

**THE IMPACT OF INDUSTRIAL EFFLUENCES ON WATER
QUALITY IN THE WATERVAL RIVER CATCHMENT**

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 ARTS

at the

UNIVERSITY OF JOHANNESBURG

SUPERVISOR: PROFESSOR J.T. HARMSE

September 2007

ABSTRACT

The goal of this study is to determine the water quality of the Klipspruit River over a six-year period, from 2000 to 2005. The Klipspruit lies within the sub-catchment area of the Waterval River, which in itself forms part of the Upper Vaal Catchment. The Klipspruit runs through the city of Secunda in Mpumalanga Province, South Africa, its catchment area providing two percent of the water to the Vaal Dam. In its turn, the Vaal Dam is the main raw water source for Rand Water that provides potable water to 10 million people in its 18 000 square kilometre service area.

This study specifically focuses on the long-term trends of six selected water-quality parameters related to the effluent generated at the Sasol Secunda Industrial Complex (SSIC) during its coal-to-fuel operations. Certain physical, chemical and organic water-quality parameters of the Klipspruit were investigated on the basis of samples taken from three monitoring points in it. The water samples were analysed in terms of the water quality guidelines stipulated by the Department of Water Affairs and Forestry (DWAF), as well as the In-stream Water Quality Guidelines laid down by the Waterval River Catchment Management Agency. This was done to determine how industrial effluent impacts upon water quality in general and also how it affects water usage in other respects. The water-use categories considered in this study include aquatic ecosystems, domestic systems, livestock watering and irrigation systems.

The results of conducting a regression analysis on the data collected from the monitoring points on the Klipspruit and assessing it in terms of the specifications laid down by the guidelines in question show that the respective concentrations of a number of water quality parameters in the upper part of the Klipspruit often exceed the ideal water quality levels. However, these concentration levels stabilize over time as the river continues to flow downstream. This is mainly due to the location of the first monitoring point which is close to the Sasol Secunda Industrial Complex (SSIC), where the effluent is generated, and also because the Secunda Sewage Treatment Plant is in the vicinity.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to the following institutions and people who supported me during this study:

- Rand Water, especially Head: Catchment Management Francoise van Wyk, who supplied the raw data,
- My supervisor, Professor Tertius Harmse, for his guidance and support,
- My family for their support.



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1. INTRODUCTION

South Africa has been classified as a water-scarce region (Fakir, 1999), with some parts being described as water-stressed areas (Rand Water, 2005). This is mainly due to South Africa's location within the arid and semi-arid latitudes of the Southern Hemisphere, and is one reason why South Africa receives an average annual rainfall of about 500mm (Abram, 2001), which amounts to slightly more than half of the world's average annual rainfall (900mm).

What aggravates this region's lack of water resources even more is an unstable water cycle on account of South Africa's irregular seasonal rainfall and high evaporation rates, the latter owing to the region's sunny and hot climate. The fact that 70 percent of the earth's surface is occupied by water is well-known, but other realities are often overlooked. Such neglected considerations include the following facts:

- that the amount of water on earth is constant and cannot, therefore, be increased or decreased;
- that only 0.6 percent of the world's fresh water supply (i.e. surface and groundwater) is available for utilization; and
- that the available water resources are unevenly distributed across the globe.

Thus it is apparent that any country, especially in this part of the world, needs to effectively manage and monitor the water resources at its disposal and that it consumes, no matter how copious or limited that supply is. Owing to the distribution of people across South Africa and the country's current population growth, rapid changes are being made to South Africa's land-use patterns. These changes have made great impacts on the catchment areas drained by the larger rivers, thereby affecting the availability of fresh water in South Africa even more. For example, many industries are located along river banks for easy access to potable water that can be utilized during the various industrial processes. Unfortunately, many industries over-exploit these rivers, using them as dumping grounds into which they discharge their industrial waste products, which often contain a variety of pollutants.

By releasing industrial effluent (waste water) into rivers, industries contribute to one of the most serious of environmental problems, namely water pollution. Other factors contributing to the destruction of catchment areas include urbanization, deforestation, the damming of rivers, the destruction of wetlands, accidental water pollution events, and the allocation of land in such environmentally-sensitive areas for the purposes of mining, agriculture and the generation of electricity.

Hence, as South Africa's population increases and her economy grows so too will the demand for access to and the use of potable water increase. There are many different categories of water users who, in their efforts to secure their own supply of potable water come to compete against one another. Unfortunately, each one's water requirements differs from the others', which means that water suitable for one use may be declared unfit for another. For example, some aquatic organisms are adapted to live only in fresh water and therefore depend on fresh water for their survival: they could not survive in seawater. For that reason, the Department of Water Affairs and Forestry (DWAF) has found it necessary to establish different water quality guidelines which suit the requirements of the various water users (DWAF, 1996a). These guidelines ensure that each water user functions at an optimum level without harming the environment and/or jeopardizing the water resources for other water users when it discharges effluent into a river system. The water quality guidelines from the DWAF, along with other guidelines, are used in this study to determine the net effects of industrial effluent on water quality and how this type of effluent affects other water users.

Thus, the main aim of this study is to determine the impacts of industrial effluent from the Sasol Secunda Industrial Complex (SSIC) on the water quality of the Klipspruit River, which flows through Secunda in Mpumalanga Province. The Klipspruit River lies in the Waterval River sub-catchment area, forming part of the Vaal River Catchment area. It constitutes the third-largest part of the main Upper Vaal River Catchment area. In turn, this main catchment area supplies the Vaal Dam, a major source of raw unpurified water for the Rand Water Board, which provides potable water to its clients.

Figure 1 represents a flow diagram of themes that were researched and which will be discussed in the subsequent chapters of this dissertation.

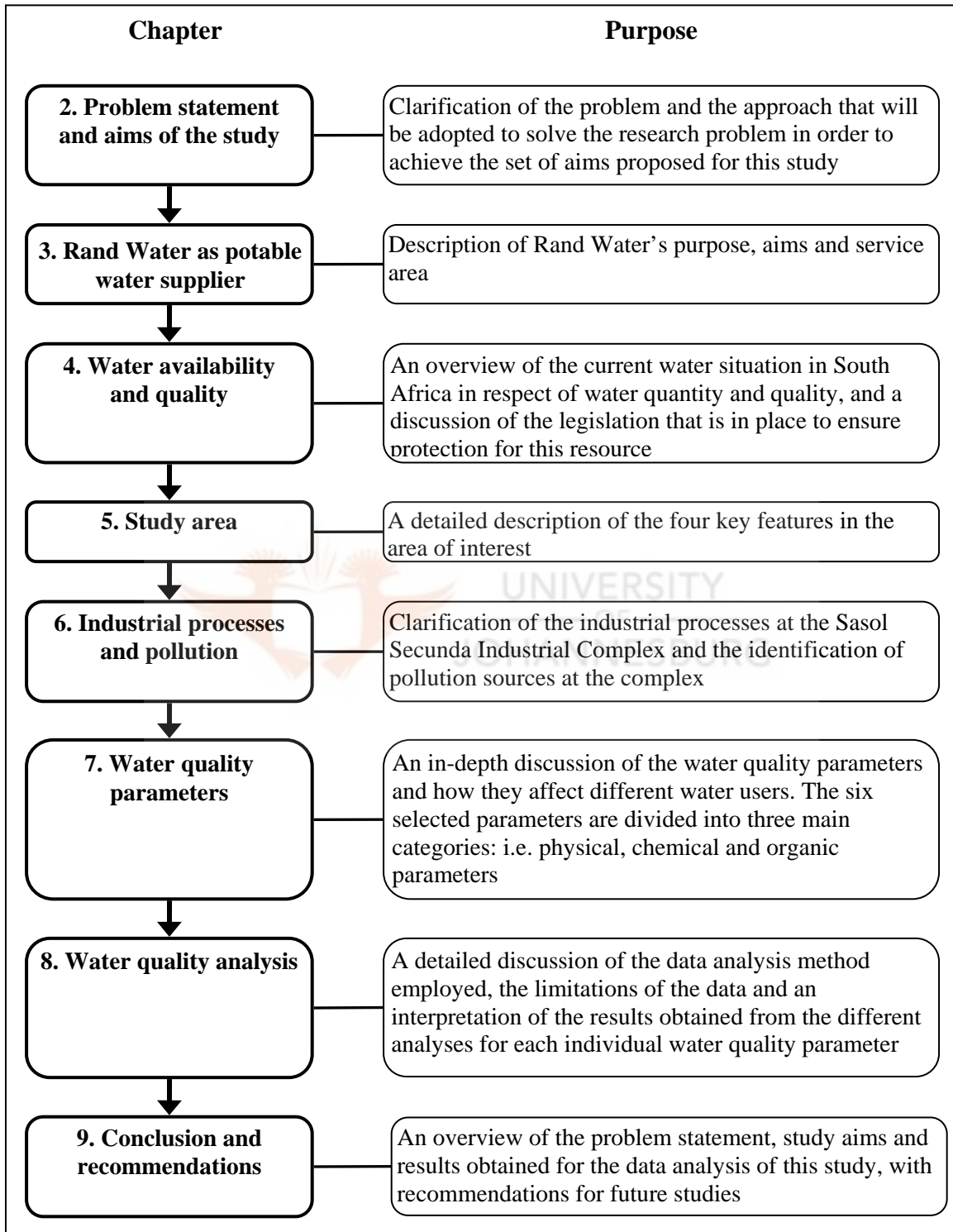


Figure 1: Chapter layout

2. PROBLEM STATEMENT AND STUDY AIMS

It was made clear in the introduction that the scarcity of South Africa's fresh water resources is due to interrelated natural and human-induced factors. The quality of this scarce resource is also deteriorating, on account of the following factors:

- the inflow of various pollutants from different sources into an inter-connected river system; and
- the degradation of river catchment areas.

Apart from being prevalent in the study area, these problematical factors are also increasing in frequency - in fact, at an alarming rate. Furthermore, South Africa's perennial rivers have become seasonal: they are carrying increasing silt loads, thereby altering the chemical composition of the rivers (Fuggle & Rabie, 1992, and Silberbauer *et al.*, 1999). Brooks *et al.* study on the water quality of effluent-dominated ecosystems found that 'when industrial wastewater effluents are discharged to streams, effluents may comprise the majority of stream flows' (2006, p365).

Thus it is apparent that, if sustainable development is to be achieved and maintained in the years to come, South Africa needs to learn how to effectively monitor and manage the use and consumption of this scarce and precious resource, as well as the effluent that is generated through industrial and agricultural processes. In this study, the term "sustainable development" is used to describe industrial development that is constant, without environmental damage, and that is beneficial towards the people (Manahan, 2001). If people are to survive while maintaining a reasonable living standard, a concept such as 'sustainable development' must include the minimized use of non-renewable resources as far as possible, and incorporate the enhancement of the capability to exploit renewable resources. In order for industries to establish an effective environmental management strategy, which will help them to achieve the water quality objectives laid down by the DWAF, it is necessary to identify the type of pollution, as well as the source, and understand the interrelationships between pollution and the environment. These requirements must be met if water pollution is to be effectively managed.

The intention of this study is to help identify such pollutants and their sources, as well as to explain the consequences of their occurrence to the environment, while indicating how such substances can influence the suitability of water for other water users. According to Van Wyk (2001), by quantifying the impacts of pollution sources, essential information can be provided to assist industries in formulating and implementing appropriate pollution strategies which are unique to their circumstances, conditions and processes. Therefore the primary research aim of this dissertation is:

to determine the water quality of the Klipspruit River in order to establish the overall impacts and effects of industrial effluent that is produced at the Sasol Secunda Industrial Complex in Mpumalanga.

It is also the researcher's intention to achieve certain objectives through conducting this study. These include the following:

- To determine the ripple effects of deteriorated water quality; caused when industrial effluent enters into an aquatic ecosystem. These ripple effects will assist the researcher in identifying the necessity, if indeed so, of implementing better control measures in order to achieve a particular standard in the quality of the water;
- To discover how industrial effluent pollution impacts upon other water users;
- To determine where and why there are high levels of particular pollutants;
- To indicate what parameters are of concern owing to the presence of extreme concentrations of pollutants that exceed given standards;
- To provide useful and vital information to authorities (local and national) which they can use during the decision-making process regarding the control measures that need to be created or re-evaluated in order to successfully manage the aquatic environment (if current control measures are inadequate);
- To conclude whether the SSIC is complying with and meeting local, as well as national, water quality standards, and whether there has been an increase or a decline in pollution over a six-year period.

In order to establish the quality of the water in the Klipspruit River, it was found necessary to analyse the trends of six water-quality parameters, namely pH levels, conductivity, nitrate, phosphate and sulphate concentrations in the water, and chemical oxygen demand. These parameters were chosen after consulting with Mr. van Wyk (Head: Catchment Management at Rand Water). He explained that these parameters are good indicators of the impact of industrial activities at the SSIC on the surrounding environment. The fact that these parameters are persisting at high levels points to the serious light in which these impacts must be considered (Van Wyk, 2006; Waterval Forum, 2005a). The choice of parameters also 'depends on the pollution sources existing at the location and the intended use of the water' (Abrahamo, *et al.*, 2007, p459).

The following procedures for data collection and processing were undertaken:

- Water sampling data taken from three sampling points at different points in the Klipspruit were obtained for a six-year period (2000 to 2005). These water samples were collected by Rand Water which conducted the chemical analysis of them at the Rand Water laboratories, and then stored the results in Rand Water's database.
- After the electronic data were collected from Rand Water, two quantitative data analyses were conducted on the data, namely a comparative analysis and a regression analysis relating to the individual water quality parameters. These data analyses, carried out mainly by means of the Microsoft Excel computer programme, produced a number of charts and tables for purposes of reference in this dissertation in order to facilitate the process of data interpretation.
- The data for the comparative analysis were assessed in terms of the DWAF's and the Waterval River Catchment Management Agency's Water-quality Guidelines to determine the extent of water pollution caused by industrial activities. These results were subsequently examined in terms of the guidelines set out specifically for the following water users: freshwater aquatic ecosystems, domestic systems and for agricultural purposes, including livestock watering and irrigation.

2.1 Terminology

To facilitate the reader's full comprehension of this research problem, this chapter sets out to clarify the reasons for and purpose of such a study, along with the method according to which this study was conducted. Certain key terms are used regularly within this study and will be defined in the section below.

Water quality describes the physical, chemical, organic and aesthetic properties of water. These properties determine the suitability of water for a variety of purposes and the protection of the health and integrity of aquatic ecosystems.

Many of these properties are controlled or influenced by various substances which are either dissolved or suspended in the water (DWAf, 1996a). Rand Water found that by looking at the quality of a stream that flows through a settlement, the lifestyle for that particular community could be determined. Therefore, water quality can be used as an environmental indicator that points out the socio-economic conditions, as well as the environmental awareness and mindset of the community members. According to Rand Water (2004), 'Everything that happens in a catchment area is reflected in the quality of the water that flows through it, because the results of human activities and lifestyles ultimately end up in rivers, through surface runoff.'

Raw water is water found in rivers and dams. This water is bought and used by Rand Water to render its service of providing potable water.

Pollution, according to the National Water Act (1998), means the direct or indirect alteration of the physical, chemical or organic properties of a water resource so as to make it,

- a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or
- b) harmful, or potentially harmful, to
 - the welfare, health or safety of human beings;
 - any aquatic or non-aquatic organisms;
 - the quality of the resource; or
 - property.

Water pollution is thus the consequence of the introduction of an unwelcome concentration of substances into a body of water. It is often beyond the capacity of the natural environment to dilute these high concentrations of pollutants, and when some of these substances are ingested by living organisms, their effects on them could be detrimental. Water pollution can also be defined as the consequence that occurs because of a deviation in what is perceived to be the normal state of water, rather than what is perceived to be its pure state (Abrahamo, et al., 2007). This is because water is a natural solvent and is, therefore, never found in its purest form in the natural environment, and explains why the problem of water pollution is so complex.

As mentioned previously, there are a number of different users of normal water, so water that is suited for one use may be considered polluted by another user.

Catchments include the land surfaces which contribute water and other materials, through precipitation and surface runoff, to the river channel, which is in turn shaped by the action of the river and hill slope processes (Fox & Rowntree, 2003). A catchment is also regarded as the area into which any rainfall water will drain, through surface flow, towards a common point such as a water course or part of a water course.

Water quality parameters provide important information regarding the state of health of a water body, which is controlled by four aquatic properties, namely the physical, chemical, organic and aesthetic properties. These parameters are used to determine whether the quality of water is good enough for various uses, such as drinking and recreational purposes, irrigation and livestock watering and for sustaining aquatic life forms and ecosystems.

Dilute or *dilution* is the potential water has to weaken high concentrations of polluted substances that are discharged into a water body. This potential is enhanced when fresher or cleaner water is added to a water body. For this reason, previous pollution strategies made use of the 'control pollution through dilution' approach.

3. RAND WATER AS POTABLE WATER SUPPLIER

Because the Klipspruit River falls within the Waterval River Catchment Area, which in turn supplies water to the Vaal Dam, the aim of this chapter is to discuss the roles and functions that the Rand Water Board performs as potable water supplier, since most of its raw water is drawn from the Vaal Dam.

Rand Water has had the daunting task, since 1903, of providing various consumers in its service area with potable water. This service is ensured through Rand Water's effective management of the environment, constant monitoring of the water quality of its supply sources and its undertaking to draw raw water supplies from only the cleanest rivers, even those in remote Lesotho. The largest percentage (46 percent) of Rand Water's annual budget is set aside for purchasing raw water from the DWAF. **Figure 2** depicts the breakdown of Rand Water's expenses.

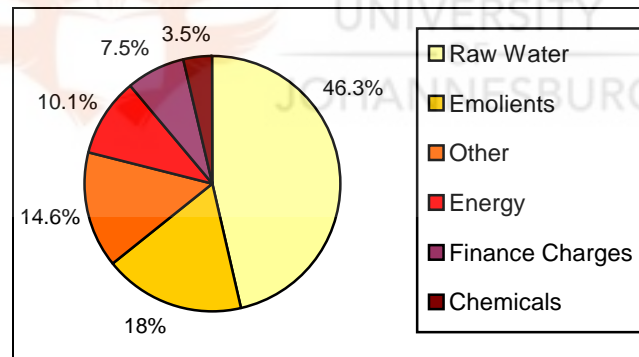


Figure 2: Cost of raw water in relation to other expenses (adapted from Van Wyk, 2001).

Currently, 99 percent of the water that Rand Water draws and treats in its task of providing potable water to its clients is surface water taken from the Vaal Dam (Kayle, 2007) with a capacity to hold 2.75 billion cubic metres of water. Unfortunately the current demand for Rand Water's potable water already exceeds this figure. Rand Water's recent estimates indicate an average growth rate of 2.76 percent per annum in potable water consumption (Rand Water, 2005).

This growth rate implies that the annual average daily demand of 2 800 megalitres per day will increase to 5 200 megalitres per day in 2020. This projection for water demand must be set in the context of the availability and cost of raw water. According to Rand Water (2005), the average growth rate for potable water consumption between 1971 and 1995 was four percent per annum. Since 1995, however, the growth rate has dramatically slowed down owing to the effect of water restrictions that were imposed during the 1995 drought. Since 1995, tariffs have also increased substantially and the extra income has funded current major inter-catchment transfer schemes, such as the Lesotho Highlands Water Project and the Olifants-Vaal Water Project. *Inter-catchment transfer schemes* involve the movement of bulk water from catchment areas with good supplies and a limited demand for the resource to those areas where there is a large demand for water but where the supplies are poor. The largest of the inter-catchment transfer schemes that are in operation in South Africa is the Orange-Fish River Scheme. **Table 1** summarizes the yield of each inter-catchment transfer scheme, as well as the total cumulative yield of water that these schemes provide together.

Table 1: The major inter-catchment transfer schemes and their respective capacities
(Rand Water, 2005).

SOURCE	YIELD (Ml/d)	Total Cumulative Yield (Ml/d)
Vaal River and Eastern Transvaal Transfer Schemes	3086	3086
Thukela-Vaal Scheme	1889	4975
Lesotho Highlands Scheme (Phases 1A & 1B)	2059	7034

As the population within Rand Water’s area of supply continues to grow steadily, inter-catchment transfer schemes are becoming increasingly necessary in order to augment water supplies. The Lesotho Highlands Scheme, for example, should supply all consumer needs until at least 2012. These inter-basin transfer schemes have been developed at enormous cost to the consumer, and, according to Rand Water (2004), ‘making it imperative that all possible actions are taken to secure future water supplies, in terms of both volume and quality’.

Unfortunately, these schemes are becoming less feasible due to the high construction cost involve in building such schemes. This involves hydraulic pumping and high energy costs, which eventually exceed the income generated from supplying and selling potable water.

These schemes are also subject to socio-economic disputes, as some of the supply areas are located in different provinces and/or in neighbouring countries. Moreover, on account of the development and population growth taking place in South Africa and her neighbouring countries, there are now fewer available regions with an abundance of water where the demand for it is limited that can accommodate such transfer schemes.

Another important aspect to consider is that rivers are natural landscape features that ignore political boundaries, thus presenting another subject for socio-political debate concerning the right of access and use thereof. Some rivers which could supply raw water to the Rand Water Board are polluted to such an extent that it would be against the policy of the board to draw water from them. The costs that Rand Water would incur by drawing and treating this polluted water would exceed the profit gained by providing clean potable water. Such highly polluted and poor quality rivers include the Klipspruit and the Blesbokspruit, and the Suikerbosrand and Jukskei Rivers.

Thus, by monitoring the quality of the water that it uses from various sources, Rand Water is able to ensure that its supply of potable water is dependable and reliable, while meeting the different water quality requirements of its consumers. In fact, Rand Water makes it possible for 13 local authorities within its service area to deliver safe, affordable drinking water to their customers. At the same time, the board serves the needs of other water users (Rand Water, 2003). Rand Water has deliberately made it an overall goal to minimize deterioration in the quality of raw water, and has, therefore, developed monitoring points and programmes with the intention of keeping an eye on the quality of the water sources (Rand Water, 2005).

Because any pollution that may occur within a river and ultimately in the catchment areas into which it flows (e.g. the Waterval River Catchment) will eventually lead to the pollution of the Vaal River and the Vaal Dam, monitoring points have been set in place in a number of rivers.

Currently, Rand Water is one of 15 water boards active in South Africa. It supplies potable water to 10 million people in its 18 000 square kilometre supply area, which includes Gauteng Province and smaller areas in the adjacent provinces (illustrated in **Figure 3**). More than half of South Africa's economic activities take place within the borders of Rand Water's service area. Thus it is vital for Rand Water's consumers to use water wisely, and in a sustainable manner, and to take the matter of water quality more seriously.



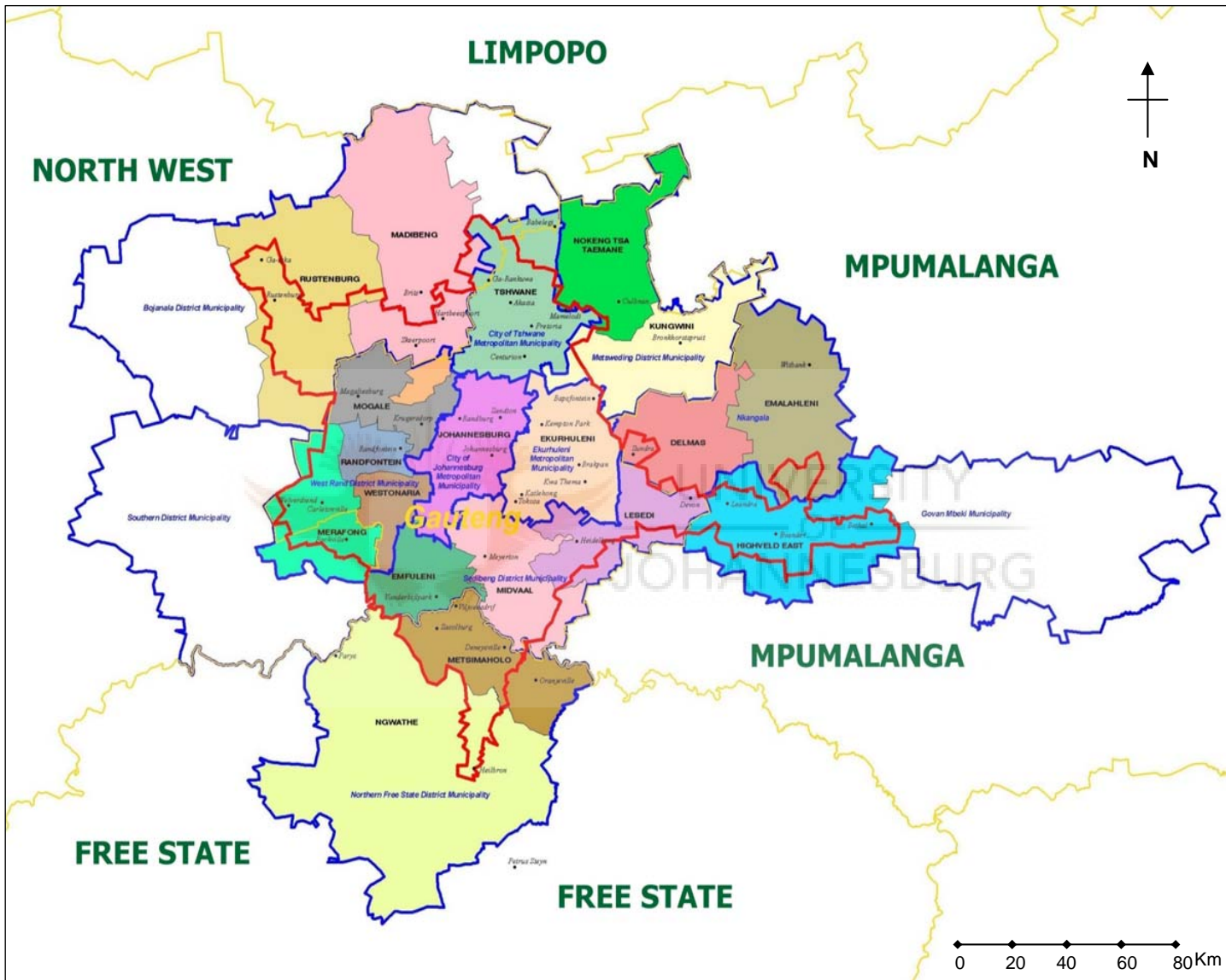


Figure 3: Rand Water’s supply area (Waterval Forum, 2005b).

Although its main function is to manage and treat raw water sources for the purpose of supplying potable water, Rand Water also recognizes the requirements of other water users that might be even more stringent than those set for the potable water users. This is important, considering that there are three main users of the water supplied by the board. They are:

- potable water consumers,
- aquatic ecosystems, and
- recreational users (Rand Water, 2003).

To ease the monitoring and management processes of water quality in its service area, Rand Water has divided the Upper Vaal Water Management Area into three main catchment areas, namely Kromdraai, the Vaal Barrage and the Vaal Dam Catchment, and has subdivided each of these into sub-catchment areas. The Waterval River Catchment, which is the focal Catchment Management Agency (CMA) for this study, is a sub-catchment in the Vaal Dam Catchment Area. **Figure 4** depicts the division of the Upper Vaal Catchment Area into sub-catchment areas.

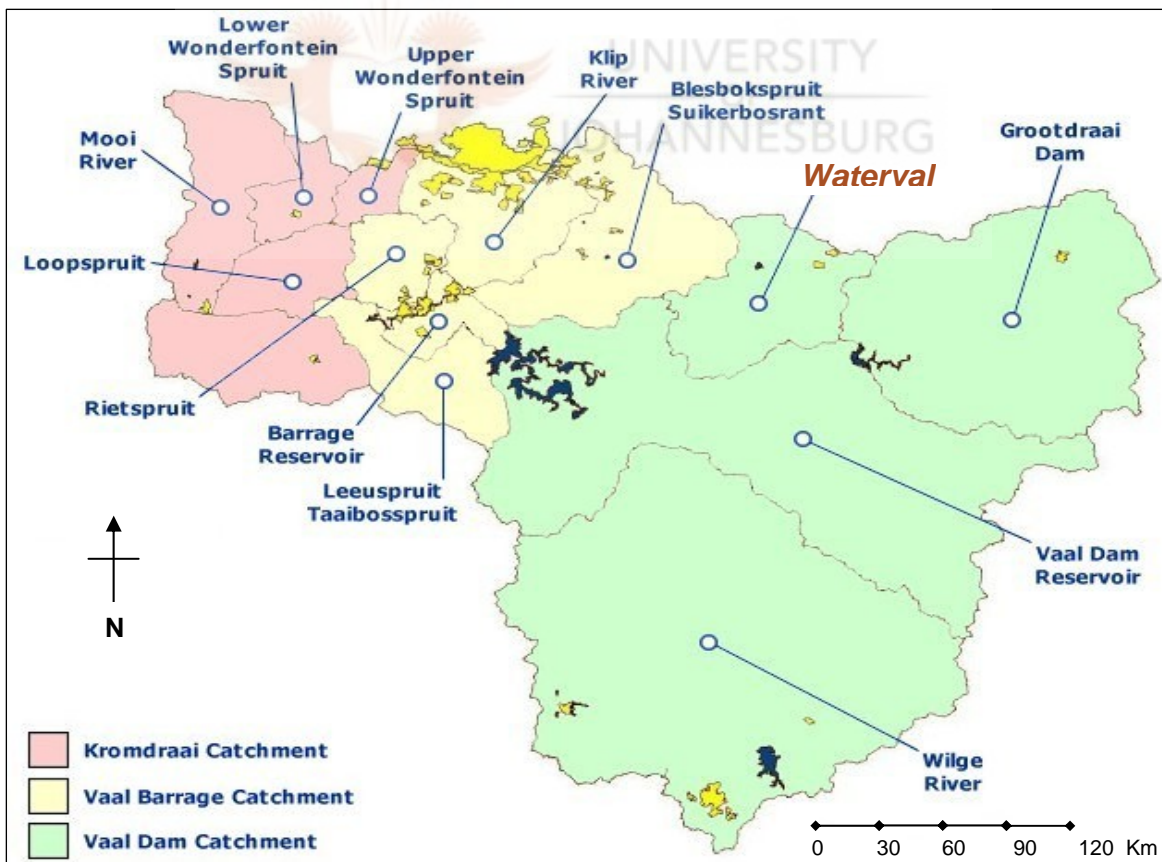


Figure 4: The Upper Vaal Catchment Area (Waterval Forum, 2005b).

The latest figures show that the Waterval River annually contributes $111 \times 10^6 \text{ m}^3$ of water to the Vaal River (Gyedu-Ababio & van Wyk, 2004). Although the Waterval River provides only two percent to the total volume of the Vaal Dam, however, it accounts for 12 percent of pollution to the Vaal Dam (DWAF, 2004). This is because of the various areas set aside for different land-uses through which the Waterval River and its tributaries flow. The Klipspruit is a good example of such a tributary. As the river finds its way towards its destination, the Vaal Dam, it accumulates different pollutants from various points and diffused sources along the areas adjacent to it. Apart from the rivers that supply water to the Vaal Dam, the following dams also contribute to the dam's total volume of water, namely the Katse, Sterkfontein, Grootdraai and Woodstock Dams. Rand Water draws water from the Vaal Dam's total store at a rate of one percent per week (Kayle, 2007).

Because water quality combines the physical attributes (such as colour and taste) along with the chemical elements found in water - which determine its usefulness for a particular purpose, Rand Water (2005) sets out to maintain high quality water standards in order to provide water that is safe, potable (drinkable) and appealing to all Life on Earth. Thus, according to Rand Water's mission statement, its water should contain no chemical or radioactive substance that could be harmful to the health of any form of life. For this reason, the water should be free of disease-carrying organisms and stable in terms of corrosion and scaling (Rand Water, 2004).

This objective has been achieved by Rand Water as it makes it its task to provide sustainable water services, while giving equal weight to addressing the relevant legal requirements and ethical obligations. To assist Rand Water with this task, in-stream water quality guidelines have been specified by each Catchment Management Agency (CMA) (e.g. the Waterval River Catchment Management Agency). These guidelines act as a short-term measure to determine whether the water quality within the catchment boundaries has deteriorated or not.

According to Kotze (2005) Rand Water's purification process can remove almost all of the suspended materials present in the raw water. According to Heath, Steynberg and Viljoen (Kotze, 2005), this purification process implies that Rand Water can allow the water quality to deteriorate to a certain extent, because the purification technology used by this board is so advanced that the purified water can meet the required standards in question. However, other water users could be affected negatively should the water quality in the natural environment be allowed to deteriorate. Aquatic ecosystems and natural environmental systems, for instance, would suffer great damage as these natural systems do not have access to any such advanced technologies.

Although alternative methods, such as inter-catchment transfer schemes, are being considered to find a solution to South Africa's inadequate water resources, this does not imply that the country's current and available sources can now be neglected. Among the alternative methods are plans to buy eventually water from South Africa's neighbouring states such as Botswana (from the Okavango River) and Zimbabwe (from the Zambezi River). However, the exploitation of these alternative water sources might bring added economic and strategic political constraints.

On taking all of the abovementioned factors into consideration, it soon becomes clear why it is so vital for Rand Water to protect and monitor the current available resources to ensure their sustainability. In a local newspaper article (Kayle, 2007) Rand Water made the point that in order to ensure that there will be enough water in 20 years' time, "the responsibility of managing water properly starts today". Through constructive discussion, talking and listening, and respecting the opinions of all water users and stakeholders, Rand Water believes that common problems regarding South Africa's water resources can be overcome.

4. WATER AVAILABILITY, QUANTITY AND QUALITY

The aim of this chapter is to provide clarity on the current water status of South Africa, along with the reasons for this situation. In view of the aforementioned aims, the discussion that follows deals with the quantity and quality of South Africa's available water resources. This chapter will also consider current legislation regarding water management and the development of such legislation within the South African context.

Kadewa . (2005) found that despite its importance as a vital resource in maintaining life, as well as in sustaining agriculture, manufacturing, transportation and many other economic activities, water is the most poorly managed resource in the world. As a result of the inefficient management of this resource, the trend worldwide has been reflected in a deterioration in water quality. Thus other global aspects such as food shortages, ecosystem well-being, and human health are being jeopardized.

Figure 5 represents the current situation in terms of water availability and distribution on a global scale.

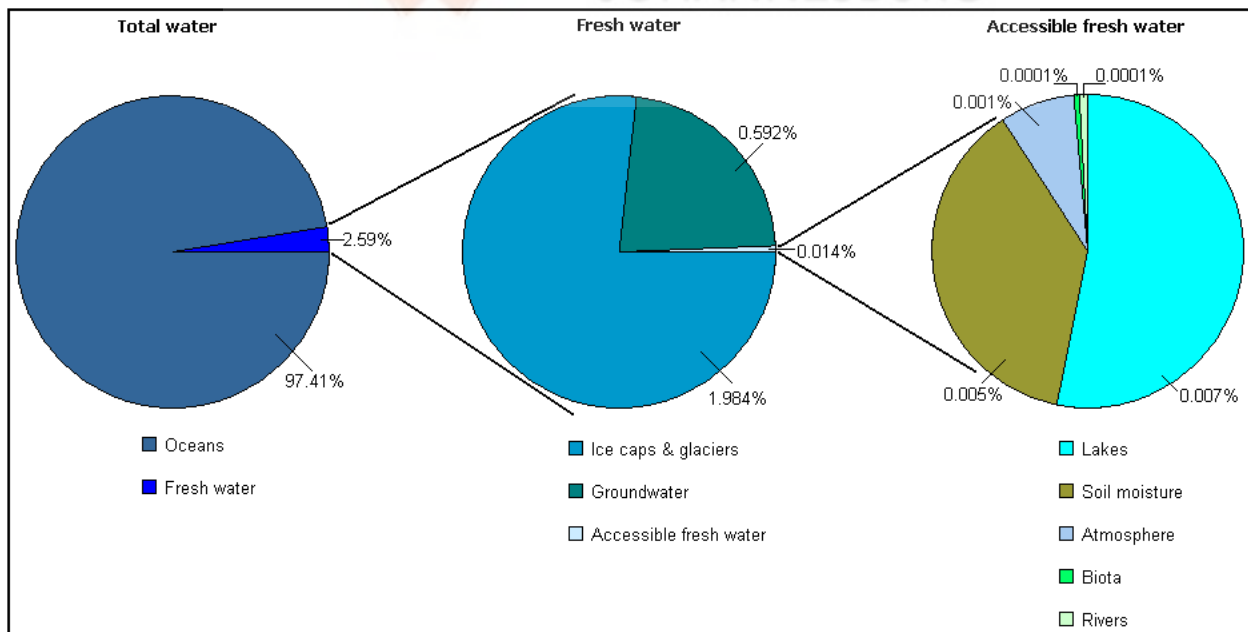


Figure 5: Global water availability (adapted from Miller, 2005).

South Africa's circumstances in terms of her water resources are somewhat different from the global water situation. It has been estimated by WISA (2006) that the annual rainfall runoff from all the rivers in South Africa adds up to about 53 500 million cubic metres. However, only 62 percent of this runoff, along with 5 400 million cubic metres of groundwater, are available for consumption to support the various activities that contribute to the economic well-being of this country.

In terms of the above-mentioned statistics, it can be estimated that South Africa could only provide 805 litres of water per person per day for her 2004 population of 45 million people. This value falls between the world figure, which current studies have estimated to be sufficient for one person per day (De Fontaine, 2006). De Fontaine's (2006) study determined that 461 litres of water per day is required by people who maintain a low standard of living, while 1 106 litres of water per day is considered necessary for people who sustain a high standard of living.

As mentioned before, various users and sectors require a specific amount of water of a particular quality in order to perform in a sustainable manner at their respective optimal productivity levels. Unfortunately, as each sector uses up its allocated share of the water supply for its specific purpose, the properties of the water are altered since pollutants and other materials are added to the water as it is used in the various production processes. This emphasizes that water management needs to become a matter of concern for all sectors and at all management levels.

Figure 6 represents the demands for potable water by the different sectors. It also shows the estimated proportional growth or decrease in water demands for each sector over a 34 year period from 1996 to 2030.

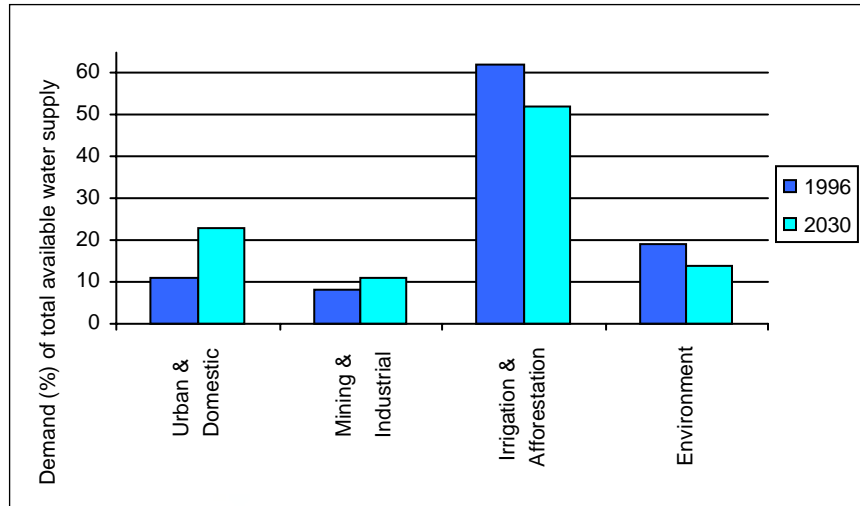


Figure 6: Proportional water demand by different sectors in South Africa (adapted from Basson & Rossouw, 2003).

This figure emphasizes the reality that as the water demand increases in the urban and domestic sector as well as in the mining and industrial sector increases, whilst a decrease in the water demand is indicated for the irrigation and afforestation sector. The abovementioned figure also emphasizes that the proportion of water available to the environment decreases. This decrease implies that it will become difficult for the environment to renew groundwater levels and to maintain various river and estuarine ecosystems. Therefore, efficient water usage and the management of natural and human impacts on water quality are essential if the sustainability of the current water resources is to be assured for current and future consumption.

4.1 Reasons for South Africa’s scarce water resources

The amount of fresh water South Africa receives is determined largely by natural factors. As explained in the introduction, South Africa is located in the arid to semi-arid subtropical region in the Southern Hemisphere.

In general, South Africa enjoys a mild to hot climate, with a scattered, seasonal rainfall. This is why the country is largely dependent on rivers, dams, and underground water sources for her fresh water supply (Davies & Day, 1998).

The reliability of surface water is jeopardized, however, by the fact that South Africa's hydrology is characterized by low surface water runoff, which is also highly variable. According to the Department of Environmental Affairs and Tourism (DEAT, 1999), only 8.6 percent of South Africa's rainfall will eventually end up as surface water. Furthermore, 61 percent of the country receives less than 500 mm rainfall per annum, while 21 percent receives less than 200 mm (Abram, 2001). The above-mentioned conditions explain why South Africa relies largely on the bulk water transfer schemes discussed in the previous section.

In his research regarding the future of water in southern Africa, Fakir (1999) explains that South Africa is prone to recurrent El Niño-related droughts and the region is also subjected to high temperatures, which in their turn contribute to high and rapid evaporation rates. Although high evaporation rates may not be problematical for other countries, this factor contributes to the scarcity of water in South Africa since the mean annual evaporation levels almost always exceed the mean annual precipitation levels that feed the major catchment areas in South Africa (see **Figure 7**).

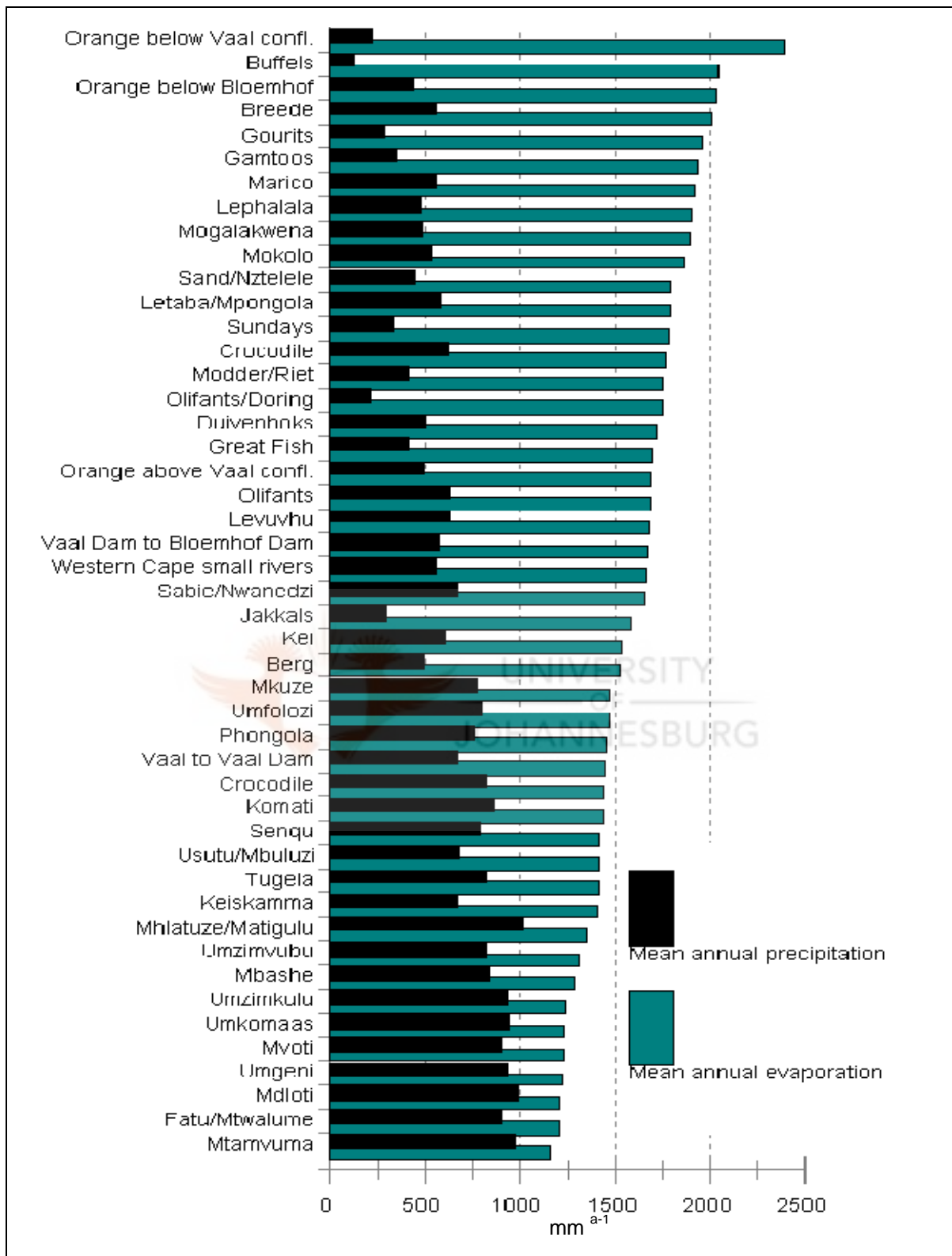


Figure 7: Mean annual precipitation and evaporation in South Africa's catchment areas (DEAT, 1999).

As regards the quality of South Africa’s water, one finds that the water chemistry in one region may differ from that in another region even if this resource is not affected as a result of human activities. This is because various natural elements and factors also contribute to the quality and chemical make-up of water. These natural contributing factors are mainly the result of South Africa’s diversity in terms of climate, geology, geomorphology and soils, along with the country’s diverse terrestrial and aquatic biomes (Davies & Day, 1998).

Thus, according to Manzungu (2004), South Africa is facing four major water challenges. These are summarized in **Table 2**. All of these challenges have one underlying problem in common, namely that the environmental, social and economic objectives are often in conflict with one another.

Table 2: Challenges with regard to South Africa’s water resources (Manzungu, 2004).

Water challenge	Description in relation to South Africa
Water scarcity	Due to semi-arid and arid environment and low level of water development
Polluted water bodies	Caused by poor waste-disposal systems, aggravated by a rapidly increasing and urbanizing population without adequate water sanitation facilities
Management of river basins	Basins extend across national borders, resulting in the current socio-political challenges
Watershed degradation	Poor understanding and knowledge of effective and sustainable water usage

In conclusion then, it is clear that the problem of South Africa’s scarce water supplies is due to a wide range of natural and human factors, which are often interrelated. In order to ensure the availability of fresh water for current and future consumption, it is necessary that efficient water usage, effective water management and well-researched land-use practices be recognized for their importance and implemented and/or practised today. These tasks could be demanding and difficult to carry out if the human population continues to increase and operate without the basis of any proper education about efficient water usage. Other factors that will hamper the accomplishment of these tasks include prevailing climatic change and our desire to live in comfort, the latter leading to higher levels of consumption of the already limited resources. Thus “we need to interact better with the environment and the resources it provides” (Bjorklund, *et al.*, 1997, p151).

4.2 Evolution of water legislation in South Africa

During the first half of the 20th century, South Africa started to experience worsening environmental pollution problems as urban areas increased and grew and industries started developing at an alarming rate all over the country, with waste accumulation becoming a particular problem of the built-up areas. Along with these developments, an economic shift occurred at the turn of the mid 20th century. The pre-1950 South African economy was driven by the agricultural sector, but from 1950 onwards, industry and mining became the major role players, with serious repercussions for the environment. This period also saw the transformation of the early Department of Irrigation to the present Department of Water Affairs and Forestry (DWAF). The DWAF considers water and associated aspects of water (such as water pollution and its control) as national issues and therefore placed water as a resource under national control and jurisdiction, these functions being managed and administered solely by this Department.

According to the DWAF (2006) the next major milestone was the promulgation of the Water Act, 1956 (Act 54 of 1956), which was aimed at controlling the industrial use of water and the treatment and disposal of this sector's effluent. These objectives were formulated because the demand for water started to exceed the water supply, and the re-use of effluent was seen as the answer to the management of South Africa's scarce water resources. The Water Act of 1956 set into operation the requirement that all effluent should be returned to the water body from which the water was originally drawn. However, in 1984, the DWAF found it necessary to broaden some aspects of water quality management and accordingly developed the Uniform Effluent Standard, the General and Specific Standards and the Special Standards for Phosphates, which were documented in the Water Amendment Act in 1984 (Act No.96 of 1984).

Thereafter, it was deemed necessary for the water quality requirements of the different water users to be considered in order to ensure the sustainable consumption of South Africa's limited water resources. Thus a new era came to light in the South African water industry with the promulgation of the National Water Act (Act 36 of 1998). Some of the new concepts that were introduced by this Act include: Water Management Areas, Catchment Management Agencies, Integrated Catchment Management and Catchment Forums.

4.3 Current Legislation affecting South Africa's water resources

The current legislation that is relevant to the protection and management of water resources in South Africa will be discussed in this section. Although most of the legislation and policies are in place to protect only the environment, they also have a direct or an indirect effect on South Africa's water resources.

Water in South Africa is treated, first and foremost, as a social commodity to which people and the aquatic environment have a legal protected right (Du Plessis, 2003). This resource is also regarded as an economic entity ("goods") that can be exploited in order to increase the well-being of the country. For an economic value to be attributed to water, careful assessment is required to determine the true economic value of such an environmental entity, considering that it is often used as a catalyst to generate wealth for a country. Since water is now also used as an economic entity (economic goods), economic instruments (e.g. the "polluter-pays principle" and emission charges) are being developed and implemented in order to increase, guide and ensure responsible behaviour in respect of efficient and effective water usage amongst the water users of South Africa.

As mentioned previously, one the most important pieces of legislation is the National Water Act 36 of 1998. Emphasized in this Act is the necessity for a transparent and participative approach to water management and for making provision for a 'reserve'. According to the National Water Act (1998), "reserve" is defined as follows:

"It is the quantity and quality of water required

- a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act 108 of 1997), for people who are now, or who will, in the reasonably near future, be:
 - i) relying upon;
 - ii) taking water from; or
 - iii) being supplied from,
the relevant water resources; and
- b) to protect aquatic ecosystems in order to secure ecologically-sustainable development and use of the relevant water resource."

The National Water Act (no. 36 of 1998) is based on the principles of sustainable water consumption and fair water distribution. According to DEAT (1999) and Oosthuizen (2002), in addition to the conservation of the environment, the main provisions in this Act that affect the conservation and management of water resources are the following:

- The development of a national water resource strategy that sets out strategies, objectives, plans, guidelines, procedures and institutional arrangements relating to the protection, use, development, conservation, management and control of water resources;
- The conservation of South Africa's water resources by developing a classification system and setting resource-quality objectives;
- The assurance that the water resources will be used in an environmentally-friendly and sustainable way;
- The implementation of pollution prevention measures, including emergency measures;
- The setting of a pricing strategy as a form of demand management where social equity is taken into consideration;
- The establishment of Catchment Management Agencies (CMAs) to delegate water resource management relevant to the catchment level in order to complement the National Water Management Strategy;
- The condition that the allocation of water will no longer be permanent, but for a reasonable period, and that provision be made, with Ministerial consent, to facilitate the transfer or trade of this right between users;
- The promotion of the efficient use of water by charging users for the full financial costs of providing them with access to water, including infrastructural development and catchment management facilities;
- The condition that all major water-use sectors should develop a water usage conservation and protection policy, and regulations be introduced to ensure compliance with the policy in key areas;
- The condition that the conservation of the resource be assured for the optimal social and economic benefits of the country.

Even The Constitution of South Africa (Act 108 of 1996) includes water as a basic right under Section 24 as it states that ‘every person shall have the right to an environment which is not detrimental to his or her well-being’, thus ensuring that water of a specific quality will not be harmful to the residents of South Africa. This section states further that everyone has the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –

- (i) prevent pollution and ecological degradation;
- (ii) promote conservation; and
- (iii) secure ecologically-sustainable development and use of natural resources while promoting justifiable economic and social development.

The aim of this chapter was to emphasize to the reader that, owing to the limited availability, quantity and quality of water in South Africa, water management in this country is a vital, yet challenging sector. Apart from the effective and sustainable use of water, human behaviour and the mind set of people regarding water usage must change. For example, in areas where water resources are scarce, people must learn that they need to adapt to the water shortages because the natural limitation factors are not going to change: on the contrary, the situation might just worsen. For industries, a more sustainable and healthy socio-economic environment can be created when they ensure that the production per unit of the total volume of water used during their production processes is maximized and that the volume and quality of effluent is effectively managed (Brouckaert & Buckley, 2003, and Strauss, 2006).

Whyte (1995) explains that the ‘rising demand to meet the basic needs of the current [growing] population and the future domestic and industrial demands, requires that attention be turned towards water conservation and reuse, [along with] the effective use of economic instruments such as water pricing’. Immediate improvements are also needed in the techniques for water collection, conservation, storage, treatment and reuse.

Table 3 summarizes other current South African Acts directly or indirectly relevant to the conservation and management of water resources.

Table 3: Main Acts affecting South Africa's water resources (DEAT, 1999).

Act	Description
<i>National Environmental Management Act 107 of 1998</i>	Provides for co-operative environmental governance by establishing principles for environmental decision-making; identifies institutions that will promote co-operative governance and determines procedures for coordinating environmental functions of state departments
<i>Water Services Act 108 of 1997</i>	Provides for the rights of access to basic water supply and basic sanitation and the institutional structures required to provide water. In the light of the uneven distribution of the water resources of the country and previous inequitable policies, the Act ensures that people's basic needs (i.e. water supply and sanitation) are met
<i>Environmental Conservation Act 73 of 1989</i>	Provides for the effective protection and controlled utilization of the environment
<i>Water Research Act 34 of 1971</i>	Established the Water Research Commission in order to promote research in respect of water resources
<i>Mountain Catchment Areas Act 63 of 1976</i>	Recognizes mountain catchments as sensitive areas and makes provision for their conservation
<i>Conservation of Agricultural Resources Act 43 of 1983</i>	Provides control over the utilization of the natural agricultural resources in order to promote the conservation of the soil, the water resources and the vegetation, and to combat weeds and invasive plants.
<i>Minerals Act 50 of 1991</i>	Although this Act does not pertain directly to water, it has important implications for the aquatic environment. It requires that all operating and prospecting mines submit an Environmental Management Programme Report (EMPR), which includes pollution management strategies. The Act regulates prospecting for and the exploitation, processing and utilization of minerals to provide for the safety and health of the persons concerned in mines and works, and regulates the utilization and rehabilitation of land during and after prospecting and mining operations.
<i>Health Act 63 of 1977</i>	Promotes the health of the inhabitants of the Republic and provides for the rendering of health-care services. It also makes provision for local authorities to monitor water quality.

5. STUDY AREA

In this chapter, the area of interest to this study specifically will be discussed. There are four key components that form the basis of the study area, namely

- *Mpumalanga Province* (within which the river under investigation and the relevant industry are located),
- the *Waterval River Catchment Area* (the associated Water Management Area) along with the *Klipspruit* (the main river under investigation), and
- the *Sasol Secunda Industrial Complex* (an external factor which affects the water quality of the Klipspruit).

The physical aspects of each of these key components will be discussed separately in order to emphasize each one's enormous impacts on the study area and thus its contribution to the research problem.

As stated in the previous chapter, the main focus of this research paper is on the water quality of the Klipspruit, which has been polluted by industrial effluent that originates in the Sasol Secunda Industrial Complex (SSIC) located in Mpumalanga Province. The Klipspruit is a tributary of the Waterval River – the main river within the Waterval River Catchment area.

5.1 Mpumalanga Province

Mpumalanga Province generally experiences a sub-tropical climate with hot, wet summers (from October to February) and mild to cold, dry winters (from May to August). According to Mpumalanga's State of the Environment Report (MDACE, 2003) the annual rainfall for this province is 767mm, with approximately 10 times more rain falling in the summer than in winter. Therefore, according to Antoniou (1999), 85 percent of the province's rainfall occurs in a six-month period (October to March), thus creating a high flow period, as increased volumes of water are introduced into the area's drainage system. During such periods, the dilution capacity of a river is enhanced, which in turn contributes to an improvement in the water quality of the river.

Antoniou (1999) consequently found that during the low flow season (April to September), the negative water quality parameters in the system become more pronounced. This is because the water level is considerably lower, with the result that pollutants are not readily diluted.

Although it has been stated that Mpumalanga receives an annual rainfall of 767mm, one should consider the fact that this province occupies a vast area made up of different topographical regions. Thus the annual precipitation varies from region to region as the topography changes from region to region. The annual rainfall varies from less than 500mm in the eastern lowveld, to about 700mm in the western highveld, and to more than 1100mm on the escarpment.

The area of interest is located on the level Highveld plateau, constituting the greater part of Mpumalanga Province. Here the landscape is dominated by a soft rolling topography, with some areas characterized by shorter interfluves. This description of the landscape explains why the topography of the study area has had a minimal impact on water pollution: the fact is that there are no steep slopes in the area to create a potential acceleratory mechanism for polluted surface runoff. This does not mean, however, that, on account of the monotonous topography, there is no pollution caused through surface runoff. The impact may be minimal yet it is indeed a factor to consider.

5.2 The Waterval River Catchment and the Klipspruit River

In order to ease the DWAF's task of monitoring and managing South Africa's water resources, the department found it necessary and helpful to divide South Africa into 19 Water Management Areas (WMA's). This was done as part of the development of DWAF's National Resource Strategy (DWAF, 2004).

Figure 8 illustrates the distribution of the different WMAs of South Africa. The Upper Vaal WMA (number 8), illustrated in **Figure 8**, is the management area in which the Waterval Catchment Area, relevant to this study, is located.

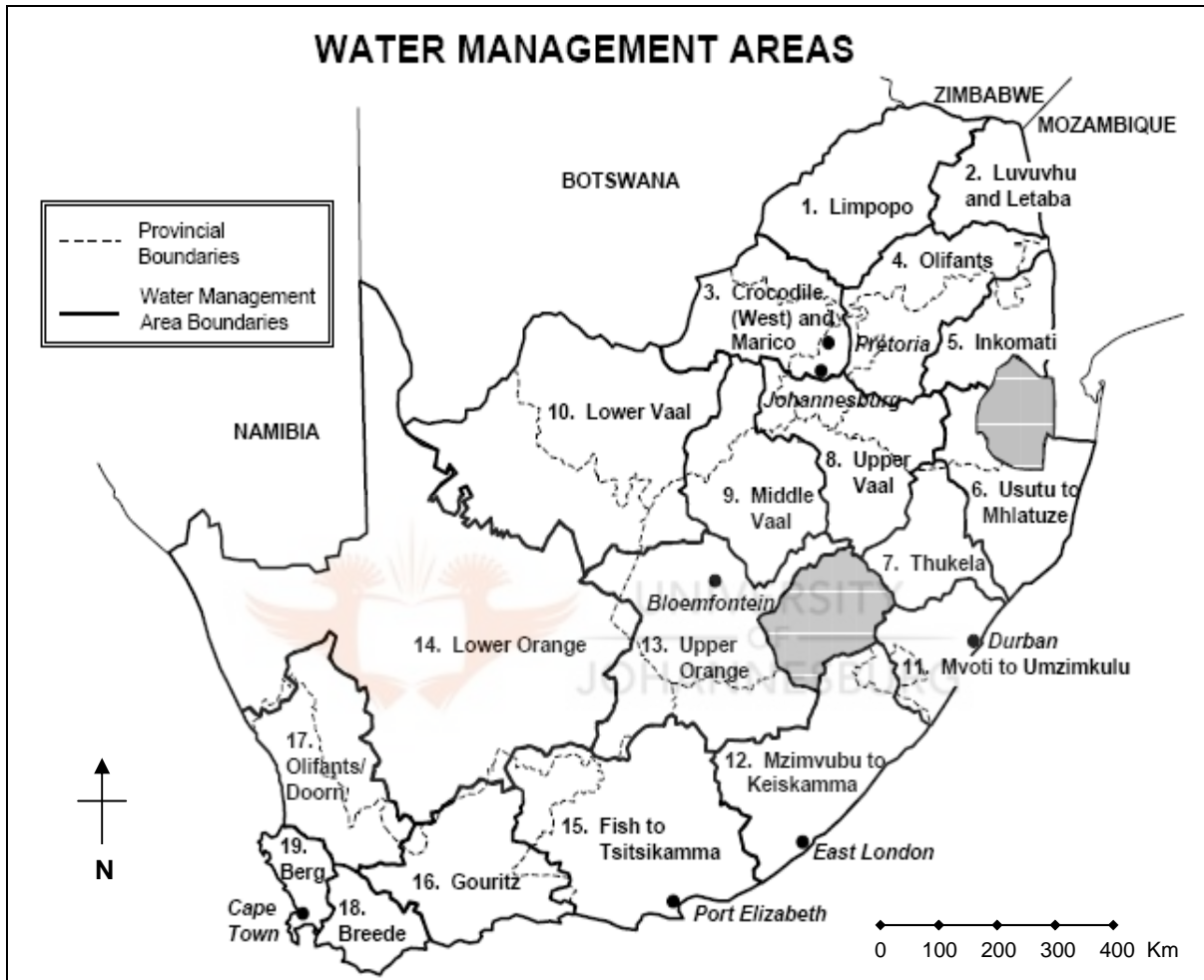


Figure 8: South Africa’s 19 Water Management Areas (Oosthuizen, 2002)

CMA’s were established under the National Water Act (Act 36 of 1998) as statutory bodies that manage the resources of individual WMAs, and which ensure that each WMA’s specific water quality requirements, as set out by the DWAF’s Water Quality Guidelines, are met. In turn, these specific water requirements are developed into in-stream water quality guidelines by the relevant CMA (e.g. the ‘In-stream Water Quality Guidelines for the Waterval River Catchment’).

Reference will be made to these guidelines at a later stage in this study when a comparative analysis will be conducted between the collected data from Rand Water, the DWAF's Target Water Quality Range Guidelines, and the Waterval River Catchment Management Agency's Guidelines.

CMAs also need to ensure that effective management procedures, protection actions, monitoring strategies and proactive decision-making processes are in place for each WMA. This is because surface runoff within this study area almost always flows through industrial, mining, agricultural and/or residential areas where various pollutants are picked up by the runoff before it enters the river channel. These pollutants evidently lead to the pollution of the water course and subsequently of the catchment area. All of these above-mentioned activities take place in the Waterval River Catchment Area. They place the catchment area under pressure as the pollution causes the quality of the water to deteriorate which can lead to more serious environmental problems and disasters.

Fox and Rowntree (2003) found that South Africa's catchment areas are characterised mainly by high-rainfall headwater areas and low-rainfall semi-arid lowlands. This means that most of the runoff in the Waterval River Catchment Area is generated in the upper part of the catchment area. For this reason, Rand Water found it necessary to place most of its monitoring points in the upper part of the Waterval River Catchment Area in order to monitor any activities possibly causing the degradation of the natural environment and pollution in such areas. By doing this, Rand Water is able to ensure that pollution events are monitored, controlled, acted upon and limited so that, in its turn, the catchment area will continue to function in a sustainable manner and thus survive.

The Waterval River Catchment Area (located between 26°19'42" and 27°09'22" S and between 28°24'49" and 29°28'34" E) consists of a main river (the Waterval River) and its tributaries (e.g. the Klipspruit and the Grootspruit). Historically, the Waterval Catchment Area was a farming area until gold mining became the dominant activity from the mid 1950's onwards.

Even in the late 1970's, when the Sasol Coal Mining and Synthetic Fuels Complex was established, the area was still primarily a rural farming area. With the expansion of Sasol's activities during the next two decades, land-use in the region changed substantially (Rose, 2005).

The selected sampling points within the Klipspruit that were chosen for the purpose of this study are: the Bossiespruit (C-WAB), the Trichardspruit (C-WAT) and the Secunda Sewage Works (SEC-SEW). These three monitoring sites were selected because they represent an even spatial distribution of water flow and because, according to the Rand Water database, they are characterized high levels of pollution. **Figure 9** shows these, as well as the other sampling points located in the Waterval Catchment Area, that Rand Water uses for monitoring the quality of the water in this catchment area.

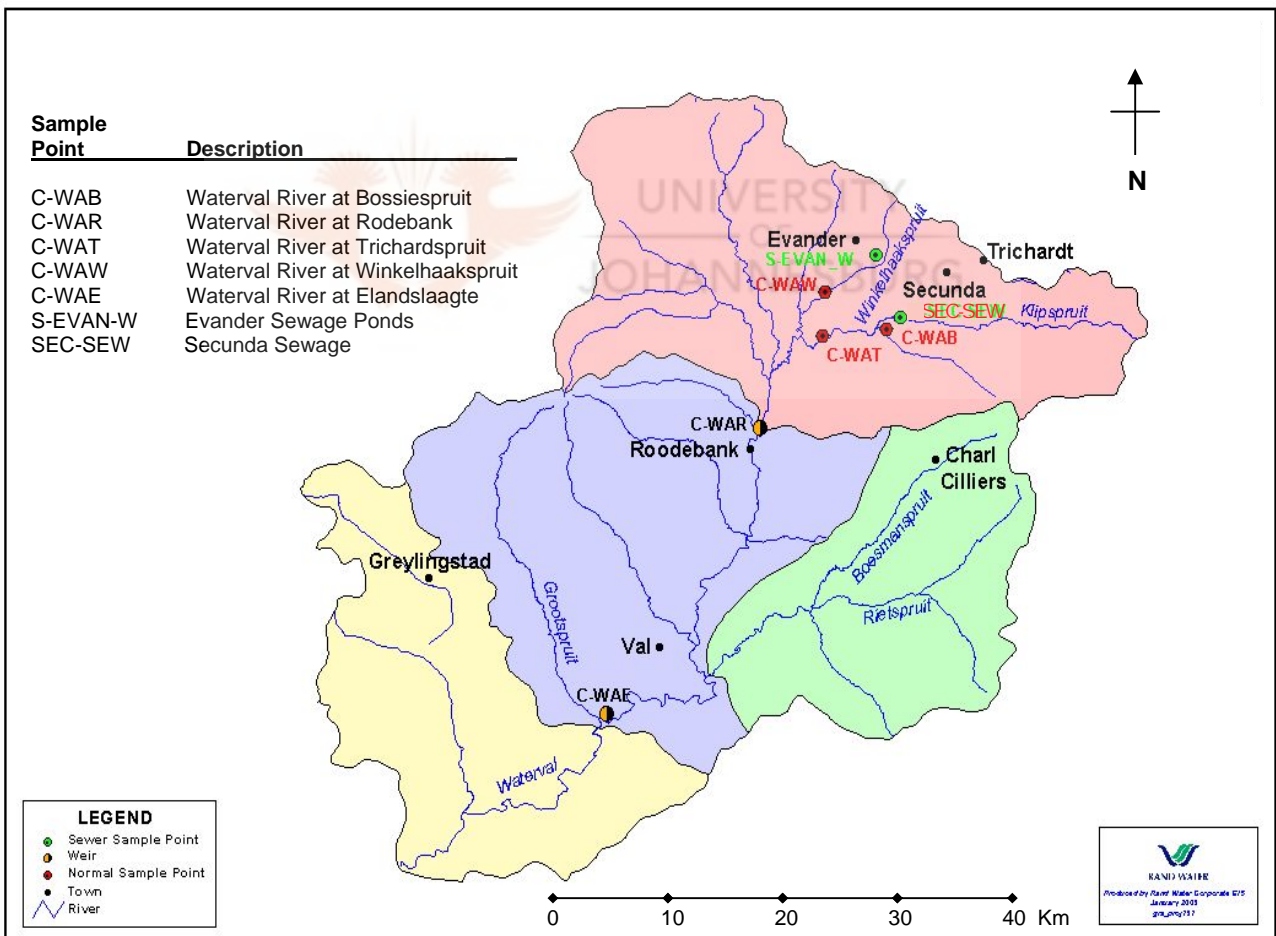


Figure 9: Sample points in the Waterval Catchment Area (adjusted from Waterval Forum, 2005b).

The Waterval River flows in a south-westerly direction towards its destination, the Vaal River, which in turn, feeds into the Vaal Dam. According to Gyedu-Ababio & van Wyk (2004), about 60 percent of the Waterval Catchment Area is used for agricultural purposes, 15 percent for industrial and mining, and another 15 percent for urban development. The Klipspruit provides water for various activities, including irrigation water for crop farming and water for livestock farms. It also sustains aquatic ecosystems and serves downstream users. The river is surrounded by rapidly expanding urban and industrial areas, and is, therefore, subjected to influences and impacts from various sources and developments.

5.3 The Sasol Secunda Industrial Complex

The Sasol Secunda Industrial Complex (SSIC) is a petro-chemical industry, and the most important industry in this study area. This is where coal is processed into petroleum. “Synfuels” is the collective term for the end-products (fuels) that are processed according to this method, which differs from the more common process of producing fuel from crude oil. Large quantities of water are required at the SSIC for this coal-to-fuel process, in, amongst others, the production of steam for gasification, the heating process, the generation of electricity, and the general cooling process.

The SSIC is located on the Highveld margin of Mpumalanga Province. The surface geology of the area is dominated by the Karoo sequence. This sequence, within which the coal strata occur, overlies the granite basement complex. Coal is excavated from various mines and used as the basic raw material in the coal-to-liquid-fuel process. The SSIC plant occupies an area of 13 square kilometres (km²) (Pretorius, 2007). This is the world’s largest production facility that converts coal into synfuel, a process, according to Sasol Watch (2005) that releases noxious and hazardous chemicals into the environment.

Figure 10 depicts the SSIC plant in the background.



Figure 10: The Sasol Secunda Industrial Plant in Secunda, Mpumalanga.

The Sasol Synthetic Fuels complex in Secunda processes approximately 40 million tons of low-grade coal into approximately nine million tons of synthetic liquid fuels and a variety of chemicals annually (Boer *et al.*, 2000). Their study found that the complex is situated in an unfavourable region with limited water resources, no perennial streams and a high occurrence of atmospheric pollution. According to Groundwork (2003), Sasol is one of South Africa's worst polluting industries.

6. INDUSTRIAL PROCESSES AND POLLUTION

Environmental change is one of the consequences that occur when industries use the earth's natural resources (e.g. water) during their manufacturing processes in order to produce a product or provide a service to consumers. Various gases are emitted into the atmosphere as a result of the combustion processes taking place in an industrial plant. At the same time, vast volumes of waste are also generated. That these solid, liquid and gaseous waste products must be disposed of, impacts upon the environment and leads to environmental change. Water that is used during the industrial process tends to accumulate various contaminants which are released at particular stages during the industrial process. This effluent (contaminated water) is often released into rivers or left, deliberately or unknowingly, to leak into groundwater sources. Some industries even “discharge their waste into the environment without the necessary treatment, since no one or no agency scrutinize their activities” (Ayotamuno, 1994, p212). **Figure 11** depicts a conceptual model of how pollution is created as industries produce their outputs.

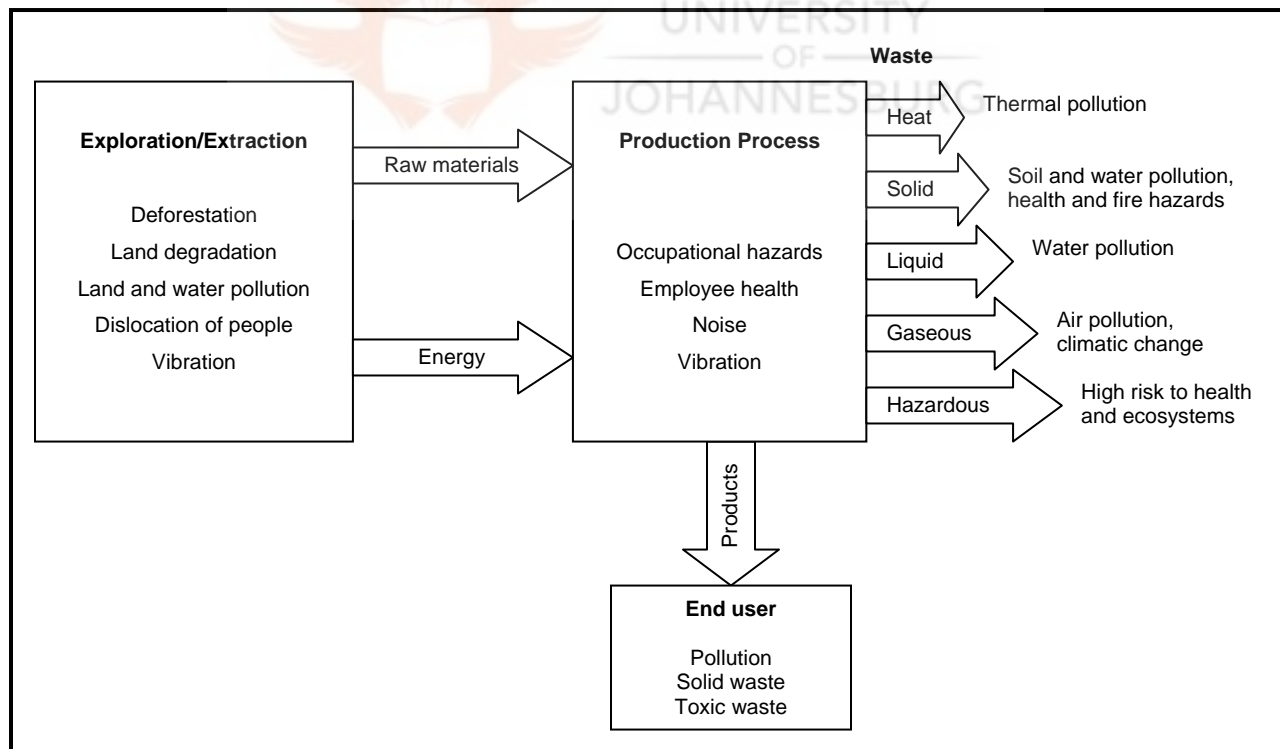


Figure 11: Conceptual model of pollution generation (Faisal, *et al.*, 2003).

The properties of industrial effluent tend to differ from one industry to the next, depending on the type of industry, the respective processes, and the relevant procedures and stages in the production process. The properties of the effluent from the SSIC will be discussed in the following section.

The impacts of industrial effluent depend on the collective properties of the waste products and their effects (e.g. the volume of suspended solids in the water, the proportions and properties of the organic and inorganic substances in the effluent, and the chemical oxygen demand). The impacts of the effluent from the SSIC will be discussed in detail later on, in Chapter 8.

Although many negative environmental impacts (e.g. water and air pollution, waste, noise and visual impacts) can be linked to the industrial sector, there are also some positive aspects associated with this sector that can enhance the well-being of a country or a community. The industrial sector creates a wide range of employment opportunities, for instance, and at the same time makes skills development and the mobility of workers from one economic sector to the other possible. This sector also holds economic benefits for local economies, and may even stimulate secondary industries, businesses and services that can support the primary industry. The positive aspects of the SSIC itself will be discussed in this chapter.

The aim of this chapter is to discuss water pollution resulting from industrial processes in terms of the SSIC, the processes taking place at this complex and the pollution sources identified at the plant. In addition to this information, this chapter will also look at what Sasol is doing at its Secunda plant to prevent or limit water pollution, and the alternatives which could be implemented to assist its environmental department in its fight against pollution.

6.1 The Sasol Secunda Industrial Complex: processes and pollution

The most important industry in the study area is the Sasol Secunda Industrial Complex (SSIC) – a petro-chemical industry. Coal that is mined locally is processed at the SSIC into petroleum, also known as synthetic fuel since it is not produced from crude oil. Through this coal-to-oil process, the SSIC produces the equivalent of 160 000 barrels of crude oil per day (Govender, 2005), thereby supplying 41 percent to the liquid fuel store that South Africa requires annually. In addition to this positive aspect, this industry also provides 200 000 direct and indirect job opportunities and contributes R34 billion annually to South Africa's gross domestic product (GDP). Furthermore, the SSIC's collieries produce 23 percent of the country's coal requirements (GCIS, 2004).

As indicated in Chapter 5, the SSIC is located within an area that has limited water resources. This is a worrying aspect for such an industry which requires potable water for and during its operations. Natural aspects are not the only limiting factor to aggravate the supply of water to this industry, however. Social problems, such as high rates of unemployment, an influx of work seekers and a high incidence of HIV/AIDS (Boer, *et al.*, 2000), also affects the amount of water available to the people living in the area. For instance, an unemployed person may not be able to afford clean water and would have to resort to alternative, possibly polluted water sources. The influx of more people into the area will put further strain on the already limited water supply.

The Vaal Eastern Subsystem Augmentation Project (Versap) was established in 2004 to relieve the SSIC of its water scarcity dilemma. This project assures the SSIC of long-term water supplies up to 2030. The Minister of Water Affairs and Forestry mandated the Trans Caledon Tunnel Authority to fund and implement the Versap project, which will not only supply the growing demands of the SSIC for water, but also those of Eskom – South Africa's electricity utility.

The processes and the end-products that are produced at the SSIC plant will be discussed in the following section. This discussion will help to establish why water is necessary for the production line of the coal-to-liquid-fuel plant and to explain how this precious resource is utilized at the plant.

6.1.1 The Sasol Secunda Industrial Complex: processes

Figure 12 is a simplified representation of the coal-to-liquid fuel production line at the SSIC. As a result of this process, effluent, various waste products and pollutants are inevitably produced. The relevant pollutants will be discussed later on in this chapter.

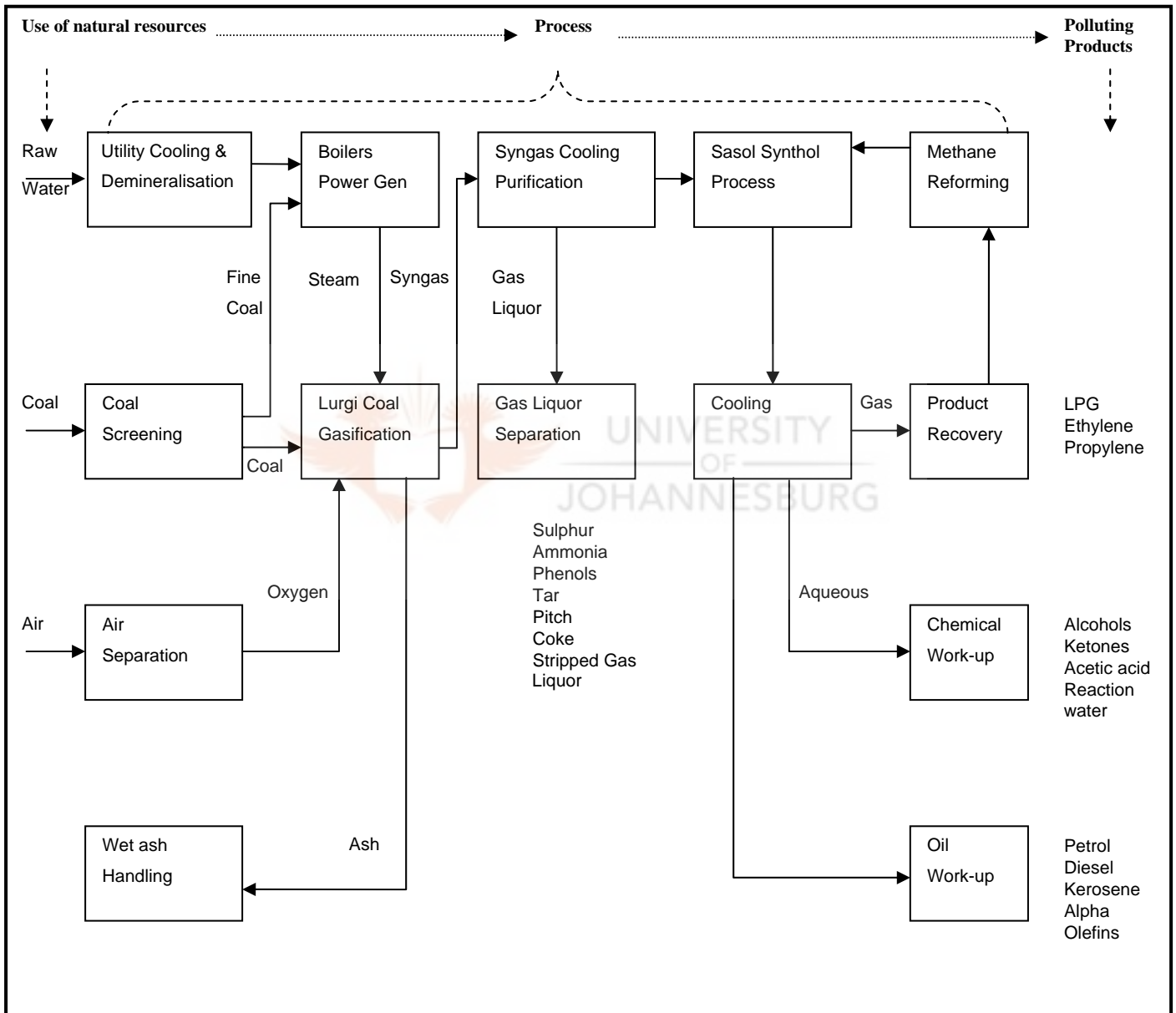


Figure 12: The Sasol oil-from-coal process and end-products (Antoniou, 1999)

As illustrated in **Figure 12**, some of the main products produced through this plant's refining processes include:

- Unleaded petrol
- Diesel
- Kerosene (for illumination)
- Liquefied petroleum gas – LPG (mainly propane and butane), and
- a mixed alcohol product (exported as a motor fuel or as a chemical feedstock)

The coal-to-fuel process carried out at the SSIC consumes large volumes of water. **Table 4** gives a breakdown of how the total water intake is distributed amongst the various water users at the synthetic fuel refinery. It is clear from this table that water usage in an industry is not applied solely to industrial activities. A certain amount of the water that is taken in and utilized by the industry is also used by personnel for domestic purposes.

Table 4: Breakdown of water usage at a synthetic fuel refinery (Govender, 2005 adjusted)

Use of water	Percent of total intake
Boilers (steam generation)	41.4
Cooling	47.2
Wash water and others	10.2
Domestic	1.2

From this total water intake, which is estimated to be 557 117 cubic metres per month, about 46 percent (254 032 cubic metres per month) of the water is changed into effluent through the operational processes at the SSIC (Govender, 2005). This percentage includes the rainfall runoff from the oil-processing areas and the effluent itself. The remaining water is primarily lost in the cooling systems through evaporation. According to Davies & Day (1998), the SSIC uses water at a rate of 2.8 cubic metres per tenth of a second and recovers only a small fraction of this figure.

6.1.2 Waste products and pollution sources at the Sasol Secunda Industrial Complex

Owing to the nature of the processes taking place at the SSIC, this industry has the potential to impact negatively on the natural environment. Prior to the implementation of the coal-to-fuel process, the SSIC was already contributing to the degradation of the environment as coal was being mined at its source collieries. The mining of coal resulted in the exposure of iron pyrites to the natural elements. Oxidation, causing a chemical reaction, was a natural consequence, resulting in the release of sulphates – a chemical parameter that will be dealt with later on in this study. Out of the five collieries that supply the coal used at the SSIC, only one, namely the Syferfontein colliery, is an open-cast mine. The rest, namely the Bosjespruit, Brandspruit, Middelbult and Twistdraai collieries are all underground mines.

If unsupervised, the polluting products (see **Figure 12**) could cause great damage to the natural environment – especially the sensitive aquatic ecosystems which are protected by the Water Act of 1998. **Table 5** summarizes the type of water pollutants that generally produced within the industrial sector, together with their sources and their effects.

Table 5: Water pollutants: their sources and effects (Mock & Revenga, 2000).

Pollutant	Primary source	Effects
Organic matter	Industrial waste water and domestic sewage	Depletes oxygen from the water column as it decomposes, thus causing stress (not “stressing”) or suffocation to aquatic life
Heavy metals	Industrial and mine sites	Persist in freshwater environments (e.g. river sediments and wetlands) for long periods. Accumulate in the tissues of fish and shellfish. Toxic to both aquatic organisms and humans, who eat them
Toxic organic compounds (industrial chemicals)	Wide variety of sources; industrial sites, agricultural sites	Display a range of toxic effects in aquatic fauna and humans, from mild immune system suppression to acute poisoning or reproductive failure
Thermal pollution	Industrial facilities such as cooling towers	Affects oxygen levels and the decomposition rate of organic matter in the water. May shift the species composition of a river.

Some of the signs and the effects of water pollution are often diverse, which contributes to the complexity of this problem. Obvious signs of water pollution include:

- Foul-tasting drinking water;
- The unchecked growth of masses of aquatic weeds;
- Disgusting odours emitted by rivers;
- A decline in the number of commercial fish;
- Oil that can be seen floating on the water surface.

The flow of pollutants is also inevitable: they spread through the environment by way of the air, water and soil. Rivers are often used as convenient systems into which industries dispose of their waste products. Thus rivers are polluted as a result of the direct disposal of effluent, waste and often sewage via artificial drainage systems into them. The transfer of pollutants through the soil is also possible as surface runoff flows over soil that has been polluted with chemical pesticides, or through contaminated catchment areas. Some of the pollutants eventually percolate down into the soil. Thus, when surface runoff drenches the soil, the water soaks up the pollutants between the soil particles and carries them down to the groundwater table where they are released into the groundwater body. Thus, the mobility of pollutants explains why water pollution is related to air pollution, land-use practices, energy use, and solid and hazardous waste.

Water pollution at the SSIC could occur through point-source releases and/or diffused inputs. An example of the former is when there are direct discharges from sewage treatment plants. An example of the latter is when air-borne particulate matter resulting from coal combustion falls onto the ground. Various pollution sources (point and diffused sources), through which pollutants are able to enter and contaminate the natural environment, have been identified in and close to the vicinity of the SSIC (indicated in **Figure 13**). Number 1, 2 and 3 (as indicated in **Figure 13**) are point sources while number 4 is an example of a diffused source.



Figure 13: Pollution sources at the Sasol Secunda Industrial Complex (accessed through Google Earth, image copyright TerraMetrics, 2007).

- 1) *The main petro-chemical plant*
- 2) *Seepage from the mine and ash dumps*
- 3) *Contaminated slimes dams*
- 4) *Air fall-out from the plant's stacks (usually associated with sulphate emissions)*

6.2 Preventative methods implemented at the Sasol Secunda Industrial Complex

Sasol is aware of the potential impacts that its production processes could have on the environment, and that is why this company has made it a priority to mitigate the effects of its so-called “environmental footprint”, caused by its mining operations right through to the waste products and effluent that it generates. According to the Sasol management team, measures are being implemented to reduce waste, atmospheric emissions, and water and energy consumption (Rose, 2005).

This commitment was exercised in January 2005 when Secunda experienced an unpredictably high rainfall. The heavy rains caused the stormwater dams, containing oily water, to overflow, with the result that an unknown quantity of this polluted water ended up in the Klipspruit River. An emergency response team was immediately called in, and the local and surrounding communities were informed of the situation. According to Rose (2005), high priority was given to the clean-up and rehabilitation of the river. After 59 days, and the positive results of an ecological health impact study that was undertaken after the clean-up, the national and local authorities declared the river clean. This effective clean-up process was achieved with the help of 80 people at a cost of R4 million (Rose, 2005). It took an additional R70 million, however, to clean up the dams containing the stormwater and oily water at the Sasol Secunda plant. After this incident, an ecological monitoring programme and a rehabilitation project were implemented. These will continue to run until the end of 2007. Biswas (2005, p236) states that “it is deeds, not words, that will be most important in solving future water issues” and the abovementioned incidence proves that the SSIC will resort to actions in order meet their commitment to reduce their environmental footprint.

Large quantities of water are required at the SSIC to produce steam and heat for gasification processes, the generation of electricity and for general cooling purposes. Because of these water consumption processes, it is important for the industry to recognize the need to optimize its water usage. This section focuses on what is currently being done at the SSIC in this respect and what alternative, if any, is available to assist the industry in achieving this goal.

Through the implementation of Electrodialysis Reversal and Reverse Osmosis processes at the plant, the SSIC is currently purifying and reusing 70 percent of its polluted mine water (Groundwork, 2003). These processes are beneficial to the environment, as well as to the industry, as, firstly, they prevent excessive discharges of polluted water from entering the environment, and secondly, they provide the opportunity for purifying the water in compliance with a particular standard that has been laid down to promote the reuse of water in various other SSIC processes.

Sasol wants to maintain its reputation as a responsible and caring company. To do so, this company is now able to reassure the public that its products are regulated in terms of the Responsible Care Guidelines (Rose, 2005) and that the following are priorities, namely:

- Pollution prevention
- Product stewardship
- Product safety
- Distribution safety
- Employee health and safety, and
- Community awareness.



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The coal-to-fuel process at the SSIC results in the emission of four types of effluent which must be neutralized before they can be disposed of. These include *clean water sewer effluent*, *oil water sewer effluent*, *reaction water* and *saline effluent*. Each of these is described in **Table 6**, which also includes a short description of the relevant treatment processes in each case.

Table 6: The main effluent types and the relevant treatment processes in each case (Govender, 2005, adjusted)

Type of effluent	Description
<i>Clean water sewer effluent</i>	Rainwater runoff is collected at the plant in a dual sewer system to keep it separated from the hydrocarbon-contaminated effluent. It gets treated here and the quality checked in order to see that it is fit for further use in the industrial process cycle. Suitable water is recycled back to the coolers for cooling where it is used for evaporation and blowdown purposes.
<i>Oily water sewer effluent</i>	Oily effluents from various production areas are collected and treated in a grit chamber. An oil-skimming tank then removes free oil. After this treatment, the effluent is passed through an oil separator which separates the free oil from the effluent. The recovered oil is reworked through the process or is disposed of at a landfill site. After this, the effluent is dosed with de-emulsification chemicals to remove the emulsified fraction of the oil in the remaining effluent. The treated effluent is then held in retention tanks where its quality is measured. Thus it can be redirected back to the inlet to the effluent plant if it does not meet the discharge specifications.
<i>Saline effluent</i>	This type of effluent originates in the demineralizers and the blowdown streams. The pH of this effluent is adjusted to near neutral through the addition of acid or caustic soda. Once neutralized, it is discharged together with the other effluents.
<i>Reaction water effluent</i>	This is a large volume effluent generated by the Fisher-Tropsch reaction used in the synthetic fuel refinery. Owing to the presence of organic acids, it has an extremely large Chemical Oxygen Demand (COD). During the treatment process, this type of effluent is dosed with micro-biological nutrients (e.g. nitrogen, phosphorus and potassium) and lime. The treated effluent is then passed through an aeration basin where the remaining organic matter is degraded.

These respective treatment processes form part of the greater effluent management system that is practised at the SSIC. Each type of effluent has its own specifications that need to be met. It is for this reason that each effluent type is treated individually. **Figure 14** is a simplification of the Effluent Management System that is carried out at the SSIC.

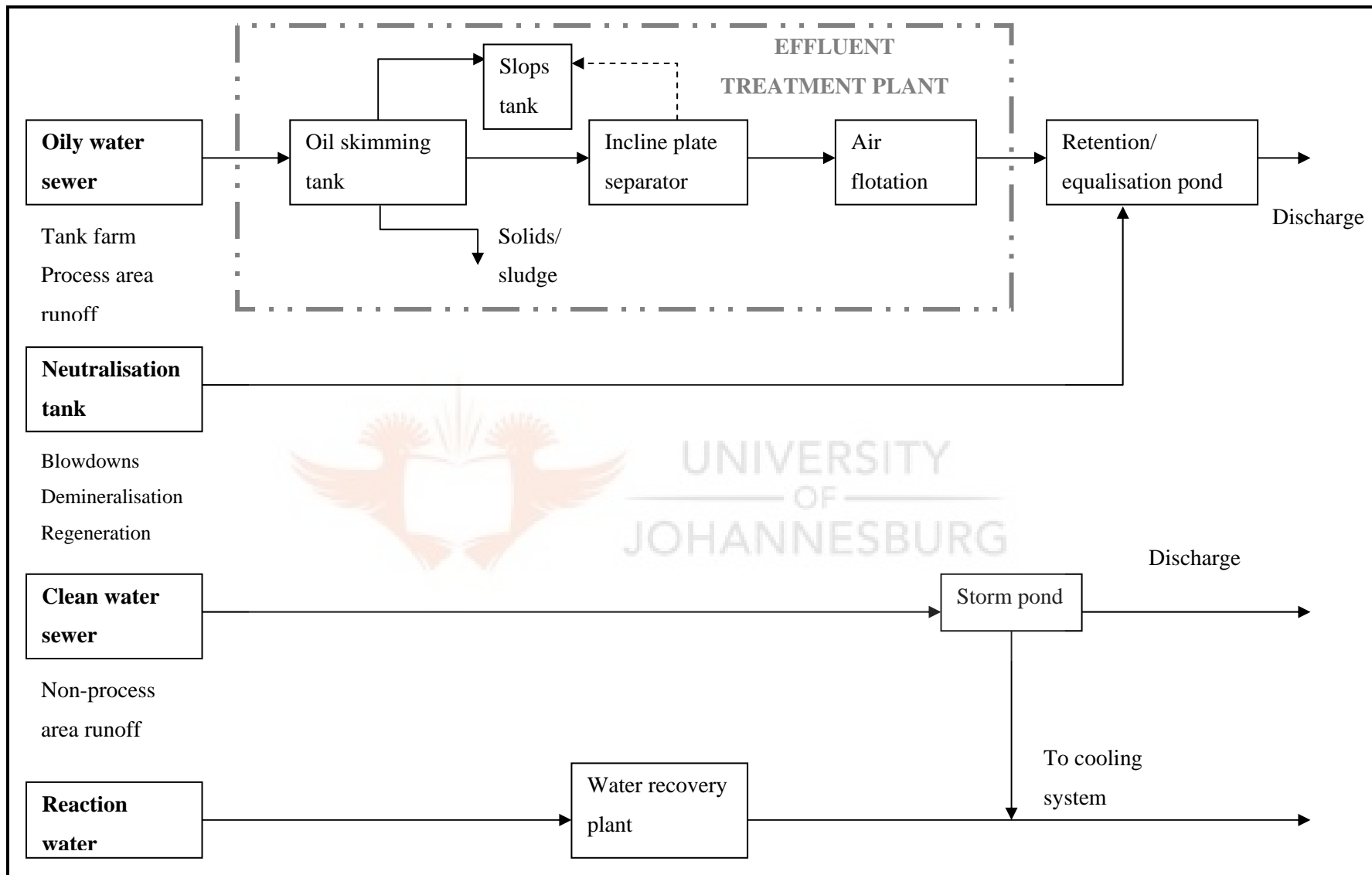


Figure 14: Simplified effluent management at a synthetic fuel refinery (Govender 2005, p23).

Sasol's sustainable development report of 2005 makes it clear that water is becoming a resource of increasing concern in many of the company's operations. According to the latest statistics, Sasol's total water usage per ton of production has increased by 12 percent in comparison with the 2004 figures (Rose, 2005). This is mainly due to the increased contribution of Sasol's more water-intensive processes.

According to Du Plessis (2003), the SSIC can conserve a particular quantity of water if some of the aspects he found in his study are considered. Among his results, he found that:

- South African refineries need to look into the practice of once-through cooling processes as they reduce the total amount of water that a refinery requires.
- Alternatives should be considered for cooling water systems as huge amounts of water are lost through evaporation.
- A significant quantity of water can be saved when condensate water is recycled in order to be re-used in the steam generation process. This recommendation is made in the light of the fact that the water used in steam generation and cooling processes adds up to more than 85 percent of the total water consumption at a refinery.
- Further reductions in water consumption can be achieved by implementing the recycling of treated effluent.

As regards the ways in which discharges of highly polluted industrial effluent can be controlled, there are generally three major options that can be considered:

- Control can take place at the point where effluent is generated within the plant;
- Effluent can be pre-treated before it is discharged into municipal treatment systems; or
- Effluent can be treated in its entirety at the plant and either be
 - reused within the plant, or
 - discharged directly into receiving waters.

Most of these preventative measures, such as those operational in the Effluent Management System, are currently being practised at the SSIC. In addition to Sasol's current environmental approach, aspects of the *Industrial Ecology* approach are also being integrated into Sasol's environmental protection programme. The *Industrial Ecology Approach* offers a practice for processing or manufacturing a product or rendering a service that is environmentally acceptable and sustainable. Manahan (2001) explains that the Industrial Ecology approach is based on systems engineering and ecological principles that it integrates into the production and consumption aspects of the design, production, use, and termination of products and services in a manner that minimizes environmental impact while optimizing the utilization of resources, energy, and capital.

In such an industrial ecology system, wastes that have been generated in one section of the production system are used as raw materials in another section. In this way, the efficiency of energy utilization is maximized, because an industrial ecology system tends to follow the flow of water, energy and materials through several process levels. Thus waste products become part of a larger system instead of being regarded as something that leaves the industrial system at the end of the production process.

7. WATER QUALITY PARAMETERS

Water quality is largely determined by the four main properties of water, namely its physical, chemical, organic and aesthetic properties. When changes occur in any or all of these properties, the end result is water pollution. These changes, no matter how small or vast, will, to a certain extent, directly or indirectly affect the living organisms in and around a water body. Thus, at the stage when water parameters were selected for the purpose of this study, due consideration was given to the fact that the parameters should represent the real impacts of pollution and relate to a type of pollution that could be measured. In this case, water pollution caused by industrial activities was chosen as the particular focus. It is for the above-mentioned reasons that the following six water quality parameters were chosen, namely pH, conductivity, nitrate, phosphate and sulphate concentrations and chemical oxygen demand. These parameters will be discussed under the relevant water properties which they affect. Hence the chapter structure, as presented in **Figure 15**, is as follows:

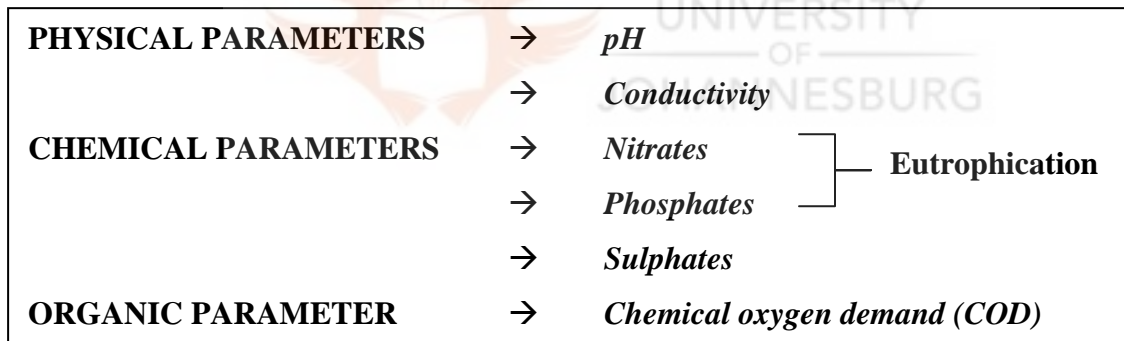


Figure 15: Outline of Chapter 7

Various substances from different sources which can be in either a suspended or a dissolved state in the water, actually influence the concentration levels of these parameters. Each parameter has a unique function. These will be referred to later on in this chapter when the various parameters are dealt with individually. When the concentration levels of these parameters are within a certain range, they are beneficial to an aquatic ecosystem and its organisms. Problems do, however, arise when such levels are either above or below a specific threshold level. The parameters then become detrimental to aquatic organisms and other water users.

This chapter deals with these ideal and critical levels which influence water quality, as laid down by the water quality guidelines. They are discussed prior to the data analysis.

As explained earlier, Rand Water revealed that the water quality within the study area is not ideal, hence specific sampling points were chosen in the Klipspruit River that indicated water quality levels that were unacceptable for particular parameters in terms of the Waterval River Catchment Water Quality Guidelines. (Reference will be made to these in the next chapter.)

The purpose of this chapter is to give an in-depth description of each of the selected water quality parameters that were analysed during this study. This chapter will assist the reader to fully comprehend not only the research problem but also the implications that industrial activities have on the parameters and on water quality in general. To assist with the logical flow of this study, each water quality parameter is discussed in terms of its background, its occurrence and its interactions with the natural environment.

Although an in-depth description of the techniques used to analyse each water quality parameter falls beyond the scope of this study, a brief summary of the techniques, along with some precautionary measurement procedures, is provided, when each parameter is discussed in the subsequent sections.

7.1 Physical parameters

The physical quality of water is affected when physical changes take place, for instance, in the pH levels and the conductivity potential of water. Both the pH and conductivity parameters will be discussed under this section.

7.1.1 pH

pH measures the acidity or alkalinity of a solution, based on the activity of hydrogen ions. As an expression of the hydrogen ion concentration present in water, the pH depends on the carbonic acid equilibrium in the water. This equilibrium is explained by Cooke (2006) as follows: ‘...when carbon dioxide from the air enters freshwater, small amounts of carbonic acid are formed which then dissociate into hydrogen ions and bicarbonate ions’. It is these concentrations of hydrogen ions that are measured.

The pH scale is a reverse logarithmic scale that starts at 0 (acidic) and runs to a value of 14 (alkaline / basic). Thus a value of 7 is regarded as neutral. This reverse type of scale works as follows: for each unit change in the pH, there is a tenfold change in the acid strength. This means that a solution with a pH of 3 has ten times the concentration of hydrogen ions than a solution with a pH of 4. Therefore, as the pH value decreases (thus making the solution more acidic), so the hydrogen ion concentration increases, which leads to the acidification of the water. For example, when acid is added to the water or when conditions prevail that produce hydrogen ions, the pH value shifts from being alkaline to being acidic. However, when carbon dioxide (CO₂) is removed from water, the reverse takes place and the pH level rises as the concentration of hydrogen ions decreases. This happens when there is an increase in biological activity, as in the case when algae and aquatic plants photosynthesize.

The pH of water is measured electrometrically by using a pH meter. Before each measurement, the pH meter should be calibrated against a standard buffer solution, the pH of which is known (Cooke, 2006). Only fresh samples should be used when determining the pH of a solution and, because temperature influences the pH levels, the temperature at which the sample is taken should be reported. By applying the above-mentioned method, an accuracy of ± 0.1 of a pH unit can be achieved. A higher accuracy level is possible when pH tests are performed in a laboratory. Such tests are able to achieve an accuracy level of ± 0.02 of a pH unit. It is important, when measuring the pH of a stream, not to take the measurement at the source where the pollutant is discharged into the water. For a more accurate measurement, the pH should be measured downstream after the contaminated water has had time to be oxidized.

Interestingly enough, Davies & Day (1998) found that even the purest, most unpolluted natural waters in South Africa lie in the pH range of very acidic ($\text{pH} < 4$) to slightly alkaline ($\text{pH} > 8.5$), buffering South Africa's freshwater resources relatively well. This buffering property is mainly due to the fact that the pH of water is affected and determined, to an extent, by natural elements such as the geology, atmospheric influences and the biotic activities in an area. Rainfall (with a pH ranging from 6.5 to 8.2) is another factor that affects a water body's pH levels, as well as a river's potential to dilute pollution when extreme pH levels prevail. Therefore, the more it rains, the higher the dilution potential of a river system. This is because the almost neutral rainwater works against extreme pH levels, whether acidic or alkaline.

Various human activities also lead to the alteration of the pH levels of water. Industrial activities, for instance, induce acidification, which lowers the pH level of water. Thorius (2004) states that when the pH levels drop to very low levels, it is a natural consequence for certain elements such as iron, aluminium, cadmium, copper, mercury, manganese, nickel, lead and zinc to be mobilized. Such elements affect the organisms in a river or water body and could have negative impacts on other industrial users of the same water.

When pH levels are higher than 9.5 or lower than 4.5, the water becomes unsuitable for most aquatic organisms. On account of their extreme sensitivity, young fish and immature aquatic insects might die when pH levels are lower than 5. According to Seager & Stoker (1972), all vertebrates, most invertebrates and many micro-organisms are destroyed at pH levels below 4. With most higher plants also being eliminated at such low pH levels, there are only a few algae and bacteria that are able to survive such high acidity levels. When pH levels rise to 9 and higher, the denaturing membranes of fish are damaged, prohibiting them from taking in sufficient nutrients for survival. Thus a pH range between 6 and 9 has been found to be suitable for sustaining aquatic life forms such as fish, as well as invertebrates living on the sea floor.

Another effect of a low pH level is that it accelerates the release of metals from sediments and rocks found in and along the river bed. Some of these sediments could contain toxic metals, which are released into the water. These dissolved metals affect the metabolism of fish and their ability to take in water through their gills, which could lead to their death.

Furthermore, if the pH levels are below 5.5, organic substances such as dead fish and plant debris will not decay. The hatching of fish eggs is jeopardized in water where the pH level is lower than 5, while any insect coming into contact with such low pH levels will die.

Davies & Day (1998) found that one of the ways in which pH affects aquatic ecosystems is by altering chemical compounds (different ionic forms for individual elements) which increases the availability and the potential toxicity of many of the heavy metals and other substances present in the water. Thus changes to the pH levels will ultimately affect the ways in which nutrients, trace metals and elements are absorbed by aquatic ecosystems.

Although changes in pH impact upon the aquatic ecosystem immensely, other aspects are also affected by changes in pH. For example, water with a pH level below 6 increases the potential of iron structures (e.g. plumbing systems, boats and piers) to be affected by corrosion. In the agricultural sector, crop damage occurs when the pH level drops below 4.5 because such acidic water increases the solubility of substances such as iron, aluminium and magnesium salts. Because pH levels are closely associated with other water quality aspects, it is extremely difficult to establish how changes in the pH levels of drinking water may affect human health.

Fortunately, soil provides a buffering system which means that irrigation water with pH levels ranging from 4.5 to 9 has limited consequences for the crop (Seager & Stoker, 1972). As regards the domestic sector, changes in the pH level of water affect certain of its aesthetic properties such as its taste. Water with a low pH level may taste sour, while high pH levels will cause a bitter or soapy taste on the palate (Cooke, 2006).

7.1.2 Conductivity

A conductivity test determines the ability of water to conduct an electrical current, and is made possible through the presence of certain dissolved substances in the water (Seager & Stoker, 1972). A conductivity test measures the salinity or salt content (caused by the total dissolved inorganic compounds in the water), along with other substances (e.g. dissolved metals, inorganic dissolved solids; nitrates, sulphates and phosphates, and hydrogen ions) that have the potential to carry an electrical charge.

Thus the conductivity level of a solution increases as additional substances, which can conduct an electrical current, are dissolved in it. Acidic water draining off from the mines is a good example of polluted water that can conduct a current on account of the presence of dissolved metals, sulphates and hydrogen ions – all substances that have the potential to conduct electricity (Seager & Stoker, 1972).

As mentioned above, polluted water is contaminated through various dissolved substances, and therefore has a higher conductivity level than an unpolluted water source. This, however, does not mean that conductivity is only possible in polluted water. Conductivity is also a natural phenomenon. The geology of an area through which a river flows also affects the river's conductivity levels as metals within the bedrock are dissolved and taken up by the river current (Kadewa, *et al.*, 2005). Thus increases in conductivity may be the result of human and/or natural processes that continuously add salts to the water, as in the case of pumping operations and rainfall. Lower conductivity concentrations are often expected during high rainfall periods, bringing into effect the natural dilution potential of a river on account of the additional rainfall water. Therefore, high levels of conductivity are usually associated with low rainfall periods.

Because a conductivity test provides a simple method for measuring the dissolved substances in a solution, it is often used as an alternative to the more complicated total dissolved solids (TDS) test, which measures the total amount of dissolved solids in a solution. Since the TDS is directly proportional to the conductivity measurement, it is possible, once the conductivity level has been measured, to estimate the TDS in terms of the conductivity measurement (Cooke, 2006). The equipment used for testing conductivity is user- friendly.

A conductivity test is useful for two reasons (Seager & Stoker, 1972). Not only does it help to determine whether a solution has the potential to conduct an electrical charge, but it also assists in identifying and locating the source of pollution – as long as numerous meter readings have been taken along a stream. In this study, conductivity has been used as a measurement to indicate the level of pollution caused by the Sasol Secunda Industrial Complex, as well as to establish the deterioration in the water quality of the Klipspruit River.

7.2 Chemical parameters

The chemical properties that contribute to the quality of water refer to the nature and concentration of the dissolved substances (e.g. salts, metals and organic chemicals) found in a solution. The chemical parameters selected for the purpose of this study are the concentrations of nitrates, phosphates and sulphates in the water. These will be discussed in the sections below.

7.2.1 Nitrates

Nitrate is one of the forms of inorganic nitrogen found in nature. The other forms of inorganic nitrogen include ammonia and ammonium. Nitrate is the end product resulting from the oxidation of nitrogen or ammonia. It is more stable and usually more abundant in the soil and in aquatic environments than is the case with the other forms of inorganic nitrogen. Owing to their soluble nature, nitrates are easily transported in rivers and in groundwater (Murphy, 2006). This explains why nitrates are ubiquitous in water and in soils. Solid nitrates are a rare phenomenon in nature on account of their propensity to dissolve in water. Only through the natural process of de-nitrification can nitrates be withdrawn from aquatic ecosystems. They are converted then into free nitrogen and released back into the atmosphere.

Regarding nitrate measurements, prior filtration may be required if the water samples are murky. Nitrate measurements must be conducted as soon as possible after the sample has been taken in order to minimize the effects of bacterial transformation and possible pH changes. This is why water samples taken for nitrate testing should be kept at low temperatures. The colorimetric method is the most common means of measuring nitrate concentrations. The object of this method is to determine the concentration of nitrates within the sample by adding a chemical to the sample and examining the colour that is reflected. The darker the colour of the water sample is, after the necessary chemical is added, the greater the concentration of nitrates.

The nitrogen cycle in an ecosystem starts off with nitrates being absorbed by microscopic and aquatic plants (plankton and algae) as certain bacteria in the soil and water convert atmospheric nitrogen into nitrate, a process called nitrogen fixation (Miller, 2005).

Nitrate is an important form of plant nutrition that stimulates plant growth. In their turn, the plankton and algae nourish microscopic animals. These plants and animals are subsequently eaten by fish. Nitrates are released when the fish and plants die and their remains decompose. Nitrates can be stored in decomposing humus or leached from soils, from whence they could be transported, in solution, to a river or stream and eventually to a groundwater body. A functional use of nitrate is in the industrial sector where nitrates are used as corrosion inhibitors in industrial processes (Holtzhausen, 2005).

Nitrate concentrations tend to increase in shallow groundwater bodies associated with runoff from farmlands and urban areas. Although there are both natural and human sources from which nitrates are generated and released, and both sources contribute to the inputs of nitrates into the environment, human activities generally exceed the natural sources in terms of the concentration of nitrates that they contribute to the environment. In fact, densely populated areas tend to have the highest nitrate concentrations.

The most extreme nitrate concentrations in South Africa are caused through point-source pollution (Holtzhausen, 2005). This includes the discharge of

- treated sewage waste that contains animal and human excretions,
- organic industrial waste, and
- surface runoff from the surrounding catchment areas where agricultural fertilizers, dissolved in the water, enter the drainage system in solution.

Although people and wildlife use nitrates as part of their nutritional requirements, excessive concentrations of nitrates can be harmful to the immune system, especially in the case of humans and more so of their infants. Excessive nitrate concentrations in the bloodstream can cause infants to develop methaemoglobinaemia, an illness known as the “blue baby syndrome”. This condition occurs when ingested nitrates cause the haemoglobin in the bloodstream to oxidize, thus forming methaemoglobin. Unlike haemoglobin, methaemoglobin does not have the capacity to transport oxygen to the blood. Therefore, as blood is deprived of essential oxygen, it starts to die off slowly. Thus, nitrate poisoning can lead to suffocation in that it causes a lack of oxygen in the body tissue (Antoniou, 1999).

As a result of South Africa's high incidence of HIV/Aids, nitrate pollution of water resources is a critical problem. This statement is made in the light of the fact that HIV-positive mothers are advised to bottle-feed their babies and to refrain from breast-feeding. This is done as a precautionary measure to prevent the virus from spreading from the mother to her baby through breast milk (Holtzhausen, 2005). However, this measure places infants at high risk as they might ingest nitrate-polluted water used during the preparation of their milk bottles. When infants digest nitrate-polluted water, their bodies convert the haemoglobin into methaemoglobin, which interferes with the oxygen-carrying capacity of the blood, as previously explained. Furthermore, expectant mothers who drink water that contains high nitrate concentrations are placed at risk: they could suffer spontaneous miscarriages and even still births.

Holtzhausen (2005) found that the first symptom of methaemoglobinaemia is blueness around the mouth, hands and feet, which is why reference is made to the condition as the "blue baby syndrome". Other symptoms include difficulty in breathing, vomiting and diarrhoea. Unfortunately, this methaemoglobinaemic condition is not restricted to humans. Very high concentrations of nitrates can also cause methaemoglobinaemia in livestock and other animals.

High concentrations of nitrates in aquatic ecosystems can cause fish to suffer from brown-blood disease. This disease is caused when nitrates are broken down to form nitrites (NO_2) in the bloodstream which cause the blood to take on a chocolate-brown colour. The brown colour indicates that the blood lacks sufficient amounts of oxygen to sustain life. Thus fish can die of suffocation, even if the oxygen concentration levels in the water are adequate. Extremely high nitrate concentrations also pose a threat in the form of *eutrophication* – an issue that will be referred to later on in this chapter.

During her investigation into the presence of nitrates in South Africa's groundwater, Holtzhausen (2005) found that excessive nitrate concentration levels were the main reason for declaring groundwater resources unfit for drinking purposes. Therefore nitrate pollution is a great challenge that needs to be addressed in South Africa in order to sustain good water quality. This will not be too daunting a task as the detection of nitrate pollution is relatively easy.

7.2.2 Phosphates

The concentration of phosphates can be determined by measuring the total proportion of dissolved phosphorous, which includes organically-bound phosphorous and phosphates (Murphy, 2006). The phosphate concentration is measured colorimetrically (as in the case of nitrate measurements). This measurement is taken after enzymatic and acidic hydrolysis tests have been carried out on the sample to convert complexes of phosphorous to phosphate species. The same precautionary measures taken for the nitrate samples are applicable to the water samples that are taken for phosphate measurements.

Phosphates are products formed by the replacement of some or all of the hydrogen in a phosphoric acid by metals (Manahan, 2001). Numerous vital processes such as the metabolic processes in both plants and animals, and plant growth, require phosphates in order to function properly. Phosphates could occur in an organic form as organically-bound phosphates or in inorganic forms as orthophosphates and polyphosphates.

Under oxidising conditions, phosphates react with numerous cations (e.g. iron and calcium) to produce insoluble compounds that settle out into water. Phosphates are not very mobile in soil. Rather than dissolving in water, they tend to remain attached to solid particles in the soil. However, through the weathering of rocks, phosphate salts can be leached out into surface water bodies. This process varies spatially, however, because it depends on the characteristics of the geology for the region in question. Phosphates also act as primary nutrients for algae (Murphy, 2006).

High phosphate levels may be the result of either point-source or diffused-source pollution. Point sources giving rise to phosphate pollution include domestic and industrial effluent and sewage discharges, while atmospheric precipitation, urban runoff and water draining off agricultural lands to which fertilizers have been applied are examples of diffused-source pollution. Rainfall events can cause elevated phosphate levels when surface runoff is increased, thereby once again suspending phosphate particles in the surface water and flushing other deposited material, which could contain phosphates, into a catchment area.

Shepard (2000) found that on a global scale the total phosphate contribution from municipal and industrial sources to surface water is less than 272,000 kilogram (kg) per annum. Phosphates can also be present in water as a dissolved gas and/or as particulate matter. Phosphates that are present in industrial effluent are classified as organically-bound phosphates, orthophosphates and polyphosphates (García, *et al.*, 2002). **Table 7** briefly explains the differences between the three forms of phosphate. The type of phosphate found in natural surface water, as well as the equilibrium of these different forms, is influenced by the pH levels.

Table 7: Description of the various forms that phosphates can assume (adjusted from Murphy, 2006).

Form of phosphate	Description
<u>Organic phosphates:</u> <i>Organically-bound phosphates</i>	This type of phosphate bonds with plant and animal tissue and is primarily formed during biological processes. Organic-bound phosphates occur as a result of the breakdown of organic pesticides containing phosphates. Organic-bound phosphates occur in solution and as loose fragments in the bodies of aquatic organisms.
<u>Inorganic phosphates:</u> <i>Orthophosphates</i>	Orthophosphates, also known as reactive phosphorous, are the most stable of all types of phosphate. They are also immediately available to aquatic organisms, which can transform them through natural processes into a more acceptable form. Orthophosphates are also found in sewage.
<i>Polyphosphates</i>	Otherwise known as metaphosphates, or condensed phosphates, polyphosphates act as a strong complex agent for some metal ions. Polyphosphates are generally used during the treatment of boiler water and in detergents. Owing to the fact that polyphosphates are very unstable, they are eventually easily converted into orthophosphates. Under controlled conditions, polyphosphates can also be added to water to prevent iron oxides or calcium carbonates from forming.

It is relatively easy to control phosphate pollution as extreme concentrations of phosphates are usually point-specific. By identifying the point source, appropriate technologies can be applied in order to reduce the phosphate levels. If priority is given to point sources, these technologies will not only reduce the phosphate levels, but also save money, as this is the most cost-effective method of controlling excessive phosphate levels. Recently, the focus has also shifted towards the evaluation of the environmentally-harmful effects of phosphates in household detergents.

According to the world standard (Huizenga & Harmse, 2005), the average concentration of phosphates in natural water is estimated at 0.73 milligrams per litre (milligrams per litre). In accordance with this guideline, South Africa ranks ninth highest in a total of 141 countries in her concentration levels of phosphates. During his research on the management of the Vaal River Barrage, Van Wyk (2001) found that a recommended 1 milligram per litre guideline for phosphate discharges would reduce the load entering the barrage. However, more importantly, if not implemented, the phosphate load could increase by 250 percent, which poses an intolerable situation. Should this simple guideline have such a positive effect on the Vaal River Barrage, just imagine the effect that it would have if implemented on a national scale.

Like nitrates, phosphates are toxic to people and animals only if high concentrations are ingested, the usual consequence being digestive problems. Another problem related to excessive nitrate and phosphate levels in an aquatic ecosystem is *eutrophication* as nitrates and phosphates stimulate excessive aquatic plant growth. Eutrophication will be discussed in detail in the following section where its effects will be clarified and explained.

7.2.2.1 Eutrophication

Under natural conditions, low concentration levels of nitrates and phosphates persist in natural waters. As described in the previous two sections, however, these levels could increase when water polluted with nitrates and phosphates is discharged from point and diffused sources. The dominant source for phosphate pollution is sewage, while nitrate-rich water is discharged mainly from sewage treatment plants and through storm-water runoff.

When nitrates and phosphates are dissolved in the water, they act as nutrients or fertilizers, stimulating regular algae and aquatic plant growth. The plants use the dissolved oxygen in the water to grow, and when they die, the oxygen plays an important role in their decomposition. This leads to a drop in the oxygen level required by an aquatic ecosystem. If the concentration of dissolved oxygen drops below a particular level, fish will have difficulty in breathing and could suffocate (Holtzhausen, 2005). The end result is the degradation of the quality of the water, reflected in its characteristic smell of stagnation.

This entire process of applying fertilizers to farmlands to stimulate plant growth, and the resultant depletion of the dissolved oxygen in the water is known as *eutrophication*. Although eutrophication is a natural process and sometimes necessary, its effects are exacerbated by the inevitable consequences of human actions that generate excessive amounts of nitrates and phosphates. Elevated concentrations of nitrates and phosphates entering a water body could lead to aquatic plant and algae blooms. Thus even more of the dissolved oxygen is exhausted. Through the process of eutrophication, the algae blooms also provide a source of carbon for bacterial growth.

Because human activities aggravate eutrophication, the effects of this problem can be minimized, to an extent, through better management of the artificially-created nutrient cycles generated through human activities. Considering that eutrophication is a natural process, however, its effects and associated problems can never be eliminated (Holtzhausen, 2005).

As the quality of the water in an aquatic ecosystem changes as a result of eutrophication, so do the functions of the ecosystem, since some groups of organisms are favoured above others, and bacterial growth is stimulated by the algae blooms that provide a source of carbon for their survival. It has been found that even normal fish populations in eutrophic dams cannot be supported, thereby reducing the biodiversity of the aquatic habitat and aquatic species in the food chain (Whyte, 1995).

There are other problems that arise from eutrophication. Algae blooms, for instance, produce excessive amounts of foliage in the water, tending to block filters used during the water purification process. This in turn leads to an increase in the toxicity levels of water and to problems regarding its taste and odour. Drinking water that contains high concentrations of dissolved nitrate and phosphate nutrients is also harmful to human health, as explained under the relevant headings in the previous sections.

Eutrophication also has economic implications. It raises the cost of purifying water as clogging takes place and extra filters need to be replaced. Eutrophication also interferes with the recreational use of water bodies as it can lead to skin irritations and diarrhoea in swimmers, the clouding of water by blue-green algae (Van Wyk, 2001), and can make navigation difficult or even impossible for motor-boat enthusiasts on the water. Even the fisheries industry is affected as the toxic algae blooms poison the fish to such an extent that they are declared unfit for human consumption. Sometimes, the state of eutrophication can be so bad that it affects the aesthetic value of a river or dam, thereby negatively impacting upon the leisure and tourist industries.

7.2.3 Sulphates

Sulphate is the oxy-anion of sulphur. Sulphate salts are produced when sulphates combine with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. These compounds differ in solubility. Potassium, sodium, magnesium and ammonium sulphates are highly soluble, while calcium sulphate is partially soluble, and barium and lead sulphates are insoluble.

Sulphate is a common compound occurring in water. It can arise when mineral sulphates, particularly calcium sulphate (gypsum), which might occur in soil and rock, are dissolved along with other partially soluble sulphate materials. Sulphates tend to accumulate in water, thereby gradually intensifying the sulphate concentration level, although Whyte (1995) found that these naturally-occurring sulphate concentrations in water typically amount to less than a few milligrams per litre.

The release of sulphates into a water body can occur naturally or as a result of human activities. A few ways in which sulphates are naturally released (not “release”) include the following (Cooke, 2006):

- the breakdown of leaves that have fallen into a stream, and
- water passing through rock or soil containing gypsum and other common minerals.

Human-generated point sources of sulphates include the outlets from industries discharging sulphuric acid and acid effluent drainage from the mines. Agricultural lands that have had applications of fertilizer are a diffused source of sulphate pollution.

Another diffused source of pollution occurs when fossil fuels are burnt to generate electricity. Through the last-mentioned process, sulphur dioxide is released into the atmosphere and gives rise to rainwater that contains sulphuric acid (acid rain). Thus precipitation causes the sulphates to be washed back into the surface water bodies and the environment. According to the South African Water Quality Guidelines (1996a-f) laid down by DWAF, the interactions of sulphate with other elements or compounds are governed by the associated cations, namely magnesium and sodium in natural waters, and calcium in industrial waters.

Sulphates are generally non-toxic to animals and plants, and although concentrations of 500 to 750 milligrams per litre have been found to have temporary laxative effects on humans and animals and to lead to poor productivity in young animals, doses of several thousand milligrams per litre will not cause any long-term ill effects (Cooke, 2006). The potential of sulphates to cause diarrhoea depends on the associated cations. Hence sulphate-polluted water will cause diarrhoea only if the sulphate- associated cation is magnesium, but not if it is sodium.

On the subject of the interaction of sulphates with aquatic ecosystems, algae growth will not occur if the sulphate concentrations are less than 0.5 milligrams per litre. For the industrial and metal construction sectors, it is important to realize that high sulphate levels will intensify the corrosion potential of water. Therefore, the severity of the problems associated with elevated sulphate levels relates to their ability to form strong acids, which cause pH changes in an aquatic habitat (Cooke, 2006).

7.3 Organic parameters

Owing to the chemical composition of water, oxygen will always be present in a dissolved form in any given water sample. The concentration of dissolved oxygen is not constant, however: it fluctuates diurnally under natural conditions. Naturally-induced fluctuations in the oxygen content of water result from, amongst others, the relative rates of photosynthesis and respiration of green plants and algae in and around a water source. Davis & Day (1998) found that dissolved oxygen levels are at their lowest close to dawn, and that they increase during the day, peak in the afternoon, and decrease at night. Oxygen can also be dissolved in water as a result of turbulence in a river.

Factors that influence the amount of oxygen that is dissolved in water include the following:

- the rate of aeration from the atmosphere
- temperature
- air pressure
- salinity, and
- the state of eutrophication (discussed under Section 7.2.2.1).

The presence of oxygen-demanding waste is the main factor causing water de-oxygenation. Waste substances are broken down through bacterial activity, a process that consumes dissolved oxygen and results in elevated carbon dioxide concentrations. Thus it is the presence of such material that leads to the depletion of dissolved oxygen (Seager & Stoker, 1972). The chemical oxygen demand (COD) parameter was therefore chosen for this study since it determines the amount of oxygen required to oxidize organic matter. The proportion of dissolved oxygen remaining in Rand Water's water samples therefore proved to be the crucial question in this study as the concentration of dissolved oxygen determines whether most aquatic organisms would be able to survive in such an environment.

7.3.1 Chemical oxygen demand

There are various ways in which oxygen are dissolved in water. Atmospheric oxygen is dissolved in water through the action of turbulence occurring within a river. The distribution of the dissolved oxygen continues until a water body reaches a particular saturation level. This level could vary according to the degree of turbulence within a river. Should the turbulence increase (as in the case when excessive surface runoff enters a river), so too would the level of dissolved oxygen increase as air containing oxygen is worked into the water. Another manner whereby dissolved oxygen is released into water is through the process of photosynthesis. Through this process gaseous oxygen is released into the water by green aquatic plants, algae and phytoplankton (plankton that comprise of bacteria, microscopic algae and fungi).

Dissolved oxygen within water is crucial for the survival of aquatic organisms and necessary in order to maintain certain vital functions of an aquatic ecosystem. The organisms that require the highest levels of dissolved oxygen within water bodies are fish and the least of all, bacteria. The generalization is therefore that the higher the dissolved oxygen concentration within a water body, the healthier the aquatic ecosystem.

According to the Water Quality Guidelines (1996b) laid down by DWAF, chemical oxygen demand (COD) is defined as a measure of the oxygen equivalent of the organic matter content of a sample of water that is susceptible to oxidation by a strong chemical oxidant. This definition basically means that a COD measurement is used to determine the amount of oxygen present in a water sample as opposed to the amount of organic matter in the water sample. Such organic matter is highly susceptible to oxidation by a strong chemical oxidant.

Most of the compounds that are involved in the process of water de-oxidation are carbon-enriched. These compounds undergo the following reaction when carbons are oxidised:

$C + O_2 \rightarrow CO_2$. In biochemical terms, the chemical reaction requires 32 grams of oxygen to oxidise 12 grams of carbon. This means that 9 parts per million of oxygen are needed to react with 3 parts per million of dissolved carbon. All of these ratios clarify how easily and quickly an aquatic environment can be depleted of its concentration of dissolved oxygen.

Whyte (1995) has found that a COD test is particularly useful when analysing industrial wastewater bodies and for comparing biological and chemical oxidation in a selection of treatments, processes and operations. Therefore, according to Whyte (1995), the measurement of the COD should not be used to determine the health of an aquatic ecosystem; it is more appropriate in determining the water quality requirements of effluents which are discharged into an aquatic system in order to limit the impact of industrial effluent.

Through human activities such as agriculture and stock farming, which result in the generation of domestic and industrial waste, significant amounts of organic matter are released into the aquatic environment. This organic matter can be present either in a dissolved state or as particulate matter. Organic matter in its dissolved state causes water to taste and smell unpleasant, while particulate matter contributes to the load of suspended solids in a water body.



8. WATER QUALITY ANALYSIS

The main purpose of this chapter is to discuss the results that were obtained from the conducted data analysis. In addition, this chapter also provides information on the methodology that was used during the data analysis and any shortcomings that were found in the data.

8.1 Method of analysis

It is impossible to establish whether water is fit to be used as a resource merely by observing certain of its properties, such as colour and temperature. Analyses of the physical, chemical and organic properties of water must be conducted if the quality of the water as a resource is to be determined. These analyses are helpful in determining the extent of water pollution and in identifying pollutants. This vital information can then be used by decision-makers for formulating and implementing environmental management plans in order to mitigate the effects of river pollution and to rehabilitate the rivers thus affected.

For the purpose of this study, data relating to six water quality parameters (pH, conductivity, nitrate, phosphate and sulphate concentrations, and chemical oxygen demand) were analysed in order to determine the manner in which the industrial effluent from the SSIC has impacted upon the water quality of the Klipspruit River. Rand Water supplied the chemical water quality data for the period 2000 to 2005 which was based on the few surface water samples it took once a month throughout the year but at no scheduled time, day or week.

Two types of data analysis were carried out on the data in question, namely a comparative analysis and a regression analysis. The former was conducted to determine whether the water samples that were taken from the Klipspruit River comply with two sets of water quality guidelines, namely the Target Water Quality Range laid down by the DWAF and the In-stream Guidelines of the Waterval River Catchment Management Agency (Waterval Forum, 2005a). This type of analysis also proved useful in identifying the parameters which exceed the stipulated guidelines and are therefore cause for concern.

The regression analysis was done to determine the trend of the various parameters collected over a six year time period (2000-2005) at each of the three water sampling points. Microsoft Excel was used to analyze the data. With the help of such a programme, it was possible to compile tables and various graphs for each water quality parameter and to conduct a regression analysis on the data. The resultant tables and graphs facilitated the task of interpreting the results. As regards the line graphs (the end result of the regression analysis), the time period (years of sampling) is set out along the x-axis and the water quality parameter in question along the y-axis.

The set of Water Quality Guidelines (DWAF, 1996a-f) laid down by the DWAF for particular freshwater-use categories was selected for the comparative analysis, with the focus being on the following: the aquatic ecosystem, domestic use, livestock watering and irrigation. Various substances which could impact on the suitability of the water for that specific use category were described and discussed in detail in each case. These water-use categories were specifically chosen because the water in the Klipspruit is used for these purposes and because one pollutant often affects more than one ecosystem and in turn also affects the suitability of the water for a specific purpose.

For most of the parameters that were chosen for this study, the DWAF specifies a Target Water Quality Range (TWQR) for each water-use category. A summary of these guidelines is provided in **Appendix B**. The TWQR was developed by the DWAF in reaction to its increasing concern for the deterioration in the quality of the water in the country. The TWQR is regarded as an approach for controlling water pollution caused by non-hazardous pollutants and as a set of pollution prevention procedures for hazardous substances.

The other guidelines that were used in the comparative analysis are the In-stream Water Quality Guidelines laid down by the Waterval River Catchment Management Agency (CMA). These guidelines which are laid down for each parameter (except for pH) are divided into four main categories, i.e. ideal, acceptable, tolerable and unacceptable (refer to **Appendix C**). The Waterval River Catchment Management Agency's Water Quality Guidelines are general guidelines as they do not distinguish between various water-use categories (Waterval Forum, 2005a).

The second type of data analysis used in this study was regression analysis. Geographers often work with empirical data derived from either observations and/or experiments, and they need to explain what the data signify. Statistical methods are therefore used to interpret the data so that conclusions can be drawn in relation to the problem and data at hand. The relationship between two quantitative variables could be established by means of regression analysis. It is important to include one dependent variable and one independent variable when conducting a regression analysis. In this study, the given water quality parameter in question was chosen as the dependent variable, while time was set as the independent variable.

Thus the end result was a line graph with data points representing the observed values, and a trend line with its R squared (R^2) value indicated at the end of each line. The trend line is a graphical representation of trends in the data series. The R^2 value is an indicator that ranges from 0 to 1 and reveals how closely the estimate for the trend line corresponds to the actual data.

The regression line graph also makes it possible to visualize the temporal trend of each water quality parameter throughout the period in question. The regression analysis in this study made it also possible to identify parameters that exceed the water quality guidelines and which would possibly point to future pollution problems for the study area.

The direction of river flow is also illustrated alongside the graphs to show how the distribution of the parameter values differs over time. Owing to the limited scope of this study, it was not the intention to make predictions in terms of the water quality parameters, but merely to explain the relationship between the variables in order to determine the effect of the activities of the SSIC on the quality of the water in the Klipspruit River.

8.2 Shortcomings of data

Various shortcomings came to light during this research study. These ranged from data inconsistencies to faulty methods of measurement. This section therefore describes the various shortcomings that were experienced during the study and explains, if relevant, how these shortcomings were overcome.

Firstly, the water quality data which were provided by Rand Water contained various gaps and inconsistencies in the form of extreme values. These inconsistencies could be the result of some parameters that were taken at a specific sampling point during a period when the SSIC experienced possible problems (i.e. leaking pipes or accidental pollution events such as those described in Chapter 3). For the purpose of the data analysed, and its interpretation, the received data were re-processed by means of linear interpolation in order to fill in the gaps with meaningful data. After this linear interpolation was applied to the data, it was established that there were 1 296 water quality data samples in total (**Appendix A**), and that various analytical methods could be applied to the data.

A second shortcoming was found in the water quality guidelines formulated by the DWAF. Although all of the selected parameters, along with their effects on water quality, are discussed in these guidelines, the set of Target Water Quality Range (TWQR) levels applies to some water quality parameters only, thus leaving some parameters without such guidelines (DWAF, 1996f). For instance, even though reference is made to the parameter of chemical oxygen demand under the discussion of dissolved oxygen levels in a few of the Water Quality Guidelines of the DWAF, there were no direct TWQR guidelines for any of the water-use categories for the chemical oxygen demand parameter considered in this study.

A third shortcoming is related to the method Rand Water used when the samples were collected and chemically analysed. According to Davies & Day (1998), this type of chemical analysis is unsatisfactory in that, although it provides accurate measurements for the quantities of individual substances present in the water, it only considers the water which flows past a specific point and at the time of collection.

Thus although Rand Water collects various samples throughout a 24-hour period in order to determine the monthly average readings for a specific parameter, the data are still collected only once a month. Davis & Day (1998) are of the opinion that such readings are subjective to a degree of inaccuracy as variations within the concentrations of the parameter can fluctuate greatly within the period of a month.

A fourth and final shortcoming should rather be regarded as a recommendation for future studies as the following aspect was beyond the scope of this research. Future studies might want to incorporate rainfall data in order to establish the seasonal trends associated with industrial effluent and the effects these trends might have on water quality. Such a study will be useful as it will determine the potential and effectiveness of the natural dilution potential of a river.

8.3 Discussion of results

From the comparative analysis, it was possible to determine whether Rand Water's data conform to the various stipulated guidelines that are set by DWAF and by the Waterval Forum. This analysis also made it possible to determine the proportion of data exceeding the guidelines or falling below them. This chapter highlights the levels at which different substances can become lethal or detrimental to organisms, or impact upon the quality of the water for other water users. It is important to emphasize this aspect as in certain instances the extreme levels reached by various parameters can cause long-term biological damage to organisms, interfere with the reproductive cycles of aquatic organisms, and also make them more susceptible and vulnerable to disease.

To assist with the logical flow of this section, the data analyses for each parameter will be discussed individually, while highlighting the following aspects:

- The relationship between the parameter in question and the recommended water quality levels relevant to it;
- The proportion of the data relating to the parameter in question that comply with the specifications of the relevant guidelines;
- The effects of the data values of each parameter on other water-use categories, and

→ The results obtained from the regression analysis of each parameter.

Regarding the regression analysis, a line graph and its accompanying trend line were compiled for each sampling point. This was done in order to reduce the amount of information and detail to be displayed on one graph in order to make it easy to understand and interpret.

8.3.1 pH

8.3.1.1 The comparative analysis for pH

Figure 16 explains how pH levels influence water quality. Because the ideal range for pH is between 6.5 and 8.5 (according to the Waterval River Catchment Management Agency's In-stream Guidelines), which suits most water users, the quality of the water is good only when these pH levels prevail (Waterval Forum, 2005a). Water quality deteriorates when the pH levels are higher or lower than this range.

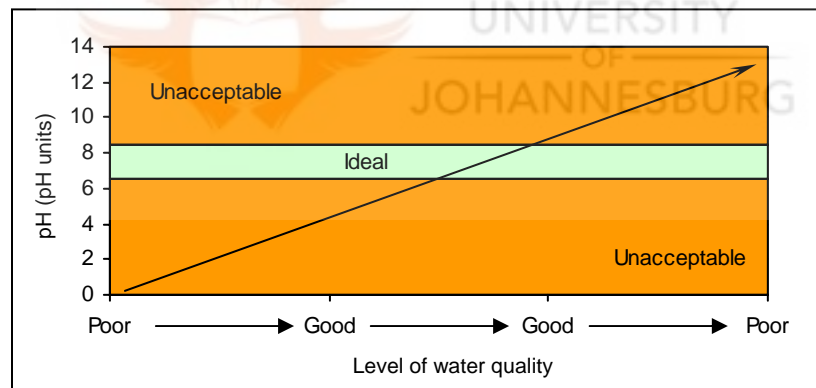


Figure 16: Relationship between pH levels and water quality

According to the DWAF's (1996e) Target Water Quality Range (TWQR) levels, all pH measurements for the site in question should lie within that range. This was largely the case at the three sampling points when Rand Water's data were compared to the Target Water Quality Range levels (see **Table 8**).

Table 8: Results obtained after assessing Rand Water's pH levels in terms of Target Water Quality Range (TWQR) levels.

Water-use categories in terms of pH	TWQR	Data Compliance (%)		
		SEC-SEW	C-WAB	C-WAT
Aquatic	6.5 – 9.0	99.00	100.00	100.00
Domestic	6.0 – 9.0	99.00	100.00	100.00
Agriculture - Livestock	NA	---	---	---
- Irrigation	6.5 – 8.4	90.00	47.00	61.00

When the same data were compared to the Waterval River Catchment Management Agency's In-stream Water Quality Guidelines, the following results, summarized in **Table 9**, were obtained:

Table 9: Results obtained after assessing Rand Water's pH levels in terms of Waterval River Catchment Management Agency's Guidelines

Water Quality category	Waterval River CMA's Specification	Point Data Compliance (%)			Total data compliance (%)
		SEC-SEW	C-WAB	C-WAT	All points
Ideal	6.5 – 8.5	96.00	72.00	85.00	84.00

The differences found in terms of data compliance for the TWQR and the In-stream Water Quality Guidelines are due mainly to the different guidelines stipulated for pH. As opposed to the TWQR levels, which stipulated individually for specific water-use categories, the Waterval River Catchment Management Agency's Guidelines are stricter and allow for very little variation for different water-use categories.

Owing to the fact that not all of the water samples from the sampling points indicated a 100 percent compliance to the various guidelines, the following section will deal with the implications of the high pH levels in the water samples. The analysed data only indicated higher pH levels than the TWQR. The maximum pH value for the whole data range was 9.12, while the minimum level found in the samples for this parameter was a pH of 7.44. This means that the sampled water pointed to a neutral to alkaline pH. In total, only 17 percent of the data did not comply with the Waterval River's In-stream Guideline for pH.

The following aspects should be kept in mind when establishing the impact of pH changes on aquatic organisms, namely the duration, extent and timing of the change. This is because small changes in the pH levels often cause larger changes such as an increase in the concentration of toxic metals.

Changes in pH levels affect irrigation water as the solubility and availability of plant nutrients (in the form of nitrates, phosphates and sulphates) depend largely on pH levels. When water with pH levels above or below the TWQR is used for crop irrigation, it is possible for the water to cause foliar damage. This in turn could lead to decreased crop yields or damage to perishable marketable products such as fruits and vegetables. The severity of the damage, however, depends on the duration of exposure of the crop to such high pH levels. Corrosion and encrustation of irrigation equipment have been found to take place when irrigation water is subject to extreme pH levels.

Aquatic organisms in general are well developed in order to adapt to pH changes that may occur within their aquatic habitat. Although the analysed data did not indicate such levels, it is estimated that a water body with a pH level of 4.0 is lethal to most of the aquatic organisms. The lowest pH value measured in Rand Water's water samples was 7.44, while the highest pH level was 9.12, both occurring at the SEC-SEW sampling point.

Table 10 summarizes the statistical values of the pH levels measured at the different sampling points.

Table 10: Summarized statistics relating to pH levels at individual sampling points

Site	Statistics	Parameter
SEC-SEW	<i>Mean</i>	8.05
	<i>Std dev</i>	0.30
	<i>Max</i>	9.12
	<i>Min</i>	7.44
	<i>n</i>	72
C-WAB	<i>Mean</i>	8.40
	<i>Std dev</i>	0.15
	<i>Max</i>	8.61
	<i>Min</i>	7.92
	<i>n</i>	72
C-WAT	<i>Mean</i>	8.30
	<i>Std dev</i>	0.22
	<i>Max</i>	8.62
	<i>Min</i>	7.53
	<i>n</i>	72

8.3.1.2 Regression analysis for pH

Because the SEC-SEW sampling point is located closest to the Sasol Secunda Industrial Complex, it was to be expected that the pH values at this point would be extreme, and this was in fact the case (indicated in **Figure 17a**). The single peak pH measurement that was recorded at the SEC-SEW sampling point in the year 2004 might be an indication of a spill. It was also anticipated that extreme pH values would stabilize or balance out as the river continued to flow, owing to the natural dilution potential of water over time. C-WAB was the only sampling point to confirm this from its data (**Figure 17b**) as, from this point onwards, the pH levels taken from the C-WAT sampling point showed a slight increase (**Figure 17c**).

The trend lines depicted on each individual sampling point regression line graph show that the overall tendency of the pH measurements is quite stable throughout the six-year data period in question.

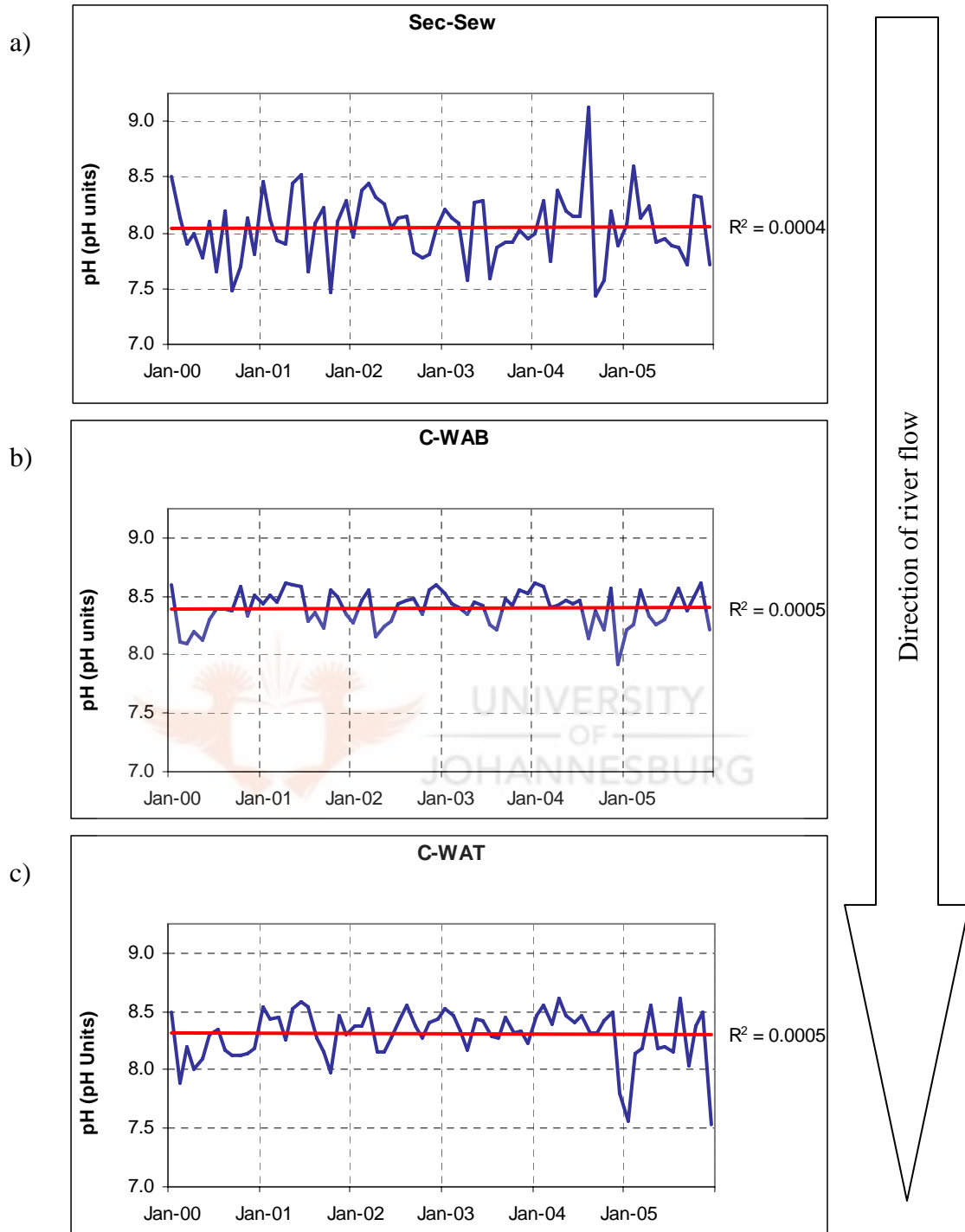


Figure 17: Regression analysis results relating to pH levels measured at individual sampling points

8.3.2 Conductivity

8.3.2.1 The comparative analysis for conductivity

The relationship between conductivity levels and water quality (represented in **Figure 18**) is based on the Waterval River Catchment Management Agency's In-stream Water Quality Guidelines. This figure shows that the lower the conductivity value, the better the water quality will be. As the conductivity level increases, so the water quality decreases.

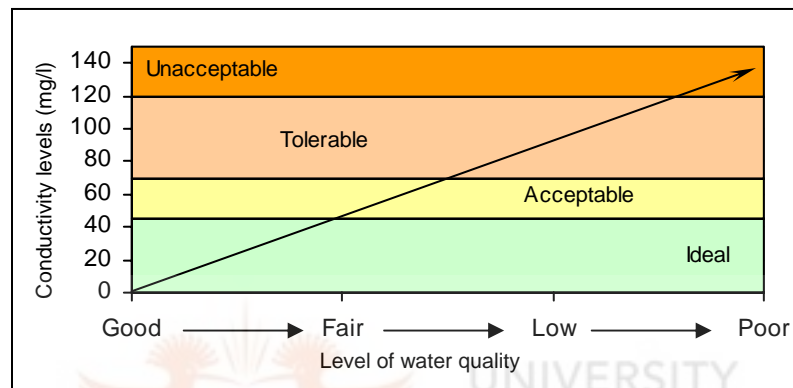


Figure 18: Relationship between conductivity and water quality.

Because conductivity is so closely related to the total dissolved solid (TDS) concentrations in water, the only conductivity guideline set by DWAF that related to this study's consideration of water-use categories, was found in the Irrigation Guidelines. According to this water-use category, the TWQR for conductivity is any value less than 40 milligrams per litre (DWAF, 1996c). Only one percent of Rand Water's data complied with this TWQR requirement.

Similar results were obtained when the data were assessed in terms of the Waterval River In-stream Guidelines. These results are summarized in **Table 11**.

Table 11: Results obtained after assessing Rand Water’s conductivity levels in terms of Waterval River Catchment Management Agency’s Guidelines

Water Quality category	Waterval River CMA’s Specification	Point Data Compliance (%)			Total data compliance (%)
		Sec-Sew	C-WAB	C-WAT	All points
Ideal	< 45	0.00	1.00	1.00	0.67
Acceptable	45 – 70	83.00	72.00	67.00	74.00
Tolerable	70 -120	17.00	26.00	32.00	25.00
Unacceptable	> 120	0.00	1.00	0.00	0.33

Therefore, according to the Waterval River Catchment Management Agency’s In-stream Guidelines, although higher and sometimes very high conductivity levels prevail, the quality of the water from the three sampling points on the Klipspruit is still acceptable and tolerable to various other water users. The conductivity parameter is however of major concern to the irrigation sector as conductivity concentrations affect crop yields. The DWAF (1996c) found that if conductivity levels within the range of 40 to 90 milligrams per litre, a moderate salt-sensitive crop could be maintained on a low-frequency irrigation system, with a 95 percent success yield rate.

Furthermore, Antoniou (1999) found, that changes in the conductivity concentrations also affect aquatic organisms. These changes take place mainly at three levels within an aquatic ecosystem as they affect:

- the adaptation of individual species,
- the community structures, and
- the microbial and biological processes (e.g. rates of metabolism and nutrient cycling) of such organisms.

8.3.2.2 Regression analysis for conductivity

In view of the positions of the trend lines at each of the sampling points, it is clear that the conductivity levels of the water samples taken at the SEC-SEW point tend to decrease over the data period in question (**Figure 19a**). On the other hand, the conductivity measurements at the C-WAB sampling point show an increase in value during the same period (**Figure 19b**). This increase in the conductivity levels is due to the fact that conductivity substances accumulate in a river as the water flows downstream. For example, salts (which are substances through which an electrical current can be conducted) are constantly being added to the river through natural and artificial processes, while limited amounts of salts are withdrawn naturally. In the case of the Klipspruit River, the conductivity level increases may be the result of domestic effluents and surface runoff from cultivated fields which enter the river between the SEC-SEW and the C-WAB sampling points. The trend line at the C-WAT sampling point shows that the conductivity levels were stabilizing over the six year period from 2000 to 2005 (refer to **Figure 19c**).



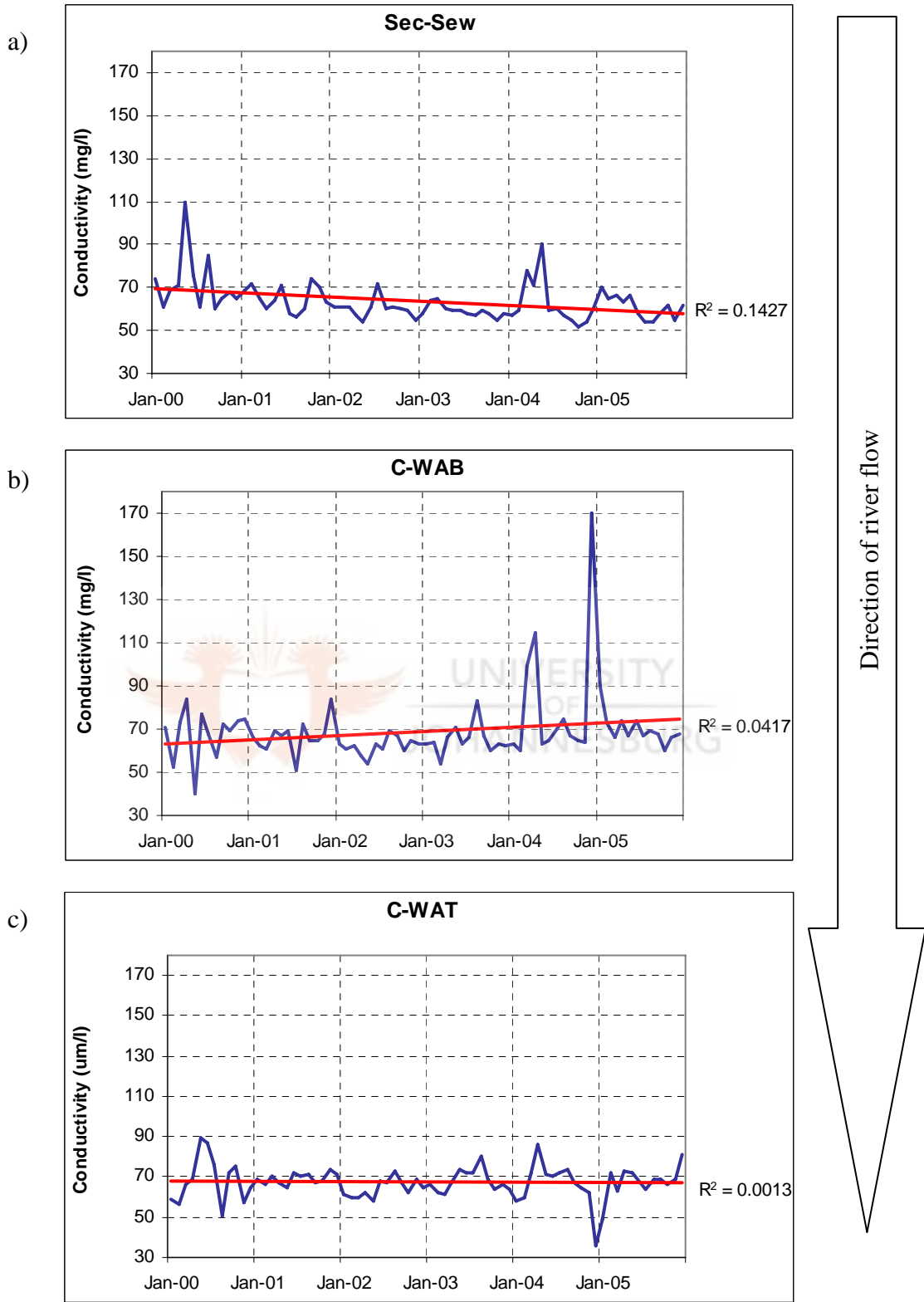


Figure 19: Regression analysis results relating to Rand Water’s conductivity levels measured at individual sampling points

8.3.3 Nitrates

8.3.3.1 The comparative analysis for nitrates

Based on the Waterval River Catchment Area Management Agency’s In-stream Water Quality Guidelines, **Figure 20** demonstrates that the water quality of a water body deteriorates as the concentration of nitrates intensifies. The Waterval River Catchment Management Agency’s Guidelines for nitrates are divided into four categories, namely ideal, acceptable, tolerable and unacceptable.

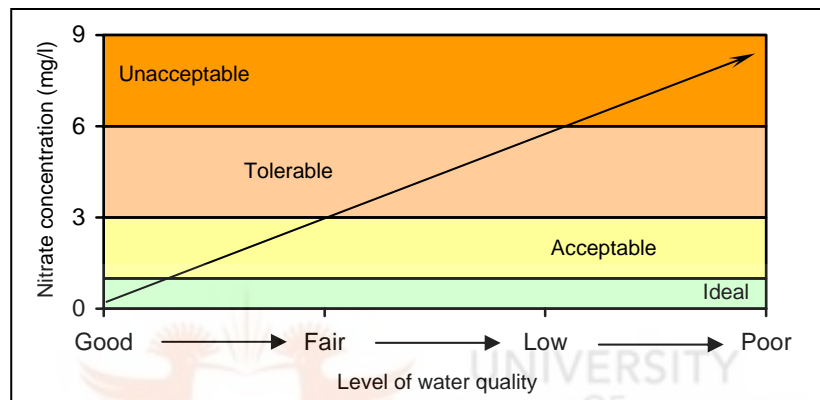


Figure 20: Relationship between nitrate concentration levels and water quality.

When these guidelines were used to analyse the compliance of Rand Water’s data to the Waterval River Catchment Management Agency’s Guidelines, it was found that the majority of the concentrations fell into the acceptable and tolerable categories. The results of this analysis are summarized in **Table 12**.

Table 12: Results obtained after assessing Rand Water’s nitrate concentration levels in terms of Waterval River Catchment Management Agency’s Guidelines.

Water Quality category	Waterval River CMA’s Specifications	Point Data Compliance (%)			Total data compliance (%)
		SEC-SEW	C-WAB	C-WAT	All points
Ideal	< 1.0	7.00	1.00	4.00	4.00
Acceptable	1.0 – 3.0	38.00	61.00	67.00	55.30
Tolerable	3.0 – 6.0	41.00	24.00	22.00	29.00
Unacceptable	> 6.0	14.00	14.00	7.00	11.70

Of the four water-use categories relevant to the Klipspruit River, and that were considered in this particular data analysis, the DWAF (1996a & 1996d) specified target water quality ranges for nitrate concentrations for only two water-use categories, namely domestic freshwater use and livestock watering. The TWQRs stipulated for each of these water-use categories showed large variations from one to the other, as is apparent from **Table 13**.

Table 13: Results obtained after assessing Rand Water’s nitrate concentration levels in terms of Target Water Quality Range (TWQR) levels.

Water-use categories in terms of nitrates	TWQR	Data Compliance (%)		
		SEC-SEW	C-WAB	C-WAT
Aquatic	NA	---	---	---
Domestic	0 – 6	86.00	86.00	93.00
Agriculture - Livestock	0 – 100	100.00	100.00	100.00
- Irrigation	NA	---	---	---

* NA – Not Available.

Thus nitrate concentrations ranging from 0 to 6 milligrams per litre are suitable for domestic water usage. On assessing Rand Water’s data it was found that 88 percent of the total data fell within the Domestic Target Water Quality Range (TWQR). At this range there would be no adverse health effects. The concentration range where rare instances of methemoglobinaemia have occurred in infants is at nitrate concentrations between 6 and 10 milligrams per litre. As regards this array, eight percent of Rand Water’s total data lies within this range. Only one measurement indicated a value above 20 (a 21 milligrams per litre nitrate concentration was measured at the C-WAB sampling point). At such high nitrate concentration levels, methemoglobinaemia would occur in infants and mucous membrane irritations in adults.

Thus, the conclusion was made that during the reviewed period, the water from the Klipspruit River posed minimal threats in terms of the stipulated guidelines for domestic usage. **Table 14** summarizes the most significant statistics found in the data set.

Table 14: Summarized statistics relating to nitrate concentration levels at individual sampling points.

		Parameter
Site	<i>Statistics</i>	NO3
SEC-SEW	<i>Mean</i>	3.69
	<i>Std dev</i>	2.76
	<i>Max</i>	17.00
	<i>Min</i>	0.05
	<i>n</i>	72
C-WAB	<i>Mean</i>	3.84
	<i>Std dev</i>	3.92
	<i>Max</i>	21.00
	<i>Min</i>	0.98
	<i>n</i>	72
C-WAT	<i>Mean</i>	2.94
	<i>Std dev</i>	2.09
	<i>Max</i>	14.00
	<i>Min</i>	0.05
	<i>n</i>	72

What is interesting to note is that, although instances have been found where methemoglobinaemia may occur in infants at concentration levels between 6 and 10 milligrams per litre, the nitrate specification for drinking water is 10 milligrams per litre (Holtzhausen, 2005). Therefore, it could be recommended that the permitted concentration level of nitrates in drinking water should be reduced as such high concentration levels may pose problems in terms of methemoglobinaemia in a country such as South Africa, with its very high incidence of HIV/Aids. As explained earlier, HIV- positive mothers are encouraged to bottle-feed their babies but this requires that the powdered milk be diluted. If drinking water containing high concentration levels of nitrates is used for this purpose, it might increase the chances of bottle-fed babies developing symptoms of methemoglobinaemia.

Regarding nitrate concentrations in livestock watering, the DWAF (1996d) states that nitrates do not cause direct toxic effects. On account of the fact that the Target Water Quality Range for nitrates is set between 0 and 100 milligrams per litre, and that the highest nitrate concentration in Rand Water's data was 21 milligrams per litre, all of the data meet the livestock watering target range specifications.

8.3.3.2 Regression analysis for nitrates

Transient elevation levels of nitrates could be observed at each of the water sampling points. These temporary increases are of less concern than continuously elevated nitrate concentrations which were found at the SEC-SEW sampling point between July 2003 and December 2003. Single peaks in nitrate concentrations may indicate the event of a spillage during the year in question.

Great variations in nitrate levels (represented in **Figure 21a**) were found at the SEC-SEW water sampling point. This might be due to the fact that the SEC-SEW point is located at the sewage treatment works, where excess nitrates are able to enter the river via the effluent from the sewage treatment plant. The three peaks featured (rather than observed) in **Figure 21b** correspond to the three smaller peaks at the C-WAT sampling point (**Figure 21c**) which is located further downstream from the C-WAB sampling point. These three smaller peaks are an indication of the effects of the natural dilution capacity of the river.

Of the three selected water sampling points, only the SEC-SEW point indicated a trend line showing only slight increases in terms of nitrate concentrations. The trend line at the C-WAB sampling point shows a definite decline while that at the C-WAT sampling point shows a more gradual decline. Therefore, SEC-SEW is the only sampling point to cause concern in terms of its nitrate concentrations.

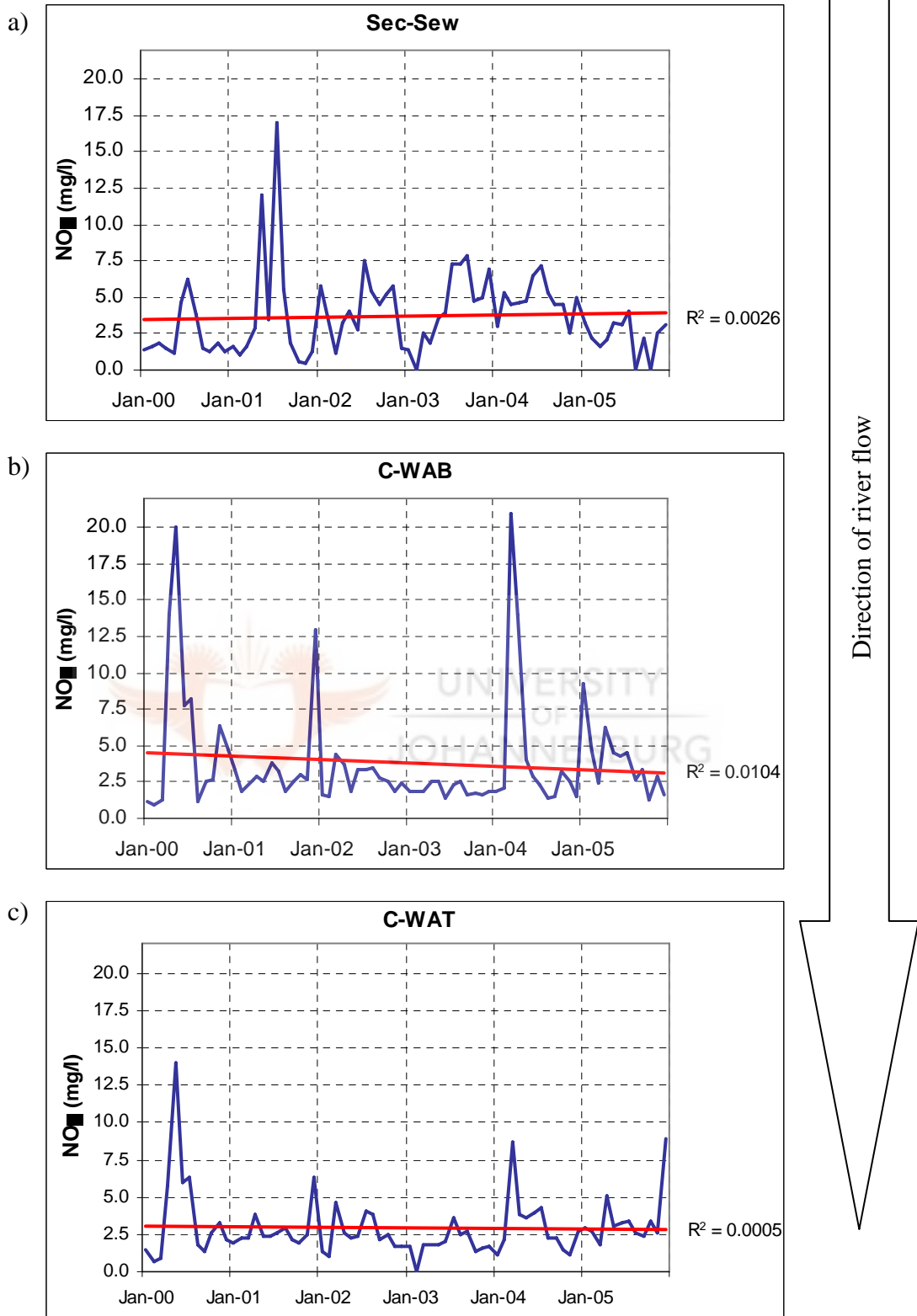


Figure 21: Regression analysis results relating to nitrate concentration levels measured at individual sampling points

8.3.4 Phosphates

8.3.4.1 The comparative analysis for phosphates

When phosphate concentrations are very low (less than 0.2 milligrams per litre), the quality of the water is very good, but if concentrations increase, the quality of the water will subsequently deteriorate. This relationship between phosphate concentration and the quality of the water is represented in **Figure 22**.

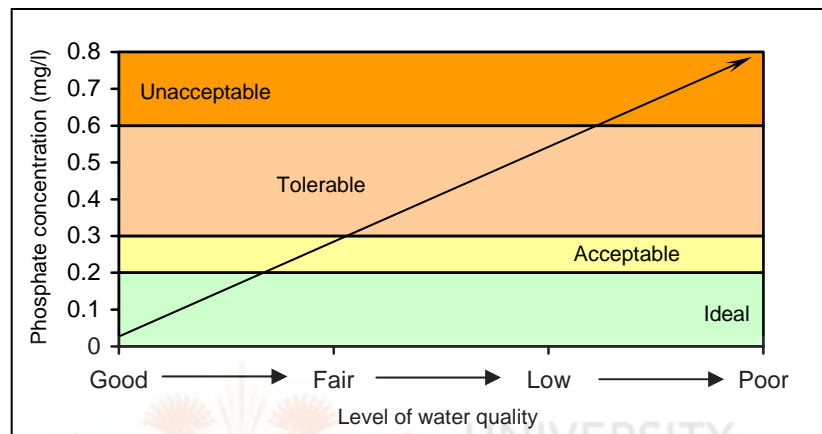


Figure 22: Relationship between phosphate concentration levels and water quality

On comparing Rand Water's data to the water quality levels laid down by the Waterval River Catchment Management Agency's Guidelines, it was found that almost 50 percent of the data for the three sampling points in the Klipspruit could be categorised into the ideal phosphate concentration level range. However, a large proportion (20 percent) of the water samples for the entire study area were found to contain phosphate concentrations above 0.6 milligrams per litre, thus placing them in the unacceptable range. Also, when data for an individual sampling point, namely SEC-SEW, were considered in isolation, it was clear that the quality of the water there was poor. Although less than 10 percent of the water samples at SEC-SEW were ideal, 50 percent of the data from that point indicated high concentrations of phosphate, which are unacceptable in terms of Rand Water's In-stream Water Quality Guidelines.

On the other hand, the water quality at the other two sampling points (C-WAB and C-WAT) was more satisfactory, with the majority of the phosphate concentrations being found to fall within the ideal range. The more acceptable water quality levels at these two sampling points could be attributed to the natural dilution potential of the river which weakens high concentrations of phosphate in its attempt to achieve a state of equilibrium.

Table 15 summarizes the findings of the comparative analysis between Rand Water’s data and the Waterval River Catchment Management Agency’s specifications.

Table 15: Results obtained after assessing Rand Water’s phosphate concentration levels in terms of Waterval River Catchment Management Agency’s Guidelines.

Water Quality category	Waterval River CMA’s Specifications	Point Data Compliance (percent)			Total data compliance (percent)
		SEC-SEW	C-WAB	C-WAT	All points
Ideal	< 0.2	9.72	83.00	56.00	49.57
Acceptable	0.2 – 0.4	23.61	10.00	32.00	21.87
Tolerable	0.4 – 0.6	16.67	1.00	8.00	8.56
Unacceptable	> 0.6	50.00	6.00	4.00	20.00

The DWAF does not directly stipulate a Target Water Quality Range (TWQR) for phosphate concentrations. However, phosphate concentrations are considered in the chapter on phosphorous in the context of various water-use categories but phosphates are not explicitly defined or explained as such.

A noteworthy effect of elevated phosphate concentrations is that they stimulate aquatic plant growth. Should this condition arise and not be attended to, it could lead to a change in the trophic status of an aquatic ecosystem.

8.3.4.2 Regression analysis for phosphates

It is important when interpreting phosphate measurements to realise that sustained high phosphate concentrations are of greater importance than the occasional raised levels that exceed the acceptable concentration range. In the case of phosphate concentration levels, this would amount to any value smaller than 0.6 milligrams per litre. SEC-SEW sampling point is the only point where the phosphate concentration levels significantly exceed the level of acceptance, as in the case of the years 2001, 2003 and 2005 particularly (**Figure 23a**). The phosphate concentration levels for the other two sampling points were found to vary between 0.0 and 2.5 milligrams per litre.

The regression analysis for the C-WAB (**Figure 23b**) sampling point indicated that, relatively speaking, the phosphate concentration levels there were most frequently the lowest for the total study area. As opposed to this, however, the trend line for the same sampling point pointed to a steady increase in phosphate concentrations. At C-WAT, the next sampling point, the phosphate concentration levels showed signs of increasing again although the general trend over the study period indicated a decreased in the phosphate concentrations (**Figure 23c**). Thus external factors have obviously contributed to the concentration of phosphates here. The sampling point causing the greatest concern in terms of phosphate concentration levels is SEC-SEW.

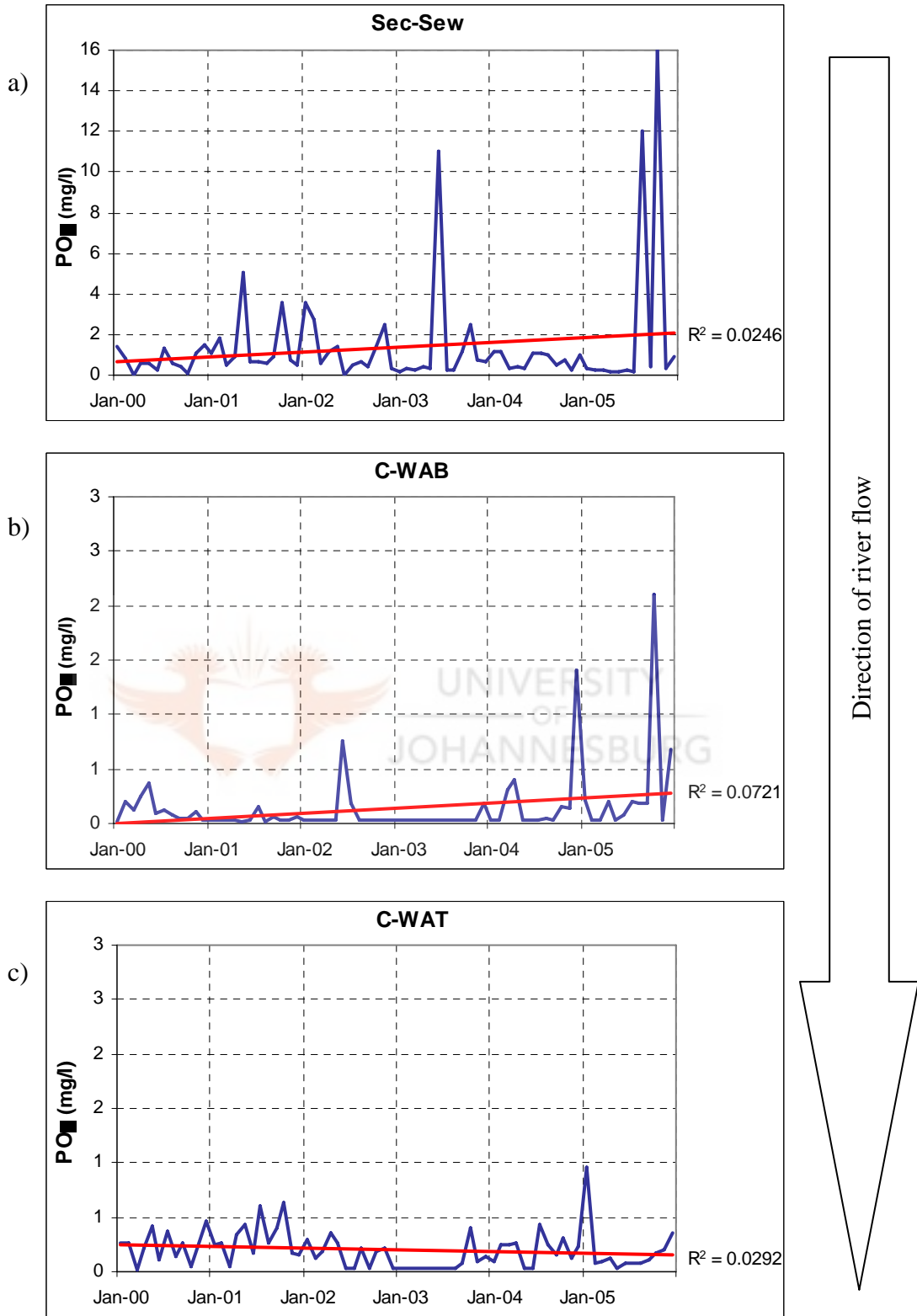


Figure 23: Regression analysis results relating to phosphate concentration levels measured at individual sampling points

8.3.5 Sulphates

8.3.5.1 The comparative analysis for sulphates

The relationship between sulphate concentrations and the water quality level (represented in **Figure 24**) works in a similar way to the respective relationships between the concentration levels of the other nutrients (nitrates and phosphates) and water quality that were described in the previous sections. It is important, therefore, to maintain low levels of sulphate concentration to ensure good water quality levels.

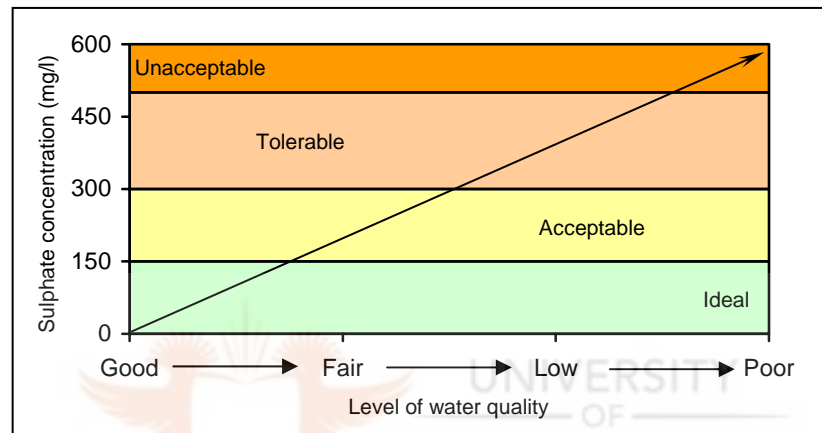


Figure 24: Relationship between sulphate concentration levels and water quality

In general, the water samples taken at all three water sampling points indicate that the water quality is good, as a 97-percent compliance to the ideal water quality range was determined. The rest of the data all fell within the 150 to 300 milligrams per litre range which, according to the Waterval River Catchment Management Agency's In-stream Water Quality Guidelines, is still acceptable for various types of water usage.

Table 16 summarizes the results of the data analysis after sulphate concentration levels were assessed in terms of Waterval River Catchment Management Agency’s Guidelines.

Table 16: Results obtained after assessing Rand Water’s sulphate concentration levels in terms of Waterval River Catchment Management Agency’s Guidelines

Water Quality category	Waterval River CMA’s Specifications	Point Data Compliance (percent)			Total data compliance (percent)
		SEC-SEW	C-WAB	C-WAT	All points
Ideal	< 150	100.00	92.00	99.00	97.00
Acceptable	150 – 300	0.00	8.00	1.00	3.00
Tolerable	300 – 500	0.00	0.00	0.00	0.00
Unacceptable	> 500	0.00	0.00	0.00	0.00

Not one measurement taken at the various sampling points met the ideal sulphate requirements for freshwater aquatic ecosystems laid down by the DWAF (1996e). This level, according to the South African Water Quality Guidelines stipulated by the DWAF, is the level at which optimal growth for aquatic organisms is assured. The guidelines laid down by this department for domestic and livestock watering purposes are based on the effects of sulphate concentrations on the palatability and aesthetic properties of water. Domestic guidelines are also based on the effects that sulphate levels have on human health.

As regards the Target Water Quality Range (TWQR) laid down for sulphate concentrations in water for domestic usage, 98 percent of the data complied with this ideal range. When individual sample point data were analysed, C-WAB was the only sampling point that fell short by six percent of the stipulated Target Water Quality Range (TWQR). The results of the TWQR data analysis are summarized in **Table 17**.

Table 17: Results obtained after assessing Rand Water’s sulphate concentration levels in terms of Target Water Quality Range (TWQR) levels

Water use category in terms of sulphates	TWQR	Data Compliance (percent)		
		SEC-SEW	C-WAB	C-WAT
Aquatic	< 0.001	0.00	0.00	0.00
Domestic	0 – 200	100.00	94.00	100.00
Recreational - Full contact	NA	---	---	---
- Intermediate contact	NA	---	---	---
Agriculture - Livestock	0 – 1000	100.00	100.00	100.00
- Irrigation	NA	---	---	---

The maximum sulphate concentration measured at the C-WAB sampling point was 290 milligrams per litre. There is a tendency for individuals who are sensitive or not adapted to such high sulphate levels to suffer from diarrhoea. Sulphate concentrations that exceed 200 milligrams per litre also affect the palatability of the water. A slightly odd taste might be noticed when the threshold level for an acceptable sulphate concentration level is exceeded. The threshold level is said to range from 200 to 400 milligrams per litre (DWAF, 1996a). Elevated sulphate concentration levels are also known to accelerate erosion rates, which can affect the metal structures that are found in water distribution systems.

By considering the effects of elevated sulphate concentrations and attempting to mitigate the associated aesthetic and palatability problems in such polluted water, the DWAF has limited the standard sulphate content level in drinking water to 200 milligrams per litre.

The data measurements for all three water sampling points complied with the Target Water Quality Range (TWQR) of zero (0) to 1000 milligrams per litre for livestock watering. What is interesting regarding the concentration of sulphates and this water-use category, is that the degree of sulphate tolerance depends on the livestock species, their age and the length of the period of adaptation.

8.3.5.2 Regression analysis for sulphates

According to the course of the trend lines of the graphs, it appears that the sulphate concentrations were, to a certain extent, historically stable during the six years in question. The most extreme sulphate concentrations were measured at the C-WAB sampling point (**Figure 25b**), but it must be noted that this sampling point accounts for only four of a total of 72 data samples. Single peaks can be attributed to pollution spillage events. One such high sulphate concentration level was measured in 2000, while all of the others occurred in 2004.

The trend line compiled from the SEC-SEW sampling data (**Figure 25a**) was the only one indicating a stable trend over the period in question. On the other hand, the trend line for the C-WAB data showed a slight increase in the sulphate concentration levels. The C-WAT sampling point (**Figure 25c**) was the only sampling point showing a tendency for the sulphate concentration levels to decline.



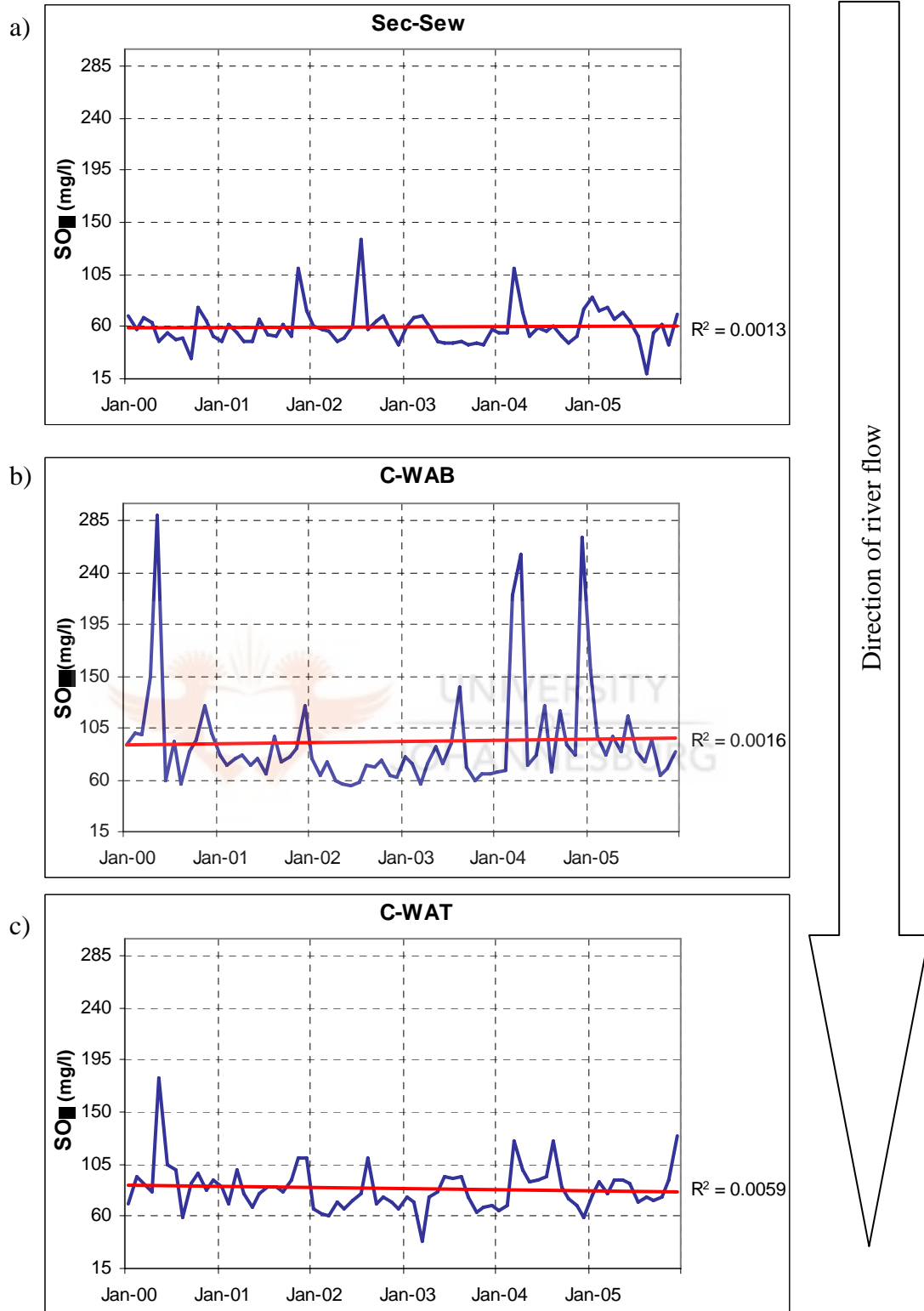


Figure 25: Regression analysis results relating to sulphate concentration levels measured at individual sampling points

8.3.6 Chemical oxygen demand

8.3.6.1 The comparative analysis for chemical oxygen demand

The relationship between chemical oxygen demand levels and water quality could be estimated on the basis of the Waterval River Catchment Management Agency's In-stream Water Quality Guidelines. This relationship simply implies that in order to achieve and maintain a good water quality level, the levels of chemical oxygen demand should be kept at their lowest. The chances are good that no adverse effects will occur at low chemical oxygen demand levels. The relationship between chemical oxygen demand levels and water quality is represented in **Figure 26**.

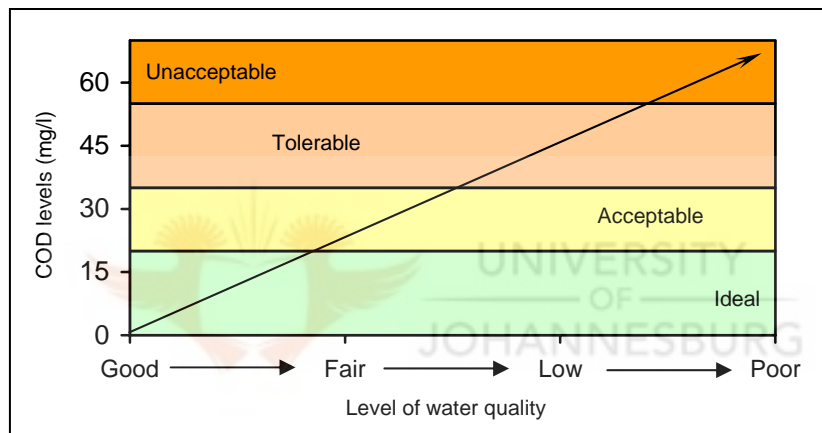


Figure 26: Relationship between chemical oxygen demand and water quality

An assessment of the Rand Water data in terms of the Waterval River Catchment Management Agency's In-stream Water Quality Guidelines revealed that most of the measurement data for all three water sampling points fell within the 20 to 35 milligrams per litre range – the acceptable range. Only a small proportion of the data (3.70 percent) complied with the “ideal” category laid down by the Water Quality Guidelines, however, as the measurements were generally lower than 20 milligrams per litre.

Table 18 summarizes the results that were obtained after the Rand Water data were assessed in terms of Waterval River Catchment Management Agency's Guidelines.

Table 18: Results obtained after assessing Rand Water's chemical oxygen demand levels in terms of Waterval River Catchment Management Agency's Guidelines.

Water Quality category	Waterval River CMA's Specifications	Point Data Compliance (percent)			Total data compliance (percent)
		SEC-SEW	C-WAB	C-WAT	All points
Ideal	< 20	5.56	5.56	0.00	3.70
Acceptable	20 – 35	56.94	52.78	71.00	60.24
Tolerable	35 – 55	23.61	31.94	21.00	25.52
Unacceptable	> 55	13.89	9.72	8.00	10.54

Thus, since 63.94 percent of the chemical oxygen demand measurements that were taken at the three individual sampling points ranged between the ideal and the acceptable levels (towards the latter to a greater extent), this parameter does not pose any undesirable threats to other potential water users in the study area for the time period between 2000 and 2005, except for a few peaking incidents.

No Target Water Quality Range (TWQR) requirements were explicitly laid down by the DWAF for chemical oxygen demand in relation to any of the water-use categories considered and discussed in this study.

8.3.6.2 Regression analysis for chemical oxygen demand

Many of the chemical oxygen demand measurements taken at the three sampling points exceeded the tolerable level of 55 milligrams per litre. The greatest decline over the research period in chemical oxygen demand levels was demonstrated by the C-WAB sampling point data (**Figure 27b**). The greatest variation in the distribution of the chemical oxygen demand data is represented in the graph for the SEC-SEW sampling point. Generally, though, the graph for SEC-SEW also shows a slightly declining trend line (**Figure 27a**). The analysis of the data for the C-WAT sampling point showed that this was the only sampling point where constantly low chemical oxygen demand levels prevailed for a one-year period or longer, as in 2002, and from 2004 to mid-2005 (**Figure 27c**).

The overall tendency of the chemical oxygen demand levels measured at the three selected sampling points along the course of the river is that the values gradually declined and leveled out up to the C-WAT sampling point, where the chemical oxygen demand level was constantly lower. However, it should be noted that the chemical oxygen demand levels start off as being widely scattered with many extreme values being measured at the first sampling point (SEC-SEW).

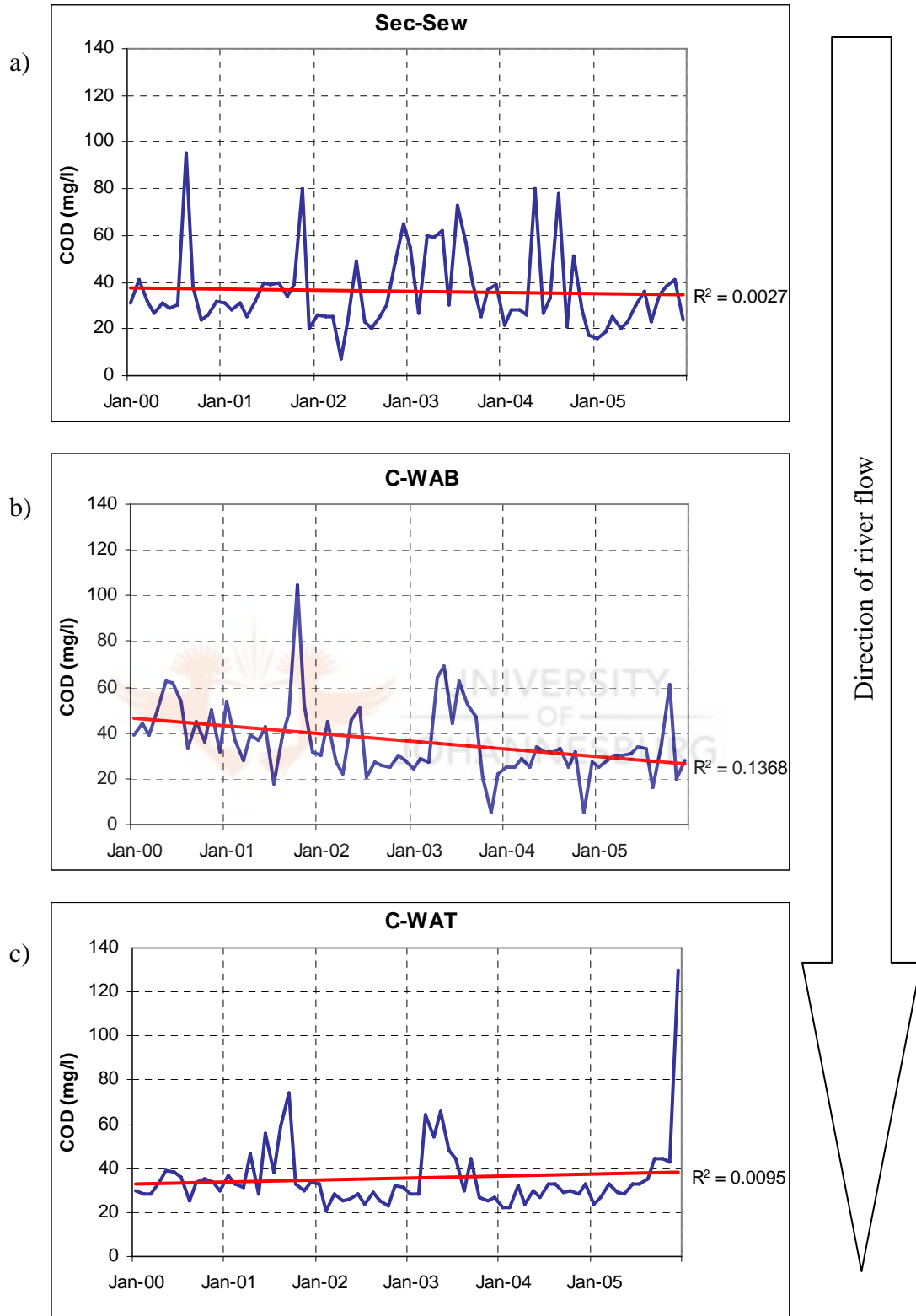


Figure 27: Regression analysis results relating to chemical oxygen demand levels measured at individual sampling points

9. CONCLUSION AND RECOMMENDATIONS

This study highlights the scarcity of South African water resources whilst the quality of available resources is deteriorating at an alarming rate. This deterioration emphasizes the need for effective management and the regulation of the activities that impact upon water quality. Although natural factors may cause changes in the quality of water, human activities and actions accelerate the rate at which this deterioration takes place. Human activities also aggravate the impacts that poor water quality have on aquatic ecosystems and other water users. Therefore water should be regarded as a precious resource which needs to be used wisely. Rand Water (Van Wyk, 2001) has tried to achieve this objective through its monitoring programme, in order to

- protect the resource from deterioration,
- predict changes in water quality that may affect Rand Water's ability to produce good quality potable water,
- produce timeous water quality audit (status) reports relevant to specific use categories, for decision-making purposes by management.

Even though improvements in water quality are possible, an area of concern that needs attention is the deterioration in the quality of water on account of pollution, especially pollution from industrial, mining, agricultural and domestic sources. Some of the pollutants that are causing the greatest concern include organic and inorganic chemicals, plant nutrients, oxygen-demanding waste, radio-active materials, sediment and microbiological contaminants. Water that has been used in the industrial, mining, agricultural and domestic sectors is normally withdrawn from the specific river that serves as the water supply for the sector in question, and pumped back into the same river after it has been used. Effluent, produced as a result of the utilization of water, contains various pollutants originating from industries, municipalities and agricultural land, to name only a few of the possible point sources of pollutants. It is, however, important to note that water seldom becomes totally unfit for consumption. Nevertheless, there is a strong link between the level of water quality and its intended use.

The primary research aim of this study was to determine the water quality of the Klipspruit River in order to establish the overall impacts and effects of industrial effluent produced at the SSIC in Mpumalanga. To achieve this Rand Water provided data of three water sampling points located along the Klipspruit for a six years period (from 2000 to 2005). The data was analysed and the results were compared to local and national standards in order to determine whether a high water quality is achieved and maintained.

Through this study, investigating the impact of industrial effluent on the water quality of the Klipspruit River, several objectives have been achieved (refer back to Chapter 2):

- In Chapter 7 an in-depth description was given for each of the selected six water quality parameters in order to describe the various implications that industrial activities and effluent have on the each parameter and water quality in general. Through this chapter the first objective was achieved. In this chapter the ripple effects of deteriorated water quality caused by the input of industrial effluent, was established. For example, slight increases in nitrate concentrations can lead to bigger problems such as eutrophication which can lead to the depletion of dissolved oxygen within a water body.
- The second objective was also achieved in Chapter 7, as it explained that industrial effluent does not only affect aquatic ecosystems but also agricultural and domestic water uses. If, for instance, water is extracted from a river that is polluted by industrial effluent for agricultural use the water needs to be treated before it can be used for irrigation purposes. Failure to do so can lead to crop failure.
- Chapter 8 dealt with the forth objectives set out in Chapter 2. By comparing the analysed data to the set water quality guidelines it became clear what parameters are more prone to deviate from the set local and national water quality guidelines, thereby helping to identify the parameters that are of great concern, such as nitrate and phosphates.

- It was also proven through the water quality analyses that the SEC-SEW water sampling point had the highest concentration levels for some of the selected parameters. The explanation for this is the fact that this water sampling point is located closest to the SSIC where the industrial effluent is produced and where it is released back into the Klipspruit, and because the Secunda Sewage Treatment Plant is in the vicinity. This point highlights that the third objectives set out for this study was achieved.

- Another objective met through this study was to establish whether the control measures set by authorities are adequate and if it needs to be re-evaluated. The Waterval River CMA and the DWAF, each developed a set of water quality guidelines. Through this study it was found the DWAF's guidelines failed to set specific water quality guidelines for specific parameters while the CMA's water quality guidelines did incorporate all the selected parameters. The current means of measuring pollution in our rivers are incomplete and therefore inadequate. These measures can be rectified by setting specific TWQR guidelines for all relevant water quality parameters such as phosphates and conductivity, as has been implemented through the CMA guidelines.

- When analysing the data for the SEC-SEW water sampling point it prove to be a point of great concern. This is the water sampling point located closest to the SSIC. Some of the most important results of the data analysis with regards to this water sampling point are listed below.
 - At this water sampling point the highest and lowest pH measurement of all water sampling points were found and the measurements for pH also proved to be very volatile.
 - No measurement taken at the SEC-SEW water sampling point had fallen in the ideal water quality range for conductivity according to the guidelines.
 - The concentrations of nitrates indicated an increase over the six year data period at this point.
 - 50% of phosphate measurements at this water sampling point were classified as unacceptable according the DWAF's TWQR guidelines, while less then 10% of the phosphate measurements were ideal.

- Between the three water sampling points, the SEC-SEW water sampling point indicated the highest percentage unacceptable chemical oxygen demand levels. This point also had the most extreme measurement values over the six year data period.

All these above mentioned results indicate that the water passing the SEC-SEW water sampling point is highly polluted through industrial effluent which originated from the SSIC. Because the Klipspruit is a potable water source for other water users, the issues regarding industrial effluent pollution need to be addressed. Strict measurements need to be put in place in order to ensure that industries, such as the SSIC, can effectively monitor and control their release of industrial effluent into our river systems, whilst understanding the consequences of their actions.

Further research is possible in various related areas based on the results of this dissertation. For example, a few surface water sampling points further upstream could be looked at to provide important information regarding the water quality of the Klipspruit prior to its entry into the local industrialized area. Thus, if present in the water, pollutants may be detected as having originated at a source point upstream from the point where the river enters the industrial area. Another aspect that fell beyond the scope of this study was the establishment of external factors between the various water sampling points that could affect the water quality of the Klipspruit River even further.

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APPENDICES

Appendix A: Original tabulated data as provided by Rand Water

C-WAB											
<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>
12-Jan-00	Conductivity	71.00	05-Sep-01	Conductivity	65.00	05-Feb-03	IC_SO4	74.00	14-Jul-04	COD	32.00
12-Jan-00	SO4	90.00	05-Sep-01	IC_SO4	75.00	05-Feb-03	PO4	0.03	14-Jul-04	pH	8.47
12-Jan-00	pH	8.60	05-Sep-01	PO4	0.06	05-Feb-03	Conductivity	64.00	14-Jul-04	Conductivity	70.00
12-Jan-00	COD	39.00	05-Sep-01	IC_NO3	2.50	05-Feb-03	pH	8.43	11-Aug-04	Conductivity	75.00
09-Feb-00	COD	44.00	05-Sep-01	COD	49.00	05-Feb-03	COD	29.00	11-Aug-04	COD	33.00
09-Feb-00	SO4	100.00	05-Sep-01	pH	8.23	05-Mar-03	COD	27.00	11-Aug-04	pH	8.14
08-Mar-00	COD	39.00	10-Oct-01	pH	8.55	05-Mar-03	IC_NO3	1.80	11-Aug-04	IC_SO4	67.00
08-Mar-00	SO4	99.00	10-Oct-01	Conductivity	65.00	05-Mar-03	IC_SO4	57.00	11-Aug-04	PO4	0.05
08-Mar-00	pH	8.10	10-Oct-01	IC_NO3	3.00	05-Mar-03	Conductivity	54.00	11-Aug-04	NO3	1.40
08-Mar-00	Conductivity	73.00	10-Oct-01	COD	105.00	05-Mar-03	PO4	0.03	08-Sep-04	Conductivity	67.00
12-Apr-00	Conductivity	84.00	10-Oct-01	PO4	0.03	05-Mar-03	pH	8.40	08-Sep-04	COD	25.00
12-Apr-00	pH	8.20	10-Oct-01	IC_SO4	80.00	09-Apr-03	Conductivity	66.00	08-Sep-04	pH	8.37
12-Apr-00	PO4	0.25	07-Nov-01	Conductivity	68.00	09-Apr-03	pH	8.34	08-Sep-04	IC_SO4	120.00
12-Apr-00	NO3	14.00	07-Nov-01	pH	8.50	09-Apr-03	COD	64.00	08-Sep-04	PO4	0.03
12-Apr-00	SO4	150.00	07-Nov-01	COD	52.00	09-Apr-03	IC_NO3	2.50	08-Sep-04	NO3	1.50
12-Apr-00	COD	50.00	07-Nov-01	IC_NO3	2.70	09-Apr-03	IC_SO4	74.00	13-Oct-04	Conductivity	65.00
10-May-00	PO4	0.37	07-Nov-01	IC_SO4	87.00	09-Apr-03	PO4	0.03	13-Oct-04	COD	32.00
10-May-00	Conductivity	40.00	07-Nov-01	PO4	0.03	07-May-03	Conductivity	71.00	13-Oct-04	pH	8.21
10-May-00	pH	8.13	05-Dec-01	IC_SO4	125.00	07-May-03	pH	8.45	13-Oct-04	IC_SO4	90.00
10-May-00	NO3	20.00	05-Dec-01	COD	32.00	07-May-03	COD	69.00	13-Oct-04	PO4	0.16
10-May-00	SO4	290.00	05-Dec-01	IC_NO3	13.00	07-May-03	IC_NO3	2.50	13-Oct-04	NO3	3.30
10-May-00	COD	63.00	05-Dec-01	pH	8.35	07-May-03	IC_SO4	89.00	10-Nov-04	Conductivity	64.00
07-Jun-00	COD	62.00	05-Dec-01	Conductivity	84.00	07-May-03	PO4	0.03	10-Nov-04	COD	5.00
07-Jun-00	PO4	0.09	05-Dec-01	PO4	0.06	04-Jun-03	Conductivity	63.00	10-Nov-04	pH	8.57
07-Jun-00	NO3	7.80	09-Jan-02	COD	30.00	04-Jun-03	pH	8.42	10-Nov-04	IC_SO4	81.00
07-Jun-00	SO4	59.00	09-Jan-02	pH	8.27	04-Jun-03	COD	44.00	10-Nov-04	PO4	0.14
07-Jun-00	pH	8.30	09-Jan-02	IC_NO3	1.60	04-Jun-03	IC_NO3	1.40	10-Nov-04	NO3	2.50
07-Jun-00	Conductivity	77.00	09-Jan-02	Conductivity	63.00	04-Jun-03	IC_SO4	74.00	08-Dec-04	Conductivity	170.00
12-Jul-00	pH	8.39	09-Jan-02	IC_SO4	78.00	04-Jun-03	PO4	0.03	08-Dec-04	IC_SO4	270.00
12-Jul-00	Conductivity	68.00	09-Jan-02	PO4	0.03	09-Jul-03	COD	63.00	08-Dec-04	PO4	1.40
12-Jul-00	COD	54.00	06-Feb-02	Conductivity	61.00	09-Jul-03	IC_NO3	2.30	08-Dec-04	COD	27.00
12-Jul-00	SO4	93.00	06-Feb-02	pH	8.47	09-Jul-03	IC_SO4	92.00	08-Dec-04	pH	7.92
12-Jul-00	PO4	0.12	06-Feb-02	COD	45.00	09-Jul-03	PO4	0.03	12-Jan-05	Conductivity	90.00

12-Jul-00	NO3	8.20	06-Feb-02	IC_NO3	1.50	09-Jul-03	Conductivity	66.00	12-Jan-05	COD	25.00
06-Sep-00	Conductivity	72.00	06-Feb-02	IC_SO4	64.00	09-Jul-03	pH	8.26	12-Jan-05	pH	8.21
06-Sep-00	pH	8.38	06-Feb-02	PO4	0.03	06-Aug-03	pH	8.21	12-Jan-05	IC_SO4	155.00
06-Sep-00	COD	45.00	06-Mar-02	COD	27.00	06-Aug-03	PO4	0.03	12-Jan-05	PO4	0.21
06-Sep-00	SO4	85.00	06-Mar-02	IC_NO3	4.40	06-Aug-03	COD	52.00	12-Jan-05	NO3	9.30
06-Sep-00	PO4	0.05	06-Mar-02	IC_SO4	76.00	06-Aug-03	Conductivity	83.00	09-Feb-05	NO3	4.60
06-Sep-00	NO3	2.50	06-Mar-02	PO4	0.03	06-Aug-03	IC_NO3	2.50	09-Feb-05	Conductivity	73.00
11-Oct-00	pH	8.58	06-Mar-02	Conductivity	62.00	06-Aug-03	IC_SO4	140.00	09-Feb-05	PO4	0.03
11-Oct-00	COD	36.00	06-Mar-02	pH	8.55	03-Sep-03	Conductivity	67.00	09-Feb-05	IC_SO4	97.00
11-Oct-00	SO4	95.00	10-Apr-02	IC_SO4	59.00	03-Sep-03	IC_NO3	1.60	09-Feb-05	COD	28.00
11-Oct-00	PO4	0.05	10-Apr-02	PO4	0.03	03-Sep-03	PO4	0.03	09-Feb-05	pH	8.26
11-Oct-00	Conductivity	69.00	10-Apr-02	pH	8.15	03-Sep-03	pH	8.48	09-Mar-05	IC_SO4	82.00
11-Oct-00	NO3	2.70	10-Apr-02	Conductivity	58.00	03-Sep-03	COD	47.00	09-Mar-05	pH	8.56
08-Nov-00	SO4	125.00	10-Apr-02	IC_NO3	3.70	03-Sep-03	IC_SO4	71.00	09-Mar-05	Conductivity	66.00
08-Nov-00	PO4	0.11	10-Apr-02	COD	22.00	08-Oct-03	IC_NO3	1.70	09-Mar-05	NO3	2.40
08-Nov-00	COD	50.00	08-May-02	COD	46.00	08-Oct-03	Conductivity	60.00	09-Mar-05	COD	30.00
08-Nov-00	Conductivity	74.00	08-May-02	Conductivity	54.00	08-Oct-03	IC_SO4	60.00	09-Mar-05	PO4	0.03
08-Nov-00	pH	8.33	08-May-02	pH	8.24	08-Oct-03	pH	8.42	13-Apr-05	pH	8.33
08-Nov-00	NO3	6.40	08-May-02	IC_NO3	1.90	08-Oct-03	COD	21.00	13-Apr-05	Conductivity	74.00
06-Dec-00	PO4	0.03	08-May-02	IC_SO4	57.00	08-Oct-03	PO4	0.03	13-Apr-05	NO3	6.30
06-Dec-00	pH	8.51	08-May-02	PO4	0.03	05-Nov-03	Conductivity	63.00	13-Apr-05	PO4	0.20
06-Dec-00	COD	32.00	05-Jun-02	PO4	0.76	05-Nov-03	IC_NO3	1.60	13-Apr-05	COD	30.00
06-Dec-00	SO4	100.00	05-Jun-02	Conductivity	63.00	05-Nov-03	PO4	0.03	13-Apr-05	IC_SO4	97.00
06-Dec-00	Conductivity	75.00	05-Jun-02	IC_SO4	55.00	05-Nov-03	COD	5.00	11-May-05	COD	31.00
06-Dec-00	NO3	4.80	05-Jun-02	IC_NO3	3.40	05-Nov-03	pH	8.56	11-May-05	PO4	0.03
10-Jan-01	pH	8.43	05-Jun-02	COD	51.00	05-Nov-03	IC_SO4	65.00	11-May-05	IC_SO4	84.00
10-Jan-01	PO4	0.03	05-Jun-02	pH	8.29	03-Dec-03	Conductivity	62.00	11-May-05	Conductivity	67.00
10-Jan-01	Conductivity	66.00	10-Jul-02	Conductivity	61.00	03-Dec-03	pH	8.53	11-May-05	NO3	4.50
10-Jan-01	SO4	81.00	10-Jul-02	pH	8.43	03-Dec-03	COD	22.00	11-May-05	pH	8.26
10-Jan-01	NO3	3.40	10-Jul-02	COD	21.00	03-Dec-03	IC_NO3	1.90	08-Jun-05	PO4	0.07
10-Jan-01	COD	54.00	10-Jul-02	IC_NO3	3.40	03-Dec-03	IC_SO4	65.00	08-Jun-05	COD	34.00
07-Feb-01	Conductivity	62.00	10-Jul-02	IC_SO4	58.00	03-Dec-03	PO4	0.19	08-Jun-05	pH	8.30
07-Feb-01	SO4	73.00	10-Jul-02	PO4	0.19	07-Jan-04	Conductivity	63.00	08-Jun-05	IC_SO4	115.00
07-Feb-01	pH	8.51	07-Aug-02	Conductivity	69.00	07-Jan-04	pH	8.61	08-Jun-05	Conductivity	74.00
07-Feb-01	NO3	1.90	07-Aug-02	pH	8.47	07-Jan-04	COD	25.00	08-Jun-05	NO3	4.30
07-Feb-01	PO4	0.03	07-Aug-02	COD	27.00	07-Jan-04	IC_NO3	1.90	13-Jul-05	Conductivity	67.00
07-Feb-01	COD	37.00	07-Aug-02	IC_NO3	3.50	07-Jan-04	IC_SO4	66.00	13-Jul-05	pH	8.43
07-Mar-01	COD	28.00	07-Aug-02	IC_SO4	72.00	07-Jan-04	PO4	0.03	13-Jul-05	NO3	4.50
07-Mar-01	pH	8.45	07-Aug-02	PO4	0.03	11-Feb-04	Conductivity	60.00	13-Jul-05	COD	33.00
07-Mar-01	SO4	79.00	04-Sep-02	PO4	0.03	11-Feb-04	pH	8.58	13-Jul-05	IC_SO4	85.00
07-Mar-01	PO4	0.03	04-Sep-02	COD	26.00	11-Feb-04	COD	25.00	13-Jul-05	PO4	0.20

07-Mar-01	Conductivity	61.00	04-Sep-02	Conductivity	67.00	11-Feb-04	IC_NO3	2.10	10-Aug-05	Conductivity	69.00
07-Mar-01	NO3	2.40	04-Sep-02	pH	8.48	11-Feb-04	IC_SO4	68.00	10-Aug-05	pH	8.57
11-Apr-01	SO4	81.00	04-Sep-02	IC_NO3	2.80	11-Feb-04	PO4	0.03	10-Aug-05	IC_SO4	75.00
11-Apr-01	PO4	0.03	04-Sep-02	IC_SO4	71.00	10-Mar-04	IC_NO3	21.00	10-Aug-05	PO4	0.18
11-Apr-01	NO3	2.90	09-Oct-02	Conductivity	60.00	10-Mar-04	PO4	0.31	10-Aug-05	NO3	2.70
11-Apr-01	pH	8.61	09-Oct-02	pH	8.34	10-Mar-04	Conductivity	99.00	10-Aug-05	COD	16.00
11-Apr-01	Conductivity	69.00	09-Oct-02	COD	25.00	10-Mar-04	COD	29.00	07-Sep-05	Conductivity	68.00
11-Apr-01	COD	39.00	09-Oct-02	IC_NO3	2.60	10-Mar-04	pH	8.40	07-Sep-05	pH	8.38
09-May-01	Conductivity	67.00	09-Oct-02	IC_SO4	77.00	10-Mar-04	IC_SO4	220.00	07-Sep-05	IC_SO4	95.00
09-May-01	pH	8.60	09-Oct-02	PO4	0.03	07-Apr-04	Conductivity	115.00	07-Sep-05	PO4	0.19
09-May-01	COD	37.00	06-Nov-02	Conductivity	65.00	07-Apr-04	pH	8.42	07-Sep-05	NO3	3.40
09-May-01	SO4	72.00	06-Nov-02	pH	8.56	07-Apr-04	COD	25.00	07-Sep-05	COD	35.00
09-May-01	PO4	0.01	06-Nov-02	COD	30.00	07-Apr-04	IC_SO4	255.00	12-Oct-05	Conductivity	60.00
09-May-01	NO3	2.60	06-Nov-02	IC_NO3	1.90	07-Apr-04	PO4	0.40	12-Oct-05	pH	8.50
06-Jun-01	IC_SO4	79.00	06-Nov-02	IC_SO4	64.00	07-Apr-04	NO3	14.00	12-Oct-05	IC_SO4	63.00
06-Jun-01	IC_PO4	0.03	06-Nov-02	PO4	0.03	12-May-04	pH	8.46	12-Oct-05	PO4	2.10
06-Jun-01	Conductivity	69.00	04-Dec-02	PO4	0.03	12-May-04	COD	34.00	12-Oct-05	NO3	1.30
06-Jun-01	COD	43.00	04-Dec-02	IC_NO3	2.40	12-May-04	IC_SO4	72.00	12-Oct-05	COD	61.00
06-Jun-01	pH	8.58	04-Dec-02	Conductivity	63.00	12-May-04	PO4	0.03	09-Nov-05	Conductivity	66.00
06-Jun-01	IC_NO3	3.80	04-Dec-02	pH	8.60	12-May-04	NO3	4.00	09-Nov-05	pH	8.61
11-Jul-01	IC_SO4	65.00	04-Dec-02	COD	28.00	12-May-04	Conductivity	63.00	09-Nov-05	IC_SO4	69.00
11-Jul-01	pH	8.29	04-Dec-02	IC_SO4	62.00	09-Jun-04	Conductivity	65.00	09-Nov-05	PO4	0.03
11-Jul-01	Conductivity	51.00	08-Jan-03	COD	24.00	09-Jun-04	pH	8.43	09-Nov-05	NO3	2.90
11-Jul-01	COD	18.00	08-Jan-03	IC_NO3	1.80	09-Jun-04	COD	32.00	09-Nov-05	COD	20.00
08-Aug-01	IC_SO4	97.00	08-Jan-03	IC_SO4	80.00	09-Jun-04	IC_SO4	81.00	07-Dec-05	Conductivity	68.00
08-Aug-01	COD	38.00	08-Jan-03	PO4	0.03	09-Jun-04	PO4	0.03	07-Dec-05	pH	8.22
08-Aug-01	pH	8.36	08-Jan-03	Conductivity	63.00	09-Jun-04	NO3	2.90	07-Dec-05	IC_SO4	85.00
08-Aug-01	Conductivity	72.00	08-Jan-03	pH	8.52	14-Jul-04	PO4	0.03	07-Dec-05	PO4	0.68
08-Aug-01	IC_NO3	1.80	05-Feb-03	IC_NO3	1.80	14-Jul-04	NO3	2.30	07-Dec-05	NO3	1.60
						14-Jul-04	IC_SO4	125.00	07-Dec-05	COD	28.00

C-WAT											
<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>
12-Jan-00	COD	30.00	05-Sep-01	IC_NO3	2.20	05-Feb-03	PO4	0.03	14-Jul-04	pH	8.46
12-Jan-00	SO4	71.00	05-Sep-01	IC_SO4	81.00	05-Feb-03	Conductivity	62.00	14-Jul-04	Conductivity	72.00
12-Jan-00	pH	8.50	05-Sep-01	pH	8.15	05-Feb-03	pH	8.47	11-Aug-04	Conductivity	74.00
12-Jan-00	Conductivity	59.00	05-Sep-01	PO4	0.40	05-Feb-03	COD	28.00	11-Aug-04	COD	33.00
09-Feb-00	COD	28.00	05-Sep-01	COD	74.00	05-Mar-03	PO4	0.03	11-Aug-04	pH	8.32
09-Feb-00	SO4	94.00	05-Sep-01	Conductivity	67.00	05-Mar-03	Conductivity	61.00	11-Aug-04	IC_SO4	125.00
08-Mar-00	SO4	89.00	10-Oct-01	Conductivity	68.00	05-Mar-03	pH	8.33	11-Aug-04	PO4	0.24
08-Mar-00	Conductivity	66.00	10-Oct-01	pH	7.98	05-Mar-03	COD	64.00	11-Aug-04	NO3	2.30

08-Mar-00	pH	8.20	10-Oct-01	IC_NO3	1.90	05-Mar-03	IC_NO3	1.80	08-Sep-04	Conductivity	67.00
08-Mar-00	COD	28.00	10-Oct-01	IC_SO4	92.00	05-Mar-03	IC_SO4	39.00	08-Sep-04	COD	29.00
12-Apr-00	Conductivity	69.00	10-Oct-01	PO4	0.63	09-Apr-03	IC_NO3	1.80	08-Sep-04	pH	8.32
12-Apr-00	pH	8.00	10-Oct-01	COD	33.00	09-Apr-03	IC_SO4	77.00	08-Sep-04	IC_SO4	85.00
12-Apr-00	COD	34.00	07-Nov-01	Conductivity	74.00	09-Apr-03	PO4	0.03	08-Sep-04	PO4	0.16
12-Apr-00	SO4	81.00	07-Nov-01	pH	8.47	09-Apr-03	Conductivity	67.00	08-Sep-04	NO3	2.30
12-Apr-00	PO4	0.21	07-Nov-01	COD	30.00	09-Apr-03	pH	8.17	13-Oct-04	Conductivity	65.00
12-Apr-00	NO3	5.70	07-Nov-01	IC_NO3	2.50	09-Apr-03	COD	54.00	13-Oct-04	COD	30.00
10-May-00	Conductivity	89.00	07-Nov-01	IC_SO4	110.00	07-May-03	Conductivity	74.00	13-Oct-04	pH	8.42
10-May-00	PO4	0.42	07-Nov-01	PO4	0.17	07-May-03	pH	8.44	13-Oct-04	IC_SO4	75.00
10-May-00	NO3	14.00	05-Dec-01	COD	34.00	07-May-03	COD	66.00	13-Oct-04	PO4	0.31
10-May-00	COD	39.00	05-Dec-01	pH	8.30	07-May-03	IC_NO3	1.80	13-Oct-04	NO3	1.50
10-May-00	SO4	180.00	05-Dec-01	Conductivity	71.00	07-May-03	IC_SO4	81.00	10-Nov-04	Conductivity	62.00
10-May-00	pH	8.10	05-Dec-01	IC_SO4	110.00	07-May-03	PO4	0.03	10-Nov-04	COD	28.00
07-Jun-00	Conductivity	87.00	05-Dec-01	PO4	0.15	04-Jun-03	Conductivity	72.00	10-Nov-04	pH	8.50
07-Jun-00	pH	8.30	05-Dec-01	IC_NO3	6.30	04-Jun-03	pH	8.42	10-Nov-04	IC_SO4	69.00
07-Jun-00	SO4	105.00	09-Jan-02	IC_NO3	1.30	04-Jun-03	COD	48.00	10-Nov-04	PO4	0.13
07-Jun-00	PO4	0.11	09-Jan-02	IC_SO4	66.00	04-Jun-03	IC_NO3	2.00	10-Nov-04	NO3	1.10
07-Jun-00	COD	38.00	09-Jan-02	Conductivity	61.00	04-Jun-03	IC_SO4	95.00	08-Dec-04	pH	7.80
07-Jun-00	NO3	6.00	09-Jan-02	pH	8.38	04-Jun-03	PO4	0.03	08-Dec-04	NO3	2.70
12-Jul-00	COD	36.00	09-Jan-02	COD	33.00	09-Jul-03	PO4	0.03	08-Dec-04	COD	33.00
12-Jul-00	SO4	100.00	09-Jan-02	PO4	0.30	09-Jul-03	COD	44.00	08-Dec-04	Conductivity	36.00
12-Jul-00	PO4	0.37	06-Feb-02	Conductivity	60.00	09-Jul-03	IC_NO3	3.60	08-Dec-04	IC_SO4	59.00
12-Jul-00	NO3	6.30	06-Feb-02	pH	8.37	09-Jul-03	IC_SO4	93.00	08-Dec-04	PO4	0.23
12-Jul-00	pH	8.34	06-Feb-02	COD	21.00	09-Jul-03	pH	8.29	12-Jan-05	Conductivity	49.00
12-Jul-00	Conductivity	76.00	06-Feb-02	IC_NO3	1.00	09-Jul-03	Conductivity	72.00	12-Jan-05	COD	24.00
06-Sep-00	Conductivity	72.00	06-Feb-02	IC_SO4	62.00	06-Aug-03	PO4	0.03	12-Jan-05	pH	7.56
06-Sep-00	pH	8.12	06-Feb-02	PO4	0.12	06-Aug-03	pH	8.27	12-Jan-05	IC_SO4	78.00
06-Sep-00	NO3	1.30	06-Mar-02	COD	28.00	06-Aug-03	IC_NO3	2.50	12-Jan-05	PO4	0.96
06-Sep-00	COD	34.00	06-Mar-02	IC_NO3	4.60	06-Aug-03	COD	30.00	12-Jan-05	NO3	2.90
06-Sep-00	SO4	89.00	06-Mar-02	Conductivity	60.00	06-Aug-03	IC_SO4	94.00	09-Feb-05	Conductivity	72.00
06-Sep-00	PO4	0.27	06-Mar-02	pH	8.52	06-Aug-03	Conductivity	80.00	09-Feb-05	NO3	2.70
11-Oct-00	Conductivity	75.00	06-Mar-02	PO4	0.19	03-Sep-03	pH	8.45	09-Feb-05	IC_SO4	90.00
11-Oct-00	COD	35.00	06-Mar-02	IC_SO4	61.00	03-Sep-03	PO4	0.08	09-Feb-05	pH	8.14
11-Oct-00	SO4	98.00	10-Apr-02	COD	25.00	03-Sep-03	IC_SO4	77.00	09-Feb-05	COD	27.00
11-Oct-00	pH	8.13	10-Apr-02	pH	8.16	03-Sep-03	Conductivity	69.00	09-Feb-05	PO4	0.08
11-Oct-00	PO4	0.05	10-Apr-02	Conductivity	62.00	03-Sep-03	COD	44.00	09-Mar-05	COD	33.00
11-Oct-00	NO3	2.60	10-Apr-02	IC_NO3	2.60	03-Sep-03	IC_NO3	2.70	09-Mar-05	PO4	0.09
08-Nov-00	Conductivity	57.00	10-Apr-02	PO4	0.35	08-Oct-03	Conductivity	64.00	09-Mar-05	IC_SO4	80.00
08-Nov-00	COD	34.00	10-Apr-02	IC_SO4	72.00	08-Oct-03	COD	27.00	09-Mar-05	pH	8.19
08-Nov-00	SO4	83.00	08-May-02	Conductivity	58.00	08-Oct-03	PO4	0.40	09-Mar-05	Conductivity	63.00

08-Nov-00	PO4	0.23	08-May-02	pH	8.16	08-Oct-03	pH	8.32	09-Mar-05	NO3	1.80
08-Nov-00	NO3	3.30	08-May-02	IC_NO3	2.30	08-Oct-03	IC_NO3	1.40	13-Apr-05	COD	29.00
08-Nov-00	pH	8.14	08-May-02	PO4	0.27	08-Oct-03	IC_SO4	63.00	13-Apr-05	IC_SO4	92.00
06-Dec-00	Conductivity	65.00	08-May-02	COD	26.00	05-Nov-03	IC_SO4	68.00	13-Apr-05	Conductivity	73.00
06-Dec-00	NO3	2.10	08-May-02	IC_SO4	66.00	05-Nov-03	IC_NO3	1.60	13-Apr-05	pH	8.55
06-Dec-00	COD	30.00	05-Jun-02	PO4	0.03	05-Nov-03	COD	25.00	13-Apr-05	PO4	0.12
06-Dec-00	SO4	92.00	05-Jun-02	Conductivity	68.00	05-Nov-03	PO4	0.10	13-Apr-05	NO3	5.10
06-Dec-00	pH	8.19	05-Jun-02	pH	8.27	05-Nov-03	Conductivity	66.00	11-May-05	COD	28.00
06-Dec-00	PO4	0.46	05-Jun-02	IC_SO4	74.00	05-Nov-03	pH	8.33	11-May-05	PO4	0.03
10-Jan-01	Conductivity	69.00	05-Jun-02	COD	28.00	03-Dec-03	Conductivity	64.00	11-May-05	pH	8.18
10-Jan-01	PO4	0.25	05-Jun-02	IC_NO3	2.40	03-Dec-03	pH	8.23	11-May-05	NO3	3.00
10-Jan-01	SO4	85.00	10-Jul-02	Conductivity	67.00	03-Dec-03	COD	27.00	11-May-05	Conductivity	72.00
10-Jan-01	NO3	1.90	10-Jul-02	pH	8.44	03-Dec-03	IC_NO3	1.70	11-May-05	IC_SO4	91.00
10-Jan-01	pH	8.54	10-Jul-02	COD	24.00	03-Dec-03	IC_SO4	69.00	08-Jun-05	COD	33.00
10-Jan-01	COD	37.00	10-Jul-02	IC_NO3	4.10	03-Dec-03	PO4	0.14	08-Jun-05	pH	8.20
07-Feb-01	Conductivity	66.00	10-Jul-02	IC_SO4	79.00	07-Jan-04	Conductivity	58.00	08-Jun-05	IC_SO4	89.00
07-Feb-01	pH	8.43	10-Jul-02	PO4	0.03	07-Jan-04	pH	8.47	08-Jun-05	Conductivity	68.00
07-Feb-01	SO4	71.00	07-Aug-02	Conductivity	73.00	07-Jan-04	COD	22.00	08-Jun-05	NO3	3.30
07-Feb-01	PO4	0.27	07-Aug-02	pH	8.55	07-Jan-04	IC_NO3	1.10	08-Jun-05	PO4	0.08
07-Feb-01	COD	33.00	07-Aug-02	COD	29.00	07-Jan-04	IC_SO4	65.00	13-Jul-05	Conductivity	64.00
07-Feb-01	NO3	2.30	07-Aug-02	IC_NO3	3.80	07-Jan-04	PO4	0.10	13-Jul-05	COD	33.00
07-Mar-01	SO4	100.00	07-Aug-02	IC_SO4	110.00	11-Feb-04	Conductivity	60.00	13-Jul-05	pH	8.15
07-Mar-01	Conductivity	70.00	07-Aug-02	PO4	0.21	11-Feb-04	pH	8.56	13-Jul-05	IC_SO4	73.00
07-Mar-01	NO3	2.30	04-Sep-02	COD	25.00	11-Feb-04	COD	22.00	13-Jul-05	PO4	0.08
07-Mar-01	COD	31.00	04-Sep-02	PO4	0.03	11-Feb-04	IC_NO3	2.20	13-Jul-05	NO3	3.40
07-Mar-01	pH	8.45	04-Sep-02	Conductivity	67.00	11-Feb-04	IC_SO4	69.00	10-Aug-05	Conductivity	69.00
07-Mar-01	PO4	0.05	04-Sep-02	pH	8.37	11-Feb-04	PO4	0.25	10-Aug-05	pH	8.62
11-Apr-01	Conductivity	67.00	04-Sep-02	IC_NO3	2.10	10-Mar-04	pH	8.39	10-Aug-05	IC_SO4	76.00
11-Apr-01	pH	8.26	04-Sep-02	IC_SO4	71.00	10-Mar-04	PO4	0.25	10-Aug-05	PO4	0.07
11-Apr-01	SO4	79.00	09-Oct-02	Conductivity	62.00	10-Mar-04	IC_SO4	125.00	10-Aug-05	NO3	2.60
11-Apr-01	PO4	0.34	09-Oct-02	pH	8.28	10-Mar-04	Conductivity	72.00	10-Aug-05	COD	35.00
11-Apr-01	NO3	3.80	09-Oct-02	COD	23.00	10-Mar-04	IC_NO3	8.70	07-Sep-05	Conductivity	69.00
11-Apr-01	COD	47.00	09-Oct-02	IC_NO3	2.50	10-Mar-04	COD	32.00	07-Sep-05	pH	8.03
09-May-01	Conductivity	65.00	09-Oct-02	IC_SO4	77.00	07-Apr-04	Conductivity	86.00	07-Sep-05	IC_SO4	74.00
09-May-01	pH	8.52	09-Oct-02	PO4	0.19	07-Apr-04	pH	8.61	07-Sep-05	PO4	0.11
09-May-01	COD	28.00	06-Nov-02	pH	8.40	07-Apr-04	COD	24.00	07-Sep-05	NO3	2.40
09-May-01	SO4	68.00	06-Nov-02	Conductivity	69.00	07-Apr-04	IC_SO4	100.00	07-Sep-05	COD	44.00
09-May-01	PO4	0.44	06-Nov-02	COD	32.00	07-Apr-04	PO4	0.27	12-Oct-05	Conductivity	66.00
09-May-01	NO3	2.40	06-Nov-02	IC_NO3	1.70	07-Apr-04	NO3	3.80	12-Oct-05	pH	8.37
06-Jun-01	IC_SO4	79.00	06-Nov-02	IC_SO4	73.00	12-May-04	IC_SO4	90.00	12-Oct-05	IC_SO4	77.00
06-Jun-01	Conductivity	72.00	06-Nov-02	PO4	0.22	12-May-04	PO4	0.03	12-Oct-05	PO4	0.17

06-Jun-01	IC_PO4	0.17	04-Dec-02	IC_SO4	66.00	12-May-04	NO3	3.60	12-Oct-05	NO3	3.40
06-Jun-01	pH	8.59	04-Dec-02	PO4	0.03	12-May-04	Conductivity	71.00	12-Oct-05	COD	44.00
06-Jun-01	COD	56.00	04-Dec-02	Conductivity	65.00	12-May-04	pH	8.46	09-Nov-05	Conductivity	69.00
06-Jun-01	IC_NO3	2.40	04-Dec-02	pH	8.43	12-May-04	COD	30.00	09-Nov-05	pH	8.49
11-Jul-01	Conductivity	70.00	04-Dec-02	COD	31.00	09-Jun-04	PO4	0.03	09-Nov-05	IC_SO4	92.00
11-Jul-01	COD	38.00	04-Dec-02	IC_NO3	1.70	09-Jun-04	NO3	3.90	09-Nov-05	PO4	0.20
11-Jul-01	IC_SO4	86.00	08-Jan-03	COD	28.00	09-Jun-04	Conductivity	70.00	09-Nov-05	NO3	2.60
11-Jul-01	pH	8.54	08-Jan-03	IC_NO3	1.70	09-Jun-04	pH	8.41	09-Nov-05	COD	43.00
08-Aug-01	Conductivity	71.00	08-Jan-03	IC_SO4	77.00	09-Jun-04	COD	27.00	07-Dec-05	Conductivity	81.00
08-Aug-01	IC_SO4	85.00	08-Jan-03	PO4	0.03	09-Jun-04	IC_SO4	92.00	07-Dec-05	pH	7.53
08-Aug-01	pH	8.27	08-Jan-03	Conductivity	66.00	14-Jul-04	IC_SO4	95.00	07-Dec-05	IC_SO4	130.00
08-Aug-01	COD	59.00	08-Jan-03	pH	8.53	14-Jul-04	PO4	0.44	07-Dec-05	PO4	0.35
08-Aug-01	PO4	0.26	05-Feb-03	IC_NO3	0.05	14-Jul-04	NO3	4.30	07-Dec-05	NO3	8.90
08-Aug-01	IC_NO3	2.90	05-Feb-03	IC_SO4	73.00	14-Jul-04	COD	33.00	07-Dec-05	COD	130.00

SEC-SEW

<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>	<u>DATE</u>	<u>PARAMETER</u>	<u>VALUE</u>
12-Jan-00	pH	8.50	09-Jan-02	PO4	3.60	07-May-03	IC_NO3	3.60	08-Sep-04	IC_SO4	51.00
12-Jan-00	Conductivity	74.00	09-Jan-02	IC_SO4	61.00	07-May-03	IC_SO4	48.00	08-Sep-04	PO4	0.49
08-Mar-00	pH	7.90	09-Jan-02	COD	26.00	07-May-03	PO4	0.32	08-Sep-04	NO3	4.50
08-Mar-00	Conductivity	69.00	06-Feb-02	Conductivity	61.00	07-May-03	COD	62.00	08-Sep-04	Conductivity	55.00
12-Apr-00	pH	8.00	06-Feb-02	pH	8.38	04-Jun-03	IC_NO3	3.90	08-Sep-04	pH	7.44
12-Apr-00	Conductivity	71.00	06-Feb-02	IC_NO3	3.70	04-Jun-03	IC_SO4	46.00	13-Oct-04	Conductivity	52.00
12-Apr-00	PO4	0.60	06-Feb-02	IC_SO4	57.00	04-Jun-03	PO4	11.00	13-Oct-04	COD	51.00
12-Apr-00	NO3	1.50	06-Feb-02	PO4	2.70	04-Jun-03	COD	30.00	13-Oct-04	pH	7.58
10-May-00	Conductivity	110.00	06-Feb-02	COD	25.00	04-Jun-03	pH	8.29	13-Oct-04	IC_SO4	46.00
10-May-00	pH	7.78	06-Mar-02	Conductivity	61.00	04-Jun-03	Conductivity	59.00	13-Oct-04	PO4	0.72
10-May-00	PO4	0.60	06-Mar-02	pH	8.44	09-Jul-03	PO4	0.27	13-Oct-04	NO3	4.50
10-May-00	NO3	1.20	06-Mar-02	COD	25.00	09-Jul-03	COD	73.00	10-Nov-04	Conductivity	54.00
07-Jun-00	PO4	0.22	06-Mar-02	IC_NO3	1.10	09-Jul-03	IC_NO3	7.30	10-Nov-04	COD	28.00
07-Jun-00	NO3	4.60	06-Mar-02	IC_SO4	56.00	09-Jul-03	IC_SO4	46.00	10-Nov-04	pH	8.20
07-Jun-00	Conductivity	76.00	06-Mar-02	PO4	0.60	09-Jul-03	pH	7.59	10-Nov-04	IC_SO4	52.00
07-Jun-00	pH	8.10	10-Apr-02	IC_NO3	3.20	09-Jul-03	Conductivity	58.00	10-Nov-04	PO4	0.24
12-Jul-00	Conductivity	61.00	10-Apr-02	COD	7.50	06-Aug-03	COD	57.00	10-Nov-04	NO3	2.50
12-Jul-00	pH	7.65	10-Apr-02	IC_SO4	48.00	06-Aug-03	pH	7.87	08-Dec-04	PO4	0.98
12-Jul-00	PO4	1.30	10-Apr-02	pH	8.32	06-Aug-03	Conductivity	57.00	08-Dec-04	Conductivity	60.00
12-Jul-00	NO3	6.20	10-Apr-02	Conductivity	57.00	06-Aug-03	IC_SO4	47.00	08-Dec-04	NO3	5.00
06-Sep-00	Conductivity	60.00	10-Apr-02	PO4	1.20	06-Aug-03	PO4	0.29	08-Dec-04	IC_SO4	75.00
06-Sep-00	PO4	0.43	08-May-02	Conductivity	54.00	06-Aug-03	IC_NO3	7.30	08-Dec-04	COD	17.00
06-Sep-00	NO3	1.50	08-May-02	COD	24.00	03-Sep-03	IC_SO4	45.00	08-Dec-04	pH	7.89
06-Sep-00	pH	7.48	08-May-02	IC_NO3	4.10	03-Sep-03	pH	7.92	12-Jan-05	Conductivity	70.00

11-Oct-00	Conductivity	65.00	08-May-02	pH	8.25	03-Sep-03	IC_NO3	7.90	12-Jan-05	COD	16.00
11-Oct-00	PO4	0.05	08-May-02	IC_SO4	50.00	03-Sep-03	Conductivity	59.00	12-Jan-05	pH	8.07
11-Oct-00	pH	7.70	08-May-02	PO4	1.40	03-Sep-03	COD	40.00	12-Jan-05	IC_SO4	85.00
11-Oct-00	NO3	1.30	05-Jun-02	pH	8.04	03-Sep-03	PO4	1.20	12-Jan-05	PO4	0.35
08-Nov-00	NO3	1.80	05-Jun-02	IC_SO4	60.00	08-Oct-03	pH	7.91	12-Jan-05	NO3	3.20
08-Nov-00	PO4	1.10	05-Jun-02	IC_NO3	2.80	08-Oct-03	PO4	2.50	09-Feb-05	NO3	2.20
08-Nov-00	Conductivity	68.00	05-Jun-02	COD	49.00	08-Oct-03	IC_SO4	46.00	09-Feb-05	IC_SO4	74.00
08-Nov-00	pH	8.14	05-Jun-02	Conductivity	61.00	08-Oct-03	IC_NO3	4.70	09-Feb-05	COD	19.00
06-Dec-00	Conductivity	65.00	05-Jun-02	PO4	0.03	08-Oct-03	Conductivity	58.00	09-Feb-05	pH	8.60
06-Dec-00	pH	7.80	10-Jul-02	Conductivity	72.00	08-Oct-03	COD	25.00	09-Feb-05	PO4	0.25
06-Dec-00	NO3	1.30	10-Jul-02	pH	8.14	05-Nov-03	pH	8.02	09-Feb-05	Conductivity	65.00
06-Dec-00	PO4	1.50	10-Jul-02	IC_NO3	7.50	05-Nov-03	Conductivity	55.00	09-Mar-05	Conductivity	66.00
10-Jan-01	pH	8.46	10-Jul-02	IC_SO4	135.00	05-Nov-03	IC_SO4	45.00	09-Mar-05	pH	8.14
10-Jan-01	Conductivity	69.00	10-Jul-02	PO4	0.48	05-Nov-03	PO4	0.75	09-Mar-05	PO4	0.24
10-Jan-01	NO3	1.60	10-Jul-02	COD	23.00	05-Nov-03	COD	37.00	09-Mar-05	IC_SO4	76.00
10-Jan-01	PO4	1.10	07-Aug-02	Conductivity	60.00	05-Nov-03	IC_NO3	5.00	09-Mar-05	NO3	1.60
07-Feb-01	pH	8.12	07-Aug-02	pH	8.15	03-Dec-03	Conductivity	58.00	09-Mar-05	COD	25.00
07-Feb-01	NO3	1.00	07-Aug-02	IC_NO3	5.50	03-Dec-03	pH	7.94	13-Apr-05	Conductivity	63.00
07-Feb-01	Conductivity	72.00	07-Aug-02	IC_SO4	58.00	03-Dec-03	IC_NO3	6.90	13-Apr-05	COD	20.00
07-Feb-01	PO4	1.80	07-Aug-02	PO4	0.70	03-Dec-03	IC_SO4	58.00	13-Apr-05	pH	8.24
07-Mar-01	pH	7.93	07-Aug-02	COD	20.00	03-Dec-03	PO4	0.66	13-Apr-05	PO4	0.17
07-Mar-01	Conductivity	65.00	04-Sep-02	IC_SO4	65.00	03-Dec-03	COD	39.00	13-Apr-05	NO3	2.10
07-Mar-01	NO3	1.60	04-Sep-02	IC_NO3	4.50	07-Jan-04	Conductivity	57.00	13-Apr-05	IC_SO4	67.00
07-Mar-01	PO4	0.52	04-Sep-02	PO4	0.45	07-Jan-04	pH	8.00	11-May-05	Conductivity	66.00
11-Apr-01	PO4	0.93	04-Sep-02	COD	25.00	07-Jan-04	IC_NO3	3.00	11-May-05	PO4	0.14
11-Apr-01	Conductivity	60.00	04-Sep-02	Conductivity	61.00	07-Jan-04	IC_SO4	54.00	11-May-05	NO3	3.20
11-Apr-01	pH	7.90	04-Sep-02	pH	7.83	07-Jan-04	PO4	1.20	11-May-05	pH	7.92
11-Apr-01	NO3	2.90	09-Oct-02	Conductivity	60.00	07-Jan-04	COD	22.00	11-May-05	IC_SO4	73.00
09-May-01	Conductivity	64.00	09-Oct-02	pH	7.77	11-Feb-04	Conductivity	59.00	11-May-05	COD	23.00
09-May-01	pH	8.44	09-Oct-02	IC_NO3	5.20	11-Feb-04	pH	8.29	08-Jun-05	COD	30.00
09-May-01	PO4	5.07	09-Oct-02	IC_SO4	69.00	11-Feb-04	IC_NO3	5.30	08-Jun-05	NO3	3.10
09-May-01	NO3	12.00	09-Oct-02	PO4	1.40	11-Feb-04	IC_SO4	54.00	08-Jun-05	Conductivity	58.00
06-Jun-01	IC_PO4	0.69	09-Oct-02	COD	30.00	11-Feb-04	PO4	1.20	08-Jun-05	PO4	0.28
06-Jun-01	Conductivity	71.00	06-Nov-02	IC_NO3	5.80	11-Feb-04	COD	28.00	08-Jun-05	IC_SO4	65.00
06-Jun-01	IC_SO4	66.00	06-Nov-02	IC_SO4	55.00	10-Mar-04	IC_NO3	4.50	08-Jun-05	pH	7.94
06-Jun-01	IC_NO3	3.50	06-Nov-02	PO4	2.50	10-Mar-04	Conductivity	78.00	13-Jul-05	pH	7.89
06-Jun-01	pH	8.52	06-Nov-02	COD	48.00	10-Mar-04	pH	7.74	13-Jul-05	Conductivity	54.00
11-Jul-01	IC_SO4	53.00	06-Nov-02	pH	7.80	10-Mar-04	COD	28.00	13-Jul-05	IC_SO4	51.00
11-Jul-01	IC_NO3	17.00	06-Nov-02	Conductivity	59.00	10-Mar-04	IC_SO4	110.00	13-Jul-05	COD	36.00
11-Jul-01	Conductivity	58.00	04-Dec-02	IC_SO4	44.00	10-Mar-04	PO4	0.32	13-Jul-05	PO4	0.18
11-Jul-01	pH	7.65	04-Dec-02	PO4	0.30	07-Apr-04	Conductivity	71.00	13-Jul-05	NO3	4.10

08-Aug-01	PO4	0.56	04-Dec-02	IC_NO3	1.50	07-Apr-04	pH	8.38	10-Aug-05	Conductivity	54.00
08-Aug-01	IC_NO3	5.60	04-Dec-02	Conductivity	55.00	07-Apr-04	IC_SO4	73.00	10-Aug-05	pH	7.87
08-Aug-01	pH	8.09	04-Dec-02	pH	8.04	07-Apr-04	PO4	0.45	10-Aug-05	IC_SO4	20.00
08-Aug-01	Conductivity	56.00	04-Dec-02	COD	65.00	07-Apr-04	NO3	4.60	10-Aug-05	PO4	12.00
08-Aug-01	IC_SO4	52.00	08-Jan-03	IC_NO3	1.40	07-Apr-04	COD	26.00	10-Aug-05	NO3	0.05
05-Sep-01	Conductivity	60.00	08-Jan-03	IC_SO4	60.00	12-May-04	Conductivity	90.00	10-Aug-05	COD	23.00
05-Sep-01	pH	8.23	08-Jan-03	PO4	0.18	12-May-04	pH	8.20	07-Sep-05	pH	7.72
05-Sep-01	IC_NO3	1.90	08-Jan-03	COD	55.00	12-May-04	COD	80.00	07-Sep-05	IC_SO4	55.00
05-Sep-01	IC_SO4	62.00	08-Jan-03	Conductivity	58.00	12-May-04	IC_SO4	52.00	07-Sep-05	PO4	0.39
05-Sep-01	PO4	0.89	08-Jan-03	pH	8.21	12-May-04	PO4	0.31	07-Sep-05	NO3	2.20
10-Oct-01	Conductivity	74.00	05-Feb-03	IC_NO3	0.05	12-May-04	NO3	4.80	07-Sep-05	COD	35.00
10-Oct-01	pH	7.47	05-Feb-03	IC_SO4	68.00	09-Jun-04	Conductivity	59.00	07-Sep-05	Conductivity	58.00
10-Oct-01	PO4	3.60	05-Feb-03	PO4	0.37	09-Jun-04	pH	8.15	12-Oct-05	Conductivity	62.00
10-Oct-01	IC_NO3	0.57	05-Feb-03	Conductivity	64.00	09-Jun-04	COD	27.00	12-Oct-05	pH	8.34
10-Oct-01	IC_SO4	115.00	05-Feb-03	pH	8.13	09-Jun-04	IC_SO4	59.00	12-Oct-05	IC_SO4	62.00
07-Nov-01	Conductivity	70.00	05-Feb-03	COD	27.00	09-Jun-04	PO4	1.10	12-Oct-05	PO4	16.00
07-Nov-01	pH	8.10	05-Mar-03	PO4	0.28	09-Jun-04	NO3	6.50	12-Oct-05	NO3	0.05
07-Nov-01	IC_NO3	0.52	05-Mar-03	Conductivity	65.00	14-Jul-04	NO3	7.20	12-Oct-05	COD	38.00
07-Nov-01	IC_SO4	110.00	05-Mar-03	pH	8.08	14-Jul-04	PO4	1.10	09-Nov-05	Conductivity	55.00
07-Nov-01	PO4	0.78	05-Mar-03	IC_NO3	2.60	14-Jul-04	pH	8.15	09-Nov-05	pH	8.32
05-Dec-01	Conductivity	63.00	05-Mar-03	IC_SO4	69.00	14-Jul-04	IC_SO4	56.00	09-Nov-05	IC_SO4	45.00
05-Dec-01	pH	8.29	05-Mar-03	COD	60.00	14-Jul-04	COD	33.00	09-Nov-05	PO4	0.30
05-Dec-01	IC_NO3	1.30	09-Apr-03	Conductivity	60.00	14-Jul-04	Conductivity	60.00	09-Nov-05	NO3	2.50
05-Dec-01	IC_SO4	74.00	09-Apr-03	pH	7.57	11-Aug-04	Conductivity	57.00	09-Nov-05	COD	41.00
05-Dec-01	COD	20.00	09-Apr-03	IC_NO3	1.90	11-Aug-04	COD	78.00	07-Dec-05	Conductivity	62.00
05-Dec-01	PO4	0.49	09-Apr-03	IC_SO4	61.00	11-Aug-04	pH	9.12	07-Dec-05	pH	7.72
09-Jan-02	Conductivity	61.00	09-Apr-03	PO4	0.38	11-Aug-04	IC_SO4	61.00	07-Dec-05	IC_SO4	71.00
09-Jan-02	IC_NO3	5.80	09-Apr-03	COD	59.00	11-Aug-04	PO4	0.98	07-Dec-05	PO4	0.95
09-Jan-02	pH	7.96	07-May-03	Conductivity	59.00	11-Aug-04	NO3	5.30	07-Dec-05	NO3	3.10
			07-May-03	pH	8.27	08-Sep-04	COD	21.00	07-Dec-05	COD	24.00

Appendix B: Summary of the DWAF's Target Water Quality Range for the various types of freshwater usage (DWAF, 1996f).

No TWQR specifications have been stipulated for these parameters:

- *Conductivity*
- *Phosphates*

pH

WATER-USE	TWQR	
Aquatic Ecosystems	6.5 – 9.0	
Domestic	<i>Human Consumption</i> 6.0 – 9.0	
Agriculture	<i>Livestock Watering</i> Not available	<i>Irrigation</i> 6.5 – 8.4

Nitrates

WATER-USE	TWQR	
Aquatic Ecosystems	Not available	
Domestic	<i>Human Consumption</i> 0 – 6	
Agriculture	<i>Livestock Watering</i> 0 – 100	<i>Irrigation</i> Not available

Sulphates

WATER-USE	TWQR	
Aquatic Ecosystems	0.001	
Domestic	<i>Human Consumption</i> 0 – 200	
Agriculture	<i>Livestock Watering</i> 0 – 1000	<i>Irrigation</i> Not available

Chemical Oxygen Demand (COD)

WATER-USE	TWQR	
Aquatic Ecosystems	Not available	
Domestic	<i>Human Consumption</i> Not available	
Agriculture	<i>Livestock Watering</i> Not available	<i>Irrigation</i> Not available

Appendix C: Waterval River Catchment Management Agency's In-stream Water Quality Guidelines

IN-STREAM WATER QUALITY GUIDELINES FOR THE WATERVAL RIVER CATCHMENT					
Variables	Measured as	Ideal	Acceptable	Tolerable	Unacceptable
Ammonia	mg/l	< 0.1	0.1 – 1.5	1.5 – 5.0	> 5.0
COD	mg/l	< 20	20 – 35	35 – 55	> 55
Chloride	mg/l	< 80	80 – 150	150 – 200	> 200
Conductivity	mg/l	< 45	45 – 70	70 – 120	> 120
Faecal coliforms	per 100 ml	< 10	10 – 100	100 – 1000	> 1000
Iron	mg/l	< 0.1	0.1 – 0.5	0.5 – 1.0	> 1.0
Manganese	mg/l	< 0.2	0.2 – 0.5	0.5 – 1.0	> 1.0
Nitrate	mg/l	< 1.0	1.0 – 3.0	3.0 – 6.0	> 6.0
pH	pH units	6.5 – 8.5			< 6.5 and > 8.5
Phosphate	mg/l	< 0.2	0.2 – 0.4	0.4 – 0.6	> 0.6
Sodium	mg/l	< 70	70 – 100	100 – 150	> 150
Sulphate	mg/l	< 150	150 – 300	300 – 500	> 500