CHAPTER 1: INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

The smallest of South Africa's nine provinces is Gauteng, comprising a surface area of 17 010 km². Although the smallest province (**Figure 1**), Gauteng is also described as the economic powerhouse of the country. Economic growth and output in the province outstrips the rest of the country, leads the whole continent and is the heart of its commercial business and industrial sectors (DBSA, 2000).

According to SEF (2003) Gauteng's contribution to the national Gross Domestic Product (GDP) grew from 32,6 % in 1995 to 33,9 % in 2002 and generates 10 % of the GDP for the African continent. Moreover, sectors such as commerce, manufacturing and finance are vitally important for an economy to grow and conform to the requirements of globalisation contributing 40 %, 41 % and 45 % respectively, to the GDP of South Africa (DBSA, 2000). Gauteng is also home to 8,8 million people which is about 20 % of the national total. Coupled with the fact that Gauteng comprises a relatively small surface area, population pressures are high, namely 517 persons per km² compared to 39 per km² for the whole of South Africa.

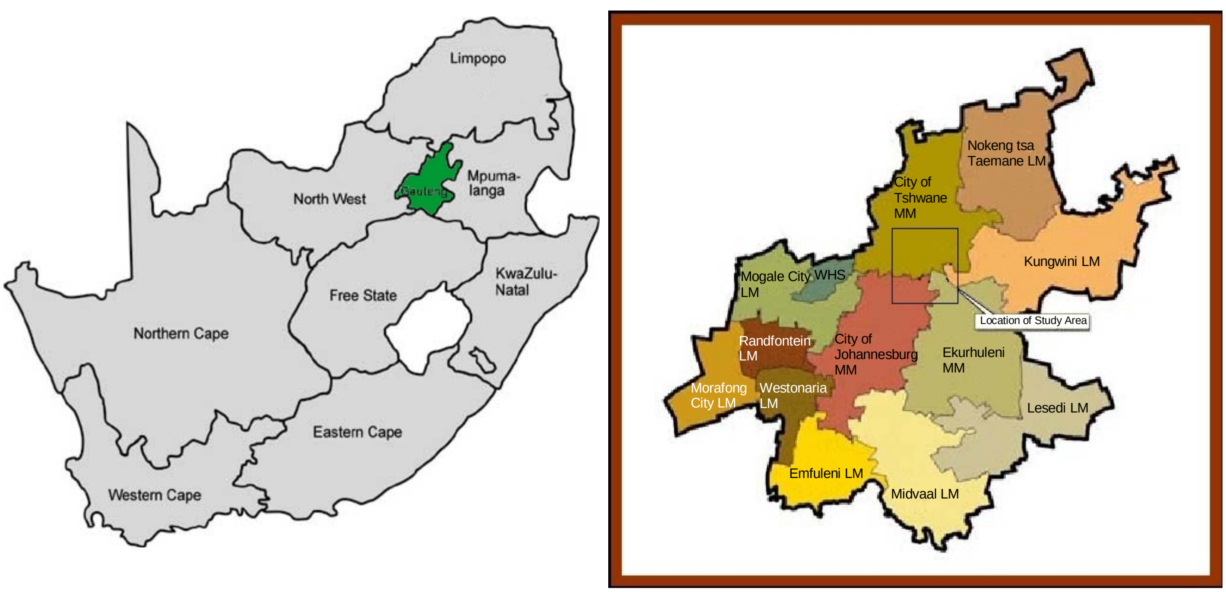

Figure 1: Gauteng in relation to the rest of South Africa

Economic growth, in whatever form or magnitude, has an effect on land use options and as a result problems and negative impacts on the environment usually occur. In Gauteng these problems include pollution of air and water as well as biodiversity depletion. Associated impacts from these are acid deposition from poor air quality, sediment and nutrient overload in water and habitat destruction and degradation of wetlands. In terms of water pollution, the province has an effect on three of South Africa's 19 identified catchments (Fakir & Broomhall, 1999), *viz*.: the Crocodile (West) – Marico, the Olifants and the Upper Vaal Catchments. The Crocodile (West) – Marico Catchment is comprised of various smaller catchments such as the Jukskei, Hennops, Pienaars and Apies River catchments. This specific research, however, will focus on the water quality and certain hydrological problems of only the Hennops River catchment. In doing so the overall causes of its degradation are ascertained and from this rehabilitative and mitigatory measures are proposed.

For most people familiar with the Hennops River, especially residents of Centurion, which is situated on the southern outskirts of Pretoria, the Hennops River is synonymous with a river flowing through the countryside, golf estates, residential areas, recreational areas, industrial areas and business areas. The Hennops River flows in a north-westerly direction through these areas including the Centurion Lake, enhancing the aesthetic value of the surroundings as a variety of trees, lush vegetation and birdlife are present along its banks. A hiking trail along this part of the Hennops River was also created during the early nineties. Business people also consider the Hennops River and Centurion Lake as vital elements in making Centurion the rapidly expanding and successful area it is renowned for today (Du Plessis, 2004)*. The Centurion Lake is almost totally surrounded by businesses, hotels, shops and restaurants which are having positive effects on the area's economy and job creation opportunities. A fewer number of businesses would have been established in this area had the Lake not been constructed more than two decades ago i.e. Centurion's Central Business District (CBD) has therefore evolved around the Lake. Along the Hennops River itself existing properties and new developments are highly priced and sought after (Strydom, 2004)*.

*Personal communication

But progressive degradation of the Hennops River owing to factors such as urban development, industrial activities, agricultural activities and informal settlements is being experienced. This degradation of the Hennops River and consequently Centurion Lake over the past three decades has reduced the benefits of having the River flowing through the centre of the Centurion CBD and the intrinsic value it offers. An increase in hydrological and water quality problems such as riverbed erosion and microbiological pollution have become issues of concern. More noticeable consequences of the Hennops River's degradation is the silting up of the Centurion Lake and the fact that the River's water has become unfit for recreational use. Recreational activities which were associated with the Centurion Lake up until the mid-nineties included boating, canoeing, windsurfing, angling and occasional swimming (Freeman, Howard & Wiechers, 2000). Garner (1998) believes that the condition of the Hennops River illustrates the lack of holistic environmental and catchment management as the river system is the responsibility of a number of local authorities, making co-ordinated planning and management difficult.

As illustrated by **Figure 2** the main source of the Hennops River is found, approximately 30 km south of the Centurion Lake, in the form of the Kaalspruit which originates in the industrial area of Lethabong and the residential area of Birch Acres in Kempton Park, Johannesburg. The Kaalspruit flows through the high density informal settlements of Tembisa and Ivory Park in a northerly direction where several tributaries such as the Olifantspruit converge with this principal stream downstream from here before entering the Centurion Lake as the Hennops River. The main tributaries downstream from the Centurion Lake are the Rietspruit and Swartbooispruit before the Hennops River ultimately converges with the Crocodile River to feed the Hartebeespoort Dam which is situated approximately 35 km north-west of Centurion Lake.

A variety of land uses within the Hennops River catchment exists causing difficulty in adequately managing and controlling the water quality and hydrological status of its rivers and streams. This is because the sources of pollution and hydrological degradation are varied, cover a large area and need to be addressed in different ways. Land uses include formal and informal housing, commercial, industrial and business developments as well as agricultural

activities. The different land uses and activities occurring within the catchment, influence various types of pollutants which enter the Hennops River and its principal tributaries. An example is microbiological contamination such as *Escherichia coli*, with high values of up to 1 000 000 cfu/100 mℓ existing in one of the Hennops River's feeder streams in the form of the Kaalspruit. Full contact with water containing *E. coli* counts of more than 130 cfu/100 mℓ should be prevented according to DWAF (1996b).

The main aim of this study is to establish the present water quality condition and hydrological status of the Hennops River. This will involve an examination of certain water quality constituents in terms of their suitability for the well-being of aquatic ecosystems as well as certain hydrological problems occurring within the Hennops River. This is only made possible by determining the status of its principal tributaries as well. Erosion of riverbanks and silting up of riverbeds are examples of hydrological problems. Water quality problems are measured against certain variables which are classified into physical, chemical and microbiological constituents. The values of the different constituents attained from collecting recorded sampling data are compared to the requirements needed by aquatic ecosystems for survival. The possible negative effects that increased urbanisation with associated activities have had on the Hennops River will also be ascertained. Rehabilitative and mitigatory measures will be proposed towards the improvement of the hydrological and water quality conditions of the Hennops River.

Entrenched in South Africa's Constitution is the fact that all residents of South Africa have a right to a clean and healthy environment and to have this environment protected for the benefit of present and future generations [Section 24 of the Bill of Rights, Constitution of the Republic of South Africa (Act No. 108 of 1996)]. Causes of water quality and hydrological problems of the Hennops River need to be addressed to protect the future of this River. In terms of this human right the causes of water quality and hydrological degradation of the Hennops River need to be addressed to protect the future conditions of the River.

This study is important because the Hennops River's principal problems with regard to the present water quality conditions and hydrological status will be determined so that mitigating and rehabilitative measures can be proposed. These measures are important because the Hennops River: is losing its aesthetic appeal and is seen as a problem in the Centurion CBD and residential areas; has become less useful for recreation, irrigation, livestock watering and less suitable for aquatic biota; and the Hennops River has deteriorating water quality and could become one of the more polluted rivers in Gauteng and the Crocodile (West) – Marico Catchment. It is also a legal obligation in terms of Section 19(1) of the National Water Act (Act no. 36 of 1998) to prevent pollution and degradation of watercourses such as the Hennops River from occurring or continuing to recur. Local authorities and municipalities need to be aware of these problems and associated causes.

1.2 THE STATEMENT OF THE PROBLEM

As previously mentioned, the Hennops River catchment is situated between Johannesburg and Pretoria within the provincial boundaries of Gauteng. Owing to the catchment's position and the associated land use, activities and urbanisation taking place within its boundaries, the Hennops River has gradually deteriorated in terms of its water quality and certain hydrological conditions. The Hennops River which was once regarded as an asset to its immediate surroundings has become a liability.

Along its course the deteriorating hydrological status and water quality of the Hennops River over the past three decades have become issues of concern for local authorities, residents, property developers and business people of Centurion as well as land users downstream of Centurion. Issues of concern include riverbed erosion, microbiological pollution, urban littering and silting-up of the Centurion Lake. Additional to these, the Hennops River and Centurion Lake have also become unfit for recreational use and are fed by water of poor quality for the well-being of aquatic ecosystems.

This study aims to establish the present water quality and condition of the Hennops River in terms of its hydrological status. Existing water quality data (physical and chemical constituent concentrations) are compared to the Water Quality Guidelines as set by the Department of Water Affairs and Forestry to determine the water's suitability for Aquatic Ecosystems.

DWAF (1996a) describes microbiological constituents as irrelevant in term of the aquatic biota. An examination of certain current pertinent hydrological problems such as erosion and siltation occurring in the Hennops River is also undertaken. The possible negative effects that an increase in the amount of residential areas (formal and informal), commercial, industrial and business developments, and agricultural activities have on the River will therefore be ascertained. Rehabilitative and mitigatory measures will be proposed towards the improvement of the water quality and hydrological problems of the Hennops River.

Problems concerning the water quality and hydrological status of the Hennops River are diverse and the increase in urbanisation and human settlement within the Hennops River catchment could be the major cause of this. To gain some insight into this and to determine the suitability of the study area's water quality for the well-being of aquatic ecosystems, the following objectives are to be met:

- To discuss the concept and various constituents of water quality as well as the meaning and relevance of certain hydrological conditions pertinent to the study area. The Water Quality Guidelines as set by the Department of Water Affairs and Forestry (DWAF) for Aquatic Ecosystems are reviewed in order to attain the accepted water quality constituent values.

- To describe the study area. Special reference is given to the location as well as the physical features, land use and activities present in the area. By acquiring knowledge and understanding of these, possible factors which may have an influence on the water quality and hydrological features of the Hennops River and its principal tributaries can be determined.

- To review the existing knowledge regarding the water quality and hydrological conditions of the Hennops River and its principal tributaries. Comparing the status of these rivers over the past three decades to the status of the past two years (from 2002), the effects incurred by urbanisation and human settlement on these rivers will be illustrated.

- To collect and order the most recent water quality data (physical and chemical constituent concentrations). Data from the years 2002 to 2004 were obtained from the Department of Water Affairs and Forestry (DWAF) and the City of Tshwane Metropolitan Municipality (CTMM).

- To examine and analyse the water quality data in terms of the Water Quality Guidelines as set by DWAF for Aquatic Ecosystems. This is done to ascertain whether or not the water quality conditions are favourable in terms of the well-being and survival of aquatic ecosystems.

- To determine and explain the additional hydrological problems experienced along the Hennops River and its principal tributaries. Only when the water quality and hydrological problems of these rivers and streams are determined can rehabilitative and mitigatory measures be recommended.

- To propose rehabilitative and mitigatory measures for water quality and hydrological problems experienced in the Hennops River and its principal tributaries in order to alleviate these problems and improve its current state.

In the following chapter, water quality, its various constituents affecting Aquatic Ecosystems and the recommended concentration ranges for the well-being of these, are discussed. Certain aspects of hydrology and its relevance in terms of this study is also dealt with.

CHAPTER 2: WATER QUALITY AND HYDROLOGY

2.1 THE TERM "WATER QUALITY"

The term **"water quality"** refers to the ideal physical, chemical and microbiological properties of water. 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 use.

The degradation of water may result due to a change in water quality caused by contamination or water pollution so that it becomes unsuitable for a number of users (Cunningham & Saigo as cited by Antoniou, 1999). In support of this, Dallas and Day (2004) define water quality as *the value or usefulness of water, determined by the combined effects of its physical attributes and its chemical constituents and varying from user to user*.

Water quality is negatively influenced by **water pollution**. Miller (2002) defines water pollution as *any physical or chemical change in surface water or groundwater that can harm living organisms or make water unfit for certain uses.*

It can be seen in **Chapter 3** that various land uses and activities are present in the study area. These have an influence on the water quality of the Hennops River and its principal tributaries. These sources of water pollution are either *point* or *non-point (diffuse)* source pollution (Miller, 2002). Point sources discharge pollutants at specific locations through pipes, ditches or sewers into bodies of surface water. Non-point sources are sources that cannot be traced to any single site of discharge (refer to **Figure 3**).

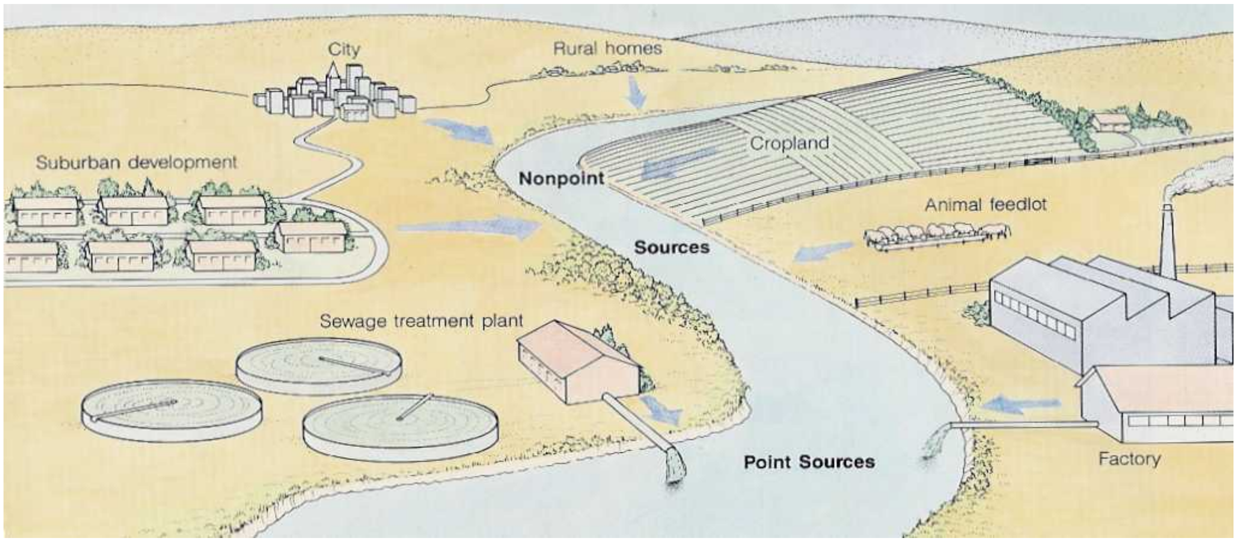

Figure 3: Point and non-point (diffuse) source water pollution (Miller, 1993)

2.2 THE SOUTH AFRICAN WATER QUALITY GUIDELINES AND TARGET WATER QUALITY RANGE (TWQR) FOR AQUATIC ECOSYSTEMS

The Department of Water Affairs and Forestry (DWAF) is the custodian of South Africa's water resources. Part of its mission is to ensure that the quality of water resources remains fit for recognised water uses and that the viability of aquatic ecosystems is maintained and protected.

To assist in this role the Department initiated the development of the *South African Water Quality Guidelines*. These guidelines, according to DWAF (1996a), serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of *marine* and *freshwater systems* in South Africa.

In terms of *freshwater systems*, the South African Water Quality Guidelines consist of seven volumes for different water uses. These freshwater uses are domestic, recreational, industrial, agricultural (irrigation, livestock watering and aquaculture) and include water uses suitable for the well-being of aquatic ecosystems. For the purposes of this study, however, only one volume's criteria are used *viz.*, **South African Water Quality Guidelines for Aquatic Ecosystems**. This is because aquatic biota such as fish have been severely affected and in some cases have almost totally disappeared in certain sections of the Hennops River and its principal tributaries.

In the context of these guidelines, DWAF (1996a) defines aquatic ecosystems as *"the abiotic (physical and chemical) and biotic components, habitats and ecological processes within rivers and riparian zones, reservoirs, lakes and wetlands and their fringing vegetation"*. Terrestrial biota dependent on aquatic ecosystems for survival are also included in this definition.

More specifically, the **Target Water Quality Range (TWQR)** for different constituents (physical and chemical) is used in terms of Aquatic Ecosystems. According to DWAF (1996a) microbiological constituents are not relevant in terms of aquatic biota as they do not affect such life forms. As such, no TWQR for microbiological constituents have been set by DWAF in terms of aquatic ecosystems. According to DWAF (1996a) the TWQR is the range of concentrations or levels within which no measurable adverse effect is expected on the health of aquatic ecosystems and should therefore ensure their protection. DWAF strives to protect South Africa's water resources by maintaining water quality within the TWQR.

2.3 PHYSICAL AND CHEMICAL CONSTITUENTS AFFECTING AQUATIC ECOSYSTEMS

A number of physical and chemical constituents can have an effect on aquatic ecosystems. The more commonly known constituents that could be augmented from a river's catchment are described in turn below and where applicable, the TWQR set by DWAF (1996a) for each constituent is given. These constituents are also sampled and analysed by most authorities and institutions such as DWAF in order to ascertain the condition of water in terms of its quality.

2.3.1 PHYSICAL WATER QUALITY CONSTITUENTS

Physical water quality refers to properties that are determined by physical methods such as conductivity, pH and turbidity measurement. Physical quality mainly affects the aesthetic quality such as appearance, taste and odour of water. However, certain physical attributes affect aquatic ecosystems.

2.3.1.1 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Material dissolved in water is commonly measured as total dissolved solids (TDS), as conductivity or as salinity. TDS represents the total quantity of dissolved material, organic and inorganic, ionised and unionised in a water sample. Conductivity is a measure of the ability of a sample of water to conduct an electrical current (Hill, 1997). TDS and conductivity usually correlate closely for a particular type of water. Salinity refers to the saltiness of water (Dallas & Day, 2004). It can therefore be said that since electrical conductivity is a function of the number of charged particles (ions) in solution, it is also a measure of the total quantity of salts and therefore of total dissolved solids in a sample of water.

According to DWAF (1996a) natural waters contain varying quantities of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material. TDS concentrations of natural waters are therefore dependent at least in part on the characteristics of the geological formations with which the water has been in contact. Physical processes such as evaporation and rainfall also have an effect on TDS concentration.

Effects on aquatic organisms can occur at three levels due to changes in the concentration of total dissolved solids, *viz.*:

- effects on, and adaptations of individual species;
- effects on community structure; and
- rates of metabolism and nutrient cycling.

The rate of change of the TDS concentration and the duration of change appears to be more important than absolute changes in the TDS concentration, particularly in systems where the organisms may not be adapted to fluctuating of TDS (DWAF, 1996a).

As can be seen in **Table 1** the TWQR for aquatic ecosystems in terms of TDS concentration does not have a specific value but variation in concentration should be prevented. According to Dallas and Day (2004) the rate of change of the TDS concentration and the duration of change appears to be more important than absolute changes in TDS concentrations. This is particularly true for systems where the organisms may not be adapted to fluctuating levels of TDS.

Table 1: Target Water Quality Range in terms of total dissolved solids for aquatic ecosystems (DWAF, 1996a)

Water Resources	Target Water Quality Range
All inland waters	• TDS concentrations should not be changed by >15 % from the normal cycles of the water body under unimpacted conditions at any time of the year; and • The amplitude and frequency of natural cycles in TDS concentrations should not be changed.

2.3.1.2 Total Suspended Solids (TSS)

Land run-off may contain high concentrations of *sediments*. Sediments may consist of relatively larger particles such as pebbles and gravel that are too heavy to be suspended in streams/rivers under normal flow conditions. Instead, these larger particulates, along with some smaller particles such as sand and silt, are transported along the bottom of streams and rivers. Laws (2000) defines this flux of particles along a streambed as the *bed load*.

Smaller particles such as sand, silt and clay remain suspended in streams and rivers rather than being transported along streambeds and are known as the *suspended solids* in the water. According to Laws (2000) the total sediment load of a stream/river is defined as the sum of the bed load and suspended load.

Concentrations of suspended solids increase with the discharge of sediment washed into rivers due to rainfall and resuspension of deposited sediment. As flow decreases the suspended solids settle out, the rate which is dependent on particle size and the hydrodynamics of the water body (DWAF, 1996a).

Natural variations in rivers often result in changes in the TSS, the extent of which is governed by the hydrology and geomorphology of a particular region (DWAF, 1996a). The major part of suspended material found in most natural waters is made up of soil particles derived from land surfaces. Erosion of land surfaces by wind and rain is a continuous and natural process.

Increases in TSS also result from anthropogenic sources, *viz.*:

- discharge of domestic sewage;
- discharge of industrial effluents;
- discharge of mining operations; and
- physical perbutations from road, bridge and dam construction.

The reader is referred to section **2.4**, p 23 where the effects of suspended loads (either in suspension or bed loads) on aquatic environments and biota are described.

The TWQR for TSS in aquatic ecosystems is illustrated in **Table 2**.

Table 2: Target Water Quality Range in terms of total suspended solids for aquatic ecosystems (DWAF, 1996a)

All Aquatic Ecosystems	Target Water Quality Range
Background TSS concentrations are < 100 mg/ℓ	Any increase in TSS concentrations must be limited to < 10 % of the background TSS concentrations at a specific site and time.

2.3.1.3 Dissolved Oxygen (DO) and Chemical Demand (COD)

Gaseous oxygen (O_2) from the atmosphere dissolves in water and is also generated during photosynthesis by aquatic plants and phytoplankton. According to DWAF (1996a) the maintenance of adequate dissolved oxygen (DO) concentrations is critical for the survival and functioning of the aquatic biota because it is required for the respiration of all aerobic organisms. Shepherd *et al.* (2000) describe that naturally occurring water has a DO concentration in the order of 9 mg/ℓ which supports aquatic biota. If the DO concentration drops below 5 mg/ℓ aquatic biota can be detrimentally affected and levels below 2 mg/ℓ fish deaths can be expected.

It can therefore be stated that the DO concentration provides a useful measure of the health of an aquatic ecosystem. DWAF (1996a) highlights that the measurement of the biological oxygen demand (BOD) or the chemical oxygen demand (COD) are inappropriate for aquatic ecosystems, but are useful for determining water quality requirements of effluents discharged into aquatic systems in order to limit their impact.

The COD is used as a routine measurement for effluents and is a measure of the amount of oxygen likely to be used in the *degradation* of organic waste. Anthropogenic activities taking place in the study area such as agriculture and the production of industrial and domestic wastes are significant sources of organic matter in the aquatic environment. DWAF (1996a) points out that in aquatic ecosystems it is unlikely that all organic matter will be fully oxidised.

The TWQR and criteria for DO concentrations (in terms of percentage saturation) are given in terms of the Minimum Allowable Values (MAV), as illustrated in **Table 3**. These concentrations provide limits which will ensure protection of aquatic biota from the adverse effects of oxygen depletion.

Table 3: Target Water Quality Range in terms of dissolved oxygen concentrations for aquatic ecosystems (adapted from DWAF, 1996a)

TWQR and Criteria	Concentration	Condition	Application
Target Water Quality Range	80 % - 120 % of saturation	06h00 sample or lowest instantaneous concentration in a 24-hour period	Will protect all life stages of most Southern African aquatic biota endemic to, or adapted to, aerobic warm water habitats. Always applicable to aquatic ecosystems of high conservation value.

For the purpose of this study, though, the DO concentration limit of > 5 mg/ℓ as described by Shepherd *et al*. (2000) was used for determining the suitability of the study area's water conditions for aquatic ecosystem well-being (**Chapter 6,** p 67).

2.3.1.4 Temperature

DWAF (1996a) defines temperature as the condition of a body that determines the transfer of heat to or from other bodies. Temperature plays an important role in water by affecting the rates of chemical reactions and therefore also the metabolic rates of organisms. Temperature is thus one of the major factors controlling the distribution of aquatic organisms in streams, rivers, dams and lakes.

Natural variations in water temperature occur in response to seasonal and diel cycles, for example, during winter months river water will be cooler than in summer months and organisms use these changes as cues for activities such as migration and spawning. In terms of the study area changes in water temperature such as point source discharges from anthropogenic sources can thus impact on individual organisms and in entire aquatic communities.

Dallas & Day (2004) explain that water quality guidelines for aquatic ecosystems in South Africa specify a TWQR whereby water temperature should not be allowed to vary from the background daily average water temperature considered to be normal for that specific site and time of day, by >2 °C or by >10 %.

2.3.1.5 pH

The pH value is a measure of the hydrogen ion activity in a water sample. The pH of pure water at a temperature of 24 °C is 7,0 i.e. the number of H^+ and OH^- ions are equal (Brady & Holum, 1996).

When the concentration of hydrogen ions $[H^+]$ increases, pH decreases and the solution becomes more acidic. Conversely, as $[H^+]$ ions decreases, pH increases and the solution becomes more basic.

Dallas and Day (2004) reviewed studies indicating that a change in pH from that normally encountered in unpolluted streams may have severe effects upon aquatic biota but that the severity of the effects depends on the magnitude of change. Some streams are naturally more acidic than others and their biotas are adapted to these conditions.

As depicted in **Table 4** no single guideline values can be set. In South Africa water quality guidelines for pH require that the TWQR be stated in terms of the background site – specific pH regime.

Table 4: Target Water Quality Range in terms of pH for aquatic ecosystems (DWAF, 1996a)

Water Resource	Target Water Quality Range
All aquatic ecosystems	pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0,5 of a pH unit, or by > 5 %, and should be assessed by whichever estimate is the more conservative.

For surface water, pH values range typically between 4 and 11. According to Fuggle & Rabie (1992) most fresh waters in South Africa are relatively well buffered and more or less neutral, with pH ranges between 6 and 8.

2.3.2 CHEMICAL WATER QUALITY CONSTITUENTS

The nature and concentration of dissolved substances such as salts, metals and organic chemicals are referred to as the chemical qualities of water. Hern as cited by Venter (2002) points out that natural occurring water's chemical composition is derived from many different sources of solutes *inter alia* gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, precipitation reactions underground and cultural effects resulting from anthropogenic activities.

The more common chemical constituents affecting aquatic ecosystems also monitored by authorities such as DWAF are discussed below.

2.3.2.1 Ammonia

Nitrogen occurs abundantly in nature and is an essential constituent of many biochemical processes. Inorganic nitrogen may be present in many forms including ammonia (NH_3), ammonium (NH_4^+), nitrites (NO_2^-) and nitrates NO_3^-) (also see section 2.3.2.3, p 20).

Ammonia is present in small amounts in air, soil and water, and in large amounts in decomposing organic matter. DWAF (1996a) further explains that natural sources of ammonia include gas exchange with the atmosphere, the chemical and biochemical transformation of nitrogenous organic and inorganic matter in the soil and water, the excretion of ammonia by living organisms; the nitrogen gas enters fixation processes whereby dissolved nitrogen gas enters the water and ground water. Ammonia, associated with clay minerals enters the aquatic environment through soil erosion. Bacteria in the root nodules of legumes fix large amounts of nitrogen in the soil and this may be leached into surrounding waters.

Manahan (1994) and DWAF (1996a) describe ammonia as a common pollutant and as one of the nutrients contributing to eutrophication. Commercial fertilizers contain highly soluble ammonia and ammonium salts. If the concentration of such compounds exceeds the immediate requirements of the plant after the application of fertilizer, transport via the atmosphere or irrigation waters can carry these nitrogen compounds into aquatic systems.

The toxicity of ammonia and ammonium salts to aquatic organisms is directly related to the amount of free ammonia in solution. The ammonium ion dominates at low to medium pH values and conversely ammonia is formed at higher pH values, the latter being more toxic to aquatic organisms.

Gammeter and Frutiger as cited by Dallas and Day (2004) found that un-ionized ammonia affects the respiratory systems of many animals either by inhibiting cellular metabolism or by decreasing the oxygen permeability of the cell membrane. Acute toxicity to fish may cause *inter alia* loss of equilibrium, increased breathing rate, cardiac output and oxygen intake and even convulsions, coma and death.

Chronic and acute toxicity of ammonia are used as norms for assessing the effect of ammonia in the aquatic environment. **Table 5** depicts the TWQR and criteria for un-ionised ammonia i.e. NH_3 in aquatic ecosystems.

Table 5: Target Water Quality Range and criteria for un-ionised ammonia in aquatic ecosystems (DWAF, 1996a)

TWQR and Criteria	Un-ionised Ammonia Concentration (µgN/ℓ)
Target Water Quality Range (TWQR)	$\leq$ 7 (0,007 mg/ℓ)
Chronic Effects Value (CEV)	15
Acute Effect Value (AEV)	100

2.3.2.2 Chlorine

Chlorine is a green-yellow gas that reacts in water to produce a strong oxidising solution (Manahan, 1994; DWAF, 1996a). Chlorine is too reactive to persist in the aquatic environment and thus not a common occurring constituent of natural waters.

Free forms of chlorine such as HOCl and OCl^- or combined available chlorine occurs in aquatic ecosystems as a result of:

- chlorination of drinking water (to remove unwanted tastes and odours, and for the purposes of disinfection);
- the textile industry (bleaching, slimicide);
- the pulp and paper industry (bleaching, slimicide);
- sewage treatment (reduce odour, algicide, bactericide);
- cooling waters (slimicide); and
- swimming pools (disinfection) (DWAF, 1996a)

According to DWAF (1996a) adverse changes in blood chemistry, damage to gills, decreased growth rate, restlessness preceding loss of equilibrium and death have been observed for fish exposed to chlorine. Invertebrates become immobile, exhibit reduced reproduction and survival on exposure to chlorine. Aquatic plants may become chlorotic whilst reduced rates of photosynthesis and respiration are observed for phytoplankton.

The TWQR and criteria for the total residual chlorine concentration in aquatic ecosystems are illustrated by **Table 6**. The norms for assessing the effects of chlorine on aquatic ecosystems are the chronic and acute toxic effects of chlorine on aquatic organisms.

Table 6: Target Water Quality Range in terms of total residual chlorine concentration for aquatic ecosystems (DWAF, 1996a)

TWQR and Criteria	Chlorine Concentration ($\mu g Cl_2/\ell$)
Target Water Quality Range (TWQR)	$\leq$ 0,2
Chronic Effects Value (CEV)	0,35
Acute Effect Value (AEV)	5

2.3.2.3 Nitrogen (Inorganic)

Various plant nutrients are required for normal plant growth and reproduction. It is nitrogen and phosphorus, however, that are most commonly implicated in excessive plant growth resulting from nutrient enrichment (eutrophication) of aquatic systems (Dallas & Day, 2004).

The term "inorganic" includes all the major inorganic nitrogen components (NH_3, NH_4^+, NO_3^-, NO_2^-) present in the water. Inorganic nitrogen is primarily of concern due to its stimulating effect on aquatic plant growth and algae. Most aquatic organisms are sensitive to the toxic affects of ammonia (see section 2.3.2.1, p 18). Natural levels of nitrates may be enhanced by municipal and industrial wastewaters, including leachates from waste disposal sites and sanitary landfills. In rural and suburban areas the use of inorganic nitrate fertilisers can be a significant source (Hill, 1997).

Table 7: Symptoms or effects associated with selected ranges of inorganic nitrogen and phosphorus concentrations (Dallas & Day, 2004)

Average Summer Concentration (mg/ℓ)		Symptoms or Effects
Inorganic Nitrogen	**Inorganic Phosphorus**	
< 0,5	< 0,005	Oligotrophic conditions with no or very few water quality problems; usually low productivity systems with rapid nutrient cycling; no nuisance growths of aquatic plants or undesirable blue-green algal blooms.
0,5 – 2,5	0,005 – 0,025	Mesotrophic conditions with moderate or occasional water quality problems; usually productive systems; occasional nuisance growths of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
2,5 – 10	0,025 – 0,25	Eutrophic conditions with frequent water quality problems; usually highly productive systems, with frequent nuisance growths of aquatic plants and blooms of undesirable blue-green algae; algal blooms may include species toxic to man, livestock and wildlife.
> 10	> 0,25	Hypertrophic conditions with almost continuous water quality problems; usually very highly productive systems; frequent nuisance growths of aquatic plants and blooms of undesirable blue-green algae, often including species toxic to man, livestock and wildlife.

The information given in **Table 7** illustrates typical symptoms associated with selected ranges of inorganic nitrogen and inorganic phosphorus.

The TWQR for inorganic nitrogen, according to DWAF (1996a), should not be changed by more than 15 % from that of the water body under local unimpacted conditions at any time of the year.

2.3.2.4 Phosphorus (Inorganic)

Phosphorus, according to DWAF (1996a), can occur in numerous organic and inorganic forms and may be present in waters as dissolved and particulate species. Elemental phosphorus does not occur in the natural environment.

Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates are found in natural waters. Of these, orthophosphate species H_2PO_4 and HPO_4^{-2} are the only forms of soluble inorganic phosphorus directly utilisable by aquatic biota (DWAF, 1996a).

Phosphorus concentrations are usually determined as orthophosphates, total inorganic phosphate or total dissolved phosphorus. Occasional increases in the inorganic phosphorus concentration above the TWQR are less important than continuously high concentrations.

Inorganic phosphorus concentrations should not be changed by more than 15 % from that of the water body under local, unimpacted conditions at any time of the year according to DWAF (1996). Typical symptoms or effects associated with selected ranges of inorganic phosphorus concentrations are illustrated in **Table 7**.

2.3.3 MICROBIOLOGICAL WATER QUALITY CONSTITUENTS

Microbiological water quality refers to the presence of organisms in water that cannot be seen by the naked eye, but can cause disease if taken in. The Water Research Commission (WRC) as cited by Venter (2002) mentions that some of these organisms include protozoa, bacteria and viruses. Many of these organisms are pathogens and cause diseases such as gastroenteritis, typhoid fever and cholera.

Faecal and total coliforms are commonly used as indicators in determining the microbiological quality of water used for *inter alia* domestic, recreational and agricultural purposes. Aquatic ecosystems do not have Target Water Quality Ranges in terms of faecal and total coliforms as humans and animals are mainly affected by such organisms. Although this is the case, faecal and total coliforms are briefly discussed as the Hennops River and some of its principal tributaries are contaminated and pose risks to human and animal health.

2.3.3.1 Faecal coliforms

Faecal coliforms bacteria are a collection of relatively harmless micro-organisms that live in large numbers in the intestines of humans and other warm-blooded animals. They aid in the digestion of food. *Escherichia coli* is the preferred indicator of faecal pollution by warm-blooded animals. Shepherd *et al.* (2000) found high *E. coli* counts ranging from hundreds to millions per 100mℓ in the Kaalspruit – a principal tributary to the Hennops River. More recent water quality data, according to Lottering (2003)*, suggests that high levels of microbiological contamination still occurs in the Kaalspruit.

The Hennops River's headwaters are therefore unfit for domestic, recreational and agricultural water uses according to the TWQR set by DWAF (1996b). It is pointed out that no counts of faecal coliforms and *E.Coli* should be present in drinking water. In terms of recreational use, DWAF (1996b) mentions that no more than 150 faecal coliform counts and 130 *E. Coli* counts per 100 mℓ water should be present in water used for full contact activities such as swimming and diving. For intermediate contact recreation such as waterskiing, canoeing and angling up to 1 000 faecal coliform counts per 100 mℓ water will be safe. In terms of agricultural use, no more than 1 faecal count per 100 mℓ is allowed for irrigation water and no more than 200 counts for livestock watering.

2.3.3.2 Total coliforms

Total coliform bacteria are frequently used to assess the general hygienic quality of water while faecal coliforms are widely used as indicators of faecal pollution. DWAF as cited by Venter (2002) mentions that the presence of total coliforms indicates inadequate treatment, post-treatment contamination and/or aftergrowth or an excessive concentration of nutrients.

As outlined in **Chapter 5** it is important to note that all of the above-mentioned constituents, except *temperature* and *microbiological constituents,* are considered in determining the suitability of the Hennops River and its principal tributaries' water quality for aquatic ecosystem well-being. The reason for temperature not being considered is because a limited number of data were available.

2.4 HYDROLOGY AND ITS RELEVANCE FOR THIS STUDY

The term **"hydrology"** refers to the science of the earth's water and its motions through the hydrologic cycle. According to Strahler and Strahler (1997) physical processes affect water in its vapour, liquid and solid states – not only in the atmosphere but also in the soil and rock and

*Personal communication

in the exposed water of streams, lakes and glaciers. The science of hydrology treats such relationships of water as a complex but unified system on the earth.

For the purpose of this study it is also important to establish which hydrological problems are present in the study area. This is due to the fact that the Hennops River and its principal tributaries have not only deteriorated in terms of water quality but also in terms of its hydrological status. Examples of such problems include *inter alia*, riverbed and riverbank erosion, high sediment volumes transported downstream and the undercutting of riparian vegetation on riverbanks along certain sections these rivers.

The aquatic environment is especially affected by sediment volumes. Suspended solids have direct and complex indirect effects on aquatic biota. Organisms are either affected by solids in suspension or, after deposition as bed load sediment, or by both. The general effects on the aquatic environment are summarised by Du Preez (1995):

- *Reduced light penetration.* This causes a reduction in photosynthesis, which results in lower primary production, which in turn, is the cause of the reduction in food available to aquatic organisms.

- *Macro-invertebrate density and diversity changes*. Silt influences macro invertebrate diversity negatively. The resulting changes in community structure are determined by tolerance levels of individuals organisms together with the magnitude of the increase in turbidity. The deposition or settling out of suspensoids will smother and abrade the aquatic biota, especially in the riffle areas where organisms are not tolerant to these depositions.

- *Habitat changes*. This will be affected by the scouring and filling of pools and riffles and changes in the bed load composition. Effects on benthos include the lavering of benthic community diversity through the disappearance or reduction of certain species. The filling of pools and riffles will dramatically change the available habitat for specific fish species, which may change species diversity, composition and biomass of the system in question.

- *Physiological impairment*. Suspensoids cause damage to fish gills and this leads to impaired respiration and a reduction in growth and foraging efficiency. Reproduction is affected as spawning habitats are destroyed and eggs damaged.

- *Predator – prey interactions*. Visibility is drastically reduced by the presence of suspensoids. This affects the food searching ability of the visually hunting fish and load predators. Owing to this, a total change in the community composition may occur.

- *Physical/chemical changes of the water body*. The water chemistry can be changed by the absorption and/or adsorption of chemicals. This can be detrimental as important nutrients become unavailable to the aquatic organisms. There is also a risk of deoxygenation of the water when solids are introduced, since particles exert an oxygen demand, both in suspension and when settled. In the extreme, this condition proves fatal to fish.

In order to ascertain and comprehend the water quality and certain hydrological problems of the Hennops River and its principal tributaries, it is necessary to describe the actual study area with the position of these rivers, associated physical features and its prevailing land uses.

CHAPTER 3: THE STUDY AREA

3.1 THE STUDY AREA IN TERMS OF SOUTH AFRICA'S PRINCIPAL CATCHMENTS

With regard to freshwater systems such as large rivers fed by smaller tributaries, South Africa consists of 19 principal freshwater catchments (**Figure 4**). Sampson (2001) mentions that the *National Water Resource Strategy* (GN 1160, GG 20491 of 1 October 1999) in terms of Section 5(1) of the National Water Act (Act no. 36 of 1998) divides the country into 19 *water management areas* in terms of these principal catchments. As such, each principal catchment is also an identified area to manage by DWAF in terms of its water quality occurring in streams, rivers, dams, lakes and estuaries. According to Le Roux (2003) each water management area will be managed by a *catchment management agency*.

Figure 4: South Africa's 19 identified water management areas

Three of these 19 identified national water management areas are situated in Gauteng; i.e. the Olifants, the Crocodile (West) – Marico and the Upper Vaal (Fakir & Broomhall, 1999). The Hennops River only forms a part of the numerous sub-catchments of the Crocodile (West) –

Marico catchment/water management area. The Hennops River together with others such as the Blaaubank, Magalies, Crocodile and the lower Jukskei Rivers, feed the Hartebeespoort Dam. The Dam's outflow continues as the Crocodile River which ultimately confluences with the Limpopo River.

The Kaalspruit, Olifantspruit, Rietspruit and Jukskei sub-catchments include various wetland areas, which include vleis, rivers, flood plains and pans and provide a transition between terrestrial and aquatic environments and therefore support a diversity of life forms. The main wetland areas in the sub-catchments are the Vorna Valley Vlei (22 ha), Kaalspruit (52 ha), Beaulieu Bird Sanctuary (16 ha), Glen Austin Pan (9.7 ha), Hennops River (±64 ha) and Jukskei River (±68 ha) (Fakir & Broomhall, 1999). Wetlands are essential to ecological systems as they: maintain water quality; act as natural filters and sponges; absorb run-off; trap sediments; and reduce erosion.

3.2 LOCATION, DEMARCATION AND OVERALL DESCRIPTION OF THE STUDY AREA

The Hennops River catchment is situated between Pretoria and Johannesburg, Gauteng. The Hennops and its principal tributaries flow in a northerly direction through four large municipal areas within the province *viz*. City of Johannesburg, Ekurhuleni, Kungwini and City of Tshwane. The catchment stretches from Kempton Park in the south to Centurion i.e. the suburbs of Sunderland Ridge and Erasmia in the north. After passing Erasmia the Hennops River cuts its way through the Skurweberg range before confluencing with the Crocodile River to feed the Hartebeespoort Dam which is situated in the North-west Province.

The Hennops River originates as the Kaalspruit which has its source as natural springs in Norkem Park and Birchleigh North, south-east of Tembisa. This area is the upstream and most southerly section of the study area. The Kaalspruit flows through Tembisa and Ivory Park in a northerly direction. Another source of dedicated water flow, according to Gouws *et al.* (1998), emanates from the wastewater treatment ponds of the Chloorkop factory upstream of Ivory

Park. This and other tributaries which have their source at, Rabie Ridge and Eskom Training College enter the river system downstream from here as well.

The Kaalspruit flows near the western boundary of Tembisa (**Figure 5**) towards Olifantsfontein, where another tributary from the south-east enters the river. Their confluence is at the start of a wetland (known as the Olifantsfontein wetland) from where the Kaalspruit continues flowing north through an eroded channel of the wetland. This tributary has two sub-tributaries which enter Clayville at the southern boundary through two concrete channels (**Figure 6**). These two channels become one main stormwater channel through Clayville, hereafter known as the "Clayville tributary". This channel consequently also receives run-off from industries and roads.

Figure 5: Kaalspruit flowing through Tembisa

Figure 6: Clayville concrete channel

Downstream of the confluence of these two streams, the Olifantspruit enters the Kaalspruit south of the Olifantsfontein Sewage Works. The Olifantspruit has its source in Glen Austin Extension 1 Agricultural Holdings. *En route* to the confluence, several minor tributaries enter the Olifantspruit which also emanate from agricultural land and small holdings (Hoffmann, 1995). George (2003) mentions that this tributary is not significantly polluted and is in a reasonable condition in terms of water quality down to its confluence with the Kaalspruit.

After the confluence of the Olifantspruit and Kaalspruit, the effluent from the Olifantsfontein Sewage Works discharges as a major point source of concern into the stream. The stream continues flowing further north through agricultural land and pastures towards the agricultural village of Irene. The Sesmylspruit joins the Olifantspruit slightly east of the Irene Country Club golf course. The Sesmylspruit originates as the Rietvlei River which, according to Van der Walt *et al.* (2001), originates in a marshy area east of Kempton Park and *en route* to the Rietvlei Dam and passes through a number of wetlands. The catchment area is utilized by agricultural activities that use large amounts of water for irrigation, while the water is augmented by natural run-off, springs and effluent from the Hartebeesfontein Sewage Works.

Figure 7: Sesmylspruit

The Rietvlei River feeds the Rietvlei Dam and the dam overflow and some return flow water from the waterworks downstream of the dam are the main source of water in the Sesmylspruit (**Figure 7**). The origin of the Rietvlei River down to and including the Rietvlei Dam does not form a significant part of this study as the influence of the Sesmylspruit on the Hennops River is handled in more detail.

Downstream of the confluence, the Olifantspruit becomes the Hennops River which flows through the golf course, a dairy farm, the rest of Irene and then through the Centurion Golf Estate further downstream. A small non-perennial stream flowing northwards through the property of the Agricultural Research Council in Irene enters the Hennops where it enters the Centurion Golf Estate. A stormwater tributary from the north in Doringkloof joins the Hennops River near the N1 Highway crossing.

Figure 8: Hazelspruit flowing through Highveld Technopark

Another tributary in the form of the Kastaiingspruit, which becomes the Hazelspruit, flows from the south through Highveld Technopark and confluences with the Hennops River (**Figure 8**). This point is at the south-eastern edge of the Centurion Cricket Stadium, approximately 600 m upstream of the Centurion Lake. The River then passes between the Centurion Cricket Stadium and a recreational waterpark (called "Splash") before entering the Centurion Lake below the Centurion Lake Hotel.

The Centurion Lake impounds and attenuates the incoming flow of the Hennops River (Hoffman, 1994). This urban impoundment has become a silt trap for the Hennops River and the effective volume has been drastically reduced. It was built in 1982 at a cost of R5,2 million on the original watercourse and no allowance was made for bypassing the lake in case of excessive silt accumulation. The lake, if clean, was constructed having a maximum depth of 2,5 m and covering an area of 7,1 ha (Freeman *et al.*, 2000).

Table 8: Characteristics of Centurion Lake

Geographic Location	25° 51' S; 28° 11' E
Elevation	1 420 amsl
Surface Area	7,1 ha
Volume	145 000 m^3
Mean Depth	1,7 m
Maximum Depth	2,5 m
Length	600 m
Width	120 m

Downstream of the Centurion Lake, the Hennops River flows through the residential suburbs of Centurion such as Lyttleton, Hennops Park, Clubview and Eldoraigne. It also cuts through golf courses, floodplains, the Zwartkops Nature Reserve and flows past the Centurion Sewage Works at Sunderland Ridge.

The Rietspruit is another principal tributary of the Hennops River and confluences with the Hennops River just before passing the Centurion Sewage Works. The Rietspruit, like the Olifantspruit, has its origin in the Glen Austin Agricultural Holdings but flows northwards towards the Hennops. The Rietspruit flows between residential and agricultural land use areas. Residential areas include Noordwyk, Blue Valley Golf Estate, The Reeds, Heuweloord and agricultural areas of Raslouw, Deltoidia and Sunderland Ridge Agricultural Holdings. Fakir and Broomhall (1999) describe the Rietspruit catchment as agricultural and semi-urban in nature.

The final principal tributary of the Hennops River before reaching the Skurweberg range is the Swartbooispruit. This tributary flows from the south through agricultural holdings such as Mnandi before confluencing with the Hennops River. This is the downstream and north-westerly northerly end of the study area as the water quality of the Hennops River is unlikely to alter substantially downstream of this point.

The Hennops River from here winds its way through the Skurweberg range which is also home to recreational resorts such as “Hennops Pride”. The River ultimately forms a confluence with the Crocodile River, not too distant from the southern edges of the Hartebeespoort Dam.

3.3 PHYSICAL FEATURES IN THE STUDY AREA HAVING AN INFLUENCE ON THE WATER QUALITY AND CERTAIN HYDROLOGICAL FEATURES

3.3.1 Climate

The area experiences a sub-humid, warm climate. According to SEF (2003) the average minimum and maximum temperatures recorded at the Irene Weather Station (station number 0513385) are 3 °C and 27 °C respectively. Average maximum temperatures vary between 25 °C and 27 °C from October to April (summer), while average minimum temperatures vary from 2,7 °C and 9,8 °C between May to September (winter). Frost is experienced during the winter period. Frost will occur when the air temperature drops below 2 °C. This occurs in valley bottoms and areas along the Hennops River and its principal tributaries. Variations in temperature experienced in the study area is therefore minimal. The Hennops River and its principal tributaries should therefore not experience significant fluctuations in water temperature unless anthropogenic sources of heat or cold is transferred to the aquatic regime. This could occur in the form of point source pollution.

Hoffmann (1994) mentions that long term rainfall records reveal a mean annual rainfall of 689 mm. Most of the rainfall occurs as afternoon thunderstorms during the months November to March. The mean annual evaporation varies around 1 700 mm. Wet seasons usually contribute to a higher yield of water pollution to rivers and streams flowing through urban areas. Hoffmann (1994) found that the water quality of the Hennops River deteriorated after rains, especially after the first rains succeeding a long period of no rain e.g. after winter. This is because collected wastes, oils, litter and other forms of pollution are washed down to rivers during rainy periods.

3.3.2 Vegetation

The types and variety of vegetation are also dependent upon the climate of the study area, especially in terms of temperature and precipitation. The natural vegetation in undeveloped areas consists of sour grassveld and is sparsely covered by trees. Trees such as *Populus canexens* and reeds are common along the upstream sections of the study area i.e. sections along the Kaalspruit and Olifantspruit. The trees lose leaves and branches and dead trees and reeds end up in these streams contributing to a large amount of vegetation debris present in them. *P. canexens, Salix babylonica* and *Celtis africana* are the most common along the downstream section of the Hennops River.

Vegetation debris ending up in streams and rivers become obstructions affecting their flow regimes and minimises available space and incoming sunlight needed by aquatic biota. This is a problem which is especially evident after heavy rains.

3.3.3 Topography

Hoffmann (1994) reveals that the topography from Tembisa to the Centurion Lake has a moderate gradient falling in elevation, from 1 620 m above mean sea level (amsl) at the source to about 1 420 m amsl at the Centurion Lake. The average gradient in this case is therefore 1 : 140.

From the Centurion Lake to the Centurion Sewage Works the altitude drops to 1 380 m. Due to the fact that the Hennops and its principal tributaries are relatively steep rivers, they should have good re-aeration capacity according to Hoffmann (1994). Since the course of these rivers flow along a gradient of 1 : 140, water is seldom stagnant and water flow is impelled by the gradient resulting in the water to become aerated. This, in turn, contributes towards the oxygen levels of the water needed for the survival of aquatic biota.

3.3.4 General geology

Knowledge of the geology of the study area is essential for an understanding of the hydrology (quantity/volume and movement of the surface and subsurface water resources) of the Hennops River and its principal tributaries. The types of rock have direct influence on the types of soil present in the study area which influence river flow regimes, erosion and sedimentation.

The principal rocks present in the study area are described by George (2003):

- *The Halfway House Granites*

  These are the oldest rocks in the area. The granites are important as most of the floodwater volumes in the Kaalspruit are originating from stormwater run-off from the high lying granitic areas.

  The granite topsoil, according to George (2003) is easily eroded when vegetation is removed. Erosion of these soils and weathered rocks contribute significant amounts of silt and sand to the Kaalspruit and ultimately, the Hennops River.

  The granites also provide good founding conditions for township developments and other urban developments. Most of the urban developments (formal townships and informal settlements) present in the Hennops River's upper catchment i.e. the Kaalspruit, are situated on granite. This has possibly also resulted in an increase in stormwater run-off volumes from these granitic occupied areas.

- *The Transvaal Sequence Rocks*

  These overlie the above-mentioned granites. In the study area the Transvaal sequence is made up of dolomites and the Pretoria Group consisting of quartzites, shales, conglomerates and breccias which overlie the dolomites.

  The quartzites, shales, conglomerates and breccias provide favourable base foundations for the Rietvlei Dam. Underground seepage is therefore minimal.

- *Karoo Sequence Rocks*

  Shales, sand and stones and tillites overlie some of the Transvaal Sequence Rocks. These contribute to the surface water run-off feeding the Rietvlei Dam.

- *Intrusive Rocks*

  The intrusive rocks comprise of dykes and silts of various compositions and ages (George, 2003). These can strongly influence the direction of ground water movement.

- *Alluvial Deposits*

  These occur along sections of the Kaalspruit, Olifantspruit, Rietvlei and Hennops Rivers. They represent a source of sediments which can be eroded and flushed downstream causing problems of siltation along downstream sections of the study area.

3.3.5 Pedology

The soils in the Hennops River catchment, like elsewhere, are associated with the underlying geology. According to SEF (2003) collapsing sands cover the granite area. The dolomite is overlain by typical red-brown, gravely soils. Along drainage channels, the granite weathers to grey clay. The chert in the catchment area is in the form of rocky outcrops which give rise to the low rounded ridges and hillocks.

The syenite that is exposed is predominantly silty (SEF, 2003). Alluvial deposits, as mentioned before, are present along the banks of the Kaalspruit, Olifantspruit and Hennops Rivers. These soils are mostly gravels and clayey material which contribute to the bed load sediment of the rivers and thus the amount of total suspended solids as well (see section 2.3.1.2, p 13).

3.4 LAND USE AND ACTIVITIES IN THE STUDY AREA HAVING AN INFLUENCE ON THE WATER QUALITY AND CERTAIN HYDROLOGICAL FEATURES

According to Fuggle and Rabie (1992) the golden rule for the management of freshwater ecosystems is to remember that the conditions, water quality and biota of any body of freshwater are the products and reflection of events and conditions in its catchment. As such, land use and activities in the study area are considered towards the formulation of rehabilitative measures for the Hennops River and its principal tributaries.

The study area receives point and non-point source pollution from different land use and activities which can broadly be classified as follows:

- *Urban development* such as residential, formal and informal housing as well as commercial and industrial developments.

- *Agricultural activities* such as the planting and harvesting of crops such as maize on agricultural and informal holdings and small scale crop planting such as maize, pumpkins and watermelons along certain sections of streams feeding the Hennops River.

- *Sewage treatment works* which include the Olifantsfontein, Hartebeesfontein and Centurion Sewage Works.

From physical site investigations and studying works by Hoffmann (1994), Shepherd *et al.* (2000) and SEF (2003) a description of the land use and activities from the upstream to the downstream section of the study area are described:

3.4.1 Tembisa, Ivory Park and Rabie Ridge – *urban development and agricultural activities*

The southern parts of the study area, where the Hennops River (at this point, Kaalspruit) originates, is where the townships of Tembisa, Ivory Park and Rabie Ridge are found. The township of Tembisa consists mainly of serviced stands (formal housing) and some informal houses and, according to Hoffmann (1994), had a population of around 500 000 in 1995 which has significantly increased since then. The area's waste water, according to Shepherd *et al.* (2000), drains into the eastern and western trunk sewers. Garner (1998) points out that the sewer lines are a major cause of pollution in the Kaalspruit. Sewer pipes drain towards the low lying river where the main sewer follows the river course *en route* to the Olifantsfontein Sewage Works. The pipe of the main sewer often becomes blocked resulting in sewage overflowing from the manholes into the Kaalspruit. Eighty-five percent of the roads within Tembisa are dirt roads which erode during heavy storms, thereby adding silt to the Kaalspruit. Most of the area's stormwater drains to the Kaalspruit (Shepherd *et al*., 2000).

Because the townships are littered with municipal general waste the stormwater augmented from these areas becomes a major contributor to the non-point source pollution entering the Kaalspruit during storms (**Figure 9**). Such wastes include cans, bottles and varying kinds of plastics. Phosphates, nitrates and pesticides could also be washed into the Kaalspruit due to the agricultural activities taking place in these areas illustrated by **Figure 10**.

Figure 9: Non-point source pollution from informal settlements

Figure 10: Small-scale agriculture along Kaalspruit

All the roads in Rabie Ridge are tarred and it has a well developed infrastructure consisting of formal housing where all the stands are serviced. Rabie Ridge should therefore have less of an influence on the non-point source pollution entering the Kaalspruit. According to Hoffmann (1994) this area's waste water drains to the western outfall sewer at Tembisa.

Ivory Park flanks the northern boundaries of both Tembisa and Rabie Ridge and is an informal housing development i.e. 75 % of dwelling units are informal and 25 % formal (Gouws *et al.*, 1998). Physical site investigations reveal that most of the on-site sanitation systems are in a poor state and sewage discharges drain towards the Kaalspruit. The spruit therefore becomes contaminated with faecal and total coliform bacteria resulting in the degradation of its water quality (see section 2.3.3, p 22).

3.4.2 Clayville and Olifantsfontein – *urban development*

Clayville is the industrial centre of Midrand and lies north and downstream of the above-mentioned areas. Stormwater and run-off from paved areas discharge into the Clayville tributary which passes through the centre of Clayville in a northerly direction. As illustrated by **Figure 11** this tributary of the Kaalspruit is contaminated with any process water and leaking effluents from the industrial processes of Clayville. Visual observations reveal that there is a continuous flow of waste water in the channel even under dry weather conditions. According to Shepherd *et al.* (2000) most of the area's industrial effluent discharges into the sewer network to be treated with the domestic wastewater at the Olifantsfontein Sewage Works.

Figure 11: Clayville tributary before confluence with Kaalspruit

It is observed that industries in Clayville include: plastic and pipe manufacturers, pharmaceutical manufacturers, beverage producers, abattoirs and food processing factories. Stormwater run-off is, therefore likely to contain some organic pollutants according to Shepherd *et al.* (2000).

As to be discussed in section **7.2**, p 90, another significant part of the study area is a natural occurring wetland situated along the Kaalspruit from its confluence with the Clayville tributary down to the Olifantsfontein Sewage Works. This wetland is known as the Olifantsfontein wetland.

On the northern boundary of Olifantsfontein is an industrial area which comprises Cullinan Refractories and a brick and tile manufacturer. Most of this area's surface water run-off, containing pollutants such as oils and litter, drains towards the Olifantspruit found downstream of the Olifantsfontein Sewage Works.

3.4.3 Olifantsfontein Sewage Works – *sewage treatment works*

The treated industrial effluent from the Olifantsfontein Sewage Works discharges as a point source pollutant into the Olifantspruit (**Figure 12**). In terms of hydrology, the Olifantspruit's flow regime is influenced as the sewage works' effluent return flow is a major contributor to the permanent flow in the Olifantspruit to later form the Hennops River. According to Rössle (2004) the volume of effluent return flow is in the order of 70 Mℓ/d with an anticipated volume of 120 Mℓ/d that could eventually be reached. The treatment works purifies the wastewater emanating from Tembisa, Ivory Park, Rabie Ridge, Clayville and Olifantsfontein.

Figure 12: Point discharge from Olifantsfontein Sewage Works

3.4.4 Olifantsfontein to Centurion Lake – *agricultural activities*

From the Olifantsfontein Sewage Works, the Olifantspruit (as it is now known), flows towards Irene through a relatively undeveloped area. Farmers in the area prefer using borehole water for irrigation purposes due to the river's poor quality (George, 2003).

The Irene Country Club (golf course) borders slightly west of the confluence of the Sesmylspruit (emanating from Rietvlei Dam) and Olifantspruit. Visual observations have revealed (**Figure 13**) that substantial sedimentation from the Olifantspruit is occurring and that water from the Sesmylspruit seems to be substantially clearer. After the confluence of these two rivers the name changes to Hennops River. Water is extracted from the Hennops River for irrigating 60 ha of the golf course.

Figure 13: Confluence of Olifantspruit and Sesmylspruit

The Irene Dairy Farm and 80 ha of pastures for cattle is situated downstream of the golf course. Water for irrigation purposes is obtained from the Rietvlei Dam via pipeline and surplus water run-off from the farm flows into the Hennops River. Possible phosphate and nitrate inflow to the Hennops River can occur here. Similar pollutants can be expected from the non-perennial tributary emanating from the property of the Agricultural Research Council.

New developments in the Centurion suburbs of Highveld and Highveld Technopark have taken place in the past few years. According to SEF (2003) further proposed developments such as "Centurion – Eco Park" will include the following: residential, home-offices, business, education, communal facilities, light industry and open space. Developments such as these will consequently have an effect on the volume and quality of water of the Kastaiingspruit which becomes the Hazelspruit. BOKAMOSO (2003) mention that any pollutants such as oils and litter found along roads and pavements will be flushed along this tributary after rains. Because this area has become urbanised and mainly covered by roads, pavements and buildings, higher stormwater run-off volumes enter the spruit. As previously mentioned, this tributary flows through Highveld Technopark to later feed the Hennops River approximately 600 m upstream of the Centurion Lake.

3.4.5 Centurion Lake – *urban development*

Freeman *et al.* (2000) describe the Centurion Lake as a classic example of the construction of a man-made impoundment in order to enhance and add value to surrounding commercial developments, as well as serving as a focus for recreational activities. Not surprisingly the Centurion Lake covering an area of 7,1 ha has formed the centre of the commercial node of Centurion. As illustrated by **Figure 14** the lake has served as the focal point around which numerous office blocks, shops, hotels, restaurants, parking facilities, garages and braai facilities have been developed. Stormwater from the surrounding areas is directed towards the lake. As such, the Centurion Lake not only receives pollution from upstream areas via the Hennops River (point source pollution) but from its immediate surroundings as well (non-point source pollution).

Figure 14: Centurion Lake forming the centre of the Centurion CBD

At present, anyone familiar with the Centurion Lake knows the lake is in a poor and problematic environmental state. It is silted-up in most places, occasional fish deaths occur, complaints about odours are common according to Lottering (2003)* and recreational activities have ceased. The lake has become a silt trap and pollution control facility for the upstream areas mentioned since the areas of Tembisa.

*Personal communication

3.4.6 Centurion Lake to the Crocodile River – *urban development, agricultural activities and sewage treament works*

The Hennops River continues as the Centurion Lake's overflow in a north-westerly direction towards the Centurion Sewage Works. This section of the Hennops flows mainly through areas of open space within residential areas.

Before reaching the sewage works and the outskirts of Erasmia, the Hennops River passes through a couple of floodplains. Personal communication with residents adjacent to these floodplains reveals that occasional flooding of these floodplains occurs during heavy rains. The Hennops River flows through residential areas, the Zwartkops Country Club (golf course) and through the southern parts of the Zwartkops Nature Reserve. *En route* stormwater tributaries enter the River transporting with them phosphates, detergents, soaps as well as oils augmented from the residential and agricultural areas (Lottering, 2003)*.

The Hennops River exits the nature reserve, flows under the R55 road and is fed by the Rietspruit (**Figure 15**) before passing the Centurion Sewage Works. In terms of the River's hydrology the sewage works, as in the case of the Olifantsfontein Sewage Works, is a major contributor to the flow volume of the River. Botha (2004)* mentions that these works release between 38 and 60 Mℓ of effluent return flow to the Hennops River each day. According to Botha (2004)* the only concern for the sewage works concerning water quality is the release of high amounts of phosphates but the situation is continually monitored.

Figure 15: Rietspruit *en route* to Hennops River

The Swartbooispruit feeds the Hennops River further downstream and could be polluted by agricultural activities. Phosphates and nitrates are forms of non-point source pollution from agricultural land run-off. The Hennops River then continues to meander through farmlands, areas of open space, the Skurweberg and recreational resorts where small-scale pollution non-

*Personal communication

point source pollution of phosphates and nitrates could occur before confluencing with the Crocodile River.

From the above it is seen that physical features, land use and activities in the study area therefore have an influence on the water quality and certain hydrological features of the Hennops River and its principal tributaries. These are considered in **Chapters 6** and **7** where the actual water quality and principal hydrological problems of the rivers are dealt with.

Before this is done, a review of existing knowledge of previous conditions of the study area is undertaken to later determine whether or not degradation of water quality and hydrological conditions have occurred.

CHAPTER 4: REVIEW OF EXISTING KNOWLEDGE CONCERNING WATER QUALITY AND CERTAIN HYDROLOGICAL FEATURES OF THE STUDY AREA

4.1 BACKGROUND

A literature review was conducted in order to gather any existing knowledge concerning the study area's previous conditions. Reviewing existing knowledge regarding the water quality and certain hydrological conditions of the Hennops River and its principal tributaries over the past 30 years (from 1972) will illustrate the effects and impacts increasing urbanisation, human settlement and activities have had on these.

Wherever possible, current water quality and hydrological conditions of the most recent years between 2002 to 2003 are also compared to the study area's previous conditions in order to determine whether degradation of the study area has increased or not. This is done in **Chapters 6** and **7** where current water quality and certain hydrological conditions are dealt with.

4.2 PAST STUDIES

Reviewing existing literature reveals that past studies were not necessarily conducted on the Hennops River's problems alone, but on different aspects pertaining *inter alia* to its tributaries, the Rietvlei Dam and Hartebeespoort Dam. Even though this is the case, certain useful information is still used for this study. It should be emphasised that the objective of this review of existing knowledge was to determine whether or not the **overall** water quality and certain hydrological conditions of the rivers have deteriorated since the seventies. As such, water quality constituents, not just affecting aquatic ecosystems (as described in **Chapter 2**), were considered in reaching this objective.

A brief review in terms of existing literature therefore follows in chronological order *viz*. studies conducted during the seventies, eighties and nineties were grouped together.

4.2.1 STUDIES CONDUCTED DURING THE SEVENTIES

Wittmann and Förstner (1976) investigated possible sources of heavy metals (mercury, cadmium, lead and zinc) discharged into the Crocodile River feeding the Hartebeespoort Dam. A preliminary survey of streams, rivers and dams which feed the Crocodile River was conducted, the Hennops and Jukskei River drainage systems being the main sources of water of the Crocodile River.

What Wittmann and Förstner (1976) found was that *"high values of mercury, cadmium, lead and zinc in the estuary of the Crocodile River …. are contributed by the Hennops River (mercury) and Jukskei (lead, cadmium and zinc)."* Their study during the seventies (1975/1976) revealed that mercury enrichment, the most toxic of all metals, of several Hennops River sampled sediments is the outstanding feature of this drainage system. This is significantly reflected by the high mercury concentration of 4,97 mg per kilogram of sediment sampled from the Hennops River near to where the Centurion Lake now exists.

Based on a study conducted by Schoeman (1976) diatoms and other groups of algae have been successfully employed to detect the degree of eutrophication of waters and to assess water quality. Schoeman (1976) conducted a study where diatom associations were used to evaluate the trophic status of four rivers contributing to the Hartebeespoort Dam. Sampling was conducted between March 1972 and August 1973 and sampling stations were situated *inter alia* on the Hennops River upstream of its confluence with the Crocodile River before feeding the Hartebeespoort Dam.

According to Schoeman (1976) examination of the diatom group analyses indicated that the waters of the Crocodile and Hennops had better water quality in comparison with those of the eutrophied Modderfontein and Jukskei Rivers. The aforementioned rivers had high values of oxygen indicators, the mean for the Crocodile being 75,8 % and that of the Hennops 78,3 %. Schoeman (1976) further explains that *"the Hennops and Crocodile Rivers also have low mean values of nitrogen heterotrophic Nitzschiae and may thus be regarded as being relatively clean with low trophic levels."* Aquatic ecosystems found in this section of the Hennops River were therefore not detrimentally affected by its water quality as sufficient oxygen was available and the water was oligotrophic.

The Modderfontein and Jukskei Rivers were both well enriched with plant growth nutrients (nitrogen and phosphorus), whereas the Crocodile and Hennops Rivers were relatively poor in these nutrients. The COD (chemical oxygen demand) values of the former are also considerably higher than those of the latter two rivers (Schoeman, 1976). **Table 9** illustrates the relevant mean constituent values established three decades ago. These can be compared to recent (2002/2003) water quality constituent values dealt with in **Chapter 6** in order to determine possible degradation of the Hennops River (section **6.2**, p 67).

Table 9: Mean constituent values of the downstream section of the Hennops River between 1972 and 1973

WATER QUALITY CONSTITUENTS				
Chemical Oxygen Demand (mg/ℓ)	Ammonia (mg/ℓ)	Nitrate & Nitrite Nitrogen (mg/ℓ)	Orthophosphate (mg/ℓ)	pH
9,2	0,2	0,1 to 1,9	0,1	8,4

Additional to the above two studies of the seventies, a study was conducted between 1973 and 1974 by Toerien and Walmsley (1979) on the chemical composition of the Hennops River and its implications on the Rietvlei Dam. It is seen in their study, that the Rietvlei River (feeding the Rietvlei Dam) was known as the upper end of the Hennops River and despite pollution of this stream with secondary treated sewage effluents, chemical quality conformed to prescribed potable water standards. Toerien and Walmsley (1979) also found that up to 70 % of the total annual inflow into the Rietvlei Dam consisted of these effluents.

The chemical loadings determined between February 1973 and January 1974 by Toerien and Walmsley (1979) were compared to chemical loadings also entering the Rietvlei Dam determined between October 1994 and May 1996 by De Wet and Mallory (1998). According to De Wet and Mallory (1998) a significant increase of all major cations (Ca, Mg, NH_4 and K) and anions (Cl, SO_4, NO_2, NO_3 and PO_4) were observed. This can be seen in **Table 10** illustrating that percentage increases of these cations and anions ranged between 45 and 2 700 %. An increase in all of the above-mentioned constituent loads entering Rietvlei Dam per annum is seen except for sodium (Na) which decreased by 16 %. A concern of these increases is that the trophic status and algal growth potential of Rietvlei Dam had significantly changed due to an increase in nutrient concentrations of nitrogen and phosphorus.

The ammonia loadings entering Rietvlei Dam were found to be 28 times higher than 22 years ago. A significant increase in phosphates was also observed. The subsequent increase in the N:P ratio favours the growth of nitrogen fixing algae which has significantly increased since the 1970's (De Wet & Mallory, 1998).

Table 10: Comparisons of mean chemical mass loads entering Rietvlei Dam during 1973/74 and 1994/96 [adapted from De Wet and Mallory (1998)]

Constituent	1973/1974 ($g/m^2/a$)	1994/1996 ($g/m^2/a$)	% increase
Total Dissolved Solids	-	3579	-
Calcium	200	991	395
Magnesium	105	680	547
Chloride	280	406	45
Sulphate	447	744	66
Ammonia	1,3	36,4	2700
Nitrite	0,4	1,7	334
Nitrate	1,6	33,9	2019
Orthophosphate	9,9	17,9	81
Chemical Oxygen Demand	192	470	145
Sodium	523	441	-16
Potassium	60	96	60

4.2.2 STUDIES CONDUCTED DURING THE EIGHTIES

In another study involving the Rietvlei Dam, Ashton (1980) studied the annual contributions of nitrogen fixation to the nitrogen budget of the Dam calculated for a three year period. It was found that the overall effect of nitrogen fixation is a net increase in the total quantity of combined nitrogen present in the impoundment. This contribution to the nitrogen pool is rapidly lost via the outflow as well as by sedimentation of particulate material (Ashton, 1980).

From the above three studies by Toerien and Walmsley (1979), De Wet and Mallory (1998) and Ashton (1980) it is therefore envisaged that certain amounts of *inter alia* cations, anions, phosphates and inorganic nitrogen could be released from Rietvlei Dam into the Sesmylspruit *en route* to the Hennops River. As previously mentioned, the Rietvlei Dam and its principal tributary, the Rietvlei River, are considered for this study but the study area's eastern demarcation borders at the origin of the Sesmylspruit i.e. the outflow of Rietvlei Dam. Even though problems such as eutrophication are experienced at Rietvlei Dam, only the outflow's contribution to the Hennops River's problems is taken into account.

Although not forming part of the applicable water quality constituents, 13 new types of aquatic fungi (Hyphomycetes) for South Africa were identified two decades ago by Sinclair *et al.* (1983). The specific study was undertaken in the Hennops River passing through Irene. This illustrates that quantities of organic material such as rotting plant material was present in the Hennops in this area. This could still be the case as Irene has numerous trees and a dairy farm situated on the banks of the Hennops River. Valuable fungal species could be threatened by the rapid siltation of riverbeds which has occurred since the early eighties and increased since the nineties.

In terms of the effects that the Hennops River has had on the Hartebeespoort Dam, Thornton *et al.* (1984) explain that this impoundment was oligotrophic since the 1930's, but since 1958 it has been classed as eutrophic and hypertrophic. As can been seen in **Table 7**, p 21, hypertrophic conditions involve frequent nuisance growths of aquatic plants and blooms of undesirable blue-green algae. Concentrations of more than 10 mg/ℓ inorganic nitrogen and more than 0,25 mg/ℓ inorganic phosphorus are needed for water to be classified as hypertrophic. The Hartebeespoort Dam's major inflows are described as the Crocodile and Magalies Rivers with the former providing more than 90 % of the inflowing water and nutrient load. Annual nutrient loads are typically in the order of 300 t phosphorus and 1660 t nitrogen (Thornton *et al.*, 1984). As the Hennops River confluences with the Crocodile before feeding the Hartebeespoort Dam it is deduced that the Hennops must have made some contribution to these loads entering the Dam.

The Hartebeespoort Dam's water quality as stated by Sutton and Oliveira (1987) is influenced to varying degrees by point and non-point source discharges. They determined that increasing urbanisation and human activity within the Dam's catchment areas have an effect on the water quality entering the Dam. *"The highest pollution loads were found at the Jukskei just before its confluence with the Crocodile and which also has the highest level of urbanisation for the catchment ….. Next highest is again the Jukskei then the Hennops and finally the Crocodile before its confluence with the Jukskei"* (Sutton & Oliveira, 1987). Their results indicate that the Hennops River's contribution to the total volume of water entering the Hartebeespoort Dam was among the poorest in terms of water quality.

Table 11 illustrates that this was determined in terms of the chloride, ammonia, nitrate and nitrite nitrogen and total phosphate loads present in the downstream section of the Hennops River between 1980 and 1981. Since the mean constituents shown in **Table 11** are also dealt with in **Chapter 6**, they will be compared to the recent (2002/2003) mean constituent values in order to determine possible degradation of the Hennops River by comparing mean values of the years 1980/1981 to 2002/2003 (section **6.2**, p 67).

Table 11: Mean constituent values of the downstream section of the Hennops River between 1980 and 1981

WATER QUALITY CONSTITUENTS			
Chloride (mg/ℓ)	Ammonia (mg/ℓ)	Nitrate & Nitrite N (mg/ℓ)	Total Phosphate (mg/ℓ)
50	0,42	27,32	1,7

4.2.3 STUDIES CONDUCTED DURING THE NINETIES

In his report to the Water Research Commission, Hoffmann (1994) deals with the non-point source pollution of the Hennops River. It was found that non-point source run-off originating in the upper reaches of the Hennops River catchment is polluted throughout the year. *"The major source of pollution is solid waste and faecal contaminants"* (Hoffmann, 1994).

Water quality sampling and analysis was also conducted as part of Hoffmann's study. Fifteen sites were selected for water quality monitoring and approximate flow measurements where five of these are considered for this study as they are similar to some of the DWAF and CTMM sampling points discussed in **Chapter 5**, p 55. Values depicted by **Table 12** are the relevant mean constituent concentrations of the five sampling points for the period between March 1993 and March 1994.

Table 12 shows that mean water quality constituent values of the Hennops River's feeding streams *viz.* Kaalspruit, Olifantspruit and Sesmylspruit down to the Hennops at Centurion Lake are available. The mean constituent values themselves can be compared to recent (2002/2003) mean values as all of these constituents are dealt with in **Chapter 6**. A comparison of constituent values of these two periods are individually described in section **6.2**, p 67 to determine whether further water quality degradation has taken place over the past decade.

Table 12: Mean constituent values of five sections of the study area between 1993 and 1994

Section of study area	pH	Chemical Oxygen Demand (mg/ℓ)	Suspended Solids (mg/ℓ)	Dissolved Oxygen (mg/ℓ)	Conductivity (mS/m)	Chloride (mg/ℓ)	Ortho-Phosphate (mg/ℓ)
Kaalspruit downstream from Tembisa	7,7	66	124	5,11	61,8	101,34	1,48
Olifantspruit downstream from Olifants-fontein Sewage Works	7,8	64	138	5,63	55	43	2,08
Sesmylspruit upstream from confluence with Olifantspruit	-	-	-	-	-	43,49	0,34
Inflow of Centurion Lake	7,8	48	143	5,57	54,7	43,59	1,74
Outflow of Centurion Lake	7,8	43	121	5,57	54,9	42,34	1,59

In terms of hydrological aspects Hoffmann (1994) concluded that the point source contribution from the Olifantsfontein Sewage Works dilutes the polluted base flow in the river. From his study conducted a decade ago Hoffmann (1994) describes the Centurion Lake as a pollution reduction facility in the form of suspended solids removal and bacteriological reduction. Also mentioned was the fact that the Lake contained 50 % silt and this was believed to be the result of soil run-off from the upper reaches of the catchment *viz*. Tembisa and Ivory Park. During more recent times the Centurion Lake had become even more silted-up due to erosional activity taking place further upstream – this being one of the study area's principal hydrological problems dealt with in **Chapter 7**, p 90.

During the late nineties Slabbert and Venter (1999) sampled six dam and six river/stream waters in the Johannesburg – Pretoria area for aquatic toxicity testing. These included: Rietvlei Dam; Bon Accord Dam; Roodeplaat Dam; Hartebeespoort Dam; Centurion Lake; Lakefield Dam; Hennops River; Moreletta Stream; Jukskei River; Illiondale Stream; Pienaars River and the Fountains Stream.

Results showed that the Hennops River and Illiondale Stream had the highest toxicity out of the 12 sampling tests. This highlights the fact that the Hennops River has become one of the more polluted rivers in Gauteng during the past decade.

A study conducted by Shepherd *et al.* (2000) supports the above statement. The study conducted during the same period focused on the water feeding the Hennops in the form of the Kaalspruit. Sampling was conducted between July and August 1999 therefore no additional significant influence of precipitation over the study area was possible as this is the winter season and consequently a dry period. Monitoring results shown in **Table 13** show that mean COD values for the period were calculated at 34,3 mg/ℓ thereby indicating organic contamination. Added to this, high mean ammonia nitrogen values (9 mg/ℓ) were also attained. Owing to the low water flow period, mean suspended solids values amounted to only 10,5 mg/ℓ. Again, these results are used in **Chapter 6**, section **6.2**, p 67 for comparing the applicable mean constituent values of 2002/2003 in order to determine possible further degradation of the study area.

Table 13: Mean constituent values of the Kaalspruit between July and August 1999

WATER QUALITY CONSTITUENTS				
Electrical Conductivity (mg/ℓ)	Suspended Solids (mg/ℓ)	Chemical Oxygen Demand (mg/ℓ)	pH	Ammonia (mg/ℓ)
72,8	10,5	34,3	7,8	9

Additional to the above Shepherd *et al.* (2000) found high *E. coli* counts in the Kaalspruit. Counts in the river ranged from hundreds to millions per 100 mℓ. This is attributed to causes such as faecal contamination augmented from the informal settlement areas as in the case of Tembisa and Ivory Park. Associated with such settlements are poor waste management practices and it was found that gross solids and litter were present in the Kaalspruit as well.

4.3 SYNTHESIS OF EXISTING KNOWLEDGE

In the above section it is evident that studies conducted during the past 30 years on the Hennops River and its principal tributaries encompassed different fields of study. Not all focused on water quality and hydrological conditions of these rivers to describe the effects that urbanisation, human settlement and activities have had on them.

By studying existing literature it can be said that the Hennops River system has gradually been affected by increasing urbanisation, industrialisation and other activities over the past two to three decades. This is also the period in which rapid human settlement and its associated activities have taken place within its catchment.

Already back in the seventies, Wittmann and Förstner (1976) determined that sediments along the Hennops were mercury enriched. Pressure from encroaching human settlement and associated pollution were already evident back then. Even though this was the case, Schoeman (1976) found that the Hennops and Crocodile Rivers were relatively clean with low trophic levels when compared to the other rivers feeding the Hartebeespoort Dam. In later years, though, it became evident from Sutton and Oliveira's (1987) study that the increase in urbanisation by the eighties had made the Hennops River third poorest in terms of water quality of the main rivers feeding the Hartebeespoort Dam.

The past decade had studies by Hoffmann (1994); De Wet and Mallory (1998); Slabbert and Venter (1999) and Shepherd *et al.* (2000) highlighting the hydrological problems and poor water quality of the Hennops River and its principal tributaries. These include faecal contamination, siltation and high suspended solid loads, toxicity, high ammonia nitrogen, COD and solid waste in these rivers and streams.

The probability that the hydrological conditions and water quality of the Hennops and its principal tributaries have during the past few years, improved or remained the same is low. A further increase in human settlement numbers, such as in Tembisa, places pressure on the water quality of the river. Not much has been done in terms of erosion control and rehabilitating the Olifantsfontein wetland and solid wastes can still be seen in the Kaalspruit and Hennops River. Additional to this, the Centurion Lake is still continually silted-up.

Knowledge gained from this review of existing knowledge can be compared to the most recent water quality data and hydrological conditions where possible. The method of water quality data collection and analysis is discussed in the chapter to follow.

CHAPTER 5: DATA COLLECTION AND METHODOLOGY

5.1 BACKGROUND

Knowledge gained from a literature review as discussed in the previous chapter can now be compared to the current status of the Hennops River and its principal tributaries. This is carried out in terms of water quality to ascertain whether the condition of these rivers has deteriorated over a period of time. The most recent water quality data are used to illustrate the present prevailing conditions of the Hennops and its feeding sources with regard to its suitability for aquatic ecosystems.

Data based on water quality monitoring conducted between January 2002 and December 2003 were collected and ordered. **This selected period of 24 months is not only the most recent but encompasses all seasons** (summer, autumn, winter, spring) **as well as wet and dry periods.** For the purpose of this study the average conditions of the whole period were calculated so that average conditions of the past could be compared to the most recent conditions. Added to this, the average conditions of sections of the study area are used to determine whether aquatic ecosystems would survive under such conditions.

5.2 DATA COLLECTION

Quantitative data in terms of water quality monitoring results of physical and chemical constituents (**Table 14**) were obtained from two authorities responsible for monitoring the Hennops River, *viz.*: the *Department of Water Affairs and Forestry* (DWAF) and the *City of Tshwane Metropolitan Municipality* (CTMM). Although the City of Johannesburg Metropolitan Municipality and the Ekurhuleni Metropolitan Municipality also conduct sampling on the upper reaches of the Hennops River catchment such as the Kaalspruit flowing through Tembisa, no data of these were used. Sampling points established by DWAF and CTMM adequately cover the most important sections of the Hennops River and its principal tributaries whereas no other authority or organisation conducts routine sampling and analyses specifically on these sections of rivers.

As previously mentioned data for this study were collected for the two year period between January 2002 and December 2003. The frequency of sampling conducted by DWAF and CTMM is twice a month but during the year 2002 DWAF conducted sampling on a monthly basis. Sampling and analyses conducted by CTMM is regular and kept up to date. Sampling conducted by CTMM goes back as far as the early 90's. In earlier years, though, fewer sampling points were monitored, fewer variables were sampled for and sampling was conducted by the former Verwoerdburg Town Council which became the Centurion Town Council. On 5 December 2000, the CTMM was formed through the consolidation of thirteen local authorities – the Centurion Town Council being one of them.

The same does not apply to DWAF as numerous months were missed and not all of the sampling points were always included during sampling. The historical database of DWAF reveals a number of shortcomings in terms of frequency of sampling and actual data of the Hennops River recorded and its associated feeding waters (see section **5.5**, p 65).

Table 14: Water quality constituents affecting aquatic ecosystems analysed by DWAF and CTMM

WATER QUALITY CONSTITUENTS	CONSTITUENTS ANALYSED BY	
	DWAF	CTMM
Physical constituents		
- Electrical Conductivity	X	X
- Total Dissolved Solids	X	
- Total Suspended Solids	X	X
- Dissolved Oxygen		X
- Chemical Oxygen Demand	X	X
- pH	X	X
Chemical constituents		
- Ammonia	X	X
- Chloride		X
- Nitrate and Nitrite Nitrogen	X	X
- Orthophosphates	X	X

As described in **Chapter 2** only certain physical and chemical constituents have effects on aquatic ecosystems. The DWAF and CTMM sample and analyse physical, chemical and microbiological constituents but, for the purpose of this study, only constituents having an effect on aquatic ecosystems (DWAF, 1996a) are collected and analysed as illustrated by **Table 14**.

5.3 LOCATION AND DESCRIPTION OF SAMPLING/MONITORING POINTS

Various sampling/monitoring points are established by DWAF and CTMM along the Hennops River and its principal tributaries i.e. DWAF has 13 and CTMM has 12. In totality these points cover the entire catchment including the Rietvlei Dam catchment.

For the purpose of this study, only the sampling/monitoring points which cover the Hennops and its tributaries having significant effects on the water quality status of the River are used. Consequently not all of the points established by DWAF are used as some do not have a direct effect on the Hennops River and also fall outside of the study area. Only five of the DWAF sampling/monitoring points are used for this study as illustrated by **Figure 16**. The sampling/monitoring points established by CTMM over the past decade represent all the sections of the Hennops River as well as its principal tributaries having an effect on the River and as such, all of these points are considered.

The various sampling/monitoring points of DWAF and CTMM which are considered for this study are described below:

5.3.1 DEPARTMENT OF WATER AFFAIRS AND FORESTRY SAMPLING POINTS

- *Sampling point no. 1: Kaalspruit 60 m downstream of Olifantsfontein-Midrand Road (R562) bridge in Tembisa*

Of the five sampling points considered for this study, this sampling point is the furthermost upstream and therefore also the most southern in the study area (**Figure 16**).

This point represents the quality of water emanating from the informal settlements of Tembisa, Ivory Park and Rabie Ridge as well as water from Birchleigh North and Birch Acres as a whole.

A great deal of foam, discoloration of the stream and urban litter were observed during site visits to this area. As discussed in section 3.4.1, p 36 activities and problems upstream of this point are causing degradation of this stream. Approximately 500 m downstream from here the Kaalspruit is also fed by the Clayville tributary which could additionally negatively affect the water before flowing through the Olifantsfontein wetland further downstream.

- *Sampling point no. 2: Hennops River at Zwartkop Lapa*

As illustrated by **Figure 16**, DWAF does not conduct sampling downstream of *Sampling point no. 5* down to where the Hennops River flows alongside the Zwartkop Lapa. The Zwartkop Lapa is situated next to the southern boundaries of the Zwartkop Nature Reserve approximately 18 km downstream of *Sampling point no. 5*. This sampling point therefore represents the quality of water exiting the larger part of the Centurion residential areas.

As described in section 3.4.6, p 41 the Hennops flows through the southern parts of the Zwartkop Nature Reserve downstream from here *en route* to its confluence with the Rietspruit before flowing past the Centurion Sewage Works. The water quality and hydrology of the Hennops could be affected by the inflow of the Rietspruit due to its own condition and flow volumes.

- *Sampling point no. 3: Hennops River at M26 road bridge near Erasmia*

This sampling point is approximately 2,6 km downstream of the confluence of the Hennops River and Rietspruit adjacent to the Centurion Sewage Works (**Figure 16**). As such, this sampling point determines the quality of water downstream of the mentioned confluence and point source discharge of treated water augmented from the sewage works. This sampling point can therefore determine the possible effects of these two influencing factors in this section of the Hennops River.

In terms of flow volumes the Hennops River is not only fed by the Rietspruit but the outflow of the Centurion Sewage Works as well. As such, the Hennops River seems to be wider at this point with an increase in water flow volumes.

- *Sampling point no. 4: Swartbooispruit at M26 road bridge near Erasmia*

As seen in **Figure 16** this DWAF sampling point is the furthermost downstream of all the sampling points considered for this study and is situated at the downstream boundary of the study area. The Swartbooispruit is also the final significant tributary to the Hennops River before its confluence with the Crocodile River further downstream from here.

The Swartbooispruit is non-perennial and therefore fewer sampling data are available on this spruit. The effects of this tributary on the Hennops should also be of minor significance due to its low flow volumes and possible non-point source pollutants which could enter it from the agricultural holdings through which it flows as described in section **3.2**, p 31.

- *Sampling point no. 5: Olifantspruit at bridge on Irene-Olifantsfontein Road*

This sampling point is downstream of the Olifantsfontein wetland, the Olifantsfontein Sewage Works and the confluence of the Kaalspruit and Olifantspruit. This point therefore represents a possible increase in total dissolved and suspended solids from erosional activity taking place in the wetland, effluent return flows from industry, as well as water passing through agricultural holdings (see **Figure 16**).

It can be observed that an increase in the flow rate of the river since the upstream R562 road bridge sampling point is significantly higher at this point. This is attributed to the fact that the Olifantsfontein Sewage Works releases, on average, 70 Mℓ return flows to the Kaalspruit per day as discussed earlier. This additional input of treated water to the Kaalspruit not only increases the flow rate but also has a possible diluting effect on the polluted water from Tembisa and surrounding settlements.

Also evident at this sampling point is the high volume of silt deposited along the riverbanks and beds (see **Figure 29**, p 94).

5.3.2 CITY OF TSHWANE METROPOLITAN MUNICIPALITY SAMPLING POINTS

- *Sampling point no. 1: Kaalspruit at Olifantsfontein-Midrand Road (R562) bridge in Tembisa*

The CTMM has for the past decade conducted sampling at this point which is one of the same points as used by DWAF (*Sampling point no.1*, **Figure 16**). This sampling point is therefore also the furthermost upstream and southern of all the points monitored by CTMM.

The possible water quality conditions which could be represented at this sampling point are discussed in section 5.3.1, p 55.

- *Sampling point no. 2: Olifantspruit at bridge on Irene – Olifantsfontein Road*

As illustrated by **Figure 16**, this sampling point is the same as the one monitored by DWAF i.e. *Sampling point no. 5*. As previously mentioned this sampling point is downstream of the Olifantsfontein wetland, the Olifantsfontein Sewage Works and the confluence of the Kaalspruit and Olifantspruit.

The possible water quality conditions which could be represented at this sampling point are discussed in section 5.3.1, p 57.

- *Sampling point no. 3: Sesmylspruit at Jan Smuts Museum before confluence with Olifantspruit*

It can be seen in **Figure 16** that this point is situated at the downstream end of the Sesmylspruit before its confluence with the Olifantspruit. Downstream of this confluence the name changes to “Hennops River”.
This sampling point is significant in that it is representative of the most downstream end condition of water from the Rietvlei Dam’s overflow and its catchment onto the Hennops River. The most downstream end of all water from the Rietvlei Dam’s overflow before entering the Hennops River is measured at this point. The condition of the water at this sampling point has a direct influence on the Hennops River downstream of this point.

- *Sampling point no. 4: Sesmylspruit at bridge on road between R21 highway and Rietvlei Dam’s dam wall*

The only outflow/spillway from Rietvlei Dam is found at its western dam wall. This sampling point represents the upstream end of the Sesmylspruit and consequently all water flowing out of the Rietvlei Dam catchment.

It is therefore seen in **Figure 16**, that sampling points no. 3 and no. 4 determine the condition of the Sesmylspruit at both its upstream and downstream ends. Results of analyses of these sampling points illustrate the quality of water entering the Hennops River and as such the influence of the Rietvlei Dam catchment as a whole on the Hennops is monitored.

- *Sampling point no. 5: Kastaiingspruit at wooden walkway bridge in Highveld Technopark*

The tributary of the Hennops River flowing through the business and residential area of Technopark is known as the Kastaiingspruit and Hazelspruit. Increasing developments occurring in this area can have negative impacts (section 3.4.4, p 39) on this tributary and consequently on the Hennops River as well.

This sampling point represents most of the stormwater collecting within Highveld Technopark. Run-off from roads, buildings and surrounding lawns collect in this spruit.

- *Sampling point no. 6: Hazelspruit at small dam in Highveld Technopark*

The Kastaiingspruit mentioned above becomes the Hazelspruit and fills a small dam in Highveld Technopark before flowing downstream to the Hennops River. This sampling point situated downstream of sampling point no. 5 (**Figure 16**) is near to the outflow of a small dam constructed on this spruit. The spruit cannot be significantly affected downstream of this sampling point as there are only lawns and office blocks situated further downstream within the boundaries of Highveld Technopark.

The spruit could, however, be impacted on downstream of Highveld Technopark. Stormwater run-off emanating from the N1 highway and other roads during rains can pollute the spruit before its confluence with the Hennops River at the south-eastern corner of the Centurion Park Cricket Stadium.

- *Sampling point no. 7: Inflow to Centurion Lake at Lenchen Road bridge*

It can be seen in **Figure 16** that this sampling point is a distance (approximately 6 km) downstream of the confluence of the Sesmylspruit and Olifantspruit. From this confluence point downstream the Hennops River could be affected by non-point source pollution emanating from the Irene Golf Course, Irene Dairy Farm, Centurion Golf Estate and the "Doornkloof" and Highveld Technopark tributaries. Point source pollution from the "Splash" waterpark takes place via a pipe directed into the Hennops River approximately 100 m upstream from this sampling point as well.

This sampling point represents the quality of water feeding the Centurion Lake. This urban impoundment is also affected by non-point source pollution emanating from its surroundings such as run-off from the shopping complex and business parks.

- *Sampling point no. 8: Outflow from Centurion Lake under bridge*

A representative sample of water flowing out of Centurion Lake is collected at this point. The River's condition downstream of the lake may be altered by stormwater and other non-point sources of possible pollution emanating from the residential areas, roads and garages.

As pointed out by Freeman *et al.* (2000) and George (2003) the amount of total suspended solids released from the lake should be less than what is fed into the lake as this impoundment acts as a sedimentation trap.

Sampling point no. 9: Rietspruit at Ruimte Road bridge near Heuweloord

As described in **Chapter 3** the Rietspruit is another significant tributary to the Hennops River. This sampling point represents the quality of water in the Rietspruit after flowing through countryside, agricultural holdings and residential areas.

Downstream of this point agricultural activities are present along the banks of the spruit. These could have an influence on the amount of phosphates and nitrates entering it.

- *Sampling point no. 10: Rietspruit at Lochner Road bridge in Raslouw*

The quality of water downstream of the above-mentioned sampling point is sampled at this point. Sampling points no. 9 and no. 10 are not too distant from one another (approximately 2 km) and should therefore provide similar analyses results provided that the Rietspruit's surrounding areas do not have an impact on its water quality.

- *Sampling point no. 11: Rietspruit at R55 road bridge in Sunderland Ridge*

As seen in **Figure 16** this sampling point is downstream of sampling points no. 9 and no. 10 of the Rietspruit. It represents the quality of water that will flow into the Hennops River downstream of this point. This sampling point therefore represents the quality of water flowing out of the Rietspruit's catchment and into the Hennops River.

- *Sampling point no. 12: Hennops River at M26 road bridge near Erasmia*

This sampling point is the most downstream of all the sampling conducted by CTMM in terms of the Hennops River catchment. It can be seen in **Figure 16** that this sampling point is used by both DWAF (*Sampling point no.3*) and CTMM.

As previously mentioned in section 3.4.6, p 41 the Hennops River should not significantly deteriorate in terms of its water quality downstream of this point as the River merely flows through the Skurweberg farmlands and areas of open space *en route* to its confluence with the Crocodile River. Only small-scale non-point source pollution of phosphates and nitrates can be expected to emanate from agricultural areas.

5.4 METHODOLOGY OF ANALYSIS

Water samples collected by DWAF are analysed by a South African National Accreditation Service (SANAS) accredited testing laboratory *viz*. the East Rand Water Care Company (ERWAT). Samples are collected in clean 1 ℓ plastic bottles as well as 250 mℓ sterilised glass bottles – the latter used to determine microbiological pollution present in the water. ERWAT follows the analysis procedures as described in the 20th edition of *"Standard methods for the examination of water and waste water"* (Swanepoel, 2004)*.

The CTMM makes use of its own laboratory services at the Daspoort laboratories, Pretoria. Water samples are also collected in clean 1 ℓ plastic bottles and 250 mℓ sterilised glass bottles which are used for the collection of microbiological samples. Collected samples are kept in a refrigerator until analysis of the samples is undertaken. Esterhuysen (2004)* mentions that the laboratories also follow the analysis procedures as described in the above-mentioned standard used by ERWAT.

*Personal communication