THE IMPACT OF KATSE DAM WATER ON WATER QUALITY IN THE ASH, LIEBENBERGSVLEI AND WILGE RIVERS AND THE VAAL DAM

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ABSTRACT

The main purpose of this study is to determine the difference in water quality of the rivers between the Katse and Vaal Dams (Wilge River and Vaal Dam reservoir sub-catchments) after the construction of the Lesotho Highlands Water Project. These rivers include the Ash, Liebenbergsvlei and Wilge Rivers. The temporal changes in water constituents, namely: electrical conductivity, chemical oxygen demand, pH, turbidity, ammonia, calcium, manganese and *chlorophyll a,* at selected water sampling points were analysed to clarify if Katse Dam water has had any impact on the water quality of the Ash, Liebenbergsvlei and Wilge Rivers and the Vaal Dam.

The water quality was studied over an eleven-year period from November 1994 until December 2005. This includes a five-year period prior to, and a six-year period following the completion of the Katse Dam. The Ash, Liebenbergsvlei and Wilge Rivers fall within the Wilge sub-catchment, and the Vaal Dam falls within the Vaal Dam reservoir sub-catchment. Both the aforementioned sub-catchments form part of the Vaal River catchment. Physical, chemical and microbiological sampling results were obtained from Rand Water. The results were compared with the in-stream water quality guidelines as set by the Vaal Barrage Catchment Executive Committee. The results of the selected constituents were depicted visually in the form of graphs. Trends in the constituents over the period were then determined. The graphs were divided into two sections namely, pre-Katse Dam (before 1999) and post-Katse Dam (1999 to 2005). Differences in water quality before and after the construction of the Katse Dam were determined from sampling and chemical analysis at six locations, and hence evaluations were made whether the release of Katse Dam water has had a significant effect on the water quality results in the Vaal River System.

The water quality results with respect to the different water constituents illustrated a distinct change in water quality over the period. Northwards, towards the Vaal Dam, the difference in water quality became less apparent. Sampling points throughout the study area experienced decreases in: electrical conductivity, chemical oxygen demand, turbidity, ammonia, and manganese. Hence, the release of Katse Dam water into the Vaal River system has had a positive influence on the water quality and thus changed the riverine environments in the Vaal River system.

The high quality water from the Katse Dam that enters the Vaal River system thus initially increases the quality of the water in the recipient system with a lesser effect downstream. The result is an improvement of water quality in the upper reaches of the Vaal River system and no significant influence on the Vaal Dam itself. However, the change in water quality may have a detrimental effect on the river environment as a result of the increased volume of water entering the system and the resultant soil erosion, which serves for further studies. Consequently, the advantageous high quality water from the Lesotho Highlands is not being optimally utilised, hence the proposed recommendation by Rand Water to alternatively transfer Katse Dam water via a gravity-fed pipeline to the Vaal Dam thereby receiving the full benefit of high quality water, leaving river environments unaltered and possibly lowering purification costs.

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ABBREVIATIONS USED

BOD	**Biological Oxygen Demand**
COD	**Chemical Oxygen Demand**
C-SPD	**Saulspoort Dam at Bethlehem (sample point)**
C-WAF	**Wilge River above Frankfort (sample point)**
C-WF	**Wilge River at Frankfort (sample point)**
C-WL	**Liebenbergsvlei River (sample point)**
C-WLA	**Liebenbergsvlei Ash River (sample point)**
C-VD3I	**Wilge River downstream of Oranjeville (sample point)**
DEAT	**Department of Environmental Affairs & Tourism**
DWAF	**Department of Water Affairs and Forestry**
EC	**Electrical Conductivity**
EIA	**Environmental Impact Assessment**
IBT	**Inter Basin Transfer**
LHDA	**Lesotho Highlands Development Authority**
LHWP	**Lesotho Highlands Water Project**
MAR	**Mean Annual Runoff**
MASL	**Meters Above Sea Level**
NTU	**Nephelometer Turbidity Units**
RSA	**Republic of South Africa**
TDS	**Total Dissolved Solids**
TOC	**Total Organic Carbon**
VBCEC	**Vaal Barrage Catchment Executive Committee**
WHO	**World Health Organisation**
WRC	**Water Research Commission**

1. INTRODUCTION

Water forms the base of all living things and is used extensively by all communities for a multitude of purposes. It is the most important commodity in many countries in the world and is of such importance in South Africa that it warrants one of the largest Government Departments (Water Affairs and Forestry) (Kelbe & Germishuyse, 1999). The quality and the protection of water resources, particularly in a water scarce country such as South Africa, are everyone's concern and should be managed on scientific principles (Water Research Commission, 1998).

South Africa is a largely semi-desert country and prone to erratic and unpredictable rainfall, which affects the reliability and variability of river flow (Government Communication and Information System, 2004). Countrywide, the average annual rainfall amounts to 497 mm, compared with a world average of approximately 860 mm for continents. Apart from this, the average annual potential evaporation is higher than the rainfall in all but a few isolated areas where rainfall exceeds 1 400 mm per year (AfricaBio, 2002). Furthermore, rainfall is poorly distributed in relation to the areas of greatest economic activity. Presently, more then 90 percent of Gauteng Province’s water is supplied from the 2 800 million m³ storage capacity Vaal Dam, situated approximately 70 km south of Johannesburg, making South Africa one of the few countries in the world where a metropolitan city is not situated close to a permanent fresh water resource such as a river or a lake (Ramsingh *et al.*, 1998). Accordingly, water is transported over great distances from areas of relative abundance to areas of increasing demand, such as the Tugela-Vaal scheme and more specifically the Lesotho Highlands Water Project (LHWP).

The potential for transferring water from the highlands of Lesotho to meet the growing demand for water in the Vaal region in South Africa was identified more than 40 years ago (Lesotho Highlands Development Authority, 1997). The increasing water demand in the economic and industrial heartland of South Africa became a matter of concern in the region because of the increasing human population and economic activity. To aid the situation an international treaty was signed between South Africa and Lesotho on the 24 October 1986

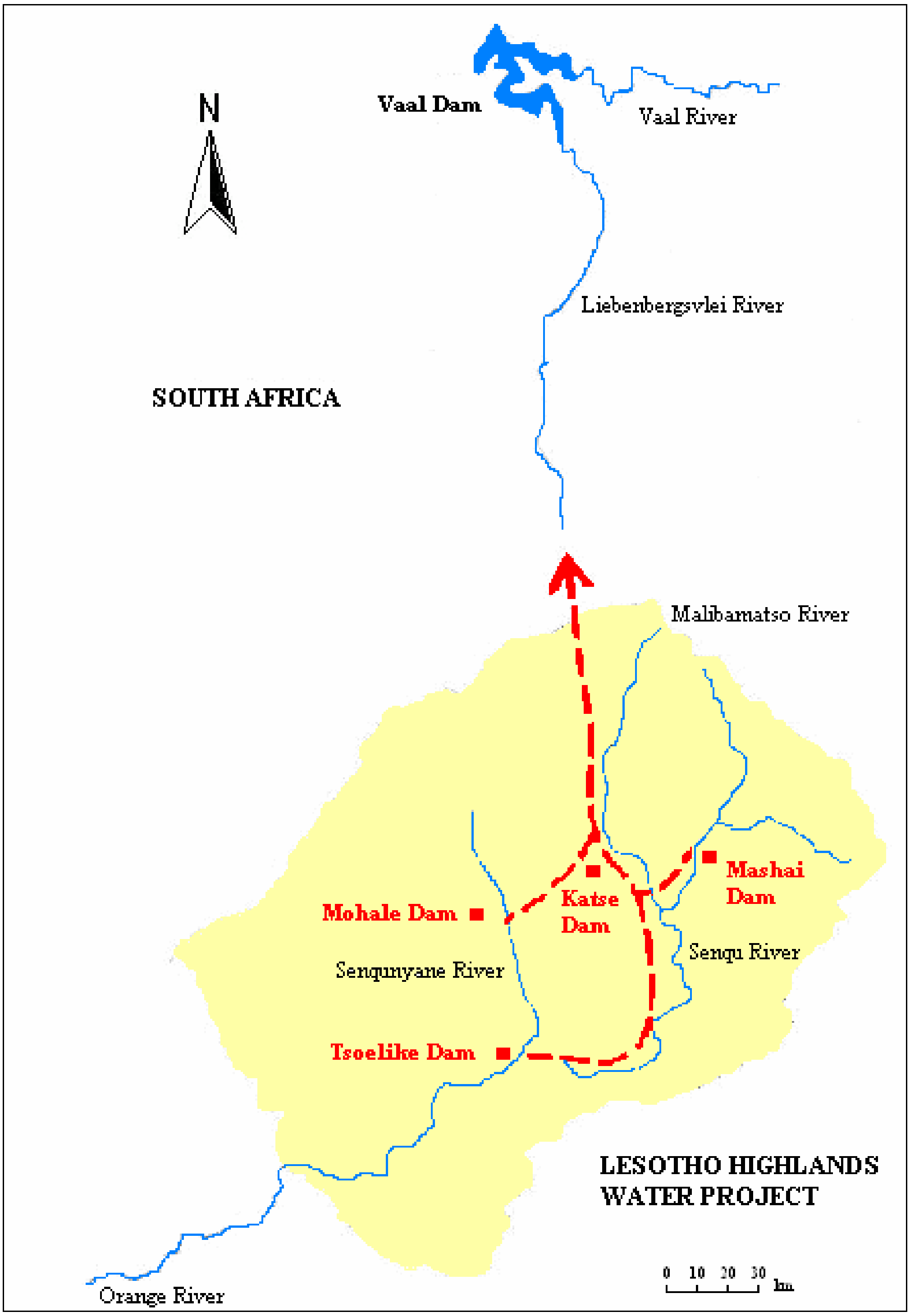

Figure 1: **Lesotho Highlands Water Project.**

(Lesotho Highlands Development Authority, 1997).

thereby initiating a transfer of water from the Lesotho Highlands to the Vaal Dam on the border of Gauteng with the Free State, South Africa. The LHWP is a four-phase project (Ramsingh *et al.*, 1998) (Figure 1). Once all phases are completed it will deliver 2.2 x 10^9 m³ of water per annum to the Vaal Dam (van Biljon & Visser, 1996) hence contributing significantly to Gauteng's water supply. In return Lesotho benefits financially from the royalties received through the provision of the water, and the money saved through the production of hydroelectricity.

It should be accepted that the abundance of water is of no use if the quality is of such a nature that makes it unfit for any usage. The quality of water is not an intrinsic characteristic of the water, but it is related to the intended use thereof. Water may be fit for one use (e.g. irrigation), but completely unfit for another (e.g. human consumption). Fitness for use plays an important role in the management of water resources and in turn forms an integral part of water quality management (Parsons & Tredoux, 1995).

There have been concerns as to (i) how water quality has been affected as a result of the release of Katse Dam water into the study area from the LHWP, (ii) what impacts these changes are having on Rand Waters present water treatment process (Ramsingh *et al.*, 1998), (iii) the impacts these changes are having on the riverine environments and (iv) alternatives for transferring Lesotho water to the Vaal Dam to eradicate or minimise any negative impacts.

The water in the Lesotho Highlands is generally characterised by excellent chemical quality, low alkalinity, low sediment content, and high clarity and therefore differs significantly from Vaal Dam water and that of its tributaries (Lepono *et al.*, 2003). The effect of such water, although advantageous in terms of cost of purification, on an environment with water of poorer quality over an elongated period is complex.

Previous studies of this nature will now be discussed.

2. LITERATURE REVIEW

Anticipated water shortages in the Gauteng area in the Republic of South Africa (RSA) as a result of an annual water demand increase of 3.8 percent, due to projected population growth and economic growth, led to the commencement of discussions between the RSA and Lesotho in the mid 1960s regarding the sale and transfer of Lesotho water. Projections at that time for the year 2000 indicated that Gauteng Province would accommodate nearly 42 percent of the urban population of the RSA and would generate 56 percent of all industrial and 79 percent of all mining output in the RSA (Ramsingh *et al.*, 1998).

After evaluation of more than 2000 variations amongst several main alternatives, proposals for the transfer of water from Lesotho to supplement the Vaal Dam were endorsed in 1986, and the LHWP came into existence through the signing of a treaty between the two governments (Lesotho Highlands Development Authority, 1997).

The prime objective of the LHWP is to abstract water from the rivers in the Highlands of Lesotho, store it in reservoirs and transfer it, through gravity, to the water deficient Vaal region in South Africa. Before transfer, the water is used to generate hydro-electricity for Lesotho. The transferred water is aimed at augmenting water supply for industrial and residential use in the Vaal region. South Africa pays the full cost of the project except the hydro-electric component and also pays US$ 45-47 million annually in royalties for the water delivered (World Bank, 1998) which brings valued foreign earnings to Lesotho.

In South Africa significant ecological impacts are expected on the Ash (also known as the As or Axle), Liebenbergsvlei and Wilge Rivers, the main rivers connecting the Katse Dam in Lesotho to the Vaal Dam in South Africa, and Saulspoort Dam. The addition of water from the Katse Dam is expected to alter the flow, temperature, chemistry and biology of these rivers and dams. Jackson (1987) explains that the increased flow of the rivers is expected to erode the river beds and alter the flows necessary to inundate riparian floodplains and probably destroy existing wetlands that are habitat for the spurwing goose, yellow bill duck and Egyptian goose populations. The increased flows are also expected to increase the size of the rivers, which is expected to impact positively on the diversity of the riverine biota. These impacts were studied by Chutter and Ashton (1990) and Chutter (1992, 1997), and were quantified by Matete and Hassan (2006).

Lepono *et al.* (2003, p. 97 - 101) in an article “Monitoring of the water transfer from Katse Dam into the Upper Vaal River system: water utility’s perspective” reported on the biological and chemical monitoring of water transferred from the LHWP. Emphasis was placed on the negative impacts on the biological communities in the recipient system. Historical data from baseline studies were compiled and assessed for three sites in the Ash and Liebenbergsvlei Rivers on selected water quality variables. An integrated habitat assessment system (Macmillan, 1997) was used to assess habitat availability for invertebrates; benthic macro-invertebrate communities were used to determine site-specific ecological integrity and fish community studies were also undertaken.

The study indicated that surface water quality variables differed between donor and recipient systems. The Ash/Liebenbergsvlei system was found to have a natural higher alkalinity, which had been lowered due to the LHWP water release. Higher mean temperatures were recorded at the Katse Dam compared to the recipient system and higher turbidity values were also recorded downstream, which were attributed to the increased flow regime, leading to scouring and erosion of riverbanks and beds (Lepono *et al.,* 2003).

It was shown that most of the potential biotopes had diminished as a direct consequence of erosion and deposition caused by the unnatural release of high velocity water from the LHWP. Good invertebrate scores were obtained during 1996 – 1997 bio-monitoring but deterioration was noted during 1999 – 2002 bio-monitoring downstream of the Katse Dam outfall (Lepono *et al.*, 2003).

Lepono *et al.* (2003) conclude by attributing their results to the following:

- “The increased flow, which tends to change plant growth patterns which in turn changes the distribution of invertebrates. The increased flow regime can also remove detritus material with the ultimate loss of food supply to detritivores.
- High amounts of suspended solids can affect the communities’ structures by reducing light penetration because of increased turbidity. This also affects the photosynthetic rates of algae and submerged macrophytes thus affecting animals that depend on them for food, shelter and support.
- Increased deposition can change the riverbed so that burrowing organisms overwhelm other organisms that depend on stones for adherence.
- Water quality deterioration was evident in the recipient system

- There is a need for detailed biological and physio-chemical water quality monitoring over long-term periods in large IBTs like the LHWP."

A previous study on the release of Sterkfontein Dam water on the Vaal Dam was carried out during the filling phase of the Sterkfontein Dam (Ramsingh *et al.*, 1998). Similar to the Katse Dam the Sterkfontein Dam, one of the dams of the Tugela-Vaal scheme, is a deep, high altitude reservoir with comparable water quality. The study also made use of the monitoring of water quality in Lesotho over a twelve-month period, in 1992 - 1993, performed by the CSIR (CSIR, 1993) to determine the water quality of the Katse Dam. Since the data were collected during the filling phase of the dam it was apparent that the quality may change as a result of an inundation of vegetation. The results are presented for reference with the findings of this study (Table 1).

Ramsingh *et al.* (1998) explain that the high-clarity water in Lesotho has a low alkalinity and therefore differs significantly from the Vaal Dam water quality. They state that the Lesotho rivers low dissolved ion content, high degree of purity and softness are consequential of the rivers mainly flowing across primary igneous rocks, which are poorly soluble in water. Ramsingh *et al.* (1998) say that, at the time of the paper, faecal coliforms had not been detected in the Katse Dam and that large algal populations were not supported due to the oligotrophic nature of the dam, but predictions had indicated that the situation could change.

The authors state that calculations indicated that the ratio of Vaal Dam to Katse Dam water was likely to be 4:1 and hence should not result in significant changes to the present conductivity, alkalinity or hardness in the Vaal Dam, and therefore it was anticipated that Rand Water's treatment process not be significantly changed (Ramsingh *et al.*, 1998).

Additional treatment requirements of water abstracted from the Vaal River system following the importation of Lesotho Highlands water have been reported (Geldenhuys *et al.*, 2001). It was expected that the water from the Katse Dam would not have a significant influence on the quality of water abstracted or released from the Vaal Dam, as by the time water released from the Katse Dam is mixed with Vaal Dam water, it has similar composition to that of the Vaal Dam water due to the displacement of minerals from the geological formation. Their results showed that the water transferred from the LHWP to the Vaal River system is of higher quality but is subject to change due to the release of minerals from geological formations. It was noted however that the changes are not necessarily detrimental to the water quality as it makes it less corrosive and less aggressive against steel and concrete structures.

Table 1: Water quality of the Katse, Vaal and Sterkfontein Dams.
(Ramsingh *et al.*, 1998).

Parameter	Katse Dam	Vaal Dam	Sterkfontein Dam
Temperature (°C)	2.93 - 22.6	9.0 - 25	9.0 - 26
Conductivity (mS/m)	7.0 - 9.8	14 - 21	7.8 - 9.0
Hardness (mg $CaCO_3$/l)	30 – 110	50 - 73	26 - 33
Turbidity (NTU)	0.32 – 13	7.1 - 340	0.55 - 39
PH	7.3 - 8.4	7.4 - 8.3	6.9 - 7.8
Alkalinity (mg $CaCO_3$/l)	29 – 41	51 - 74	30 - 33
Total Dissolved Solids (mg/l)	37 – 94	94 - 140	52 - 60
Magnesium (mg/l)	3.0 – 6.0	4.8 - 8.3	2.3 - 2.8
Calcium (mg/l)	6.6 – 38	9.7 - 18	6.5 - 8.8
Sulfate (mg/l)	0.75 – 15	10 - 23	10 - 12
Chloride (mg/l)	1.2 – 5.0	10 - 13	<10

Environmental Impact Assessments (EIAs) were conducted, adopting World Bank EIA guidelines, to identify and describe the positive and negative effects and impacts of the LHWP on the project area, on Lesotho and on rivers in the RSA and to recommend mitigative solutions for phase 1A and 1B (Lesotho Highlands Development Authority, 1997).

Phase IA consists of the Katse Dam on the Malibamats'o River, a transfer tunnel and delivery tunnel, and a reservoir and hydropower plant at Muela. This phase of the project started in 1986 and was scheduled for completion in 1997. Phase IB of the LHWP consists of the Mohale Dam on the Senqunyane River, a diversion weir on the Matsoku River and transfer tunnels delivering water into Katse Dam. This phase also included the upgrading of existing roads and the development of new roads, the development of construction camps, and the provision of power transmission and telecommunications. Figure 2 illustrates the different phases of the LHWP.

A number of environmental issues surfaced during the implementation of phase IA. When the various components of phase IA were being planned, only minimal consideration was given to the environmental and social aspects of the project. In examining the experiences from phase IA the LHDA was able to avoid a number of problems in the design, planning and implementation of phase IB.

The water quality and aquatic community data for the EIAs were collected through a water quality study. The results showed that water throughout the Senqunyane catchment had a low alkalinity and a correspondingly weakly alkaline to neutral pH. The recorded total dissolved solids (TDS) were low and calcium and magnesium were the dominant cations, with some stations showing moderately high levels of iron. Dissolved nitrogen levels were also recorded as low, as were the other nutrient parameters, including total organic carbon and phosphorous. For many chemical parameters downstream sampling showed statistically significant higher concentrations or index values than the stations above the Mohale Dam site. A trend towards higher dissolved solids with distance downstream was continued in the Senqu River. Calcium, magnesium and chlorides were significantly higher in the Senqu than in the Senqunyane, and the associated parameters of total alkalinity and electrical conductivity (EC) were also significantly higher. A characteristic of both rivers, although more marked in the Senqu than in the Senqunyane, was the high variability in water quality parameters. For some it was said that it demonstrated seasonality, with higher levels of total dissolved solids and some cations and anions that occurred in the peak flow seasons.

Modelling indicated that water near the dam wall, from which the downstream releases are drawn, would be clear, with low dissolved solids content and very low to negligible suspended material content. It was shown that released water would be cooler than river water in the summer by several degrees, depending on the depth of reservoir withdrawals, and would be substantially warmer in the winter months. It was also shown that dissolved oxygen was expected to be reduced in concentration and that the pH of released water would probably be similar to natural river water prior to the project.

The motive for this study and the objectives will be discussed in the following section.

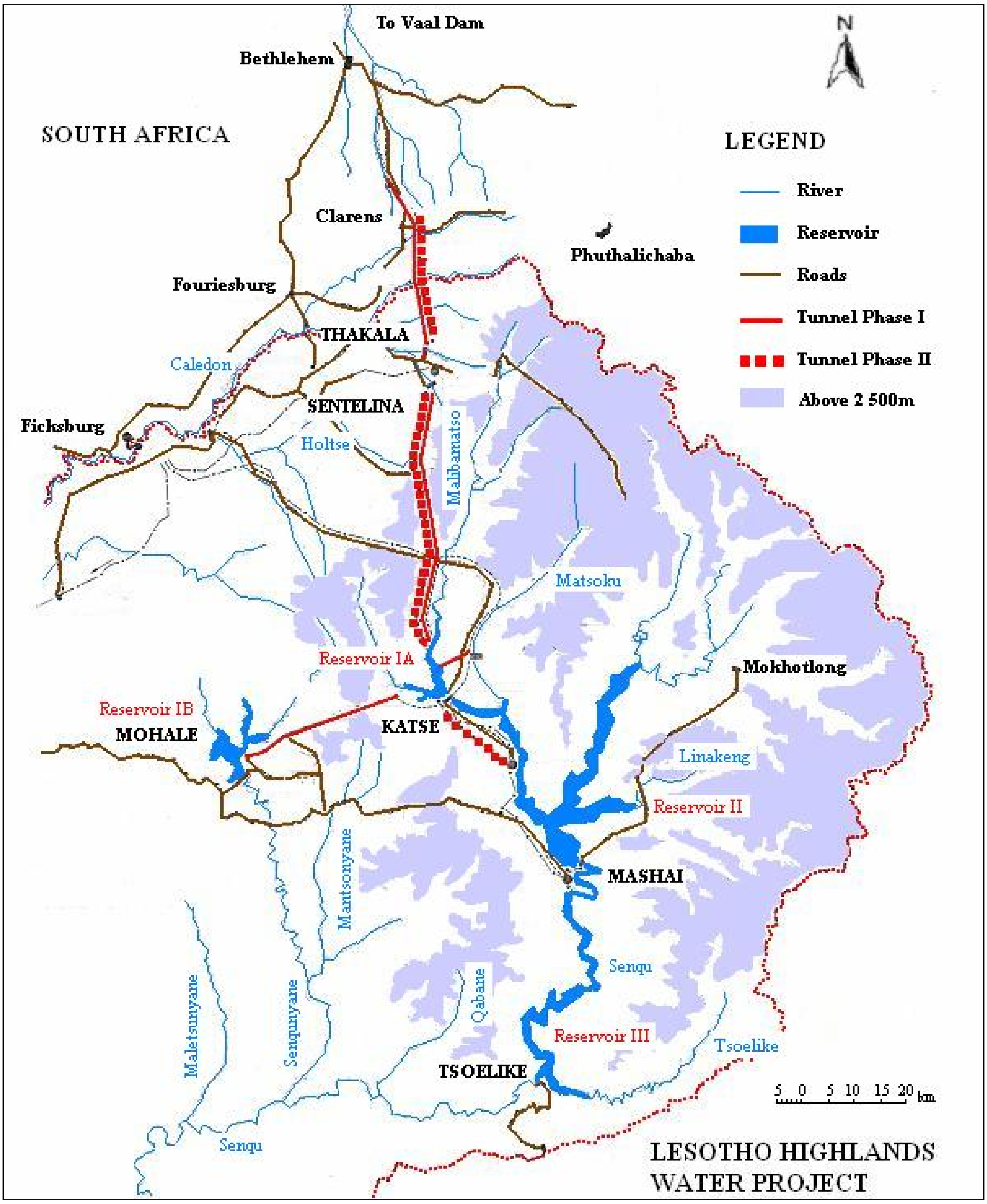

Figure 2: **Phase 1A, 1B, 2 and 3 of the Lesotho Highlands Water Project.**

(Lesotho Highlands Development Authority, 1997).

3. MOTIVATION FOR STUDY: PROBLEM STATEMENT AND OBJECTIVES

The transfer of water from areas of surplus water to areas with water deficit has become a frequent solution to water scarcity (Cyrus *et al.,* 1999). The LHWP transfer scheme is one of the largest engineering projects of this nature in the world and the largest in Africa, supplying additional water to the Vaal River system and ensuring delivery of this resource to the Gauteng industrial and economic area (approximately 70 percent of South Africa's industry).

In most instances these transfer schemes were well assessed during the initial technical planning stages, but some potential impacts were almost totally ignored (Cyrus *et al.,* 1999). In general, thus far limited research has been carried out on the impacts of inter-basin transfers. The information available does show, however, that any transfer of water within or between basins results in physical, chemical, hydrological and biological disturbances in both the donor and recipient systems.

It is suspected that the gradually increasing (until 2025) unnatural high volume flow in the Ash, Liebenbergsvlei and Wilge Rivers and furthermore, the excellent quality of the water being released into the system as a result of the release of water from the Lesotho Highlands, is modifying the river environment and adversely affecting the water quality in the area. This can be attributed to the increased volume of excellent quality water as opposed to the water quality to which aquatic species have adapted and the associated high levels of soil erosion. Hence, Rand Water has proposed an alternative for the transfer of water from Lesotho, which will result in long-term energy and cost savings as well as restoring the river environments to their original state (Rand Water, 2006).

A comprehensive study examining the effects of the aforementioned on the water quality in the recipient system over an extensive period has not been carried out. Thus, the aim of this study is to evaluate long-term temporal changes in water quality brought about by the release of Katse Dam water into the Vaal River system and to validate if the alternative proposed by Rand Water needs to be undertaken.

The LHWP transfers water from the Lesotho Highlands, in the south, northwards *via* the Ash River tunnel through the Ash, Liebenbergsvlei and Wilge Rivers and into the Vaal Dam. It is suspected that the water of the aforementioned excellent quality as well as the increased volume of water entering the Vaal River system from the LHWP could affect the water quality in recipient system. Hence, the basic experimental design of this study comprises a before and after evaluation of the water quality in the recipient system (Vaal River system) of the LHWP, using data five years before the construction of the Katse Dam (before 1999) and six years thereafter (1999 – 2005).

The study will make use of spatial and temporal variations of certain important water quality constituents in the Vaal Dam reservoir and Wilge River sub-catchment areas over an eleven-year period, taking into account the volume of water released from the Katse Dam into the Vaal River system. These two variations will be compared with the in-stream water quality guidelines developed by Vaal Barrage Catchment Executive Committee (VBCEC) with the aim of establishing whether the release of Katse Dam water has had a significant effect on the water quality results in the Vaal River system

To achieve the goals of this study the objectives are as follows:

- The study area will be described. This will be done by obtaining data on rainfall, minimum and maximum temperatures in the study area from the South African Weather Services, researching literature on the characteristics of the study area and analysing maps of the study area.
- Information on water quality and water quality constituents will be gathered. Literature and guidelines on water quality as set out by Rand Water and DWAF will be researched.
- An appropriate set of sampling points will be selected from the available data. The water quality data of samples collected at the six water-sampling points situated in the Wilge River and Vaal Dam reservoir sub-catchments, Free State Province, will be obtained from Rand Water.
- The results will be analysed and discussed. The water quality constituents used by Rand Water will be discussed and compared with the VBCEC In-Stream Water Quality Guidelines as set out by Rand Water and the Department of Water Affairs and Forestry. Data on water volumes released from the Katse Dam will be included and discussed. Flow volumes at flow register points along the study area will be discussed. Water quality results will be interpreted and discussed and recommendations will be made to highlight any negative impacts on the water quality at the water sampling points.

The description and characteristics of the study area, including the donor and recipient systems, which may have a direct influence on the water quality, will now follow.

4. DESCRIPTION OF STUDY AREA

The Upper Vaal Catchment is divided into four sub-catchments comprising of the following units: the Grootdraai Dam; Waterval River; Wilge River and Vaal Dam reservoir sub-catchments. Water from the Katse Dam, Lesotho enters the Free State Province, South Africa through the Ash River Tunnel and carries water downstream through the Wilge River sub-catchment and into the Vaal Dam reservoir sub-catchment. Hence, attention will be focused on the physical and demographic characteristics that may influence water quality in the Wilge River and Vaal Dam reservoir sub-catchments (recipient system) as well as a short overview these characteristics in the donor system (Lesotho).

4.1 Location, boundaries and size

The study area extends internationally between Lesotho and the Free State Province, South Africa, encompassing an area between the coordinates 26°45′00″ S and 29°23′00″ S and 28°00′00″ E and 28°50′00″ E as indicated in Figure 3. Water from the LHWP exits the Ash River Outfall Tunnel (Figure 4), approximately 25 km north of the international boundary between Lesotho and the Eastern Free State, and ultimately forms part of the Vaal Dam. Upon exiting the Ash River Tunnel, water flows down the Ash River, into the Saulspoort Dam, through the Liebenbergsvlei River and joins the Wilge River to enter the Vaal Dam. The focus area of this study is demarcated as from the Ash River Tunnel mouth, along the aforementioned watercourse, approximately 200 km, and into the Vaal Dam.

The Vaal Dam reservoir and the Wilge River sub-catchment each cover areas of approximately 19 200 km² and are demarcated in Figure 5. In an attempt to encompass the water transfer route from Katse Dam, Lesotho, to the Vaal Dam in the recipient system, the sample points are located at the Ash River Tunnel mouth, along the Liebenbergsvlei and Wilge Rivers as well as in the Vaal Dam. The sampling points SP1 (Liebenbergsvlei Ash River); SP2 (Saulspoort Dam at Bethlehem); SP3 (Liebenbergsvlei River); and SP4 (Wilge above Frankfort) lie within the Wilge River sub-catchment and sampling points SP5 (Wilge River at Frankfort); and SP6 (Wilge River downstream of Oranjeville) within the Vaal Dam reservoir sub-catchment (as renamed in Table 2, chapter 6). The exact sampling point locations are indicated in chapter six.

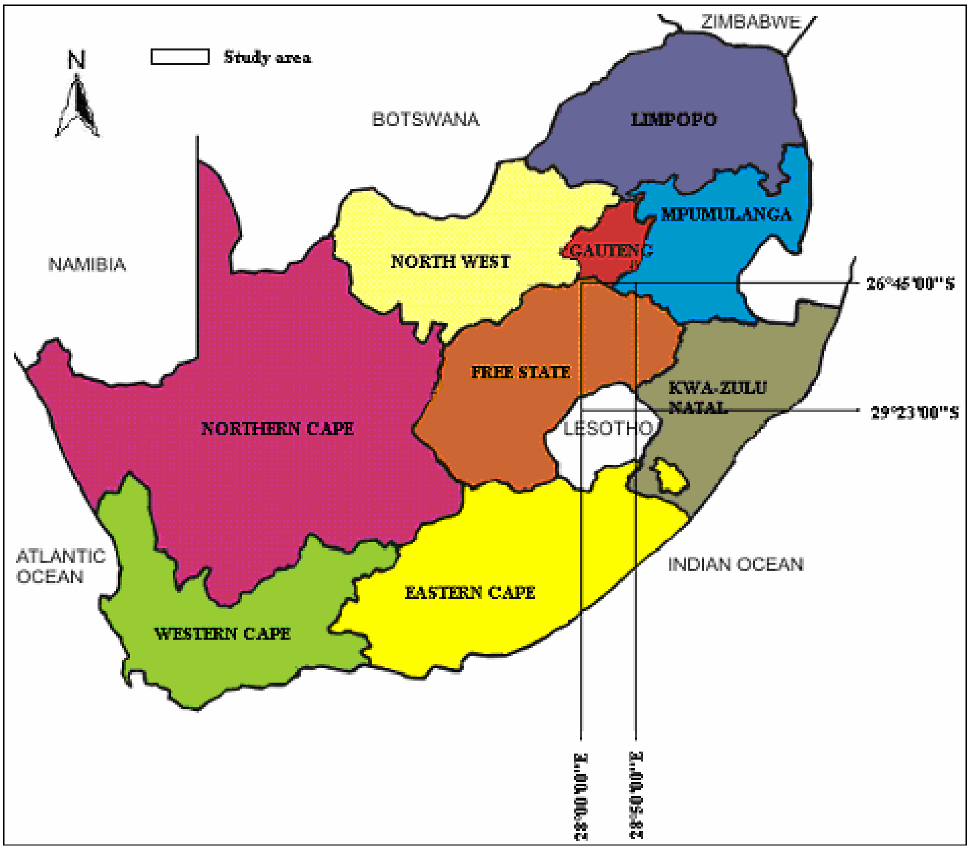

Figure 3: Location of the study area within Lesotho and the Free State province, South Africa.

(Adapted from Rand Water, 2002).

Figure 4: Ash River outfall tunnel (left) and water delivery pipe size (right).

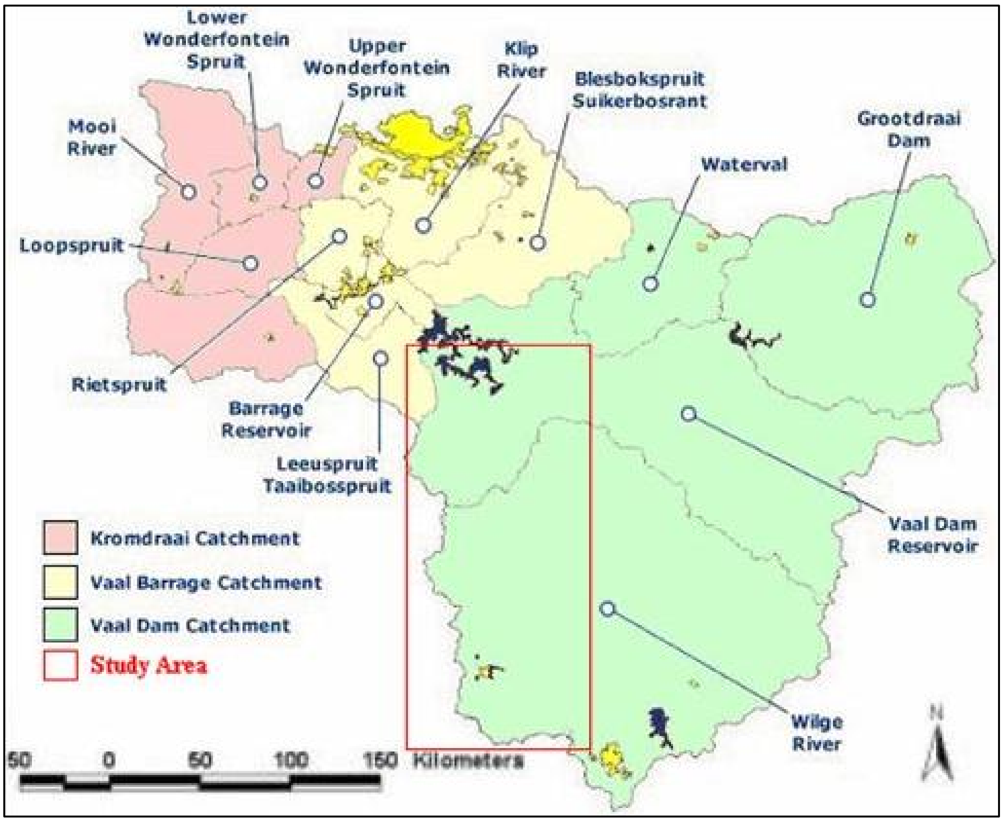

Figure 5: Location of the Vaal Dam reservoir and Wilge River sub-catchments in the upper Vaal catchment area.

(Adapted from Rand Water, 2006).

4.2 Physical factors that may have an influence on water quality

The quality of water is very sensitive to physical characteristics or factors of the area over which it flows, as well as those physical factors in a watercourse's vicinity. Physical factors that, *inter alia*, may have an influence on water quality include: climate (temperature and rainfall); geology; geomorphology; soils; vegetation; run-off and hydrology. The water quality entering South Africa from the LHWP may be affected by the physical factors in Lesotho (donor system) and may also be influenced by those in the Eastern Free State (receiving environment), that is, the Wilge River and Vaal Dam reservoir sub-catchments. Hence in this section, each of these physical factors will be discussed.

4.2.1 Climate

Donor system (Lesotho – Senqu River catchment)

The climate of Lesotho is characterised by warm moist summers - from November to March - and cold dry winters from May to July. Snow falls mainly in winter from May to September, but can occur in the mountains at any time of year. The climate is classified as semi-arid to sub-humid and continental. The southern lowlands are warmer and drier than the northern lowlands and mountains. Higher elevations (above 3 000 m above sea level) receive enough snow during winter to cover the ground for several months with sub-freezing temperatures. Frost occurs on over 80 days of the year in the lowlands and can occur on over 250 days in the year at high elevations. Temperatures in this region range from -8°C to 39°C, with an average temperature of 18°C (Lesotho Highlands Development Authority, 1997).

Lesotho lies within the summer rainfall area of Southern Africa and more than 85 percent of the annual rainfall occurs in the seven months from October to April. Mean annual precipitation ranges from 450 mm in the south-western lowlands to 1 600 mm in the northern lowlands and eastern highlands (Lesotho Highlands Development Authority, 1997).

Recipient system (Wilge River and Vaal Barrage sub-catchments - Eastern Free State, South Africa)

The climate in the eastern Free State Province is characterised by warm summers and cold winters. As with Lesotho, the eastern Free State experiences its warmest months from November to March, and its coldest months from May to July. The warmest month in the Wilge River sub-catchment is January, with an average maximum temperature of 26.9°C for this month recorded over the study period. July is the coolest month, with an average minimum temperature of -1.2°C recorded in the study period for this month and as illustrated in Figure 6.

The Wilge River sub-catchment falls within the eastern Free State and hence has a summer rainfall regime. The highest rainfall occurs in December and the lowest in July, as depicted in Figure 7.

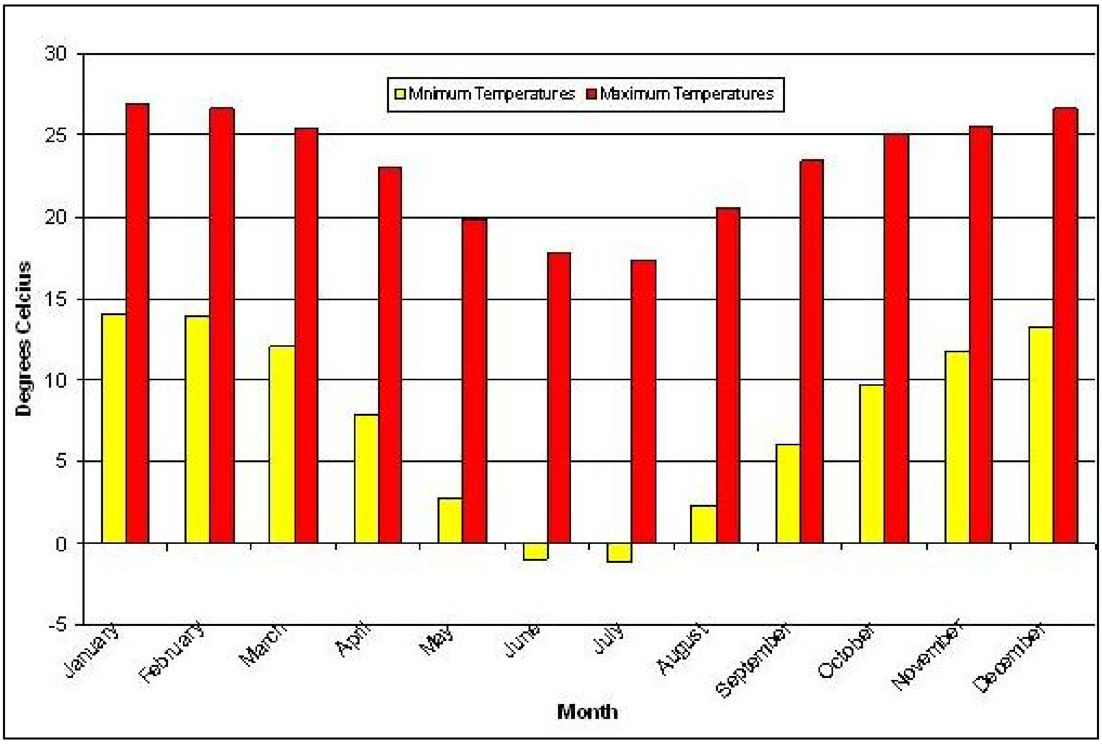

Figure 6: **Average minimum and maximum temperatures in the study area for the period January 1994 to December 2004.**

(Adapted from South African Weather Services, 2006).

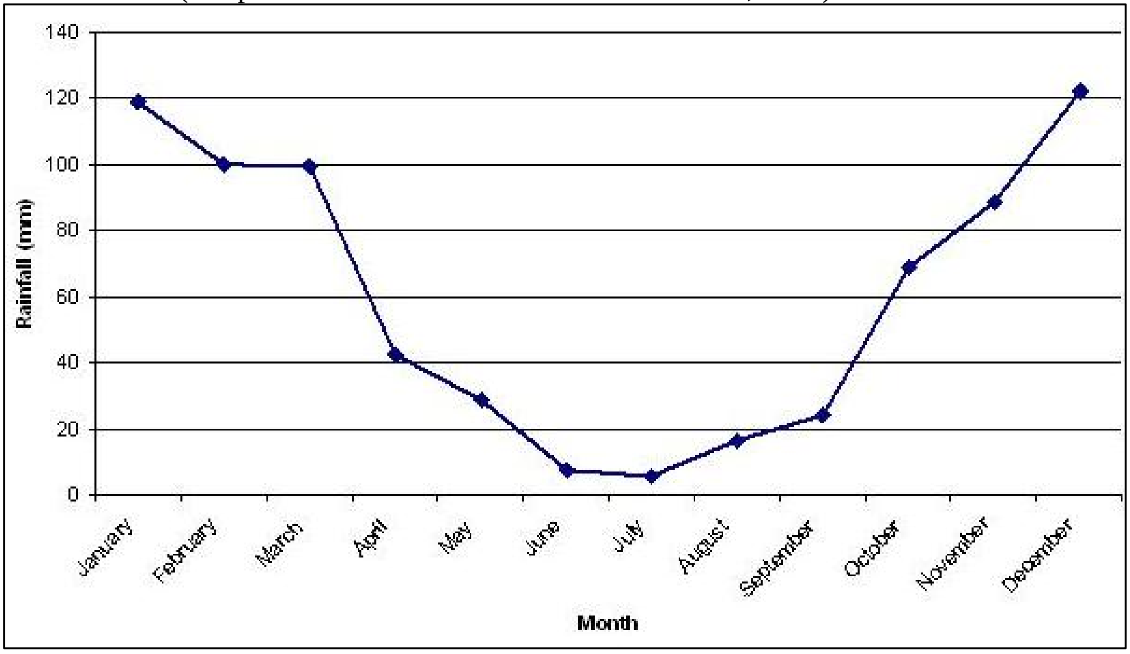

Figure 7: **Average monthly rainfall in the study area for the period January 1994 to December 2004.**

4.2.2 Geology

Donor system (Lesotho – Senqu River catchment)

Mostly arenaceous sediments and basaltic lavas of the Karoo Supergroup underlie the overall geological structure in Lesotho. These basaltic lava flows attain a thickness of at least 1 600 m and characterise the mountain region. The underlying sediments were capped by basalts during the tectonic evolution of the area in the early part of the Jurassic Period some 190 million years ago and are intruded by dolerite dykes and sills (Develay *et al.*, 1998). The sediments of the Karoo Supergroup in this region comprise the Clarens Formation, Elliot Formation, Molteno Formation and Beaufort Group. The LHWP's dams are found on either the basalt (Katse, Mohale, and Matsoku) or the underlying competent sandstone (Muela and future phase dams). Dominant rocks in the area include: sandstone; quartzite; mudstone and basalt (Van Rooy, 1993; Lesotho Highlands Development Authority, 1997).

Recipient system (Wilge River and Vaal Barrage sub-catchments - Eastern Free State, South Africa)

The geology of the South African section of the study area along the watercourse from the Ash River tunnel northerly towards its temporary base level, the Vaal Dam, is characterised initially by arenite and patches of mudstone. The Ash River upon joining the Liebenbergsvlei River extends a distance of approximately 125 km over predominantly mudstone with a few patches of arenite. Further downstream, approximately 150 km from the tunnel mouth, the river flows over predominantly shale with few patches of dolerite, mudstone and arenite. The geology of the South African section of the study area is depicted in Figure 8.

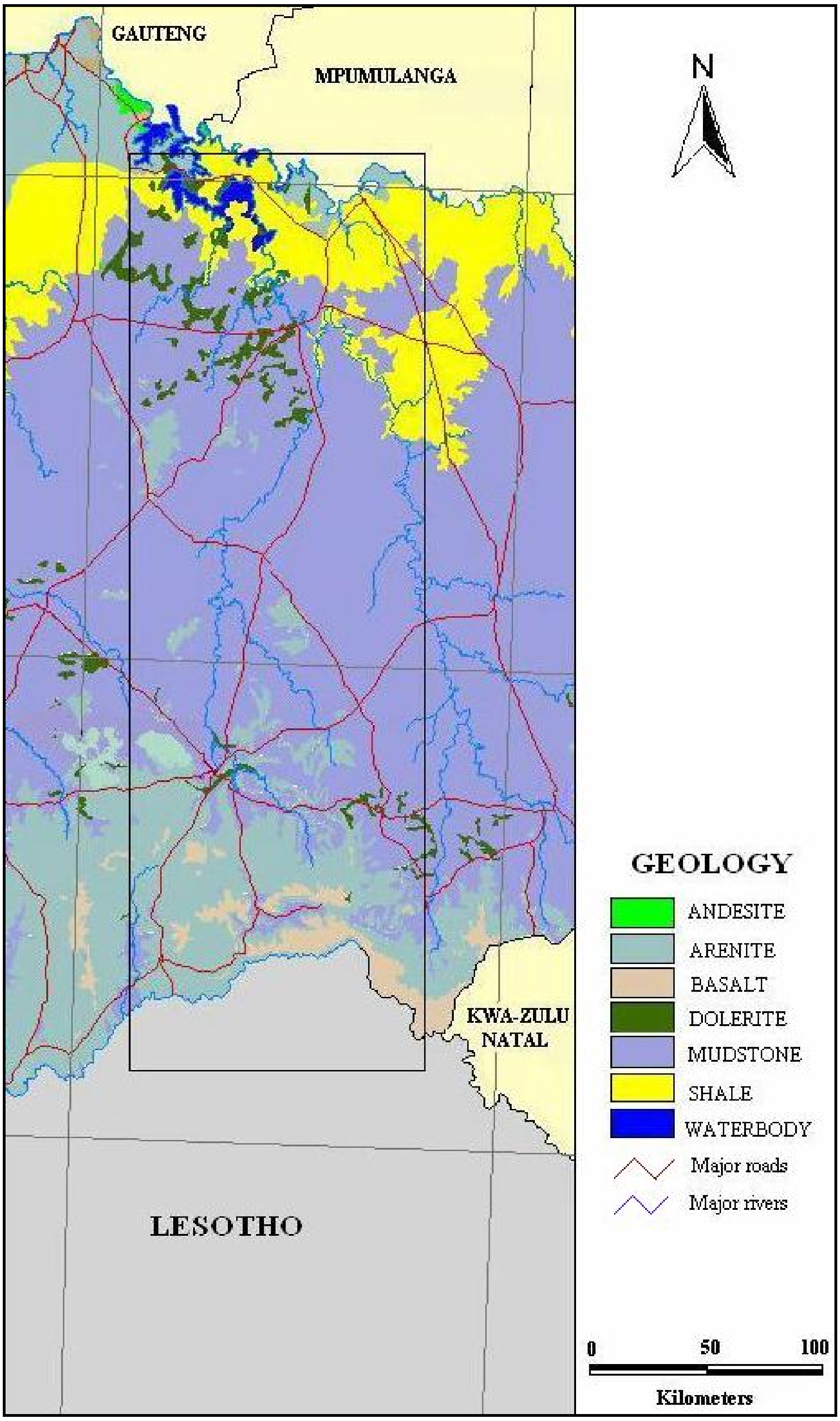

Figure 8: **Geology of the South African section of the recipient system.**

(Adapted from Council for Geoscience, 2000; Department of Environmental Affairs and Forestry, 2000).

4.2.3 Geomorphology

The regional geology of the Lesotho Highlands and the Eastern Free State, discussed in the previous section, largely determines the geomorphology of the study area. Structural discontinuities, especially major joins, fractures or faults, appear to have significantly controlled the development of the relief. Raised plateaus make up much of the higher ground in areas with contrasting weaknesses in rock type. Relief is an important physical factor that influences run-off and has the ability to cause erosion and the associated washing of sediment and pollution into streams and dams.

Donor system (Lesotho – Senqu River catchment)

The geomorphology of Lesotho can be broadly classified by the division between the lowlands and the mountains based upon geological structure and lithology. The lowlands are the regions, mainly in the west, where sedimentary strata outcrop below the escarpment formed by the Clarens Formation. The mountains include the eastern part of the country, which lies above the Clarens escarpment. The mountains are mainly formed in the basalts of the Lesotho Formation.

The LHWP originates in the highlands of Lesotho, known as the Maloti, and consists of an elevated and dissected plateau, with much of it lying above 2 000 m. The relief that is developed exhibits a high to very high landscape, which is typically gently undulating and well drained.

Recipient system (Wilge River and Vaal Barrage sub-catchments - Eastern Free State, South Africa)

The study area encompasses a mountainous area in the north and moves to an area of undulating plains in the south before joining the Vaal Dam. The Ash River tunnel, 80 km in length, protrudes northwards out of the mountainous Lesotho Highlands at an elevation of ~2 000 m above sea level. Various peaks with steep slopes are present in the southern part of the study area, ranging from 1 500 to 2 000 m above sea level. Further downstream, towards the north, the landscape gradually flattens out, to plains and hills with low to moderate relief (Figure 9).

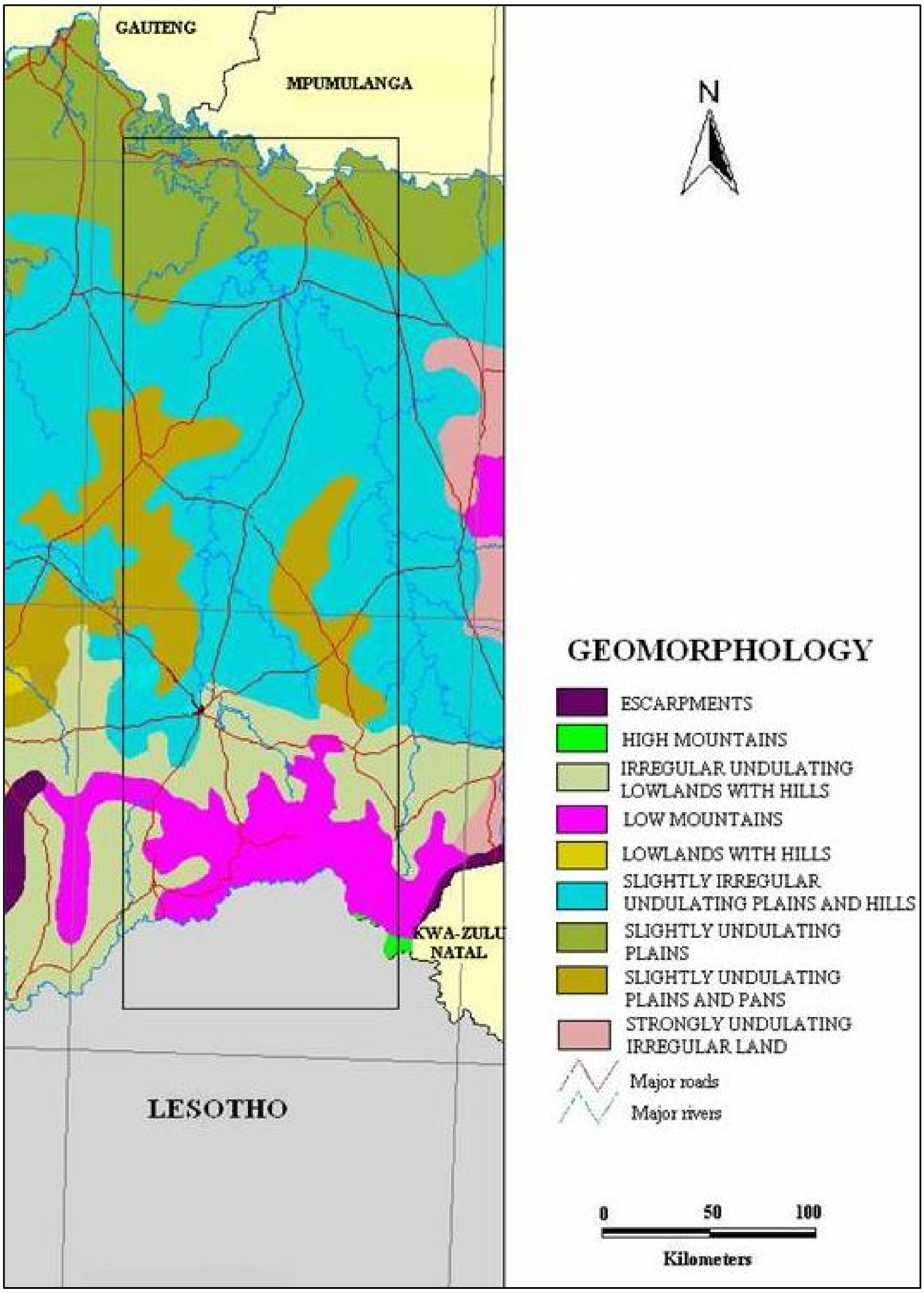

Figure 9: Geomorphology of the South African section of the recipient system.

(Adapted from Institute for Soil, Climate & Water, 2000; Department of Environmental Affairs and Forestry, 2000).

4.2.4 Soils

In both Lesotho and South Africa, a uniform underlying geology within each geomorphological unit, results in a definite set of soils.

Donor system (Lesotho – Senqu River catchment)

Predominant soils in Lesotho are sandy-clayey-loamy, sand-loam and sand-clay. Surficial deposits in the Lesotho Highlands are generally of very limited thickness. Exceptions to this occur where there are alluvial and colluvial deposits along river courses. Residual soils are seldom developed to a thickness in excess of three meters. The lack of depth of weathering is probably a consequence of the temperate climate of the Highlands.

The homogeneity of the parent material leads to soil properties that tend to differ by degree (i.e. texture, depth and drainage) rather than type. The mountainous nature of the terrain determines that large areas are steep and rocky with limited agricultural potential. Variations in soil type occur in limited areas in depositional depressions, foot slope concavities and along the main river courses. The residual soils on side and upper slopes are highly variable in depth and degree of stoniness and are more marginal for agriculture.

Recipient system (Wilge River and Vaal Barrage sub-catchment - Eastern Free State, South Africa)

Predominant soils in the eastern Free State are sandy-clayey-loamy, clay, and sandy-clay. The soils in the study area are described from south to north with reference to the soils depicted in Figure 10. The soils in the Ash River Tunnel mouth area can be described as reddish-yellow and greyish soils with a high base status. As one proceeds to move in a northerly direction the study area is dominated by soils with a marked clay accumulation (strongly structured and reddish in colour) for approximately 100 km. The northern extend of the study area is classified as black and red strongly structured clayey soils with a high base status, for a further 100 km, with areas of reddish-yellow and greyish soils with low to medium base levels on the northern perimeter of the Vaal Dam.

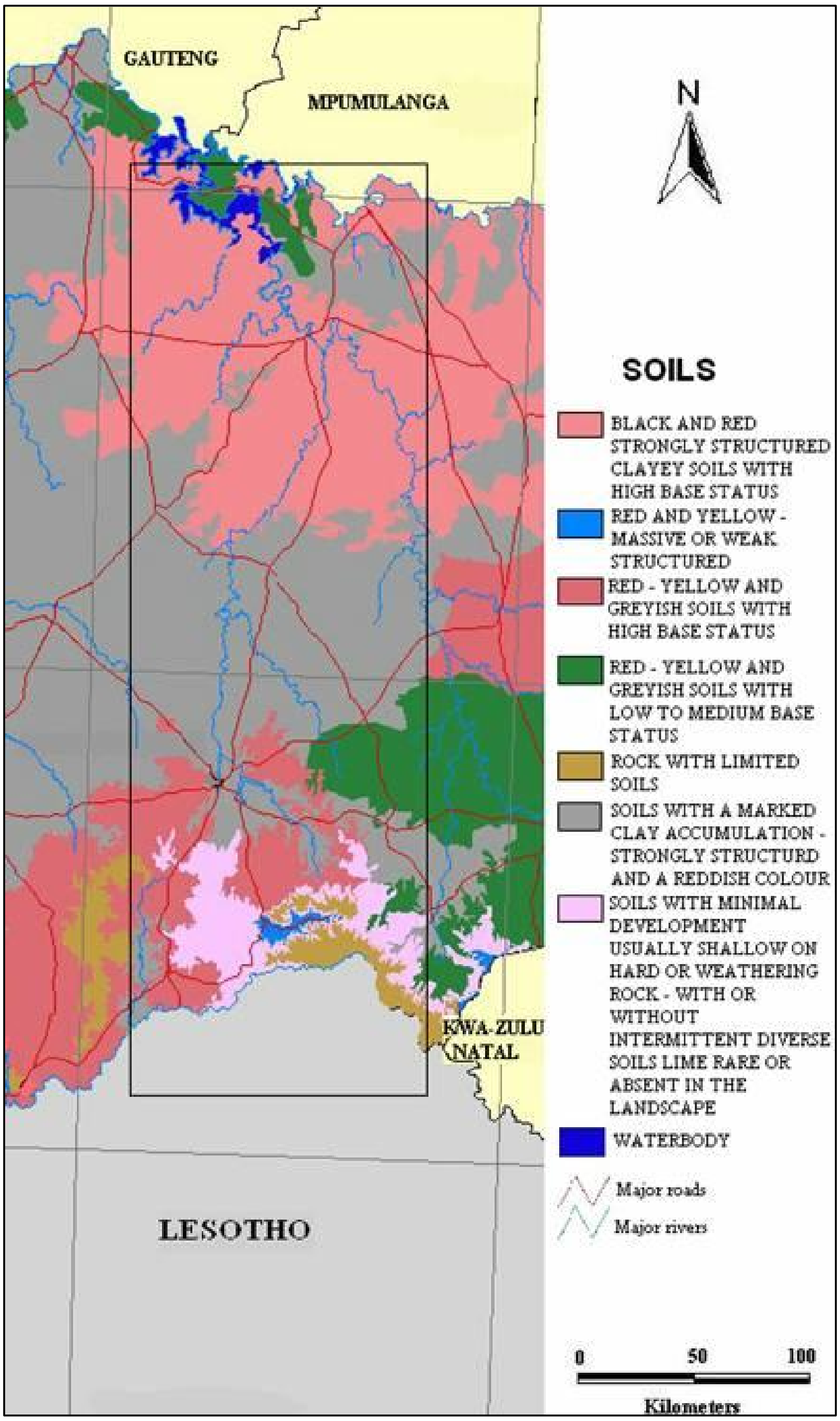

Figure 10: Soils of the South African section of the recipient system.

(Adapted from Institute for Soil, Climate & Water, 2000; Department of Environmental Affairs and Forestry, 2000).

4.2.5 Vegetation

Donor system (Lesotho – Senqu River catchment)

The lowlands of Lesotho support dense grassland with open woodlands and riverside willow thickets along major rivers. Escarpment slopes and sheltered kloofs and erosional hollows in the hills support dense woodlands with species such as *Podocarpus latifolius*, *Cussonia spicate*, *Euclea ramosa*, *Ocotea bulleta* and *Aloe capensis* (Germond 1967, Killick 1963, McVean 1977). Valley flats contain *tussock grass marshes*, *reed* and *Cyperus* beds that form natural water spreading systems over the flood plains, many of which are disappearing (McVean, 1977). These vegetation types extend to some 2 000 m above sea level and are at higher elevations succeeded by *Montana scrub*.

The sub-alpine belt contains sub-alpine scrubs which occur at elevations over 2 000 m above sea level, with the alpine belt occurring above this at 2 800 m. The former has been converted into temperate grasslands by fire (Jacot-Guillarmod, 1971; Weiland, 1982).

Recipient System (Wilge River and Vaal Barrage sub-catchments - Eastern Free State, South Africa)

Grasslands dominate the eastern Free State. The study area can be subdivided, from south to north, into areas classified as: *Highland Sour* veld and *Dohne Sour* veld; *Highland Sour* veld to *Cymbopogon-Themeda* veld transition (eastern Free State Highveld); *Cymbopogon-Themeda* veld (sandy); *Themeda* veld to *Cymbopogon* veld transition (patchy); and in the vicinity of the Vaal Dam back to *Cymbopogon-Themeda* veld (sandy) (Acocks, 1975) as depicted in Figure 11.

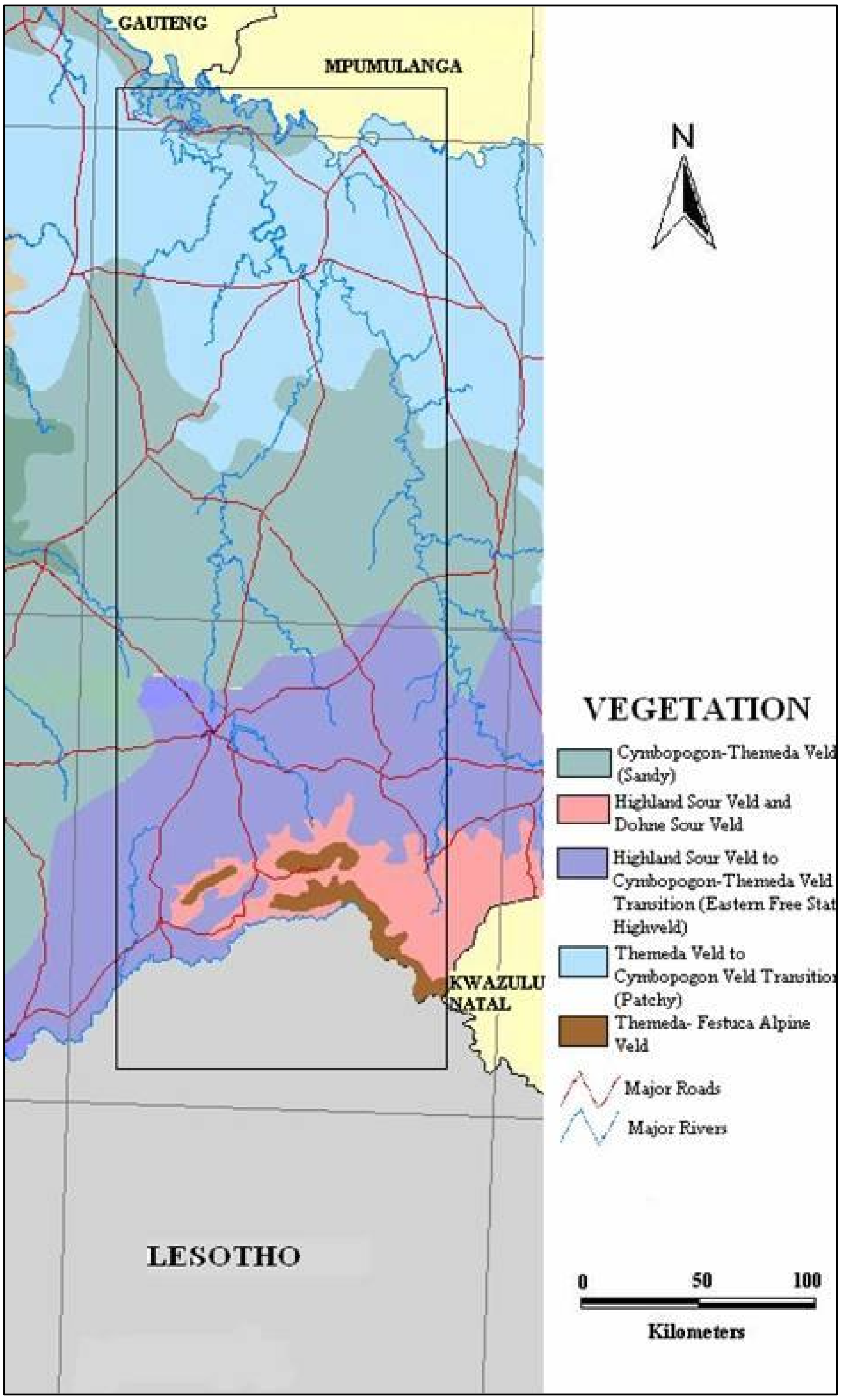

Figure 11: **Vegetation of the South African section of the recipient system.**

(Adapted from Acocks, 1975; Department of Environmental Affairs and Forestry, 2000).

4.2.6 Runoff

DWAF (2006) gives the mean annual runoff (MAR) for the eastern Free State as 600 to 900 mm and the MAR for Lesotho was given as 20 to 250 mm by the River Health Programme (2003). Runoff is important in terms of water quality because water is used as a means of transport for sediment and other polluting agents that eventually end up in streams and other watercourses.

Henning *et al.* (2002, p.26) report that in the majority of instances runoff is the prime vehicle for pollutant delivery, where contaminants from residential land use are conveyed to storm water drains and water bodies during rainfall events. Flood damage and water quality degradation is compounded by the abundance of impervious areas in the urban setting. Mountainous regions, areas with steep gradients or areas with poor vegetative cover are also more susceptible to increased runoff.

In Lesotho the areas of the catchment that have the highest mean annual precipitation also have the highest mean annual runoff. Rainfall occurs predominantly as high intensity and short duration thunderstorms. The nature of the rainfall, the rapid movement of water off the steep slopes and thin soils, results in a quick drainage reaction time in relation to surface runoff. The wet or rainy season, as previously mentioned, extends from October to March and runoff occurring during the dry or transitional months is often the result of snowmelt.

4.2.7 Hydrology – River flow characteristics

Donor system (Lesotho – Senqu River catchment)

The hydrology of Lesotho is characterised by a dendritic drainage pattern with high yields due to rapid runoff from steep slopes, and a highly variable flow regime. The Katse Dam has a capacity of 1 950 million m^3.

The Senqu River has a relatively greater base flow in relation to its flood peaks than the smaller and less altitudinally diverse catchment. Flows in both rivers decline to very low levels in the dry seasons of most years. Some large flood peaks in the lower Senqu have no corresponding flood peak in the Senqunyane as a result of localised rainfall over the upper Senqu and Malibamats'o (phase IA) catchments.

Recipient system (Wilge River and Vaal Barrage sub-catchment - Eastern Free State, South Africa)

The hydrology of the recipient system begins in the south of the study area at the Ash River tunnel. Water flows from this outlet tunnel, in a northwards direction, along the Ash River (Figure 12) and into the Saulspoort Dam (Figure 13). Two rivers flow into the Saulspoort Dam, namely, the Ash and Liebenbergsvlei Rivers, and exit north of the dam as the Liebenbergsvlei River. As the Liebenbergsvlei River continues to flow in a northerly direction (Figure 14) it is joined by tributaries, the Jordaan River (from the south) and the Klip River (from the west). The Liebenbergsvlei River then later joins the Wilge River (Figure 15) and flows into the Vaal Dam (capacity 2 603 million m^3) (Figure 16) as such (Figure 17).

Figure 12: The Ash River (northwards) in full flow after the release of Katse Dam water.

Figure 13: Looking westwards at the Saulspoort Dam, east of Bethlehem.

Figure 14: The upper Liebenbergsvlei River, Bethlehem.

Figure 15: The lower Wilge River at Frankfort.

Figure 16: The Vaal Dam, Oranjeville.

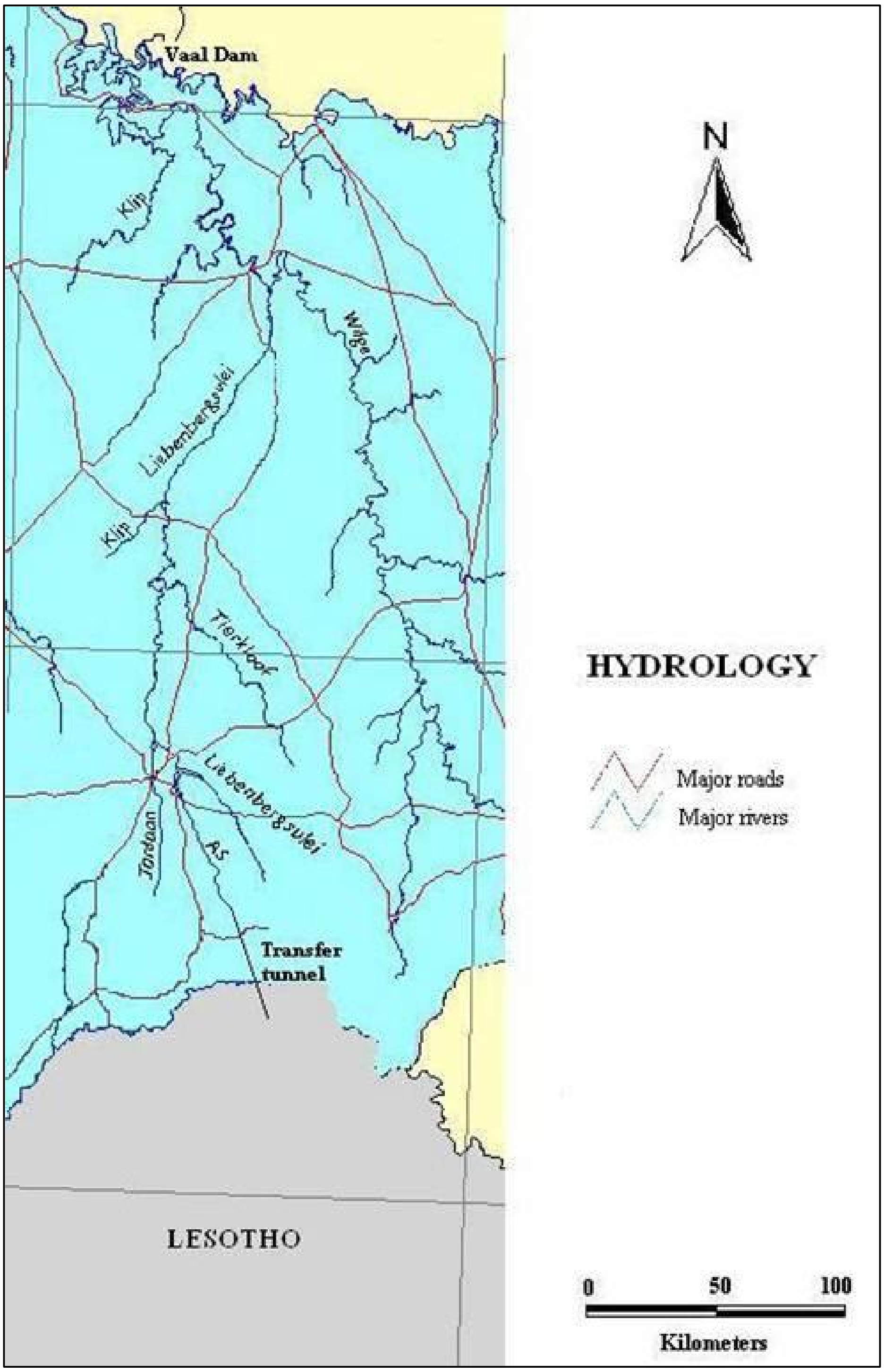

Figure 17: Hydrology of the South African section of the recipient system.

(Department of Environmental Affairs & Forestry, 2000).

4.3 Demographic factors that may have an influence on water quality

The quality of water is just as sensitive to demographic characteristics in the area as to the physical characteristics over which it flows. The demographic characteristic, that is land use in the area, will now be discussed with reference to both Lesotho (donor system) and the Eastern Free State (receiving environment).

4.3.1 Human land use

Donor system (Lesotho – Senqu River catchment)

The significant demographic factors in Lesotho that negatively affect the water quality in the study area comprise of built up areas, agriculture and mining (Lesotho Highlands Development Authority, 1997).

The human population in the Highlands generally live in villages, with a handful of larger settlements scattered through the region (Dennill *et al.*, 2003). Informal settlements do not have access to adequate sanitation. The low level of wealth, education and facilities in the area contribute significantly to diminishing the water quality in the nearby rivers (Lesotho Highlands Development Authority, 1997).

Agriculture is an important source of livelihood in the Highlands, but agricultural plots are constrained in size by the deeply incised topography and soil depths. Livestock (cattle, sheep, goats, horses and donkeys) is abundant in the area but overgrazing is a problem as livestock numbers equal wealth in rural areas. Only nine percent of Lesotho is arable land with the poor methods of agriculture resulting in soil erosion and increased sediment in surrounding rivers (Lesotho Highlands Development Authority, 1997).

Mining in Lesotho was expected to diminish the quality of water in the Kao and Malibamatso rivers due to the polluted runoff from the diamond mines but due to the mitigation measures put in place the effect has been eradicated and is at present minimal (Pottinger, 1997).

Recipient system (Wilge River and Vaal Barrage sub-catchment - Eastern Free State, South Africa)

The study area is dominated by cultivated, grazing or vacant land with few built-up areas. Both cultivated land and built-up areas can have a negative affect on water quality.

Ninety per cent of the South Africa's cherry crop is produced in the Ficksburg district (centre of the study area), while the two largest asparagus factories are also situated in this district. Soya, sorghum, sunflowers and wheat are predominantly cultivated in the study area, where farmers specialise in seed production. Approximately 40 percent of the country's potato yield comes from the high-lying section of the study area. Since of the release of Katse water, several fruit farms have been developed within the study area (Figure 18).

Figure 18: Fruit farms along the water course (Liebenbergsvlei River).

In cultivated areas fertilizers, insecticides and pesticides may be used to increase crop yields. These chemicals may be washed into streams and rivers during heavy rainfall, to join surface water or even infiltrate to join underground flow. If cultivated areas are poorly managed, they may also increase the amount of sediment washed into rivers owing to soil erosion.

Built-up areas may also affect the water quality by increasing the amount of sediments in rivers. This may be attributed to the increase in unnatural sealed surfaces, such as tar and concrete, which inhibit infiltration and therefore increase runoff. Built-up areas may also decrease water quality through pollution. This pollution may take on liquid or solid form, such as plastics, tins or sewage.

There are two built-up areas in the study area that may influence the results of this study, that of Bethlehem and Frankfort (Figure 19).

Water quality and water quality constituents will be discussed in the next chapter.

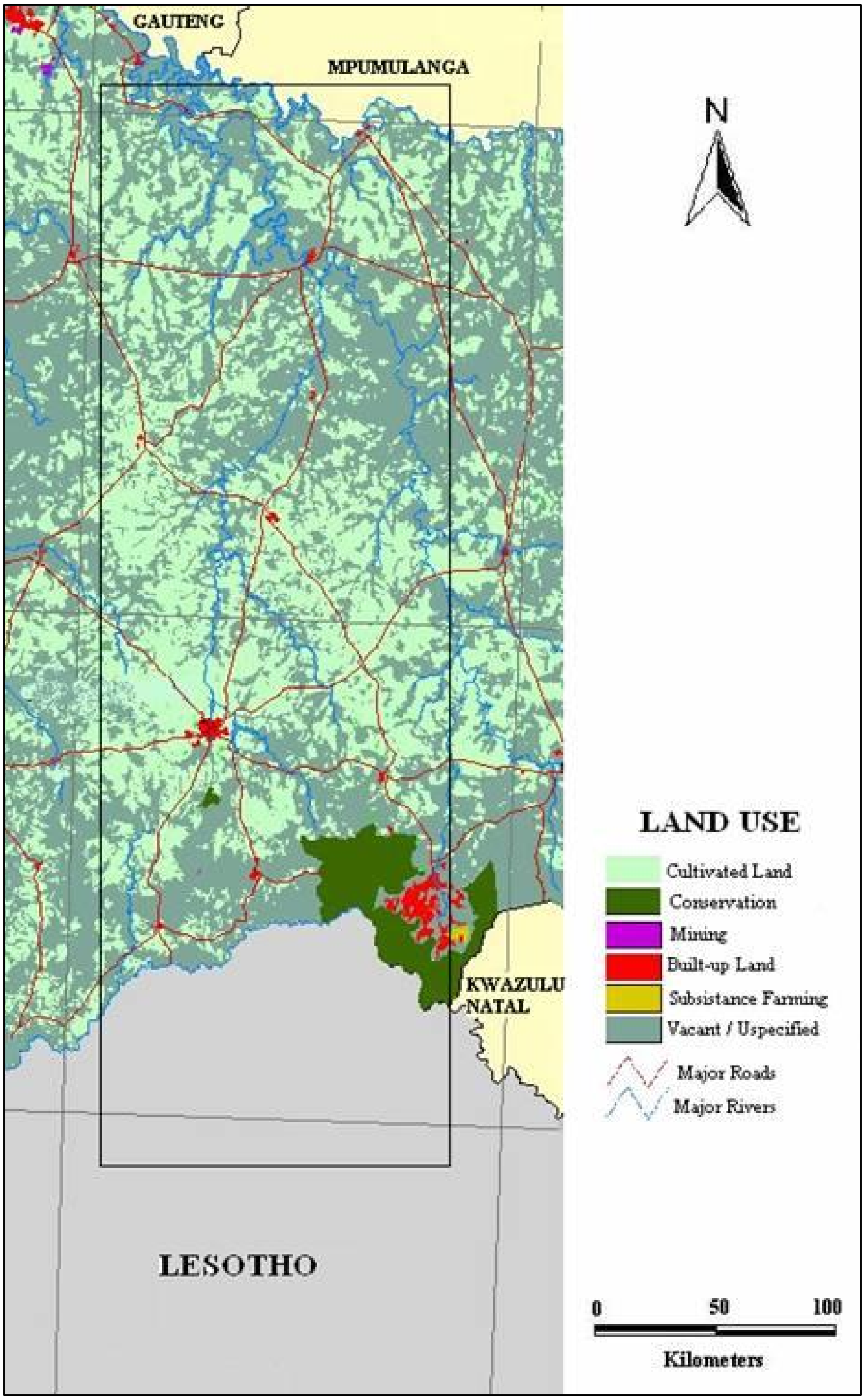

Figure 19: Land use in the South African section of the recipient system.
(Adapted from Department of Environmental Affairs and Forestry, 2000).

5. WATER QUALITY AND WATER QUALITY CONSTITUENTS

The term water quality is used to describe the physical, chemical and microbiological properties of water and it determines the fitness of the water for use (Boyd, 2000). These properties are influenced or controlled by substances, which are either suspended or dissolved in the water and can influence the usefulness of water for a specific purpose.

From a human perspective the term "water quality" was coined with reference to the quality of water required for human use: "good"-quality water is "pure", unpolluted and suitable for drinking and stock watering, and hence for agricultural and industrial purposes. It is critically important to acknowledge, however, that this is entirely a human perspective. Fresh water aquatic organisms might agree with this human perception, but it is not true for all aquatic organisms. The most obvious example is that of seawater, the quality of which is eminently suitable for marine organisms but utterly unsuitable for most human requirements (Dallas *et al.*, 1994).

This is also true for some inland waters and for all estuaries. Some wetlands naturally have highly saline or alkaline waters to which the biota are adapted. Improving the water quality of these systems would be tantamount to killing off the natural biota. Some of the biologically richest Andean lakes, the waters of which support large flocks of rare and endangered flamingos, would kill a human (Dallas *et al.*, 1994).

One must therefore be extremely wary of "improving" water quality to something approaching that acceptable to humans if, in doing so, one is making it less tolerable for the natural inhabitants. When managing aquatic ecosystems it is imperative that water quality is viewed not only from a human perspective but also from that of the natural inhabitants.

Selected water quality constituents are discussed in the following sections.

5.1 Physical constituents

Physical water quality refers to properties that are determined by physical methods such as electrical conductivity (EC), chemical oxygen demand (COD), pH and turbidity measurement. Physical quality mainly affects the aesthetic quality, such as taste, odour and appearance of water (WRC, 1998).

5.1.1 Electrical conductivity

Kempster & van Vliet (1991) explain that electrical conductivity is used to measure the ability of a water sample to conduct an electrical current. Conductivity is measured in milliSiemes per meter (mS/m). Pure water will not conduct an electrical current. According to the World Health Organisation (WHO, 1994) inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium, iron and aluminium affect conductivity levels. Conductivity increases in direct proportion to dissolved ion concentrations (Boyd, 2000).

DWAF (1996a, p.167) concludes that the total dissolved solids (TDS) concentration is directly proportional to the electrical conductivity (EC) of water and since the EC is much easier to measure than the TDS the electrical conductivity is in actual fact an estimate of the total dissolved solid concentration.

The underlying geology of an area can affect conductivity levels. Streams that run through areas with granite bedrock tend to have lower conductivity because granite rock is composed of materials that do not ionise in water. Streams that receive large amounts of runoff containing clay particles generally have higher conductivity because of the presence of minerals in clay that ionise more readily in water (Westphal, 2000). The electrical conductivity also depends on physical processes such as evaporation and rainfall.

The electrical conductivity is generally low in rainwater (less than one mg/l) and low in water in contact with granite, siliceous sand and well- leached soils (less than 30 mg/l) (DWAF, 1996a). The concentrations are much higher in water in contact with Precambrian shield areas, and in the range of 200 to 1 100 mg/l in water in contact with Paleozoic and Mesozoic sedimentary rock formations (DWAF, 1996a).

DWAF (1996g, p.125) writes that individual ions making up the TDS exert physiological effects on aquatic organisms. The changes in the concentration of the TDS can affect these organisms on three levels: effects on as well as the adaptations of individual species, the effects on community structure and on microbial and ecological processes which include rates of metabolism and nutrient cycling.

5.1.2 Chemical oxygen demand

DWAF (1996c, p.27) defines chemical oxygen demand (COD) as "…a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant." The COD gives therefore an estimate of the presence of organic matter in a water body.

Two forms of organic matter exist, namely autochthonous organic matter, which arises in a water body through the growth and death of aquatic organisms, and allochthonous organic matter, which originates outside the water body. Human activities such as agriculture and stock farming and the production of industrial and domestic wastes are significant sources of organic matter in the aquatic environment.

The COD test does not distinguish between the organic and inorganic matter in a sample. There is, however, a direct empirical relationship between the COD, the biological oxygen demand (BOD) and the total organic carbon (TOC) for samples from a specific source.

5.1.3 pH

Spellman (1998) explains that the power of hydrogen (pH) scale ranges from zero (high concentration of positive hydrogen ions, strongly acidic) to 14 (high concentration of negative hydroxide ions, strongly basic). DWAF (1996b, p. 75) summarises that at a pH of less than seven for water is acidic, while at a pH of greater than seven, water is alkaline.

According to DWAF (1996d, p.127) the pH of most raw water lies in the range of 6.5 to 8.5. Biological activities such as the nutrient cycling and anthropogenic source (industrial effluent discharge) respectively may give rise to fluctuations in the pH. DWAF (1996f, p.135) explains that precipitation is usually acidic because it contains carbon dioxide, where the atmosphere is polluted by industrial emissions of sulphur dioxide or nitrogen oxides, the pH of rain may be further decreased because of the fact that these oxides form strong acids when in contact with water.

5.1.4 Turbidity

Turbidity is a condition in water caused by the presence of suspended matter, resulting in the scattering and absorption of light rays, i.e. turbidity is a measure of the light-transmitting properties of water. Natural water that is very clear (low turbidity) allows one to see images at considerable depths whilst high turbidity water appears cloudy. Low turbidity does not mean that water is without dissolved solids. Dissolved solids do not cause light to be scattered or absorbed; thus, the water looks clear. High turbidity causes problems in water quality. In water, components that cause high turbidity can cause taste and odour problems (Spellman, 1998).

Most natural waters have turbidities less than 50 Nephelometer Turbidity Units (NTU), but values can range from 1 NTU to 1 000 NTU or more (Boyd, 2000).

5.2 Chemical constituents

The nature and concentration of dissolved substances such as salts, metals and organic chemicals are referred to as the chemical qualities of water. The chemical composition of natural water is derived from many different sources of solutes such as gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, precipitation reactions under ground and cultural effects resulting from human activities (Hern, 1989).

The ways in which solutes are taken up or precipitated and the amounts present in the solutions are influenced by factors such as the climate, structure and position of rock strata. The biological effects associated with both the microscopic and macroscopic cycles of plants and animals together with the hydrological cycle also contribute to anthropogenic pollution. The interaction if all these principles, forms the basis for the science of natural- water chemistry (Hern, 1989).

Many chemical substances in water are essential as part of the daily intake required. However, at high concentrations they make water unpalatable and may cause illnesses.

5.2.1 Ammonia

According to DWAF (1996a, p. 23) ammonia is a common pollutant and is one of the nutrients contributing to eutrophication. Holmes *et al.* (1993, p. 201) state that the eutrophication problem can be defined as "…the input of organic and inorganic nutrients into a body of water which stimulates growth of algae or rooted aquatic plants, resulting in the interference with desirable water uses of aesthetic, recreation, fish maintenance, and water supply."

DWAF (1996a, p.23) continues that commercial fertilizers contain highly soluble ammonia and ammonium salts. Other sources of ammonia include: sewage discharge; discharges from industries that use ammonia or ammonium salts in their cleaning operations; the manufacture of explosive and the use of explosives in mining and construction;

atmospheric deposition of ammonia from distillation and combustion of coal; and the biological degradation of manure.

5.2.2 Calcium

Calcium is an alkaline earth metal and the main cation in waters. It is found naturally in various concentrations in most waters and together with magnesium is responsible for water hardness. The higher the concentration of Ca the harder the water. Calcium is essential for living organisms and is an important constituent of the bony skeleton of mammals, which consists of phosphates of calcium (DWAF, 1996c).

Calcium arises in water systems either by sulphate and silicate dissolution or due to the action of dissolved carbon dioxide in water from the Ca present in limestone, dolomites and loams (Galvin, 1996). Typical concentrations of Ca in fresh water are 15 mg/l and in sea water approximately 400 mg/l (DWAF, 1996c). The small intestine regulates the uptake of calcium and excessive calcium is excreted via the urine of the animal. Failure of intestinal uptake control may result in calcification of the kidneys of livestock (Forrest *et al.*, 1991). Hypocalcaemia is often associated with hyperparathyroidism and the effect includes the softening and bending of bones, osteoporosis and an increase of calcium and phosphorus excretion in the urine. This may lead to nephrocalcinosis and renal stones. The polar effects are dependant on the calcium to phosphorus ratio (DWAF, 1996b).

Calcium is considered non-toxic for most living organisms and hence no negative health effects result there from. Except for economical reasons, such as scaling of hot water systems and pipes, no significant health effects are listed.

5.2.3 Manganese

DWAF (1996g, p. 83) states that natural sources of manganese include soils, sediments and metamorphic and sedimentary rocks. Industrial discharges account for elevated concentrations of manganese in receiving waters. Various industries use manganese, alloys of manganese as well as manganese compounds in their processes, or in their products. These industries include the steel industry, in the manufacturing of dry cell batteries; the fertilizer industry (as a micro-nutrient fertilizer additive); and the chemical industry in paints, dyes, glass, ceramics, matches and fireworks. Acid mine drainage also releases a large amount of manganese. The chemical behaviour of iron and manganese are similar, and are frequently found in association with each other. DWAF (1996e, p.91) explains that manganese is more stabilised in solution than iron and is difficult to remove form solution except at a high pH, where it precipitates as a hydroxide. Manganese at typical concentrations, up to 5.0 mg/l, has a lowered aesthetic effect on water rather than a toxic effect.

The central nervous system of vertebrates can be interfered with at high concentrations of manganese (DWAF, 1996f, p.98). Manganese acts through inhibition of the formation of dopamine (a neurotransmitter), as well as interference with other metabolic pathways.

5.3 Microbiological constituents

Microbiology is a branch of biology, the science of life, which deals with the study of organisms that are mainly microscopic in size and thus cannot be readily seen except with the aid of a microscope (Spellman, 1998).

Aquatic organisms play a central role in water quality, microscopic algae, called phytoplankton, and bacteria are organisms that have the greatest influence on water quality. Phytoplankton produce large amounts of organic matter through photosynthesis and during this process release large quantities of oxygen into water. Bacteria decompose organic matter and cause many transformations of chemical compounds. The respiration of bacteria and the respiration and photosynthesis of phytoplankton have a pronounced effect on pH and concentrations of carbon dioxide and dissolved oxygen in water. Certain bacteria and other microscopic organisms are pathogenic, and some species of algae can impart bad tastes and odours to water (Boyd, 2000).

5.3.1 Chlorophyll a

Chlorophyll is present in highly specialised organelle, the chloroplasts that are present in green leaves and stems in plants. *Chlorophyll a* is the pigment directly involved in transformation of light energy into chemical energy. In addition to *chlorophyll a*, plants possess differently coloured accessory pigments (*chlorophyll b* and *xanthophylls*) that absorb light in different wavelengths from that of *chlorophyll a* and pass the absorbed energy to *chlorophyll a*. This allows maximum absorption of solar energy for synthesis of carbohydrates during photosynthesis (Sridharan, 2006).

Chlorophyll a concentration is used as an approximate index of *algal* biomass and is measured in either µm/L or ppb (Iowa Department of Natural Resources, 2006). The amount of particulate *chlorophyll a* is the most accurate indicator of the abundance of phytoplankton *algae*. Changes in *chlorophyll a* concentrations are indicative of changes in trophic state, the extent to which a water body is enriched with plant nutrients (City of Cambridge, 2006). Two nutrients in particular, nitrogen and phosphorus, are essential to algal growth (Horner, 2006).

The presence of algae in an ecosystem is normal. However, in large amounts, algae can adversely affect water quality. When algae decompose, they consume copious amounts of dissolved oxygen, creating an oxygen-deprived environment for aquatic animals. Excessive algal growth can also inhibit the passage of sunlight through water, harming other plants by reducing the amount of light they receive (Horner, 2006). A major contributor to unwanted algal growth is the influx of nutrients from non-point sources such as over-fertilized lawns, seepage from sewage lines, and livestock waste runoff (Horner, 2006).

The following chapter deals with the data obtained from the water sampling points with respect to data collection at the sampling sites, as well as the shortcomings of the data.

6. DATA COLLECTION AND METHODOLOGY OF SURFACE WATER ANALYSIS.

6.1 Data collection and location of sample sites

Water quality data for the six sample points in the study area were collected twice monthly and analysed by Rand Water. The results range over the period from November 1994 until December 2005. The data for this study cover an eleven-year period, that is, five years prior to the completion of the Katse Dam in Lesotho, and six years thereafter.

This study will focus on selected sampling points within the Wilge River and the Vaal Dam reservoir sub-catchments. For the purpose of this study, additional site codes have been assigned to the standard Rand Water Board sample point names (Table 2). The sampling points are listed in order from points closest to the Katse Dam downstream towards the Vaal Dam (Figure 20).

Table 2: Naming of sample points operated by Rand Water.

DESCRIPTION OF SAMPLE POINT	SAMPLE POINT NAMES	
	RAND WATER SAMPLE POINTS	THIS STUDY SAMPLE POINTS (SP=Sample Point)
Liebenbergsvlei Ash River	C-WLA	SP1
Saulspoort Dam at Bethlehem	C-SPD	SP2
Liebenbergsvlei River	C-WL	SP3
Wilge River above Frankfort	C-WAF	SP4
Wilge River at Frankfort	C-WF	SP5
Wilge River downstream of Oranjeville	C-VD3I	SP6

The abovementioned sampling points are all situated in the Upper Vaal catchment area, Free State Province, South Africa. Water quality results (analyses) were obtained from Rand Water, for the period November 1994 to December 2005.

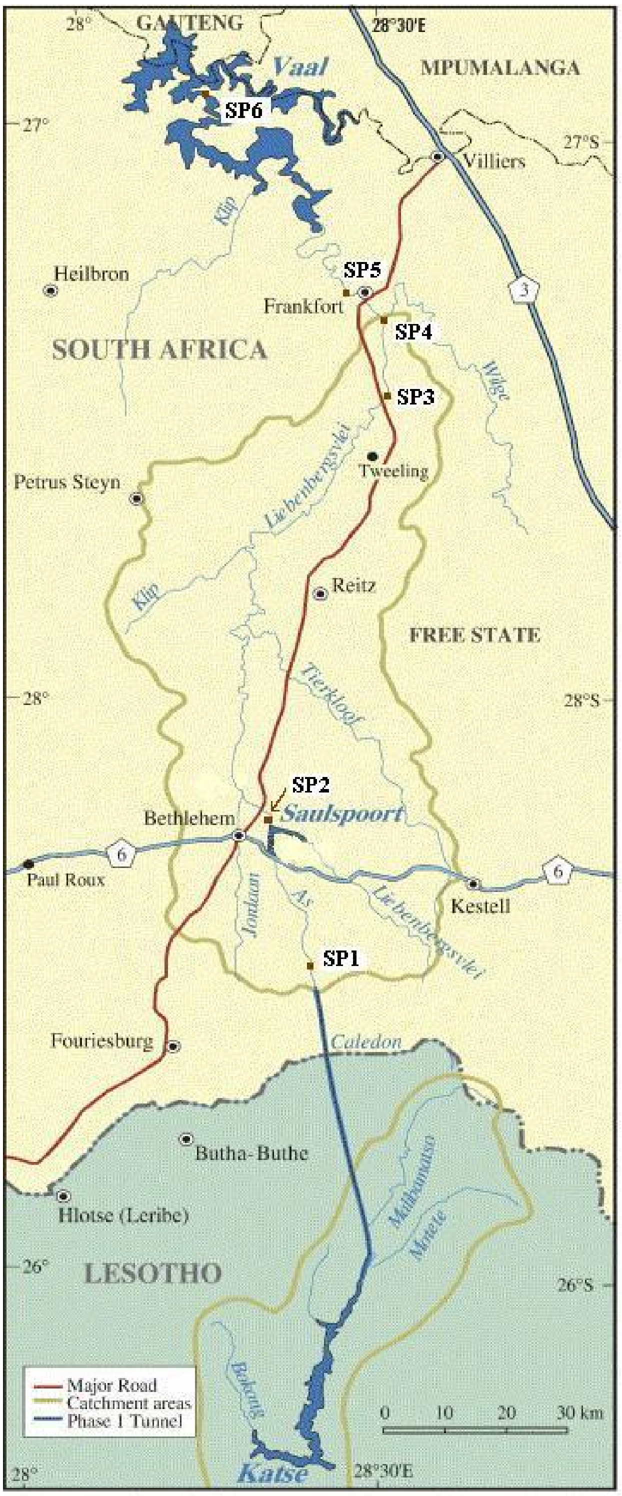

Figure 20: **Location of sample points in the South African section of the demarcated study area.**

(Adapted from Chutter & Ashton, 1990).

6.2 Analysis of data

Various physical, chemical and biological constituents of the water quality data were analysed as advised by Van Wyk (2006). The data obtained from Rand Water were used to establish spatial and temporal variations for each constituent at each of the six sampling sites over the historical period in question.

The data supplied in PDF format were converted to MS Excel format for statistical manipulation and analysis. The outliers were removed and replaced by an average for the specific parameter per locality. The data were then expressed graphically in the form of line graphs to visualise the spatial and temporal tendencies of each water quality constituent over the period prior to and after the construction of the Katse Dam.

Trends in the data for specific constituents per locality were then determined if possible and long-term tendencies for this period were indicated. The VBCEC In-Stream Water Quality guidelines from Rand Water were then used to evaluate each constituent over the historical period in question (Table 3).

Table 3: Vaal Barrage Catchment Executive Committee In-Stream Water Quality Guidelines

(Rand Water, 2006).

Variables	Units	Catchment Background	Management Target	Interim Target	Unacceptable
Physical					
EC	mS/m	<18	18 – 30	30 - 70	>70
pH	pH Units	7.0 – 8.4	6.5 - 8.5	5.0 - 6.0	<6.0; >9.0
Turbidity	NTU				
Organic					
COD	mg/l	<10	10. – 20	20 - 30	>30
Macro Elements					
NH_3	mg/l		<0.5	0.5 - 1.0	>1.0
Ca	mg/l	<15	15 – 70	70 - 150	>150
Mn	mg/l		<0.15	0.15 - 0.2	>0.2
Biological					
Chlorophyll a	ug/l	<5	5. – 15	15 - 30	>30

6.3 Shortcomings of data

Van Wyk (2006) explains that the variables shown in Table 3 above were found to be the most critical variables to be tested for in the Vaal Dam reservoir and Wilge River sub-catchments. Thus only these variables were concentrated on.

Abbreviations for the different variables, as well as the units in which they are measured, are depicted in Table 3. The limited number of analysed variables by Rand Water is considered as a shortcoming in the database used for this study, because information about other variables that could have been valuable could not be included here.

The sampling period ranges over an eleven-year period, from November 1994 until December 2005. Initially the author intended to consider data over a sixteen-year period, eight years prior to the construction of the Katse Dam and eight years thereafter, so as to have a comparable time period. As a result of the insufficient collection of data before 1995 only an eleven-year time period has been used.

The data collection was also very inconsistent, especially for the years prior to 1999, which contained a substantial number of missing data.

The volume of water released from the Katse Dam into the study area, the influence of rainfall, and the water quality analytical results, as obtained from Rand Water, will now be discussed.

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7. RESULTS AND DISCUSSION

The chemical composition of inland water is determined by many factors, including soil and rock composition of the catchment area, climatic conditions, amount and chemical composition of rainfall, flora, anthropogenic (human) influences as well as the quantity and quality of water entering the system. The water quality can therefore vary both spatially and temporally. Consequently, water quality results cannot be interpreted without taking cognisance of the aforementioned.

To determine the change in water quality as a result of water entering the study area from the Katse Dam, the volume of water released into the system as well as its effect on certain constituents were examined and judged according to the VBCEC in-stream water quality guidelines while taking rainfall into consideration. The volume of water released from the Katse Dam will now be discussed followed by rainfall in the study area and the water constituents which will be divided into three main headings: physical constituents; chemical constituents and micro-biological constituents.

7.1 Volume of water released from the Katse Dam

King *et al.* (2000) inform us that the manipulation of flow regimes of rivers, to provide water when and where people need it, has resulted in a growing deterioration in the condition (health) of riverine ecosystems. Concern over worldwide deterioration in the health of rivers has historically centred mainly on problems of water quality. In the last two to three decades, however, it has become increasingly obvious that a major factor causing their deterioration relates to the quantity of water in the rivers (King *et al.*, 2000).

The flow regime is one of the overriding determinants of the character of a river ecosystem, reflecting its geographic location and the geological and topographic features of the area (Statzner & Higler, 1986). Ecosystem components such as channel type and patterns, water chemistry and temperature, and the biotas of channel, bank and associated wetlands reflect the nature of the river’s flow pattern. In rivers where man has altered the flow, all of these components are likely to change from their historical condition, with the degree to which this happens reflecting the severity of the flow manipulation (King *et al.*, 2000).

Figure 21 indicates the volume of water released from the Katse Dam into the study area from 1998 to 2005. The volume of water released has an upward trend and indicates an increase in the amount of water released over time. The volume of water released from the Katse Dam into the study area has consistently been above the required Treaty guaranteed minimum flow of 500 litres per second (Lesotho Highlands Development Authority, 2003). Over and above this, the release has at times been problematic as the volume of water released is predominantly based on Lesotho's need for hydroelectricity, and consequently large quantities of water released from Lesotho is wasted, through runoff, evaporation, etc., when South Africa has a high rainfall season, and dams and rivers are at their capacity. Hence, South Africa is paying for water and reaping no benefits from this cost.

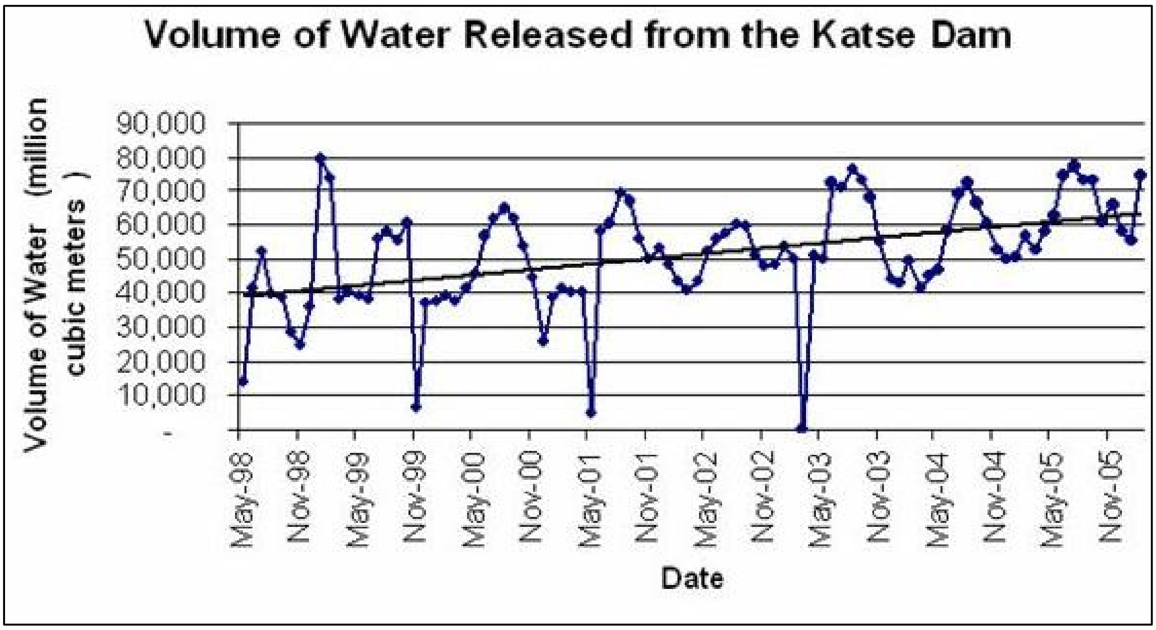

Figure 21: Monthly volume of water released from the Katse Dam.

(Adapted from Viljoen, 2006).

Figure 22 reflects the change in flow at selected registered flow points in the study area during the period. The change in flow can be attributed to rainfall at or upstream of the flow register point or the volume of water released upstream from the Katse Dam. The peaks that occur in the summer months are predominantly attributed to rainfall. Peaks in the figure that correlate with either peaks or troughs in the water quality constituents (section 8.3) may be an indication of the affect of water from the Katse Dam. The volume of water passing the registered flow points increases downstream as expected.

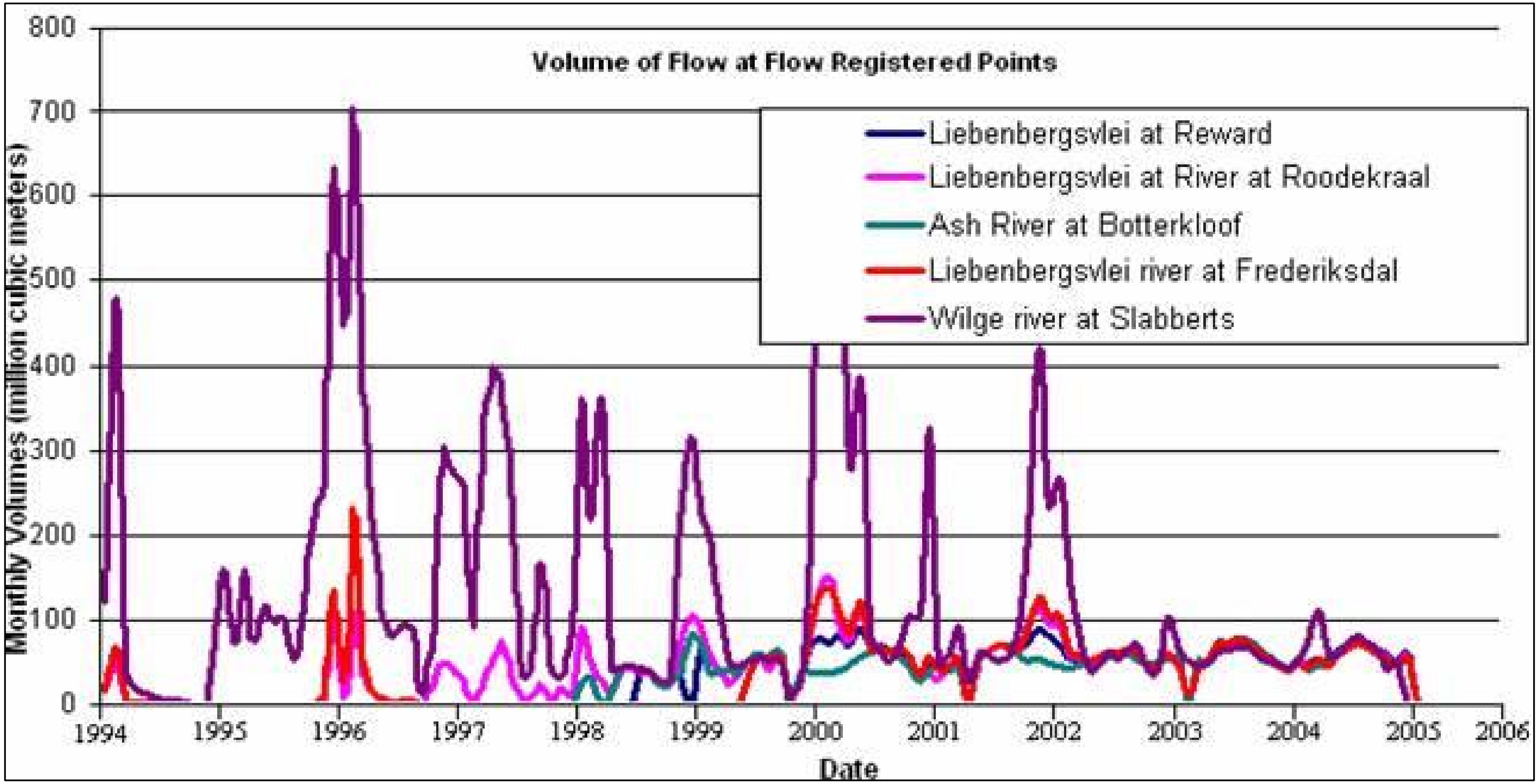

Figure 22: Volume of flow at flow registered points.

(DWAF, 2006).

7.2 Impact of rainfall on water quality

It is a fact that water is used as a means of transportation for sediment and other polluting agents that eventually end up in streams and other watercourses. Exposed soil is particularly susceptible to soil erosion during heavy rainfall by means of sheet flow and splash erosion. During variable rainfall periods, sediment is washed into streams resulting in an increase in sediment at temporary base levels. It is thus the quantity and nature of rainfall that is the major determinant of the sediment present in rivers. The author thus concludes that rainfall can have a significant effect on water quality.

Rainfall data were obtained from the South African Weather Services for the following stations: Frankfort, Parys, Barrage, Vanderbijlpark, Vereeniging, Clarens, Witsieshoek, Kestell and Reitz exclusively for the period ranging from January 1994 until December 2004. The raw data were reworked into a graphical format.

As indicated in Figure 23, it is clear that rainfall was at its peak in December 1995, and at its lowest in July 1999. Most rainfall occurred during the summer months from October until March, as previously mentioned, the winter months were mostly dry.

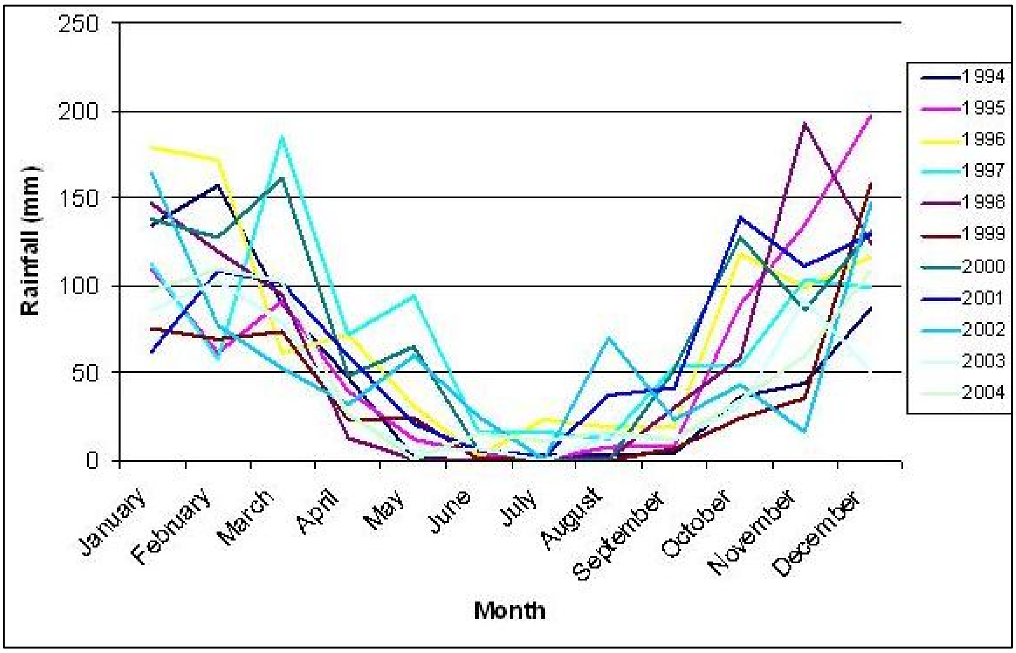

Figure 23: Average monthly rainfall in the Vaal Dam reservoir and Wilge River sub-catchments for the years 1994 until 2004.

(Adapted from SA Weather Services, 2006).

As previously mentioned (section 4.2.1), the area receives summer rainfall and hence peaks occur during the months October to March. Rainfall affects water quality and consequently peaks in the figures that follow may be attributed to this. Peaks occurring in the water quality figures during winter months may then be accredited to an associated influx of Katse Dam water, depicted in Figure 21, thus emphasizing the effect of the LHWP on the study area.

7.3 Water quality

As previously mentioned Van Wyk (2006) explains that the variables shown in Table 3 were found to be the most critical ones to be tested for, as prescribed by the VBCEC In-Stream Water Quality Guidelines. Accordingly only these variables were concentrated on. Rand Water (2001) uses the table to delineate the catchment background; management target; interim target and unacceptable values for the selected constituents against which the sampling point analytical results are compared. This study will focus on the classification by Rand Water. Recommendations will be considered by taking into account the results of this classification.

Water quality results for the different sampling points, with the corresponding sampling dates for the sampling period, namely November 1994 until December 2005, are illustrated in the form of graphs.

Only the problematic and/or significant water quality results will be concentrated on in the discussion that follows. All the water quality analytical results received from Rand Water are summarised in and depicted in the aforementioned graphs following. The graphs make use of colour coded areas to indicate in which group they are delineated into according to the VBCEC in-stream water quality guidelines.

7.3.1 Physical constituents

7.3.1.1 Electrical conductivity

Figure 24a illustrates the electrical conductivity (EC) over the eleven-year period. This indicates that there has been a change in water quality since water from the Katse Dam entered the Wilge River and Vaal Dam reservoir sub-catchments. The EC at all points are fairly stable with intervals where the EC peaks above 40 mS/m, categorised as unacceptable according to VBCEC in-stream water quality guidelines. Majority of these peaks (sample points: SP1, SP4, and SP5) occur during the rainy seasons. This seems unusual since, as

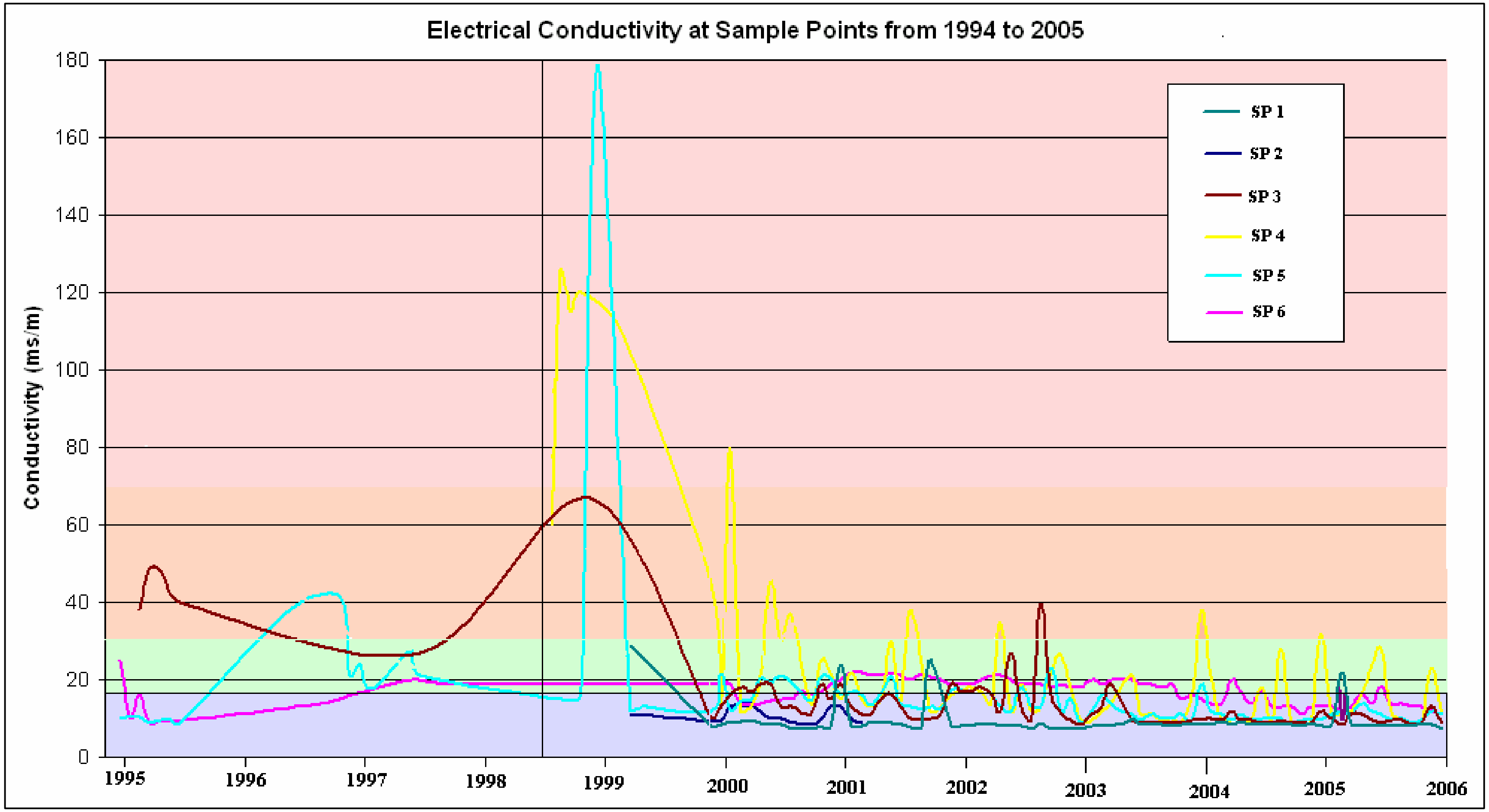

Figure 24a: Electrical conductivity at sample points.

mentioned, rainwater has a low conductivity. This difference may be attributed to these sample points being in areas dominated with clay soils. As previously mentioned in chapter six, clay particles generally have a higher conductivity because of the presence of minerals in clay that ionise more readily in water. These sampling points may receive large amounts of runoff rich in clay particles as well as various other pollutants.

As with rainfall, Katse Dam water has a low conductivity, accredited to a large percentage of water in the catchment comprising of snowmelt that originated in the Lesotho Highlands. Consequently, the effect of Katse Dam water on the study area is evident where troughs in EC, depicted in Figure 24a, correspond with crests in the flow volume illustrated by Figure 21 during the winter months. This finding is most evident at SP1 and SP3 during the period April to September in 1999. In general the EC values for the sample points closest to the Ash River tunnel outlet are greatest affected by Katse Dam water.

Table 4 indicates the percentage of EC values that fall within the VBCEC in-stream water quality guidelines categories. In accordance with Figure 24a the table indicates that there was a change in EC values within all the categories, from 46 to 81 percent in catchment background; 26 to 17 percent in management target; 18 to two percent in interim target and 15 to zero percent unacceptable before and after water from the Katse Dam entered the study area respectively.

Table 4: Percentage of electrical conductivity values within each category in accordance with the VBCEC in-stream water quality guidelines.

Sample Point	Catchment Background		Management Target		Interim Target		Unacceptable	
	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)
SP1	0	96	100	4	0	0	0	0
SP2	100	100	0	0	0	0	0	0
SP3	0	87	14	11	86	2	0	0
SP4	0	67	0	22	20	10	80	1
SP5	60	86	20	14	10	0	10	0
SP6	70	52	30	48	0	0	0	0
TOTAL	**46**	**81**	**26**	**17**	**18**	**2**	**15**	**0**

The long-term trends in Figure 24b indicate a decrease in EC over the time period and may indicate a decrease of sediment over the years. Figure 24b also indicates very low conductivity for SP1 and SP2 in comparison with the other sample points with a very slight decrease over the period. This can be attributed to the clear water being input into the system ten and 25 km upstream of these points respectively. EC at SP6 is also low which can be attributed to the damming of the water at the Vaal Dam. In general there is an increase in EC from the Ash River outlet tunnel up until the water reaches the Vaal Dam which is to be expected, but the increase in EC downstream, as previously mentioned, is decreasing with time. The long-term trends in the figure indicate that the largest decrease in EC over the period is at SP4. This too can be a consequence of the clear water entering the system upstream from the LHWP or alternatively from water joining the system from the Wilge River.

7.3.1.2 Chemical oxygen demand

The chemical oxygen demand (COD) over the eleven-year period indicated in Figure 25a illustrates a slight decrease in COD in the study area over the period with the lowest levels at SP1. This decrease was anticipated given that Katse Dam water has a lower COD value attributable to a lesser amount of organic matter. The irregular peaks present in all sample points are most likely caused by storm water running into the system directly after heavy periods of rainfall, predominantly in the rainy seasons.

The long-term trends in Figure 25b make noticeable a uniform COD pattern over the period with slight decreases further downstream from the outlet tunnel. This can be attributed to the decrease in turbidity of water and sediment downstream. The readings recorded at SP2 in the years prior to the completion of the LHWP (1994 to 1999) is an indication that higher COD values were experienced when Katse Dam water was absent in the system. The impact of the storm water from the residential area at Frankfort is clearly noticeable at SP5 during the raining season. COD values prior to the inflow of water to the system from the Katse Dam were above the VBCEC in-stream water quality management target of ten to 20 mg/l. Thereafter COD values for all points have decreased and have since correlated with the stipulated management target. The long-term trend indicates a steep decrease in COD for SP2 and could be a result of the water being more susceptible to change as it is only 25 km from the LHWP output tunnel.

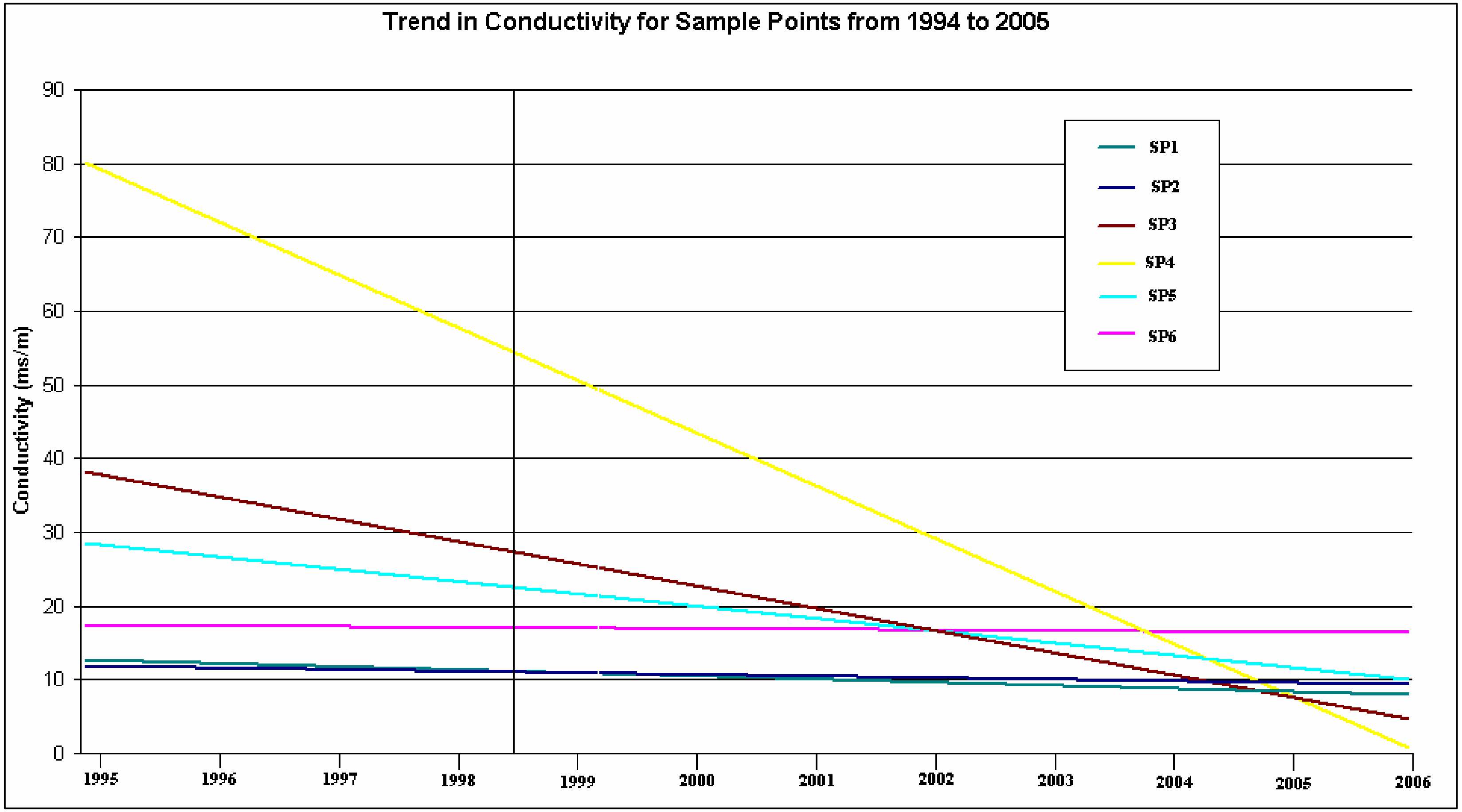

Figure 24b: Trends in electrical conductivity.

The percentages of COD values that fall within the VBCEC in-stream water quality guideline categories are given in Table 5. Table 5 quantifies what is depicted in Figure 25a, that is, the change in COD values from zero to 52 percent for the catchment background; 19 to 41 percent in the management target; 71 to five percent in the interim target and from ten to two percent unacceptable before and after water from the Katse Dam entered the study area respectively.

Table 5: Percentage of chemical oxygen demand values within each category in accordance with the VBCEC in-stream water quality guidelines.

Sample Points	Catchment Background		Management Target		Interim Target		Unacceptable	
	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)
SP1	0	94	0	4	100	1	0	1
SP2	0	80	0	20	100	0	0	0
SP3	0	56	0	37	63	7	37	0
SP4	0	20	0	72	100	7	0	1
SP5	0	45	56	45	28	9	16	1
SP6	0	19	55	66	36	7	9	8
TOTAL	**0**	**52**	**19**	**41**	**71**	**5**	**10**	**2**

The decrease in COD values (Figure 25a) together with the increase in quantity of water with time from the Katse Dam into the study area (Figure 21) indicates that the greater the increment of water released into the study area from the Katse Dam the lower the COD value, hence Katse Dam water has an effect on COD.

7.3.1.3 pH

The pH tendencies indicated in Figure 26a show a fairly stable pH varying between pH 6.5 and pH 8.5 over the period. At SP1 and SP2 there is an increase in pH over the period whilst samples SP3, SP4 and SP5 experience a negligible decrease in pH over the period. Overall the figure depicts a tendency for pH to increase downstream prior to the input of Katse Dam water whilst thereafter the difference in pH between the sample points decreases over the period. This change may be credited to the increase in impacts caused by urbanisation and agriculture (Antoniou, 1999) or the increase in neutral water to the system, from the Katse Dam. The irregular elevated peaks are most likely a result of rainfall and the consequent increase in runoff. The VBCEC guidelines for in-stream water quality management target of between pH 6.5 and pH 8.5 is met at all points during the period except at SP3 and SP6 which only occurred two percent of the time before water from the Katse Dam joined the system and one percent thereafter, as depicted in Table 6. The low pH at SP1 and SP2 may be attributed to Katse Dam water, a high proportion of water that was originally neutral snowmelt, entering the system through the Ash River tunnel

Table 6: Percentage of pH values within each category in accordance with the VBCEC in-stream water quality guidelines.

Sample Points	Catchment Background		Management Target		Interim Target		Unacceptable	
	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)
SP1	100	81	0	19	0	0	0	0
SP2	100	100	0	0	0	0	0	0
SP3	86	96	0	4	0	0	14	0
SP4	80	96	20	4	0	0	0	0
SP5	100	95	0	4	0	0	0	1
SP6	100	90	0	7	0	0	0	3
TOTAL	**94**	**93**	**4**	**6**	**0**	**0**	**2**	**1**

SP6 has a very constant and stable pH of eight, this stability in pH could be attributed to the aquatic vegetation present in and around the Vaal Dam at this point and possibly lightning as well.

7.3.1.4 Turbidity

The lowest turbidity values throughout the study area were experienced at SP1, located in closest proximity to the Ash River tunnel, and the highest values were experienced at SP5 as depicted in Figure 27a. The irregular peaks at all points, as with COD, are probably caused by storm water that runs into the system directly after heavy periods of rainfall and occur predominantly in the rainy seasons.

The long-term trends in turbidity (Figure 27b) indicate a general decrease in turbidity over the study period with the largest decrease in SP2. Slight increases in turbidity were experienced at SP1 and SP6 over the period. The general overview shows a decrease in turbidity, with turbidity increasing downstream. The VBCEC did not stipulate any in-stream water quality guidelines for turbidity.

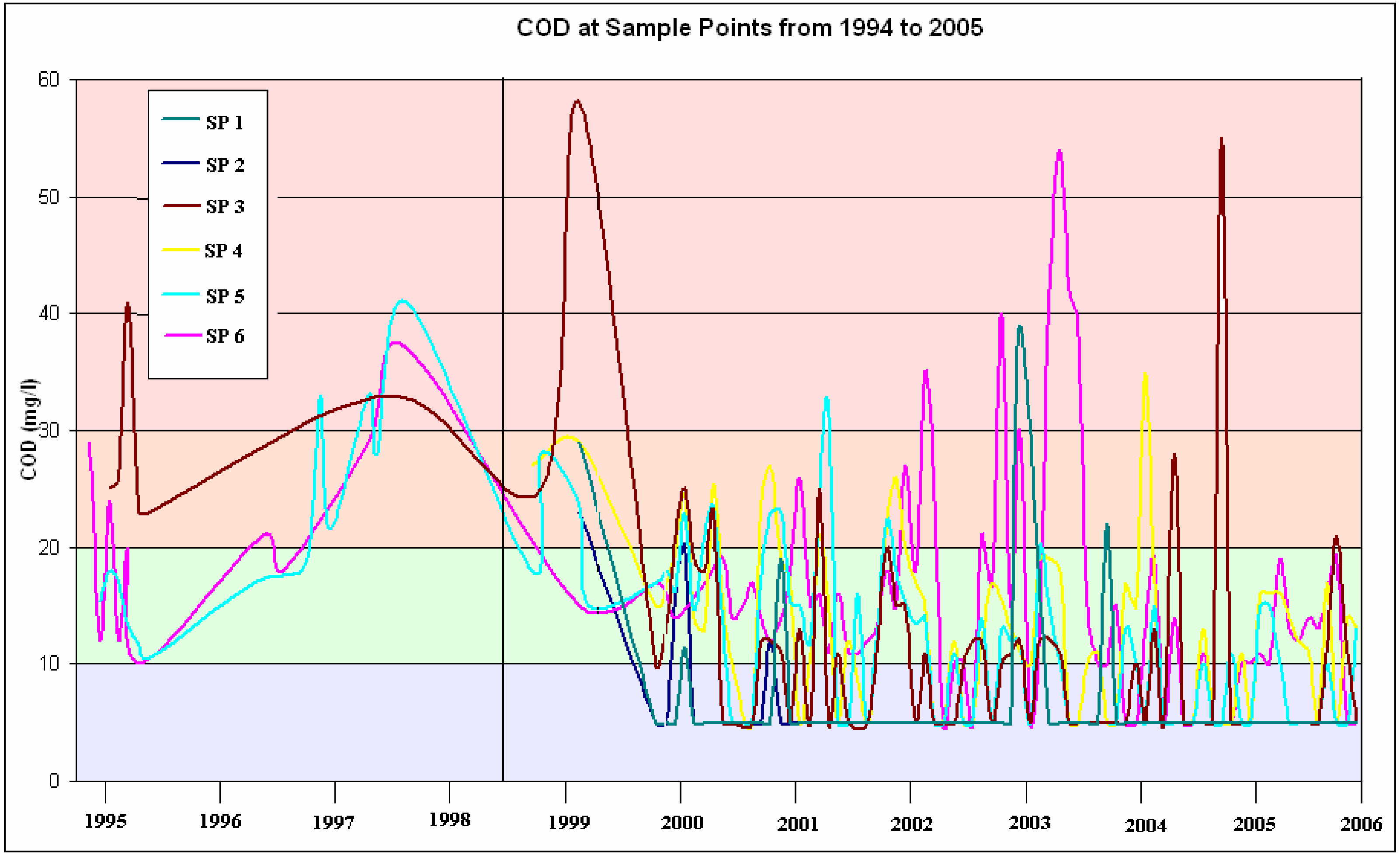

Figure 25a: Chemical oxygen demand at sample points.

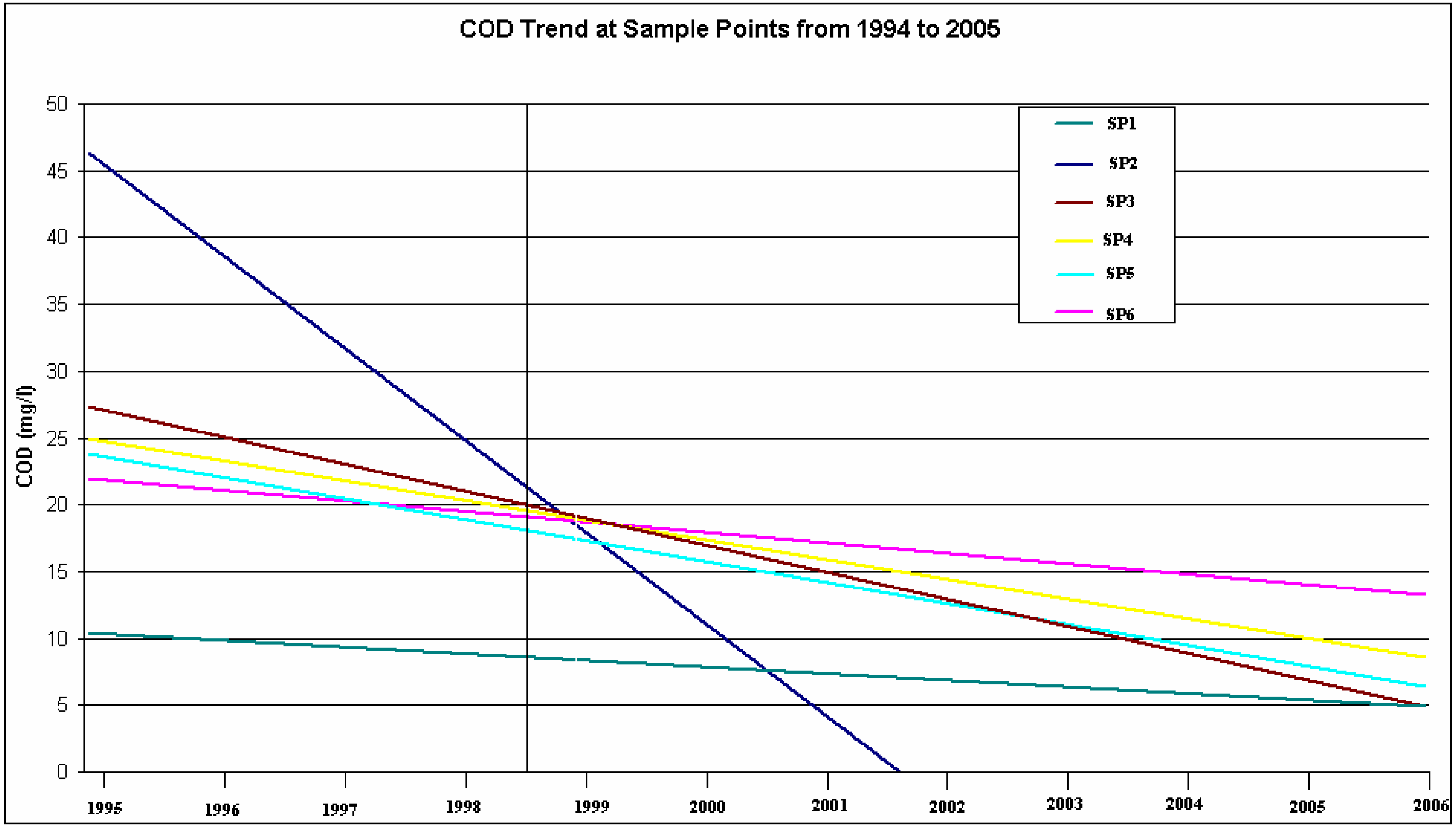

Figure 25b: Trends in chemical oxygen demand.

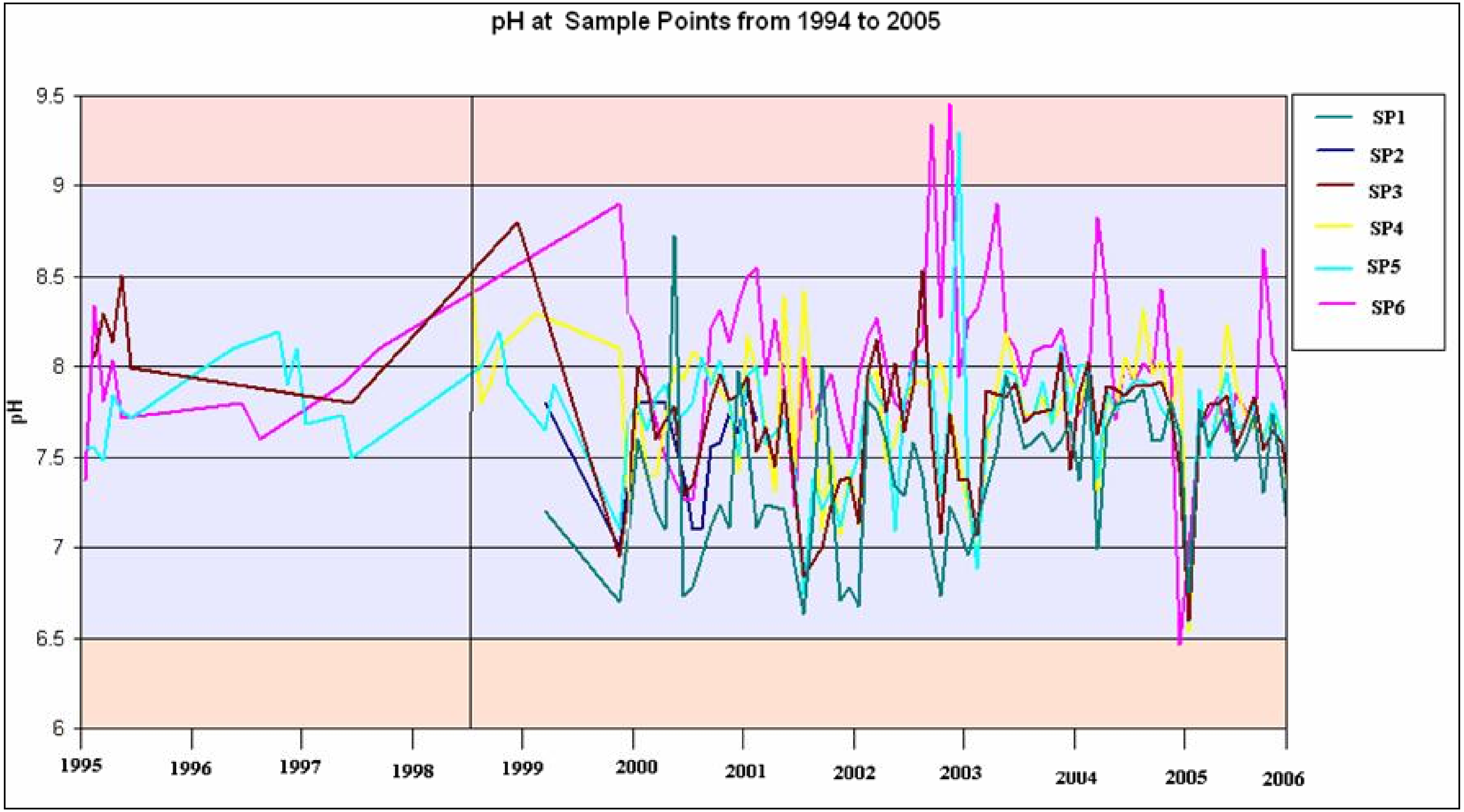

Figure 26a: pH at sample points.

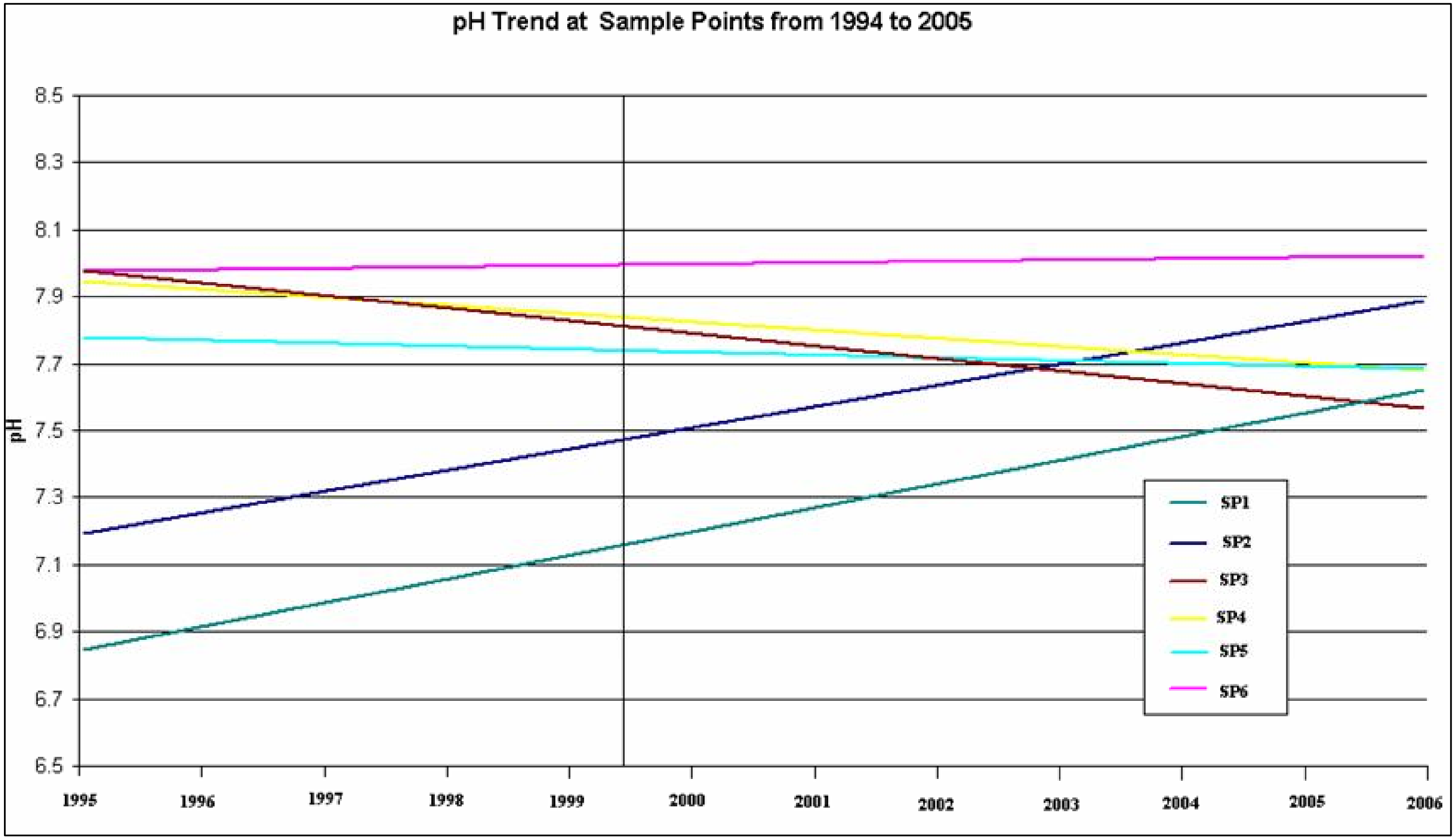

Figure 26b: Trends in pH.

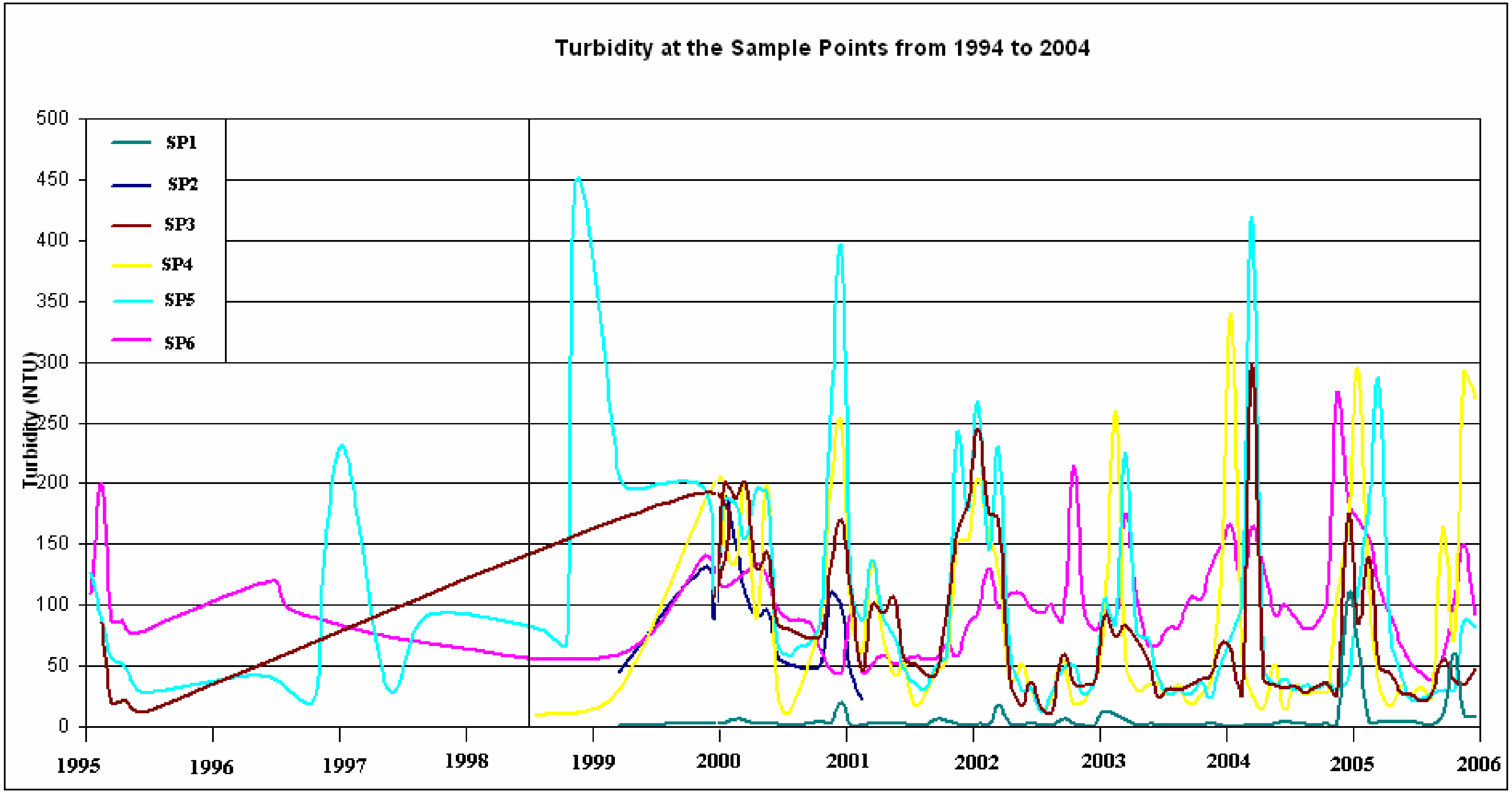

Figure 27a: Turbidity at sample points.

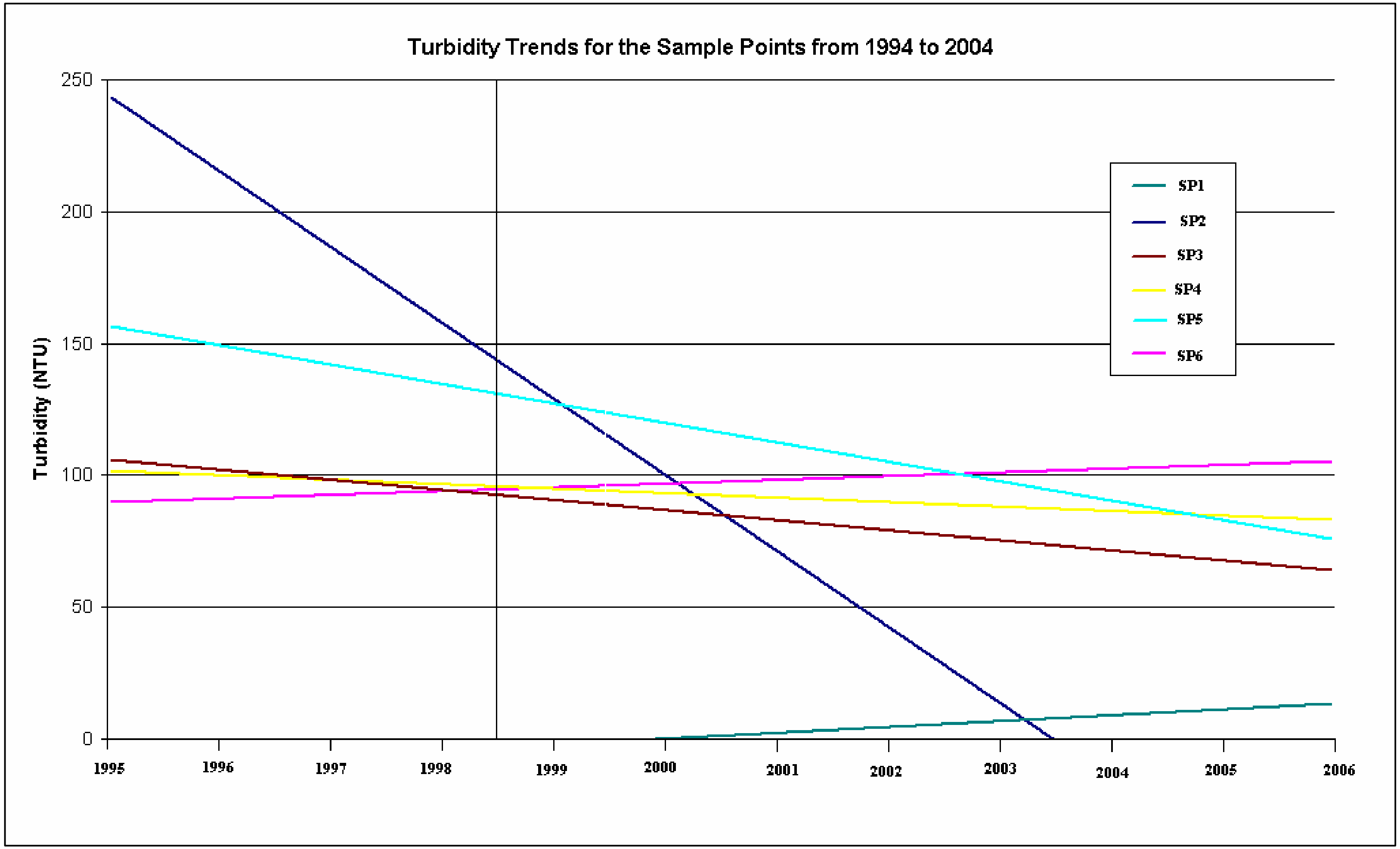

Figure 27b: Trends in turbidity.

7.3.2 Chemical constituents

7.3.2.1 Ammonia

The ammonia levels over the eleven-year period are indicated in Figure 28a, none of which exceeded the unacceptable classification set out by the VBCEC in-stream water quality guidelines of 1.0 mg/l. There is a decline in ammonia levels from a maximum of 0.575 mg/l to 0.05 mg/l.

Irregular elevated ammonia values are present as illustrated in Figure 28a. The high levels recorded may be caused by polluted run off from built up areas. These elevated values are still below the unacceptable classification mark and hence are no cause for concern.

The long-term trends indicated in Figure 28bshow a decline in ammonia levels at all monitoring points over the period. It can therefore be concluded, as expected, that Katse Dam water is of high quality and has lowered the ammonia levels in the study area.

7.3.2.2 Calcium

Figure 29a illustrates calcium in the water samples over the eleven-year period. Figure 29b indicates that there has been a change in calcium at the sample points over the period except at SP1 and SP6. The calcium in the water has decreased over the period at sample points SP3 and SP4 (negligibly slight decrease in SP4) and increased at SP2.

Calcium at the sample points falls within the catchment background or management target categories of the VBCEC in-stream water quality guidelines as depicted in Figure 29a. The percentage of calcium values in the catchment background and management target changed from 76 to 86 percent and 24 to 14 percent before and after the inflow of Katse Dam water into the study area respectively (as depicted in Table 7).

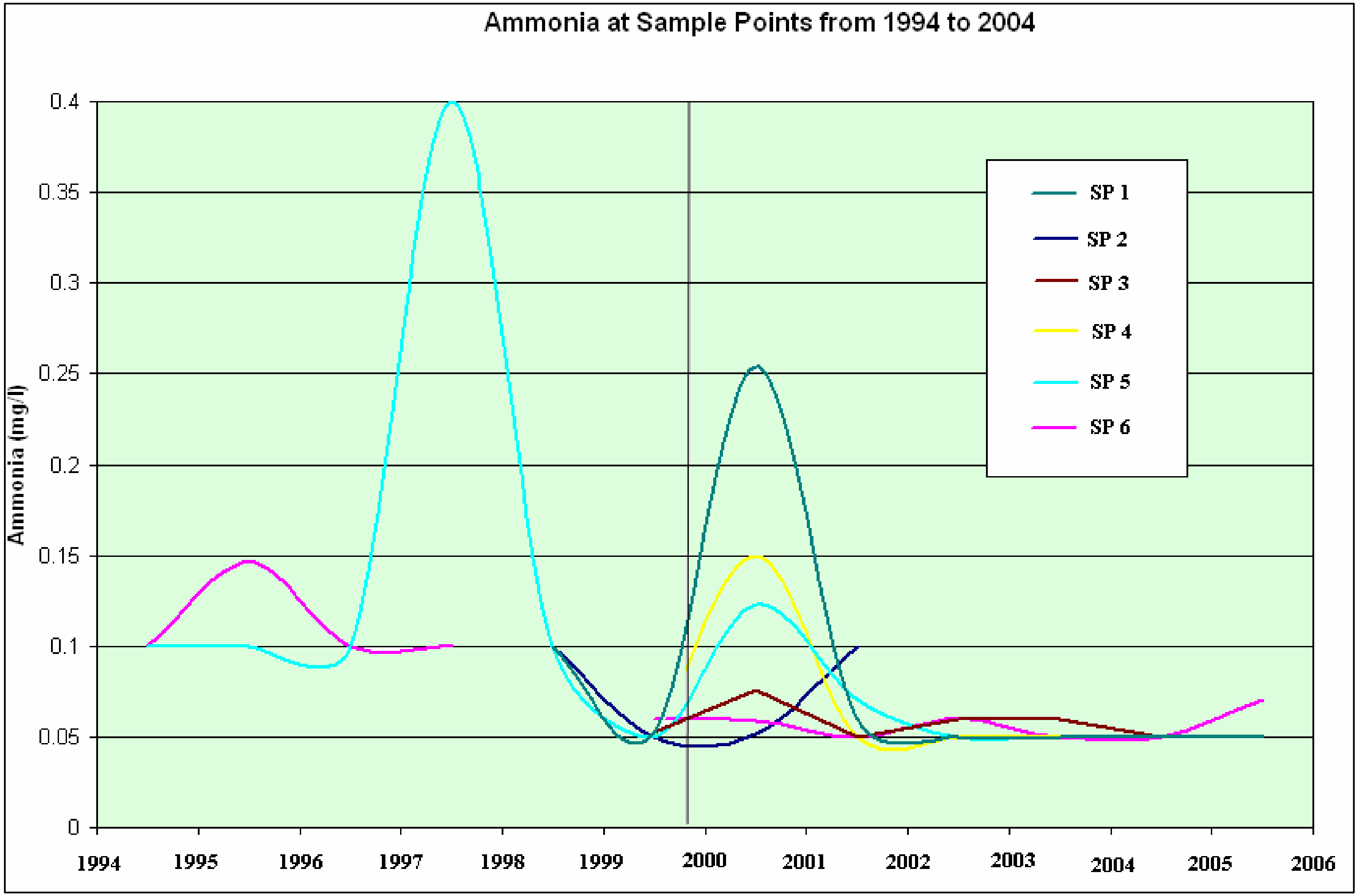

Figure 28a: Ammonia at sample points.

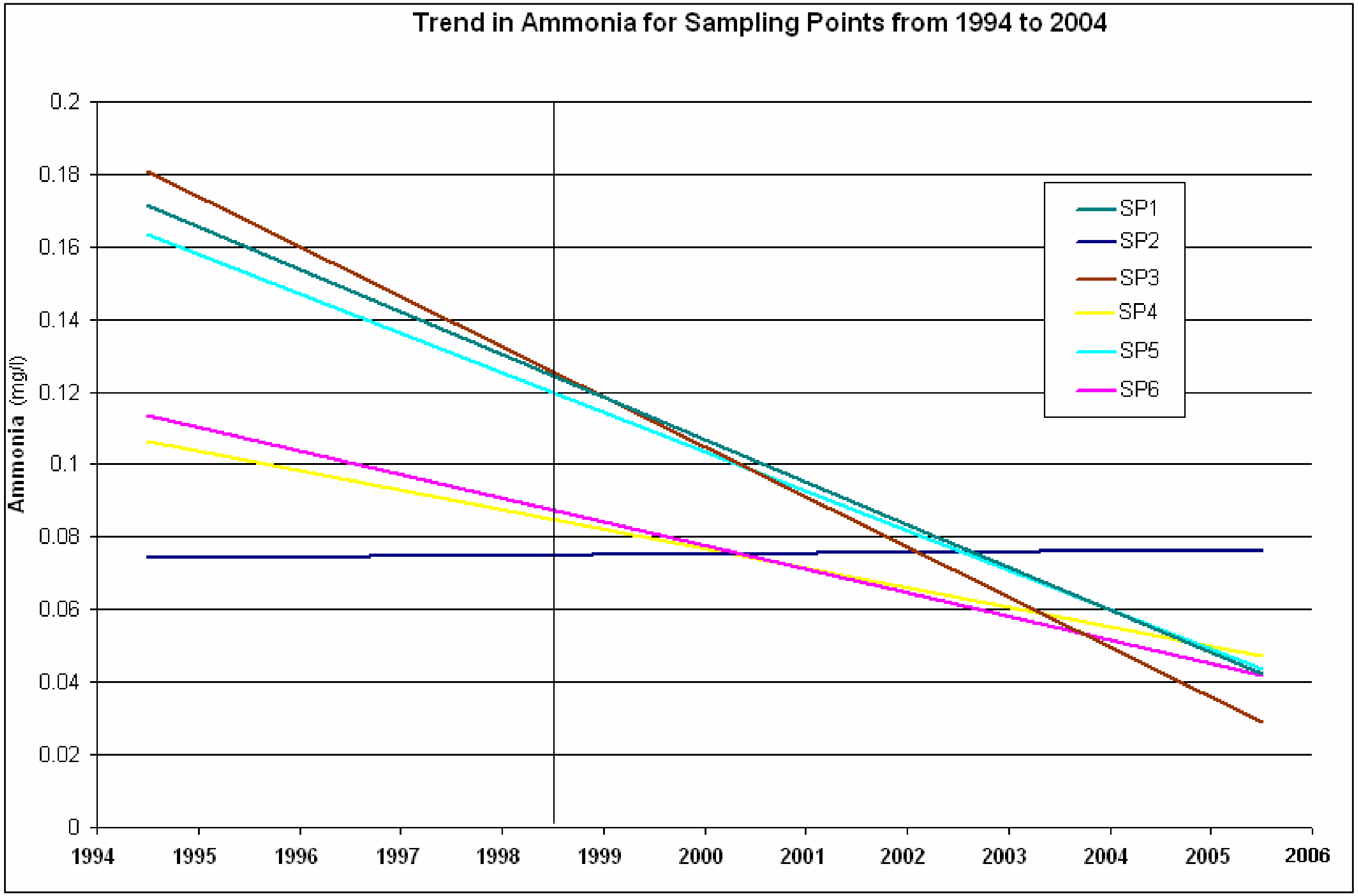

Figure 28b: Trends in ammonia.

Table 7: Percentage of calcium values within each category in accordance with the VBCEC in-stream water quality guidelines.

Sample Points	Catchment Background		Management Target		Interim Target		Unacceptable	
	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)	Before (%)	After (%)
SP1	100	99	0	1	0	0	0	0
SP2	100	92	0	8	0	0	0	0
SP3	0	94	100	6	0	0	0	0
SP4	100	70	0	30	0	0	0	0
SP5	78	80	22	20	0	0	0	0
SP6	80	83	20	17	0	0	0	0
TOTAL	**76**	**86**	**24**	**14**	**0**	**0**	**0**	**0**

The long-term trends in Figure 29b indicate an overall decrease in calcium over the period for sample points SP3, SP4 and SP5. There is an increasing trend for sample point SP2 and no change over the period at SP1 and SP6.

7.3.2.3 Manganese

Data for manganese were annual in nature and therefore Figure 30 has less depth than the other water constituents previously analysed. Manganese values prior to the inflow of Katse Dam water to the system were constant at a value of 0.3 mg/l and thereafter were less then 0.1 mg/l, hence there has been a decrease in manganese after the inflow of Katse water. The VBCEC in-stream water quality guidelines show that the water initially did not comply with management target but since 1999 have been categorised as acceptable.

7.3.3 Microbiological constituents

7.3.3.1 Chlorophyll a

As *chlorophyll a* data were not available prior to 1999 only the results after the release of water from the Katse Dam can be examined. *Chlorophyll a* values in the study area are illustrated over a five-year period in Figure 31a. In general these values have remained constant throughout the period with irregular peaks and troughs. SP6 is the most erratic in nature.

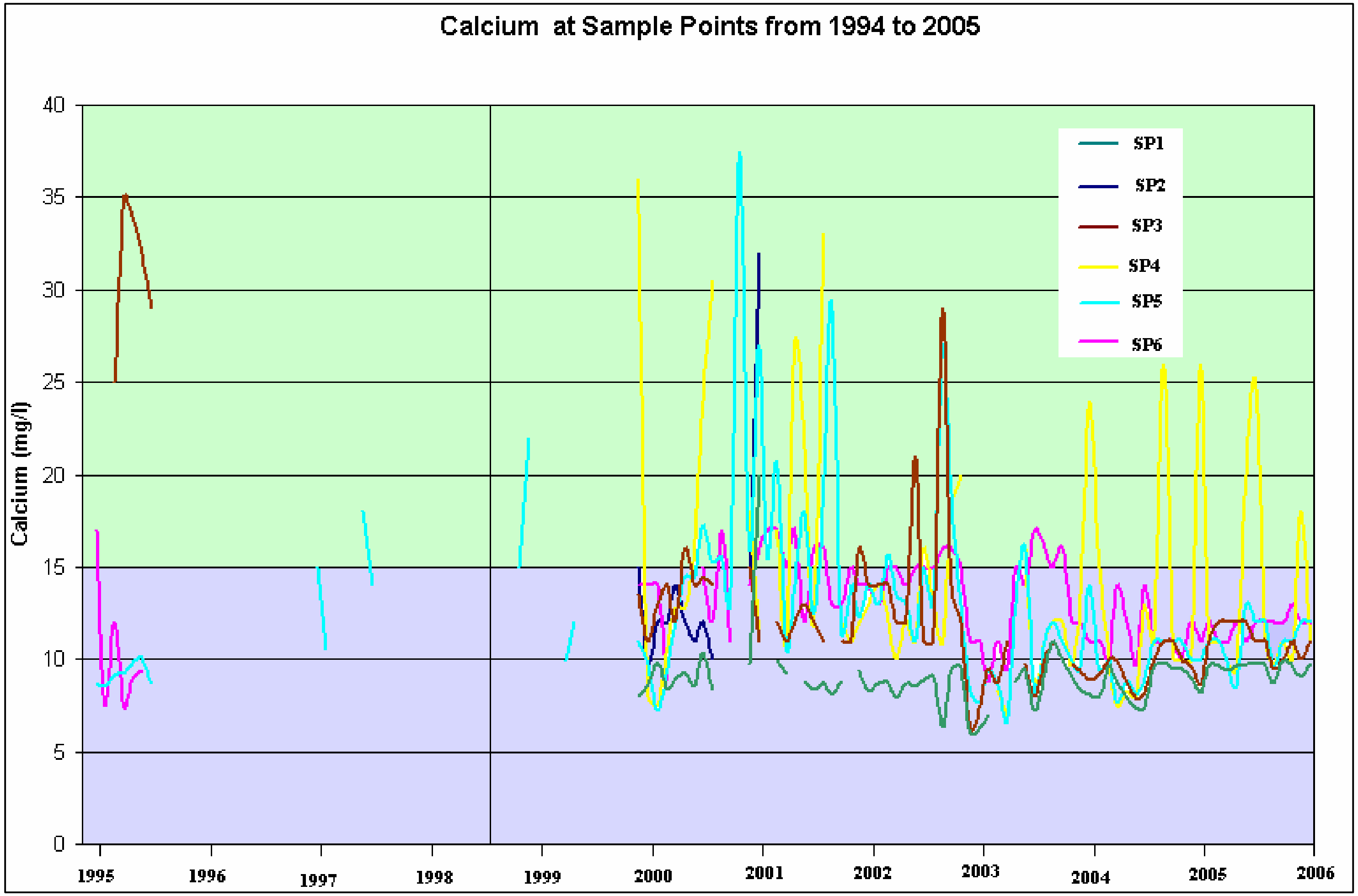

Figure 29a: Calcium at sample points.

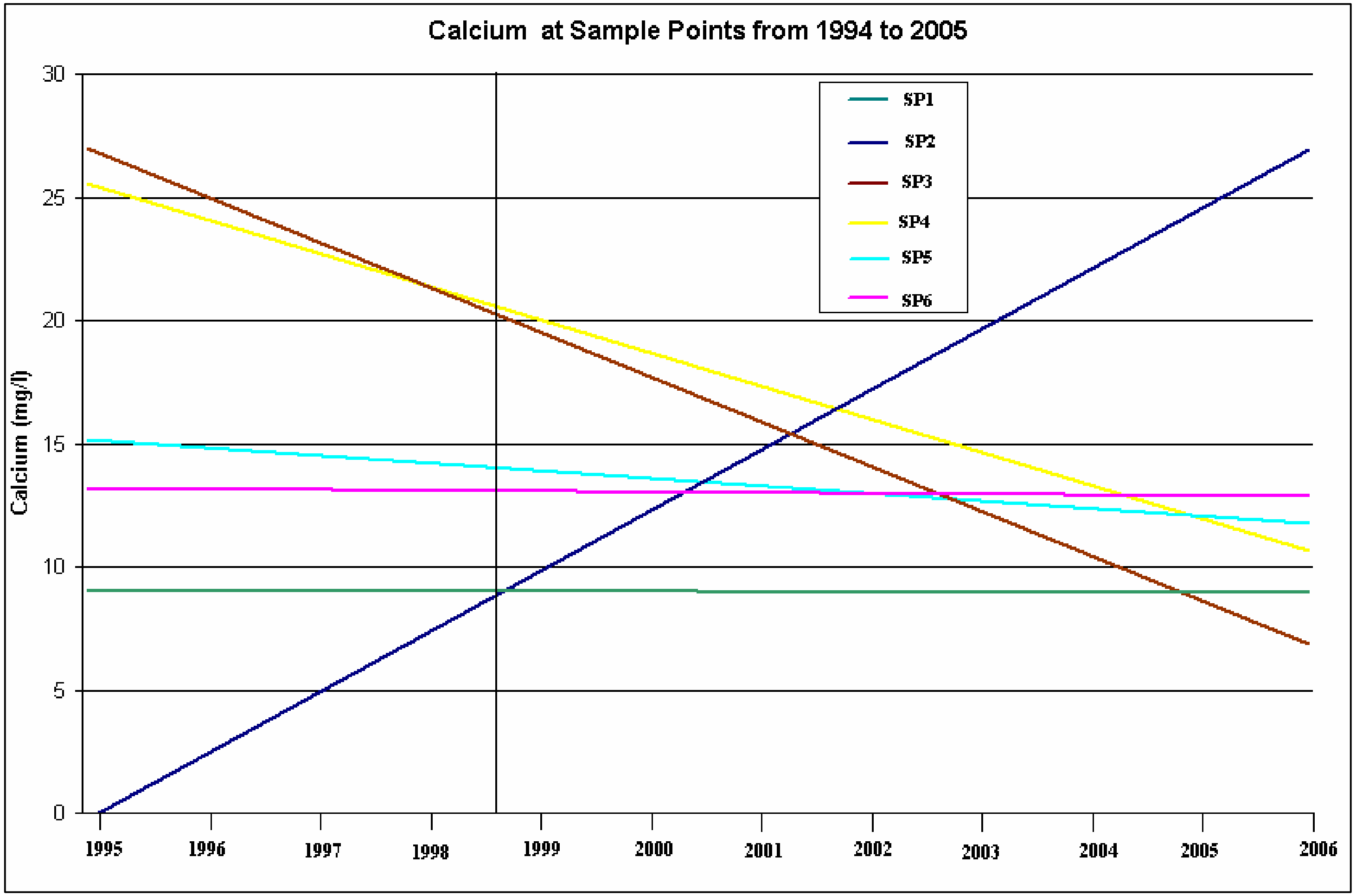

Figure 29b: Trends in calcium.

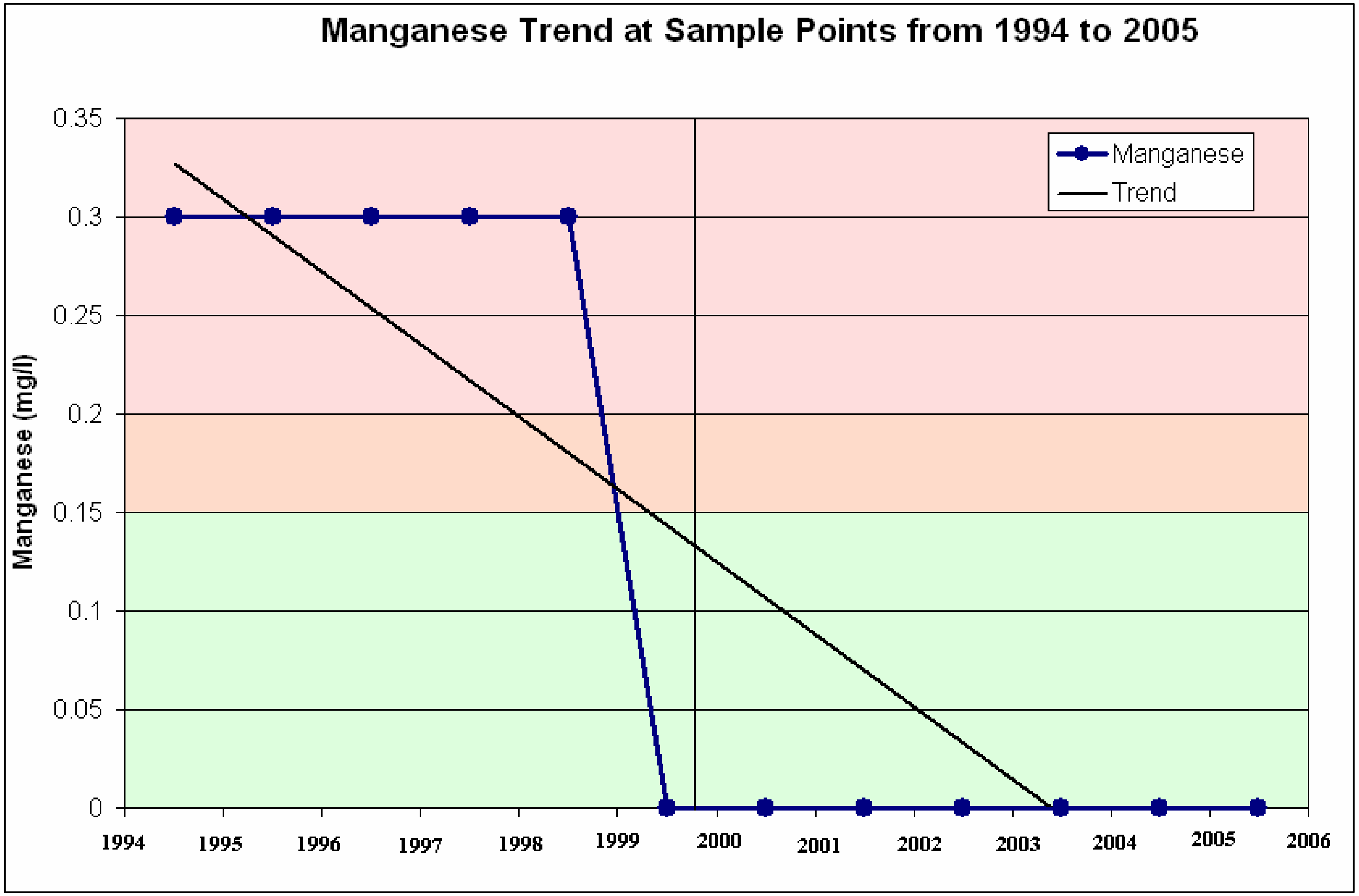

Figure 30: Manganese values and trends at sample points.

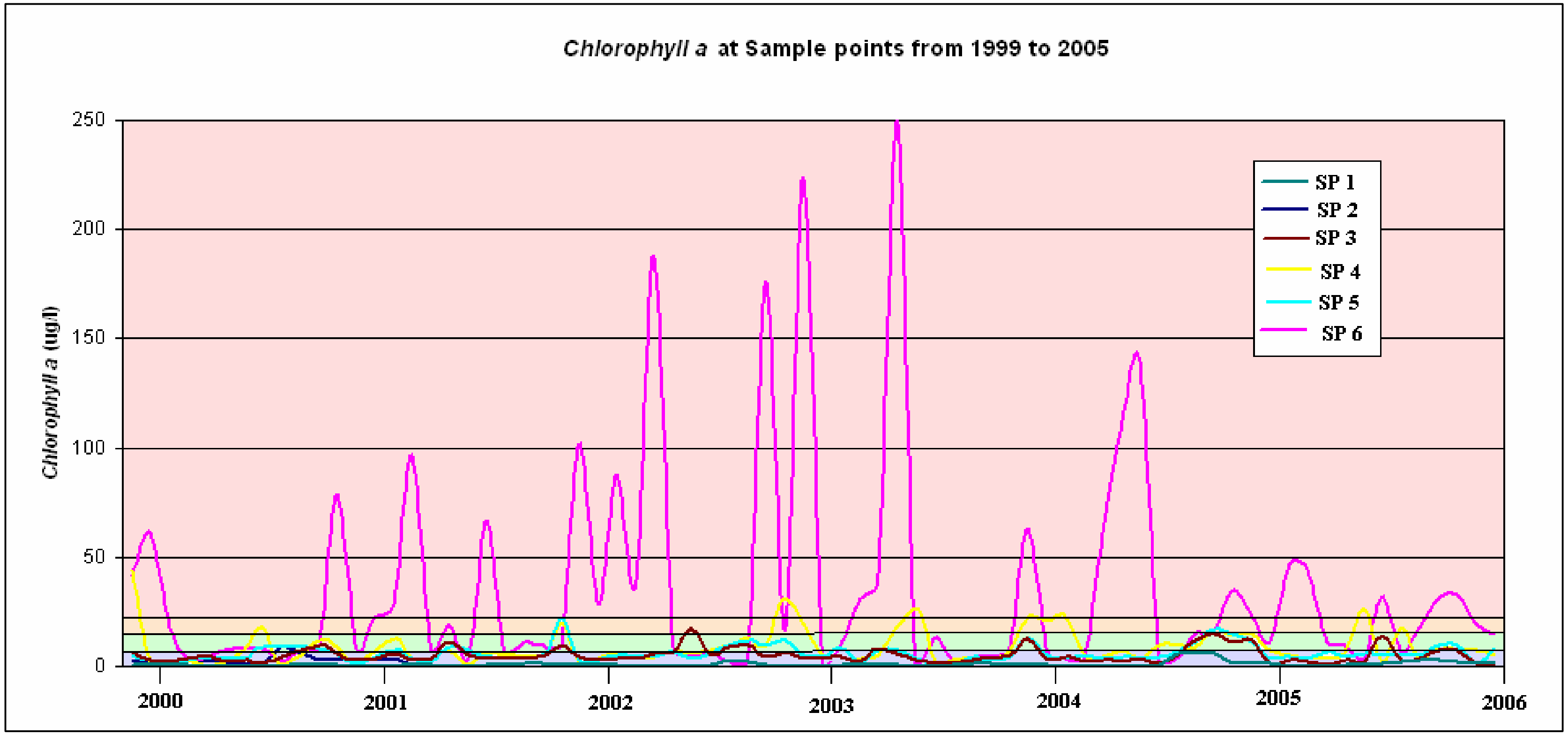

Figure 31a: *Chlorophyll a* at sample points.

Table 8 indicates the percentage of *chlorophyll a* values that fall within the VBCEC in-stream water quality guidelines categories. In accordance with Figure 31a the table indicates that the *chlorophyll a* values within the categories are: 61 percent in catchment background; 29 percent in management target; five percent in interim target and five percent unacceptable after water from the Katse Dam entered the study area.

Table 8: Percentage of *chlorophyll a* values within each category in accordance with the VBCEC in-stream water quality guidelines.

Sample Points	Catchment Background		Management Target		Interim Target		Unacceptable	
	Before	After (%)	Before	After (%)	Before	After (%)	Before	After (%)
SP1	No Data	95	No Data	5	No Data	0	No Data	0
SP2	No Data	93	No Data	7	No Data	0	No Data	0
SP3	No Data	66	No Data	33	No Data	1	No Data	0
SP4	No Data	37	No Data	47	No Data	13	No Data	3
SP5	No Data	49	No Data	48	No Data	3	No Data	0
SP6	No Data	23	No Data	33	No Data	14	No Data	30
TOTAL	**No Data**	**61**	**No Data**	**29**	**No Data**	**5**	**No Data**	**5**

There is no general long-term trend in *chlorophyll a* over the selected sample points. The trends in Figure 31b indicate decreases in *chlorophyll a* at SP3 and SP6, and increases in SP1, SP2, SP4 and SP5 over the period. C*hlorophyll a* is directly proportional to algal biomass and hence an increase in *chlorophyll a* is indicative of an increase in algal biomass and vice versa.

As mentioned in chapter six, changes in *chlorophyll a* concentrations are indicative of changes in trophic state, the extent to which a water body is enriched with plant nutrients. Hence, the water released from the Katse Dam is changing the trophic state of the study area. Over one seventh of the water in the study area has unacceptable levels of *chlorophyll a*, adversely affecting the water quality. If this is not curbed an oxygen deprived environment, to the detriment of aquatic animals, may result.

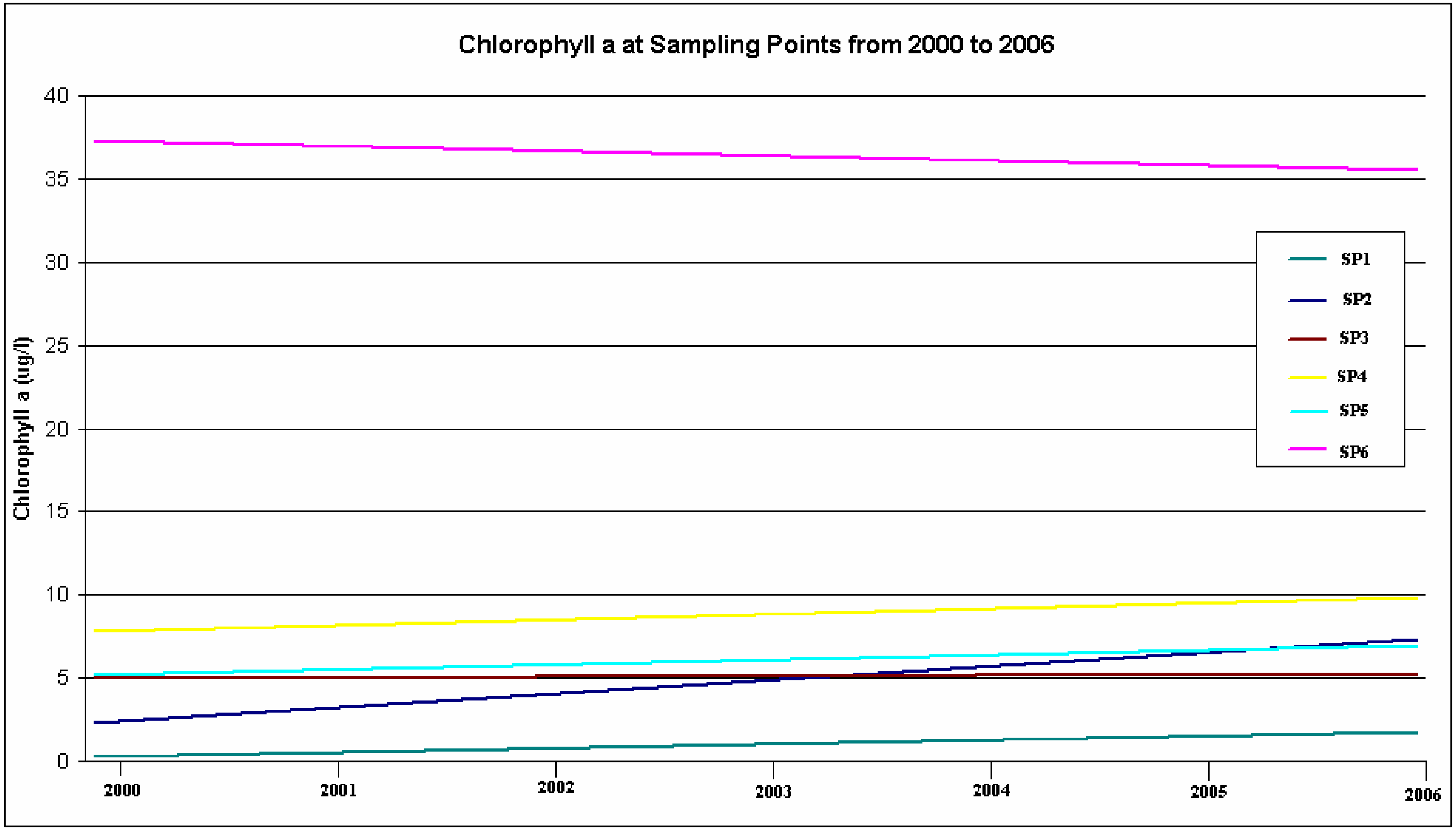

Figure 31b: Trends in *chlorophyll a.*

The larger concentration of *chlorophyll a* at SP6 may be attributed to an influx of nutrients from non-point sources in the surrounding built up areas or farmlands such as over-fertilized lawns, seepage from sewage lines, and livestock waste runoff.

The author's conclusion on the water quality in the study area will be discussed in the next chapter.

8. CONCLUSIONS

The overall objective of this study was to determine the effect of the inter-basin water transfer scheme on the water quality of the Ash, Liebenbergsvlei, Wilge Rivers and the Vaal Dam (recipient system).

The physical, chemical and microbiological water quality parameters were examined for six sampling points situated in the Wilge River and Vaal Dam reservoir sub-catchments. The sampling period ranged over an eleven-year period, from 1995 to 2005. Sampling was done frequently over this period, by Rand Water, and taken twice monthly, but there were gaps in the data, which make the data not ideal. Long-term trends for eight water quality parameters were determined, compared with the VBCEC in-stream water quality guidelines and summarised in graphical format. Due to the complexity of water quality it was deemed essential to investigate the natural and anthropogenic factors, in both the donor and recipient systems, which could affect the water quality results. In addition, all available information on the system was collated and synthesized from an array of unpublished data and published literature.

The study was of particular significance since water quality and quantity had to be integrated to establish the effect of Katse Dam water on the study area. Even though the data are not ideal, some conclusions can be drawn.

Eight water quality parameters were studied of which not all exceeded the VBCEC in-stream water quality guidelines but ***all eight parameters at all sample points illustrated a change after the release of Katse Dam water,*** indicating that Katse Dam water has a significant impact on the water quality in the study area. SP1, the outflow tunnel at the *Ash River mouth*, experienced the lowest values for all parameters. Here water quality values never exceed VBCEC's in-stream guidelines. These low values can almost certainly be explained by the input of Katse Dam water, because of the LHWP transferring excellent quality water from the Lesotho Highlands into the study area (as discussed in chapter two).

Both the *EC* and *COD* parameters show a *marked decrease* for all sample points during the study period. At *SP4* and *SP5*, the guidelines for *EC* were seldom exceeded, the highest recorded reading was more than *180 ms/m*. The *COD* values after the release of Katse Dam water had *improved* according to the guidelines with unacceptable values dropping from *ten percent* to *two percent.* This shows a significant change after the input of Katse Dam water.

The *pH* of the study area ranges from *6.5* to *9.5***.** Of concern are the readings recorded at *SP5* and *SP6* from *August* to *December 2002* that exceeded guidelines. At *SP5* the fluctuations in *pH* may be a result of effluent discharge being washed into the system upstream from the built up area *Frankfort*. It is illustrated that the *pH* closest to the Ash tunnel outfall is significantly lower then the *pH* further downstream. There is no definite trend in *pH* as a result of the release of Katse Dam water as both increasing and decreasing trends were experienced at sample points in the study area. The only trend that may be identified is the tendency of the *pH* towards neutral, thus *not diminishing the quality but altering it nonetheless.*

No guidelines were given by the VBCEC for *turbidity*. A definite *decrease* in *turbidity* was experienced over the study period at all sample points except at SP1 and *SP6* where *turbidity* increased. *Ammonia* is also identified as a parameter, which underwent change during the period. The water quality guideline of *0,1 mg/l* was never exceeded at any monitoring point during the study period but illustrated a *significant decrease*. This could be due to the high volume of inflow from the Lesotho Highlands being excellent in quality and therefore having a low *ammonia* value.

Calcium concentrations never exceeded the management target of *70 mg/l.* As with the *pH* values no general trends were illustrated. *No significant changes* in calcium were evident at sample points *SP1, SP5* and *SP6***.** Sampling point *SP2* experienced an increase in calcium whilst calcium values at *SP3* and *SP4* decreased over the period.

Manganese levels are the most evident of change in water quality in the study area over the period as all sample points experienced a *decrease* in *manganese* from *0.3 mg/l* to *less then 0.1 mg/l* after the release of Katse Dam water into the study area. That is, *manganese* levels dropped from *unacceptable* to *management target* according to the VBCECs guideline classification. Although this is indication that water quality has improved in terms of the VBCEC in-stream water quality guidelines, the water quality has changed significantly thereby *altering the river environment and possibly altering the ecology of the area*.

Chlorophyll a data were not available prior to the release of Katse Dam water into the system and hence only the change in *chlorophyll a* values for the six years after the release of Katse Dam water could be analysed. The trends are thus not as apparent as expected. Overall *chlorophyll a* values *increased* over the period for all sample points except SP6. Five percent of the *chlorophyll a* values were above unacceptable.

This study revealed that the transfer of water from the Katse Dam into the study area *affected all water quality parameters* and a change over the period was evident at *all sample points.* The transfer of water was found to be *beneficial* to the water quality in the study area, as water quality improved thereafter. The improvement in water quality was *most evident in the southern reaches* of the study area but the effect *diminished northwards*, towards the Vaal Dam, with distance, so much so that the effect, *in the Vaal Dam, is in essence negligible.* Hence, Rand Waters water treatment process (Rand Water draws water only from the Vaal Dam; the Vaal River, at the Lethabo weir; and a small amount from borehole wells at Zuurbekom, Lenasia. There are two pump stations on the Barrage but they are emergency standby only, due to poor water quality) need not be altered, as although the release of Katse Dam water has altered the water quality parameter values throughout the study area, the change in these parameters at the Vaal Dam has been minimal.

Another concern, however, is that since the water quality has changed, negatively or positively, throughout the study area it may *compromise the ecological integrity* of the system. Most of the negative effects were associated with the interference that the transfer scheme has had on the natural hydrological regime in the system. Consequently, an alternative to the transfer of water from Lesotho may be financially beneficial, in terms of purification costs, and more ecologically friendly. Some recommendations will now follow.

9. RECOMMENDATIONS

As aforementioned flow in the Ash, Liebenbergsvlei and Wilge Rivers are unnaturally high due to the release of water from Lesotho. Releases are expected to increase gradually until the year 2025 (Rand Water, 2006). River environments in the study area (especially the upper reaches of the Ash River) are currently being modified and eroded due to the high volumes of water released.

Since the water delivered from Lesotho is of excellent quality, it could be easily treated to potable standards and at low cost. However, as indicated in this study, when released into the Vaal River System, the water is exposed to various forms of pollution and is mixed with water of lower quality along its route via the Ash, Liebenbergsvlei and Wilge Rivers to the Vaal Dam forfeiting the advantage of having exceptional quality water.

To support economic growth and development in the supply area, Rand Water is required to provide a safe and secure supply of water. However, at present the majority of water is obtained from a single source, namely the Vaal Dam. Given that the Vaal Dam is located at a much lower altitude than most of the reservoirs and booster stations in the Rand Water supply area, water is pumped to the various users at high cost and energy use. Hence, the security of the water supply would be greatly improved if water from the LHWP were not released into the Vaal River System.

If water is gravity-fed to a water treatment works located on higher ground, less pumping would be required which would result in long-term energy and cost savings. A further benefit would be that less water would be lost due to high quantities of water being evaporated in the rivers and the Vaal Dam itself.

Rand Water is currently investigating the technical, economic and environmental feasibility of constructing pipelines to gravity feed the water (delivered by the LHWP) from the transfer tunnel outlet near Clarens northwards to the Gauteng area. The Project would involve construction of: a storage dam of approximately 60×10^6 m^3 immediately below the LHWP transfer tunnel outlet near Clarens; two to three gravity pipelines (three to four meters in diameter) from this storage dam northwards to Gauteng; and a new water treatment works located on relatively high ground in Gauteng (probably near Suikerbosrant).

To comply with South Africa’s environmental legislation, Rand Water has initiated an environmental feasibility and scoping study. This recommended project is currently at feasibility level to select the optimum route for the pipeline and optimum positions for the storage dam and water treatment works. Biophysical and socio-economic components of the environment, as well as financial and technical constraints, will also need to be taken into account. If approved further engineering studies and a full EIA will be conducted.

In the event of this project being put into operation, water delivered from Lesotho will be gravity-fed via the pipeline to Gauteng and the release of large volumes of water from Lesotho into the Ash River will be discontinued. Consequently, the flow in Ash, Liebenbergsvlei and Wilge Rivers will largely revert back to the original (normal) condition.

Furthermore, within the scope of this study, research on the extent and effects of soil erosion on the river environment as well as an impact assessment of the proposed recommendation should be undertaken.

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