to Human Health

Faecal coliforms are used to indicate the presence of bacterial pathogens such as *Salmonella spp.*, *Shigella spp.* and *Vibrio Cholerae* which can be transmitted via the faecal/oral route by contaminated or poorly treated drinking water and may cause disease such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996a).

6.3. Aesthetic Properties

Although the aesthetic water quality aspects of the study are not included as part of the analysis in Section 8, it is an important aspect of water quality (Kruger, 2004) due to the fact that humans can easily observe the pollution through various senses due to the appearance and smell thereof.

Eutrophication (which has a major aesthetic impact on water quality) is caused by high nutrient loads (predominantly phosphates and nitrates) which enriches the water and makes it ideal for growth of unwanted vegetation and algae (Thompson, 2006). Refer to Figure 6-1 for an example of the level of eutrophication observed in the study area. Jarvie *et al.* (2006) are of the opinion that point source pollution provide the largest risk for river eutrophication than diffuse sources of pollution.
Figure 6-1: Eutrophication in the Vaal River Barrage Reservoir.

The following chapter will discuss the data collection methods followed for the purposes of this research report.
7. DATA COLLECTION

This section will discuss the data collection methods, and describe the shortcomings of the data and the reliability thereof.

7.1. Data collection methods

Rand Water undertakes weekly water sampling for water quality monitoring at the different sampling points (as indicated in Figure 7-1). There were numerous instances where data for a specific variable were missing. Data were manipulated in these instances in order to get meaningful results. The process of data manipulation for analysis included the following steps.

Step 1: Determine average values where data were omitted or not available.

Averaging techniques using values directly before and after omitted readings were used to calculate the estimated values (Gujarati, 1995). Moving averages were used to calculate values for omitted data over extended periods (predominantly for values of N03 and S04 from May 2001 to December 2001).

Step 2: Determine the value for readings indicating a less than value (<0.1, <0.25)

Values from previous years supported the estimation of smaller than values at 75% of the indicated value (e.g. 0.75 of <0.1= 0.075).

Step 3: Identifying outliers in data leading to distorted data

Weekly outliers that deviated extensively from the weekly averages from previous, corresponding and following weeks were omitted and replaced with average values when the outlying value could not be explained.
Step 4: Converting weekly values to monthly values

Weekly water quality readings taken in a specific month were averaged as monthly readings.

Step 5: Converting monthly values to values per semester

Monthly water quality averages were used to determine half-yearly averaged values. Half-yearly averaged values were then compared to rainfall in low and high rainfall periods. As mentioned previously, high rainfall months include the months October to March and low rainfall months April-September). Please see Appendix A for averaged monthly graphs and Appendix B for averaged yearly graphs.

7.2. Reliability and Shortcomings of the Data

The water quality data provided by Rand Water contained various gaps and inconsistencies due to missing data for certain periods, or certain water properties, as explained in the section above. The researcher wanted to include Faecal Coliforms for discussion, but due to large gaps in the data received, it was decided not to because seasonal trends will not be observed if moving averages are used.

It should be noted that the flow in the Vaal Barrage Reservoir is not dependent on rainfall alone. Water is added to the system by return flows from waste water treatment works and pumped mine water. Furthermore, releases from the Vaal Dam also impacts on the flow (and water quality) of the Vaal Barrage Reservoir due to a dilution effect it has. For the purposes of this research, these aspects weren’t taken into consideration during the analysis of the data.

Water quality monitoring in VRB 24 and VRB 37 commenced in January 1992. Monitoring at V2 and V17 has been conducted for a much longer period. The time period 1992 – 2006 was therefore used for the purposes of this research report.
7.3. Sampling points

For the purpose of this research report, four sampling points were used to gain a temporal spatial perspective of the Vaal Barrage Reservoir catchment area. The regional location of these sampling points are discussed in section 4 and indicated in Figure 4-3. Google Earth images as shown in Figure 7-1 depicts the local area of each of these four (4) sampling points.  

Figure 7-1: Sample points of the Vaal Barrage Reservoir Catchment  
(Images from Google Earth)

5 Figure 7-1 is Google Earth images of the four sampling points of the study area. For the regional setting of these sampling points, please refer to Figure 4-3.
In the next section, the data analysis is described to determine the main pollutants to the Vaal Barrage Reservoir. Furthermore it is established whether or not seasonal influences are experienced in terms of the pollutant loads at the four sampling points.
8. RESULTS AND DISCUSSION OF ANALYSIS

8.1. Temporal-spatial comparison of sample points

The water quality parameters were analysed using averaged six monthly data in order to compare these with rainfall figures (as discussed in section 8.2). Therefore groups ending with 1 indicates the high rainfall season, and groups ending with 2 indicates the low rainfall season.

8.1.1. Electrical Conductivity

Sampling point V2 is located close to the Vaal Dam outlet. It is clear from the results on Figure 8-1 that EC at this sampling point occurs at much lower concentrations than measurements at the other points. During the period 1992 – 1996 the water quality in terms of EC stayed in the ideal category of the VBCEC in stream water quality guidelines for the Vaal Barrage Reservoir. For the period 1996 – 2005, the EC concentrations deteriorated, but still fell in the acceptable category of VBCEC’s in stream water quality guidelines for the Vaal Barrage Reservoir. From 2004 the water quality progressed towards the ideal category, and actually reached it during the low rainfall season of 2006.

The EC concentration at the three other sampling points (VRB 24, VRB 37 and V17) showed similar characteristics during the whole monitoring period (1992 – 2006).

A definite pattern can be observed where the concentration increases during the low rainfall seasons and decreases during periods of high rainfall. Electrical Conductivity seems to increase progressively after every low rainfall season. Water quality is observed at falling within either the tolerable classification of the Vaal River Barrage in stream water quality guidelines (which is the same for domestic use according to DWAF guidelines), with occasional peaks into the unacceptable levels of the Vaal River Barrage in stream water quality guidelines. This pattern is observed up to the period after the high rainfall season of 1998, where a dramatic drop and subsequent decrease in Electrical Conductivity is observed which is not in line with the pattern it has followed for the previous seven years.
A dramatic increase in EC is observed after the low rainfall season of 1999, which pushes the EC to the unacceptable in stream water quality guidelines for the Vaal Barrage Reservoir. The EC remains within this unacceptable water quality classification for the majority of the following number of years, and only experiences a decrease after the high rainfall period of 2005. A rise in EC levels can be observed during the low rainfall period of 2006.
Figure 8-1: Electrical Conductivity - Comparison Between Vaal River Barrage Sampling Points
8.1.2. pH

As can be seen from Figure 8-2 the pH values between all four sampling points vary little between different classifications of the in stream water quality guidelines for the Vaal Barrage Reservoir. It can however be observed that sampling points V2 and V17 do not follow the same seasonal trends observed at sampling points VRB24, VRB37.

The pH values fall within the ideal classification of the in stream water quality guidelines for the Vaal Barrage Reservoir with only two peaks which extend towards the acceptable level of the in stream water quality guidelines for the Vaal Barrage Reservoir. These peaks are observed at V17 during the 1995 high rainfall period and in VRB24 in the 1998 low rainfall period.

pH concentrations are also in line with the DWAF Domestic and Recreational use of water quality guidelines.
Figure 8-2: pH - Comparison Between Vaal River Barrage Sampling Points
8.1.3. Nitrates

DWAF water quality guidelines for domestic use are the same as the tolerable level for in stream water quality guidelines of the Vaal River Barrage Reservoir. The ideal classification of the in stream water quality guidelines of the Vaal River Barrage Reservoir correspond to the ideal target water quality guideline for aquatic ecosystems.

Figure 8-3 depicts the seasonal averages for nitrates at the four sampling points. A general trend between sampling points VRB24 and VRB37 can be observed. Generally the concentration at VRB37 is slightly higher than measurements indicate at VRB24, but the trend remains the same for the majority of the study period. The only change in this trend is evident during the low rainfall period of 2001 to the low rainfall period of 2002. It should however be noted, that raw data for nitrate for this period (low rainfall period of 2001 to the low rainfall period of 2002) were not available and it was therefore averaged (using moving averages), and is therefore not a definite indication of the true values of nitrates as measured at this sampling point.

Generally, sampling point V17 follows the same pattern as observed for VRB24 and VRB37, with exception of the periods between the high rainfall season of 1997 and the high rainfall season of 2004. The measurements remain within the acceptable levels of water quality for the in stream water quality guidelines for the Vaal Barrage Reservoir. During 2004 moving averages were used to calculate values, because data were not available, and the measurements are therefore not a definite indication of the true values of nitrates as measured at this sampling point. The measurements for nitrate are considerably lower than that of VRB24, but the seasonal trend tends to be the same.

Once again, sampling point V2 does not follow the same pattern observed for the other sampling points. Generally the level of nitrates is considered as ideal in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir, with only one dramatic spike during the high rainfall season of 2003 where it reached tolerable levels in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir. The same dramatic fall was
experienced from the low rainfall season of 2003 up to the high rainfall season of 2004, where the water quality improved to ideal again.
Figure 8-3: Nitrates - Comparison Between Vaal River Barrage Sampling Points

NO3 Nitrates

- NO3 (V2)
- NO3 (V17)
- NO3 (VRB24)
- NO3 (VRB37)
- VBCEC Guideline Ideal
- VBCEC Guideline Acceptable
- VBCEC Guideline Tolerable
8.1.4. Phosphates

Generally all the phosphate measurements are considered to be unacceptable in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir as can be observed from Figure 8-4.

Water quality at sampling point V2 has progressively improved from the high rainfall season in 1993. Water quality reached tolerable levels in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir during the high rainfall season of 2001 to the high rainfall period of 2002 and once again during the low rainfall period of 2003 to the low rainfall period of 2005.

Water quality at sampling point VRB24 generally remains between 0,15 – 0,4 mg/l which falls within the unacceptable levels in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir during the during the whole sampling period. Measurements peaked during the high rainfall season of 2004 at 0,8 mg/l.

Water quality at sampling point VRB37 generally remains between 0,12– 0,55mg/l which falls within the unacceptable levels in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir during the during the whole sampling period. Measurements reached its lowest measurements during the high rainfall period of 2002 at 0,1 mg/l.

Water quality at sampling point V17 generally remains between 0,05– 0,25mg/l which falls within the unacceptable levels in terms of the in stream water quality guidelines for the Vaal Barrage Reservoir during the during the whole sampling period. Measurements reached its highest measurements during the low rainfall period of 1999 at levels between 0,2 – 0,5mg/l.
Figure 8-4: Phosphates - Comparison Between Vaal River Barrage Sampling Points

PO4 Phosphates

- PO4 (V2)
- PO4 (V17)
- PO4 (VRB24)
- PO4 (VRB37)
- VBCEC Guideline Acceptable
- VBCEC Guideline Tolerable

mg/l

Time

8.1.5. Sulphates

Figure 8-5 depicts the sulphate measurements taken from 1992 – 2006. The DWAF target water quality guidelines correspond to the upper limit of the tolerable guideline of the Vaal Barrage Reservoir in stream water quality guidelines.

Sampling points VRB24 and VRB37 follow the same trend and fall within the tolerable classification of the Vaal Barrage Reservoir in stream water quality guidelines. Unacceptable measurements in terms of the Vaal Barrage Reservoir in stream water quality guidelines for these two sampling points were observed during the low rainfall period of 1996 and during the low rainfall period of 2002.

Measurements at V17 also mimics the trend of that identified at VRB24 and VRB37 to a certain extent. V17 reached acceptable levels in terms of the Vaal Barrage Reservoir in stream water quality guidelines during the low rainfall period of 1995 and reached unacceptable measurements in terms of the Vaal Barrage Reservoir in stream water quality guidelines during 1995 low rainfall period until the high rainfall period of 1996.

The water quality as measured at sampling point V2 tends to be much better than any of the water quality samples at the three other sampling points. The water quality is classified as ideal in terms of the Vaal Barrage Reservoir in stream water quality guidelines for the majority of the sampling period. Deterioration in water quality occurred during the high rainfall period of 1998 to tolerable levels in terms of the Vaal Barrage Reservoir in stream water quality guidelines, but improved to acceptable levels during the high rainfall period of 1999.
Figure 8-5: Sulphates - Comparison Between Vaal River Barrage Sampling Points

SO4 Sulphates

- SO4 (V2)
- SO4 (V17)
- SO4 (VRB24)
- SO4 (VRB37)
- VBCEC Guideline Ideal
- VBCEC Guideline Acceptable
- VBCEC Guideline Tolerable

mg/l

Time

8.1.6. Chemical Oxygen Demand

Figure 8-6 depicts the seasonal water quality measurements at the four sampling points. No DWAF water quality guideline exists for COD.

The period 1992 – 2000 is categorised by extremely high fluctuations in water quality, and no trend is evident between any of the sampling points. After the high rainfall period of 2000 however, sampling points V17, VRB24 and VRB37 remained within the tolerable classification of Vaal Barrage Reservoir in stream water quality guidelines.

Sampling point V2 remains within the tolerable class up to the low rainfall period of 1994 – 1995, where the quality improves to acceptable levels in terms of the Vaal Barrage Reservoir in stream water quality guidelines. Water quality deteriorates slightly thereafter, but recovers and water quality improves from the 1999 high rainfall period and water measurements all fall within the acceptable levels again.

Measurements at sampling point VRB37 remains within unacceptable levels in terms of the Vaal Barrage Reservoir in stream water quality guidelines and experiences seasonal fluctuations in intensity, but improves drastically in the low rainfall period of 1999.

Measurements at sampling point VRB24 fluctuates between tolerable and unacceptable levels in terms of the Vaal Barrage Reservoir in stream water quality guidelines. Drastic deterioration occurs between the low rainfall periods of 1997 – 1999.
Figure 8-6: Chemical Oxygen Demand - Comparison Between Vaal River Barrage Sampling Points

Chemical Oxygen Demand

<table>
<thead>
<tr>
<th>COD (V2)</th>
<th>COD (V17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (VRB24)</td>
<td>COD (VRB37)</td>
</tr>
<tr>
<td>VBCEC Guideline Ideal</td>
<td>VBCEC Guideline Tolerable</td>
</tr>
</tbody>
</table>

mg/l

Time


mg/l

0.00  10.00  20.00  30.00  40.00  50.00  60.00  70.00  80.00  90.00  100.00
8.2. Influence of Rainfall

Seasonal variation in water quality is an important tool for evaluating temporal variations of pollution due to point and diffuse sources of pollution (Ouyang et al. 2006). This section will discuss the influence of rainfall on each of the discussed water quality parameters, at the four different sampling points.

For determining the influence of rainfall on the water quality parameters a correlation was performed between the data of the specific water quality parameter and the rainfall figures for a six monthly period (high rainfall period, and low rainfall period). Correlation matrices are provided for each of the water quality parameters in Table 8-1 to 8-6.

### Table 8-1: Correlation between Electrical Conductivity and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>Electrical Conductivity (V2)</th>
<th>Electrical Conductivity (V17)</th>
<th>Electrical Conductivity (VRB24)</th>
<th>Electrical Conductivity (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>0.25</td>
<td>0.24</td>
<td>0.18</td>
<td>0.01</td>
</tr>
<tr>
<td>V17</td>
<td>0.25</td>
<td>1.00</td>
<td>0.95</td>
<td>0.84</td>
<td>-0.74</td>
</tr>
<tr>
<td>VRB24</td>
<td>0.24</td>
<td>0.95</td>
<td>1.00</td>
<td>0.91</td>
<td>-0.67</td>
</tr>
<tr>
<td>VRB37</td>
<td>0.18</td>
<td>0.84</td>
<td>0.91</td>
<td>1.00</td>
<td>-0.50</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.01</td>
<td>-0.74</td>
<td>-0.67</td>
<td>-0.50</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Table 8-2: Correlation between pH and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>pH (V2)</th>
<th>pH (V17)</th>
<th>pH (VRB24)</th>
<th>pH (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>0.42</td>
<td>0.51</td>
<td>0.54</td>
<td>-0.03</td>
</tr>
<tr>
<td>V17</td>
<td>0.42</td>
<td>1.00</td>
<td>0.78</td>
<td>0.70</td>
<td>-0.35</td>
</tr>
<tr>
<td>VRB24</td>
<td>0.51</td>
<td>0.78</td>
<td>1.00</td>
<td>0.75</td>
<td>-0.27</td>
</tr>
<tr>
<td>VRB37</td>
<td>0.54</td>
<td>0.70</td>
<td>0.75</td>
<td>1.00</td>
<td>-0.23</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.03</td>
<td>-0.35</td>
<td>-0.27</td>
<td>-0.23</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Table 8-3: Correlation between Nitrate and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>NO3 (V2)</th>
<th>NO3 (V17)</th>
<th>NO3 (VRB24)</th>
<th>NO3 (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>0.07</td>
<td>0.33</td>
<td>0.36</td>
<td>-0.23</td>
</tr>
<tr>
<td>V17</td>
<td>0.07</td>
<td>1.00</td>
<td>0.78</td>
<td>0.81</td>
<td>-0.69</td>
</tr>
<tr>
<td>VRB24</td>
<td>0.33</td>
<td>0.78</td>
<td>1.00</td>
<td>0.90</td>
<td>-0.66</td>
</tr>
<tr>
<td>VRB37</td>
<td>0.36</td>
<td>0.81</td>
<td>0.90</td>
<td>1.00</td>
<td>-0.67</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.23</td>
<td>-0.69</td>
<td>-0.66</td>
<td>-0.67</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 8-4: Correlation between Phosphates and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>PO4 (V2)</th>
<th>PO4 (V17)</th>
<th>PO4 (VRB24)</th>
<th>PO4 (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>-0.40</td>
<td>-0.19</td>
<td>0.09</td>
<td>0.21</td>
</tr>
<tr>
<td>V17</td>
<td>-0.40</td>
<td>1.00</td>
<td>0.70</td>
<td>0.43</td>
<td>-0.11</td>
</tr>
<tr>
<td>VRB24</td>
<td>-0.19</td>
<td>0.70</td>
<td>1.00</td>
<td>0.44</td>
<td>-0.17</td>
</tr>
<tr>
<td>VRB37</td>
<td>0.09</td>
<td>0.43</td>
<td>0.44</td>
<td>1.00</td>
<td>-0.15</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.21</td>
<td>-0.11</td>
<td>-0.17</td>
<td>-0.15</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 8-5: Correlation between Sulphates and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>SO4 (V2)</th>
<th>SO4 (V17)</th>
<th>SO4 (VRB24)</th>
<th>SO4 (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>-0.20</td>
<td>-0.21</td>
<td>-0.32</td>
<td>0.08</td>
</tr>
<tr>
<td>V17</td>
<td>-0.20</td>
<td>1.00</td>
<td>0.79</td>
<td>0.70</td>
<td>-0.70</td>
</tr>
<tr>
<td>VRB24</td>
<td>-0.21</td>
<td>0.79</td>
<td>1.00</td>
<td>0.87</td>
<td>-0.62</td>
</tr>
<tr>
<td>VRB37</td>
<td>-0.32</td>
<td>0.70</td>
<td>0.87</td>
<td>1.00</td>
<td>-0.42</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.08</td>
<td>-0.70</td>
<td>-0.62</td>
<td>-0.42</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 8-6: Correlation between Chemical Oxygen Demand and Rainfall

<table>
<thead>
<tr>
<th>Date 6-Monthly</th>
<th>COD (V2)</th>
<th>COD (V17)</th>
<th>COD (VRB24)</th>
<th>COD (VRB37)</th>
<th>6-Monthly Rainfall Average per Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>1.00</td>
<td>0.82</td>
<td>0.32</td>
<td>0.43</td>
<td>0.33</td>
</tr>
<tr>
<td>V17</td>
<td>0.82</td>
<td>1.00</td>
<td>0.13</td>
<td>0.58</td>
<td>0.13</td>
</tr>
<tr>
<td>VRB24</td>
<td>0.32</td>
<td>0.13</td>
<td>1.00</td>
<td>0.38</td>
<td>-0.11</td>
</tr>
<tr>
<td>VRB37</td>
<td>0.43</td>
<td>0.58</td>
<td>0.38</td>
<td>1.00</td>
<td>-0.21</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.33</td>
<td>0.13</td>
<td>-0.11</td>
<td>-0.21</td>
<td>1.00</td>
</tr>
</tbody>
</table>
It is evident from the correlation matrices that an inverse correlation exists between rainfall and the water quality parameter. This means that in periods of high rainfall, lower concentrations of the pollutant loads for the water quality parameters can be expected. Three of the sampling points (VRB24, VRB37 and V17) all share similarities in terms of the correlation values. Sample point V2 however, shows no such correlation, and it can therefore be concluded that rainfall has no influence on the water quality at this sampling point.

This statement is especially true in the case of Electrical Conductivity, Nitrates and Sulphates at sampling points VRB24, VRB37 and V17, which shows the highest inverse correlation values.

Sample point V17 tends to have the highest inverse correlation to rainfall for the above mentioned three water quality parameters, followed closely by VRB24. The influence of rainfall at VRB37 is slightly less, but also worth mentioning.
9. SYNTHESIS

9.1. Main Pollutants to the Vaal Barrage Reservoir over time

As discussed in section 8.1, the pollutants to the Vaal Barrage Reservoir which represent the biggest threat can be summarised as Phosphates, Electrical Conductivity and Sulphates. Chemical Oxygen Demand posed a big threat up to the high rainfall period of 2001, but has since decreased drastically and stabilised (with minor fluctuations) in the tolerable classification of water quality in terms of the Vaal Barrage Reservoir in stream water quality guidelines.

Sampling point VRB37 shows the highest Electrical Conductivity measurements. At the end of the study period (2006) it was found that sampling point V17 experienced the highest phosphate measurements and VRB 37 the highest sulphate concentrations.

9.2. Influence of Rainfall

It is evident from the correlation matrices that an inverse correlation exists between rainfall and the water quality parameters. This means that in periods of high rainfall, lower concentrations of the pollutant loads can be expected. This statement is especially true in the case of Electrical Conductivity, Nitrates and Sulphates at sampling points VRB24, VRB37 and V17, which show the highest inverse correlation values. Sample point V17 tends to have the highest inverse correlation to rainfall for the above mentioned three water quality parameters, followed closely by VRB24.

Sample point V2 however, shows no correlation, and it can therefore be concluded that rainfall has no influence on the water quality at this sampling point, taking into account that V2 is influenced by releases of the Vaal Dam, which has a dilution effect. For the purposes of this research, these aspects weren’t taken into consideration during the analysis of the data.
10. CONCLUSION

South Africa is classified as a semi-arid country, which implies that water is not readily available. Further stress is applied to the water resource through population growth, increased urbanisation and industrial activities.

The study area is considered to be the most populated area of the Upper Vaal WMA, which is the most important WMA in terms of economic productivity in South Africa. This research report focused on assessing the temporal and spatial variations between four different sampling points located in the Vaal Barrage Reservoir, which is located in the heart of the Upper Vaal WMA.

Pollutants which currently pose the biggest threat in terms of water quality for the Vaal Barrage Reservoir are Phosphates, Electrical Conductivity and Sulphates. These three water quality variables do not comply with the minimum standards as set by VBCEC. The occurrence of these pollutants in the Vaal River can be explained by the vast inputs of return flow water from sewage treatment plants, underground mine water and discharge from industries.

It was found that there are seasonal variations in terms of water quality. Sample point V17 had the highest inverse correlation for the three pollutants which pose the biggest threat to the health of the Vaal Barrage Reservoir water body.

Sample point V2 had extremely low correlation figures, which implies that rainfall has little or no impact on the level/concentration of a pollutant. This can be explained by two factors. Firstly the dilution effect which water releases from the Vaal Dam has due to the close proximity to V2, and secondly because urban, mining and industrial activities are much less evident at this point than at the other three sampling points.
11. **RECOMMENDATIONS**

This research report focussed on determining the temporal and spatial perspective on the main pollutants to the Vaal River Barrage, and the influence that rainfall exerts thereon. The results of the research raised new questions, which are beyond the scope of this research. More detailed studies are required in order to determine:

- The water quality between sampling points V2 and VRB37
  - This should be done in order to determine where the water quality deteriorates, and due to what factors.
- The main contributors to the phosphate load to the Vaal River Barrage
  - This is of importance due to the fact that the phosphate level falls within the unacceptable classification of water quality in terms of the in stream water quality guidelines of the Vaal Barrage Reservoir.
  - Furthermore, the identification of the main contributors to the phosphate pollution could lead to more stringent water quality conditions for releasing water into the water body through application for water use licences in terms of the National Water Act (Section 21).
12. REFERENCES

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Appendix A: Averaged Monthly Graphs for Water Quality Variables
Nitrates NO3

- NO3 (V2)
- NO3 (V17)
- NO3 (V24)
- NO3 (V37)
Appendix B: Averaged Yearly Graphs for Water Quality Variables
Chemical Oxygen Demand

- COD (V2)
- COD (VRB24)
- Rand Water Guideline Ideal
- Rand Water Guideline Acceptable
- Rand Water Guideline Tolerable

Time


mg/l