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A situation analysis of the water quality in the Hartbeespoort dam catchment: nutrients and other pollutants' assessment on rivers entering the dam

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1 INTRODUCTION

This study is concerned with water quality and nutrient loads in the catchment of Hartbeespoort (HBS) Dam, a hypertrophic water body which had challenged stakeholders, governmental bodies, scientists and researchers for many decades (Hutchinson *et al.,* 1932; Allanson, 1961; Toerien & Walmsley, 1976; National Institute for Water Research, 1985; Chutter, 1989 and van Ginkel, *et al*, 2001). The hypertrophic state of this water body is a consequence of many years of excessive external nutrient input, historical internal nutrient loading and nutrient input currently.

The HBS Dam is utilized for a variety of uses including irrigation, recreation, domestic water supply etc; its trophic state has rendered it unsuitable for such activities. However, some of these activities continue with potentially catastrophic consequences. The Dam is of great concern to the water authorities who are presently engaged in trying to find solutions for recovering the dam's water quality and the improvement of its bad environmental conditions (NWP DACET, 2004a, NWP DACET, 2004b). The control of nutrient input into the Dam is considered as the most important intervention strategy.

An improvement in the control of nutrient input into the dam was achieved by the implementation of stringent effluent standards in the 1990s (i.e. total phosphorus(TP) < 1 mg/l and total nitrogen (TN) < 2 mg/l). Despite the decrease of nutrient loads in the catchment (National Institute for Water Research, 1985), and improvement of the trophic state in the Dam, it seems that internal nutrient load is still exceptionally high. The nutrient input in the HBS Dam as periodically measured by the Department of Water Affairs and Forestry (DWAF) is still high. The high nutrient input makes it impossible to maintain the Dam in the likely meso-eutrophic conditions as predicted in eutrophication prediction models (OECD, 1982 & NIWR, 1985).

The monitoring of water quality (WQ) parameters and nutrient load of the rivers in the HBS Dam catchment is of great importance to provide data required for:

- Water quality assessment and water pollution status of the catchment;
- Employing a strategic approach to the pollution abatement suitable for the catchment;
- Planning of pollution and nutrient control measures;
- Monitoring of the success of measures already implemented; and
- Water quality modelling and prediction of trends and long term conditions in the dam.

Besides the routine measurements of WQ parameters as well as hydrological parameters in selected points of the Catchment as carried on by DWAF, there are many other research efforts facilitated by private and public educational institutions whose aim is to contribute in better understanding and defining of the whole situation and consequently better approach to combat the problem.

This study's main aim is to contribute in the above mentioned efforts. It is directed at the assessment of water quality in the HBS Dam Catchment and to draw attention to the estimation of nutrient mass flow at the significant points of the catchment. Its scope and extent of work was limited to the extent of available funds and resources.

1.1 Study Objectives

The objectives of the study were as follows:

- Periodic measurement of water quality at selected points of the catchment during the wet and dry season;

- Identification of the level of pollution discharges into HBS Dam from the whole catchment (i.e. Crocodile River, Magalies River, and Swartspruit) as well as from the sub-catchments of the Crocodile River (i.e. Upper Crocodile River, Jukskei River, and Hennops River);
- Collection of hydrologic data and the data on nutrient concentration at selected points of the catchment;
- Computation of overall current nutrient input to the HBS Dam as well as nutrient loads from sub-catchments;
- Situational analysis of the HBS Dam Catchment considering the current point and non-point sources of pollution;
- Estimation of likely nitrogen and phosphorus loads to keep meso-eutrophic conditions in the dam; and
- Recommendations for further research.

1.2 Study Approach

The study was planned to focus on identification of the activities in the HBS Dam catchment which contribute to the nutrient load and measurement (at appropriate intervals during wet and dry season) of relevant WQ parameters in selected points representing the whole catchment and given sub-catchments as well. Basic data provided from field work and collected from DWAF hydrologic data base were used to assess water quality and to compute current nutrient load to the HBS Dam, and nutrient load discharged from sub-catchments.

A multi-pronged approach was applied to complete the research as follows:

- Literature review on material related to the subject of the research;
- Collection of data from local sources including DWAF Hydrological Data Base, research reports and papers, unpublished information and consultation of relevant stakeholders in the catchment;

- Selection of appropriate sampling points that represent analysed catchment and subcatchments;
- Sampling and laboratory analysis of water taken at chosen intervals during wet and dry season;
- Data analysis and synthesis;
- Computation of current nutrient mass flow at chosen sampling points;
- Estimation nutrient load to the dam using one of available eutrophication prediction models;
- Comparison of likely and current nutrient loads;
- Concluding on the findings of research; and
- Recommendation for future research.

The breakdown scheme applied in this study considered the external loading of phosphorus (P) and nitrogen (N) via the tributaries of the HBS Dam. Although assessment of nutrient loading resulting from precipitation was important, the meteorological data obtained could not help in estimating the contribution of precipitation on both seasons.

It was also recommended that more parameters be measured accompanying the phosphorus species and nitrogenous compounds. To avoid errors in mass flow estimates, seasonal variations were denoted as dry and wet period, which are winter and summer.

1.3 Organisation of the Report

The report consists of seven chapters:

- Chapter One is the outline of the problem in the catchment as viewed by the author and other researchers. It also discusses various ways through which the problem can be solved.

- Chapter Two discusses eutrophication in water bodies in general. An in-depth discussion on P and N as nutrients causing eutrophication is also given. The measurement, the prediction and abatement of eutrophication is also presented.
- Chapter Three presents the description of the study area and situational analysis of the catchment. A summary of the biophysical environment, the water quality and the historical nutrient loading into the HBS Dam is also presented
- Chapter Four focuses on the materials and methods used to carry out the analysis. The sampling points and the towns from which the nutrients could originate are also presented. Analytical methods used for P and N species are described.
- Chapter Five presents the results, discussion and predicted nutrient loading from the Catchment Rivers. Graphs and flow charts have been used together with data sheets to express the results. The data in appendices at end of the report had been used together with these graphs to express the results.
- Chapter Six are the conclusions and recommendations which mainly focus on proposed abatement strategies for eutrophication.
- Chapter Seven presents the reference material as cited in the text.
- Data tables and additional graphs for other parameters are presented in the appendices at the end of the report.

2 EUTROPHICATION OF WATER BODIES

Eutrophication (the coin from ancient Greek words ϵυ - plenty and τροφοϛ- food) is the "overfertilization" or over-enrichment of water bodies by nutrients (usually P and N) that support uncontrolled growth of green plants (OECD, 1982; Chapra, 2004). The process of eutrophication in relation to P is well documented and includes stimulation of the growth of algae and aquatic plants (World Bank Group, 1998). Environmental factors such as climate, catchment characteristics, morphology of the water body, composition of water in given area, etc. have a significant impact on the rate and development of the process. Nutrients levels in a water course determine the trophic state and productivity (http://ulna.bio.psu.edu/Courses) which may sometimes be visible. The trophic states of water bodies are classified (Chapra, 2004, www.epa.gov/maia/eutroph) as follows:

- *Dystrophic* state - characterized by low content of nutrients, or highly coloured with dissolved humic organic material;
- *Oligotrophic state* - characterized by clear waters with little organic matter or sediments and poorly nourished with minimum biological activity;
- *Mesotrophic state* is moderately nourished and is characterized by the presence of nutrients with some biological activity;
- *Eutrophic state* is well-nourished and is extremely rich in nutrients with high algal productivity and biological activity; and
- *Hypertrophic state* which is characterized by an excessive presence of nutrients with uncontrolled biological activity and algal growth.

When a water body is in a hypertrophic state sunlight is blocked and that result in the inhibition of photosynthesis for aquatic plant production. This further limits the production of food in the habitat for aquatic plants and organisms (OECD, 1982; Pace *et al*., 2000; Riley *et al*., 1984). Amoungst all the trophic states mentioned above, the *oligotrophic* is the most preferred, but it is acceptable for

most water bodies to be maintained in a *mesotrophic state.*

The eutrophication of water bodies is a natural process which is greatly accelerated by increased discharges of nutrients (particularly N and P) from human activities. This accelerated process is termed in the literature as "Cultural eutrophication" in order to make distinction from natural eutrophication process. It is interesting to note that nutrients which cause eutrophication were not perceived as pollutants until 1960s when severe eutrophication processes created problems in water use worldwide (Chapra, 1997). Stagnant water bodies are particularly prone to eutrophication because of hydrodynamic conditions favourable for algal growth, accumulation and recycling of nutrients on long term basis.

An indication of an over fertilized water body is the visibility of green plants and seasonal algal blooms followed by severe deterioration of oxygen regime, poor water quality and perturbances of the ecosystem. In eutrophicated water courses, alien floating plants like *Eschhornia crassipes* and a 'hyperscums' of blue green algae (*Microcystis* species) may dominate (Fuggle and Rabie, 1996). Growth of other organisms are suppressed and many of them may go extinct if the problem is not remediated (Decy, 1992).

The decomposition of organic matter formed by photosynthesis (http://ulna.bio.psu.edu/Courses/) could create anoxic anaerobic conditions in a water body and change the ecosystem. An illustration of the processes leading to productivity of a water body is presented in Figure 2.1. This illustration shows the link between the external and internal nutrient loading in a water body.

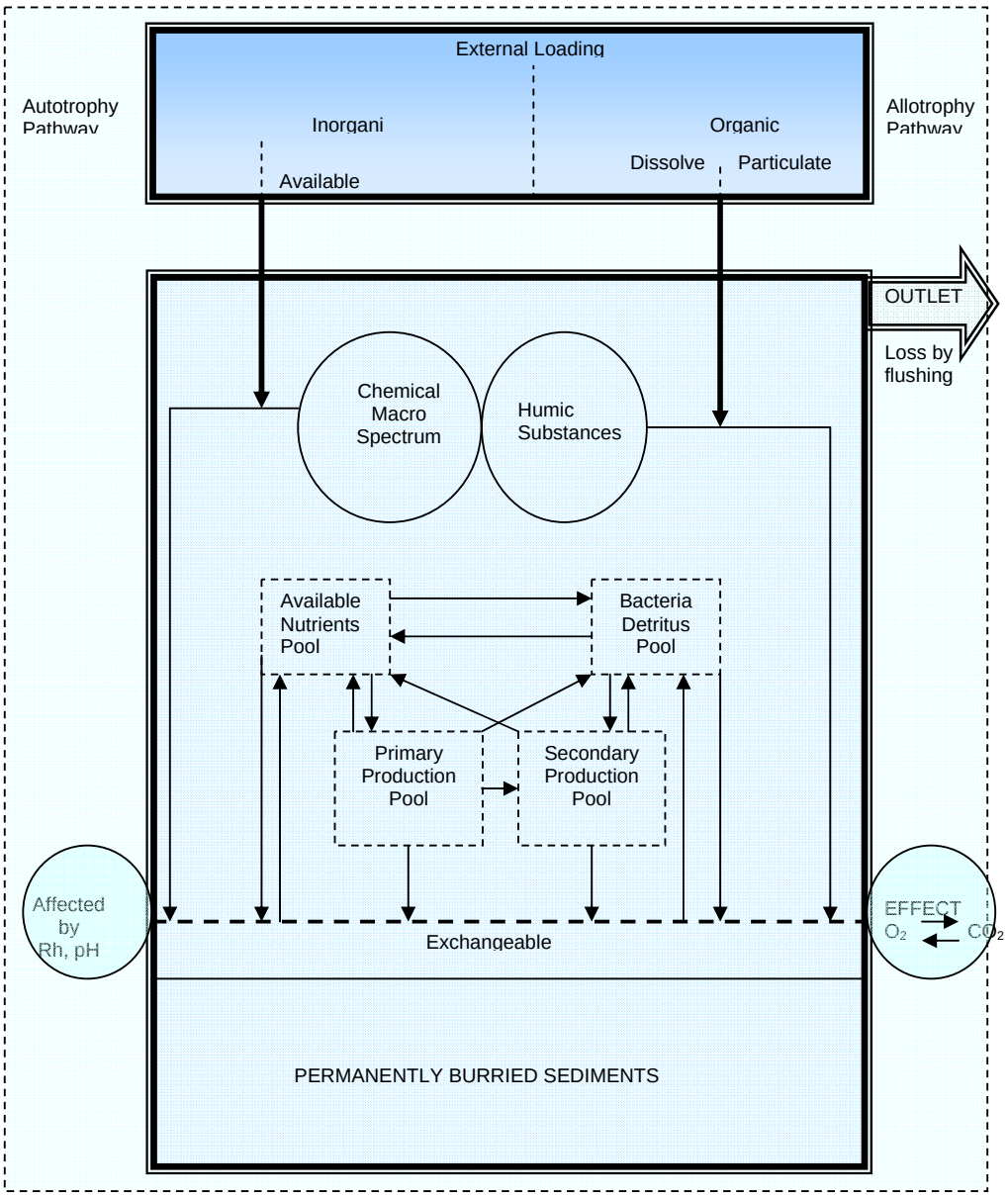


Figure 2.1: The main internal dynamics of a lake and relationships between internal and external loading (OECD, 1996).

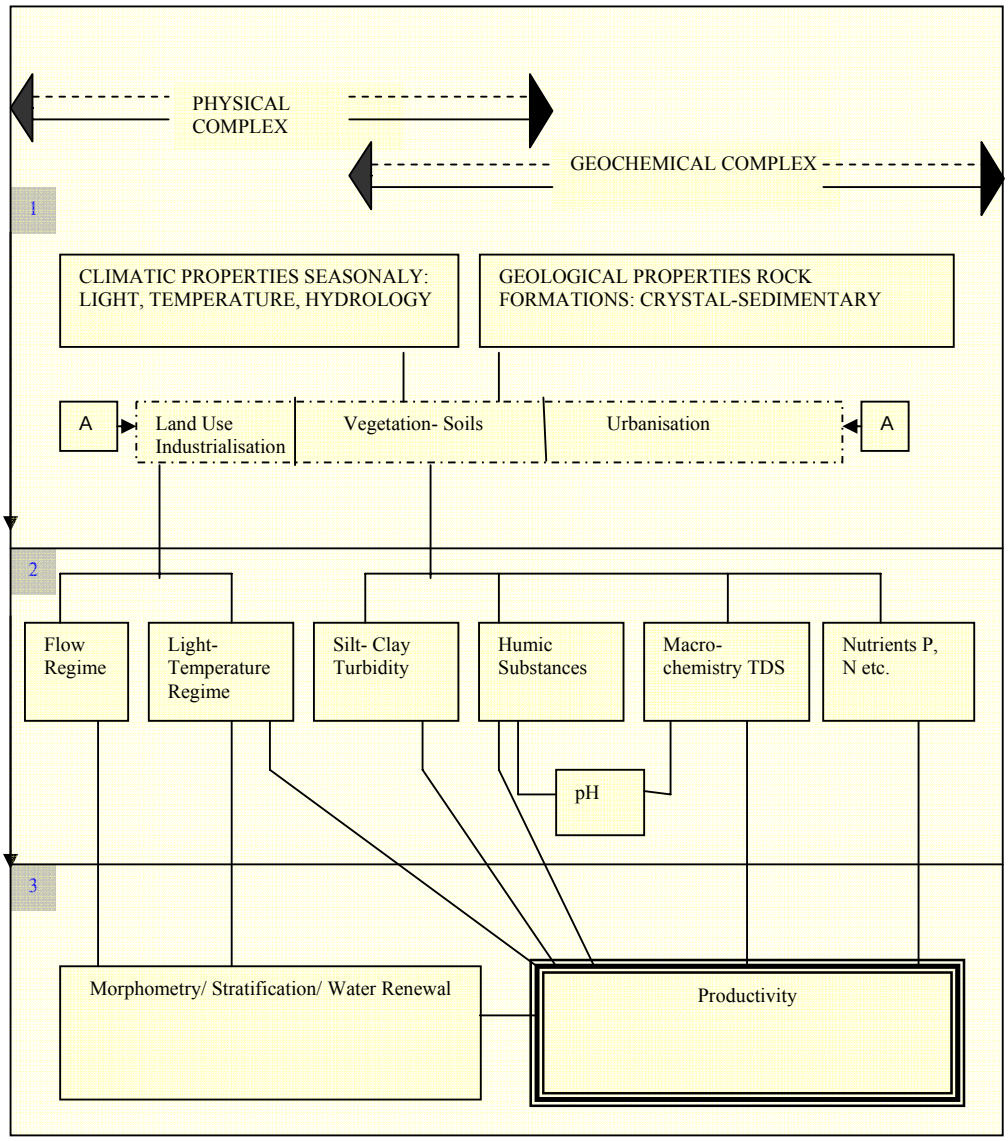
2.1 The Causes and Concequences of Eutrophication

Eutrophication occurs as a result of natural and human activities, (Rast and Thornton, 1996). Macro-nutrients in the form of P and N are the main nutrients

commonly associated with eutrophication. The external and internal loading of these nutrients into a reservoir are regarded as the main causes of eutrophication (Baccini, 1985; Fisher *et al*., 1995; Walmsley, 2003). Natural processes as well as natural eutrophication are reliant on the local geology, top soil composition and natural environmental features of a catchment (refer to figure 2.2, Level 1). Cultural eutrophication is linked to these activities which upon introduction of considerable amounts of the macro-nutrients into water courses surpass the natural process rate and lead to symptoms of accelerated eutrophication (Dercy, 1992).

Agricultural runoff, urban runoff, leaking septic systems, effluent (or sewage) discharges etc, are major sources of nutrients which enter into river systems. Thus the nutrient loading of P and N into lakes and dams are a reflection of land uses in the catchments (Clarke, 2000). In areas with inadequate sewer system or without sewer systems effluents drain directly into the impoundments (Fargan, 2003, Hoffmann, 1995, Collingwood, 1978). The untreated effluents from these systems contain high content of P and N compounds which are directly responsible for eutrophication.

In areas with adequate sanitation systems, sewage is transported to the wastewater treatment plants, where it is treated and most of pollutants including nutrients are removed (Neilson *et al*., 2005). When wastewater is partially treated, significant amounts of nutrients are discharged into the water bodies causing eutrophication.



1 = Basin properties, 2 = Water properties, 3 = Limnological properties,

A= Anthropogenic properties

Figure 2.2: Three levels determining the productivity of water bodies (OECD, 1982).

Some industries discharge wastewater after treatment directly into rivers without ensuring that the effluents comply with specified discharge standards e.g. mining activities can greatly affect the state of surface and groundwater reservoirs as well as the seepage from tailings dams. Sometimes, accidental or unauthorized industrial wastewater discharges result in increasing concentration of P in

watercourses. The causes of eutrophication from various sources are shown in Figure 2.3 below.

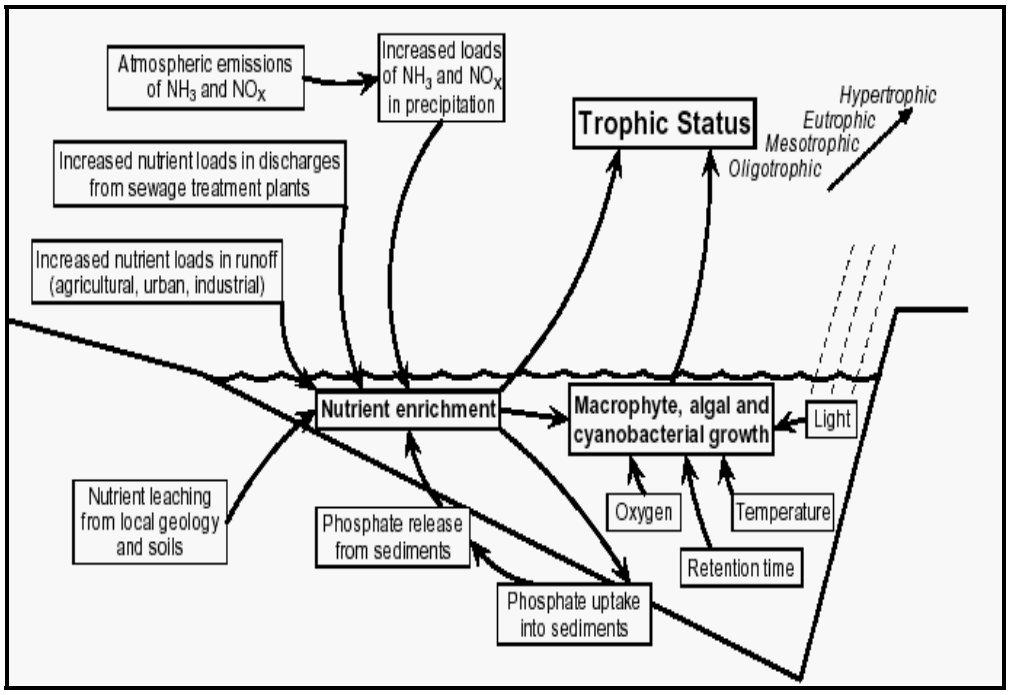


Figure 2.3: The main causes of eutrophication and other trophic states (DWAF, 2003).

The process of eutrophication is a complicated one and involves many pathways as shown in Figure 2.3. The main process is photosynthesis through which new biomass is synthesised from nutrients following the equation 1.1 below (Chapra, 1997).

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow C_{102}H_{263}O_{110}N_{16}P + 138O_2 \quad (1.1)$$

Produced biomass disturbs an oxygen regime in water body either directly (i.e. through photosynthesis and respiration) or indirectly (i.e. through decomposition of dead algae). The dissolved oxygen usage by algae also impedes respiration of aquatic organisms such as fish and crabs. Furthermore, the changing of the ecosystem conditions promotes weeds (Chapra, 2002) thus decreasing aesthetic

features of water and its recreational value. This is further exacerbated by the bad smell from decomposing algae (OECD, 1982) which negatively affects the beauty of the aquatic system (Reynolds, 1992).

The beauty and functionality of the lake or dam for recreational activities is compromised; swimming boating and other activities cannot take place due to water toxicity and boat clogging; large mats of macro algae cover some water surfaces (Rheinheimer, 1976). The economically important fish species such as trout decline in the water source. They are replaced by courser fish which has low economic value (OECD, 1982).

Many algal species produce toxins which directly impact other organisms and recreation. The cyanobacteria and other harmful algal blooms also contribute in creating unpalatable and carcinogenic chlorinated drinking water (Walsby, 1992). The existence of toxic algae is not a new problem in the world. In South Africa, livestock poisoning dates as far back as 1920. Since then, several other poisoning incidences have occurred at various South African Dams: Vaal, Witbank, Bospoort, Vaal Barrage, Hartbeespoort, Klipdrift, Allemanskraal, Voevlei, Theewatersklook, Roodeplaat and other smaller farm dams (http://www.1upinfo.com/encyclopaedia).

Algal blooms which emanate as a result of water eutrophication clog filters in water treatment plants and other water purification works. This in turn has financial implications and socio-economic concequences.

2.2 Sources of Pollutants and Nutrients that Cause Eutrophication

Pollutants can be defined as any material that is released and could be harmful to the natural aquatic environment (Fuggle *et al*., 1996). Damage caused by pollution is an impact on quality, where quality is a measure of the environment's ability to

sustain life (Prepas *et al*., 2001). *Nutrients* are inorganic compounds that provide material for building blocks which support life in aquatic systems (Chapra, 2002). They are classified into macro and micro nutrients. Pollutants and nutrients' sources could be classified as the natural and man-made ones.

2.2.1 The natural sources

In natural systems, soil and water interact. For example, rain falling on soil surface interacts with topsoil layers or may enter surface watercourses or groundwater. Pollutants and nutrients on soil may alter terrestrial chemistry and harm associated plants and animals (D'Arcy *et al*., 1997), they may also be picked up by water moving through or over the soil matrix, and carried to aquatic systems (OECD, 1982).

Natural pollutants are generated from the decomposition of plants, animal excreta, and mammal carcasses and are washed into water courses during rainy season (Fuggle *et al*., 1996). The decayed material leads to increased organic content and cause a bad smell which is usually the case in tropical areas (Allen *et al*., 2003 and DEA, 1990). The N compounds, P and other nutrients also emanate from the decayed plants and animals. In areas undisturbed by human activities, terrestrial ecosystems are balanced and the release of natural pollutants is minimal thus causing no excessive pollution pressure. In such a condition low release of nutrients to water bodies makes eutrophication processes slow and allows aquatic ecosystems to adjust themselves to the slightly altered conditions.

During rainy seasons, loss of soil from both the undisturbed and cultivated land is experienced. Extreme values have been recorded in cultivated areas with low level of soil care (Fuggle *et al.*, 1996). The eroded soil greatly contributes to water pollution and siltation in dams (DEA, 1990, Stanton, 2001). As phosphorus originates from some soils it could be washed into the water course and buried in sediments of a dam (www.agnr.umd.edu). Nutrients are

transported through soil erosion, surface water runoff, and, to a lesser extent, by wind erosion or leaching.

2.2.2 Anthropogenic sources of pollution

Man-made sources of pollution and nutrients are classified as follows:

- Agriculture and husbandry;
- Industries;
- Mining;
- Urbanisation; and
- Waste and sewage.

Agriculture and husbandry

Use of fertilizers in agriculture is the main source of nutrients. In catchments generally, agricultural activities may occupy areas which could be reserved as riparian buffer strips. During the wet season fertilized soil may be freely washed into the river thus increasing the load of nutrients (Cooke & Prepas, 1998). The practice of washing the floors of cattle steds, piggeries, chicken farms and others for hygiene reasons can lead to the production of considerable volumes of highly polluting waste liquors (Brisbin *et al*., 1995, Sharpley *et al*., 1994), which may bring much stronger pollution than ordinary sewage and may cause severe problems especially in small streams. It has been found that intensive crop harvesting; forest harvesting, forest and veld fires contribute to nutrient loading in rivers (McEachern *et al*., 2000; Martin *et al*., 2000, Prepas *et al*., 2003).

Industries

Industries contribute to pollution of water courses through nutrient rich effluents

that escape from their premises. Total phosphate from the mining industries worldwide is used in cleaning detergents that end up in these courses (Gilbert and De Jong, 1978). Fertilizers are sold and added into cultivated land and during rainy seasons are washed into water courses. Raw material processors release inorganic and organic pollutants such as acids and dissolved mineral salts into water courses (OECD, 1982). Acids and salts in aquatic systems may accelerate reactions that could lead in binding or release of P from sediments. The following are the types of industries which release pollutants to the environment: meat processing industries, grain processing including breweries, fruit and vegetable processing, sugar refineries and others (Fuggle *et al*, 1996, DEA, 1990).

Urban drainage

Urban areas are the main sources of liquid and solid waste that contain P and other pollutants. The impervious surfaces in these areas collect material from the atmosphere as well as material such as detergents from car washing and animal droppings. There are also public parks, house gardens and nature strips where significant amounts of fertilizers are used (Cullen *et al*., 1978). During rainy seasons these are washed off to the water courses causing eutrophication.

Projects such as the construction of townships and office parks where large quantities of soil are excavated could cause turbid waters that lead to high sedimentation rate in a dam. Nutrients that cause eutrophication may be buried with the sediments thus increasing internal nutrient loading which is difficult to control. Daily activities such as the use of dirt roads could promote soil erosion, which in turn can pollute natural watercourses. Dense settlements built without proper stormwater management and proper sanitation facilities are also sources of water pollution.

In urban areas wastewater is directed to sewage disposal plants where it is treated and the effluent disposed to natural water courses. These may be treated to

comply with effluent discharge standards, but could cause pollution and excessive nutrient load in water bodies that have weak receiving capacity. Additional to effluents it is common in South African township streets to encounter leaking sewage pipes which also contribute to nutrient load in water bodies. Garages, trade premises and other workshops also release nutrient rich detergents into water bodies.

Solid waste and wastewater

Untreated or partially treated sewage could be regarded as the main source of nutrients. Effluents from waste water treatment plants also bring nutrients as there is no known method for their complete removal. Another consequence of sewage pollution is the impact of organic carbon enrichment which leads to eutrophication of a water source (Fuggle *et al*., 1996). Leachate from solid waste disposal sites can also cause the pollution of a water source.

2.3 Water Quality Variables and their Significance to the Trophic States

Environmental regulations of most countries set limits for the discharge of various chemicals and nutrients into aquatic systems. However, these limits are sometimes not low enough to comply with natural receiving capacity.

Natural waters have low concentrations of nutrients that balance the cycles of production, food transfer, death, decay, and regeneration. Nutrients generated from human activities are transported to these systems leading to the development of more plant material than usual, which decompose and lead to some other problems (Clarke, 2000). Oxygen is consumed during decomposition to lower levels thus, causing the suffocation of aquatic organisms. It should be noted that some nutrients such as ammonia (NH_3) nitrate (NO_3^-) and nitrite (NO_2^-) are toxic to human beings if they exceed certain levels in water.

In natural aquatic systems, chemical reactions leading to some toxic nutrients are accelerated by other physical parameters such as temperature, pH, light flow rates and presence of other inorganic compounds.

In a lake system there are shallow areas in which aerobic reactions occur and deep areas where anaerobic reactions occur. Although nutrients are regarded as drivers of the trophic states in water systems it is eminent to asses the presence of other substances which could cause inhibition of biological processes (such as heavy metals or some organic compounds) or which could cause direct intoxication of aquatic organisms and users of water.

2.4 Phosphorus in Aquatic Systems

Phosphorus (P) as an essential element for life (Chapra, 2002) plays a major role in energy transfer inside living cells. In normal conditions, P in water is in short supply as compared to other nutrients because of low solubility of its compound that exist on the earth crust. P in aquatic environments may be introduced by rivers from the catchment, precipitation, dry fallout and through internal forces by sediments accumulated in water body (Imboden *et al*., 1985 and OECD, 1982). The phosphorus cycle (Figure 2.4) shows how P from the terrestrial environment is linked to the aquatic system.

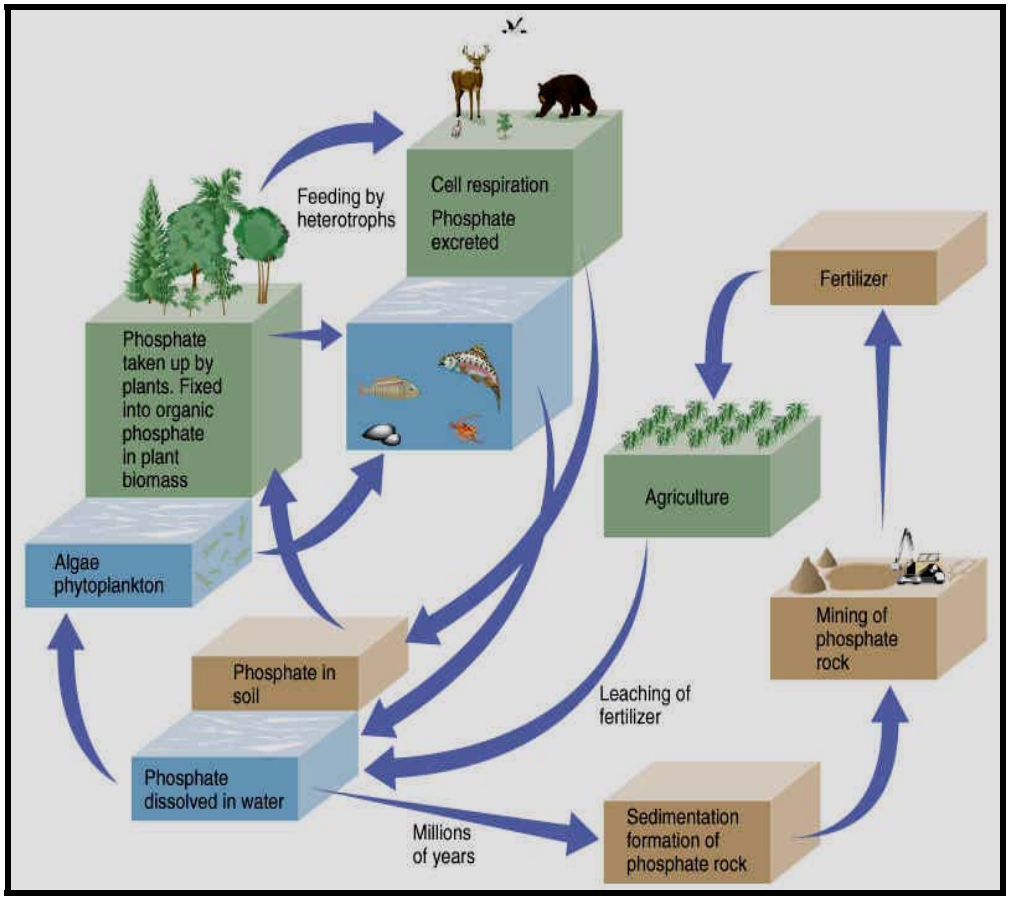


Figure 2.4: The Phosphorous cycle (TCL's courses 2005).

Both internal and external P are divided into soluble reactive P (orthophosphate), particulate organic P, non-particulate organic P, particulate inorganic P and non-particulate inorganic P (Spivakov *et al*., 1999). Amoung these types the most frequent soluble form is orthophosphate and it dominates the natural waters. This form of P is readily available for assimilation by organisms.

P can be precipitated by aluminium (Al^{3+}), iron (Fe^{3+}) and calcium (Ca^{2+}) ions. It has high affinity for inorganic compounds and it binds to these ions to form complexes which are ultimately buried in sediments. Depending on the geochemical nature of the suspended solids the following complexes are common in aquatic environment: vivianite $Fe_3PO_4.8H_2O$, ludlamite [Fe, Mn, $Mg_3(PO_4)_2.4H_2O$], phosphoferrite (Fe, Mn)$_3$ $(PO_4)_2.3H_2O$, klinostrengite

$FePO_4.2H_2O$, and anapaite $Ca_2Fe_3(PO_4)$ $2.8H_2O$ (Spivakov *et al.*, 1999). Figure 2.5 below show some of these inorganic compounds and their association with water.

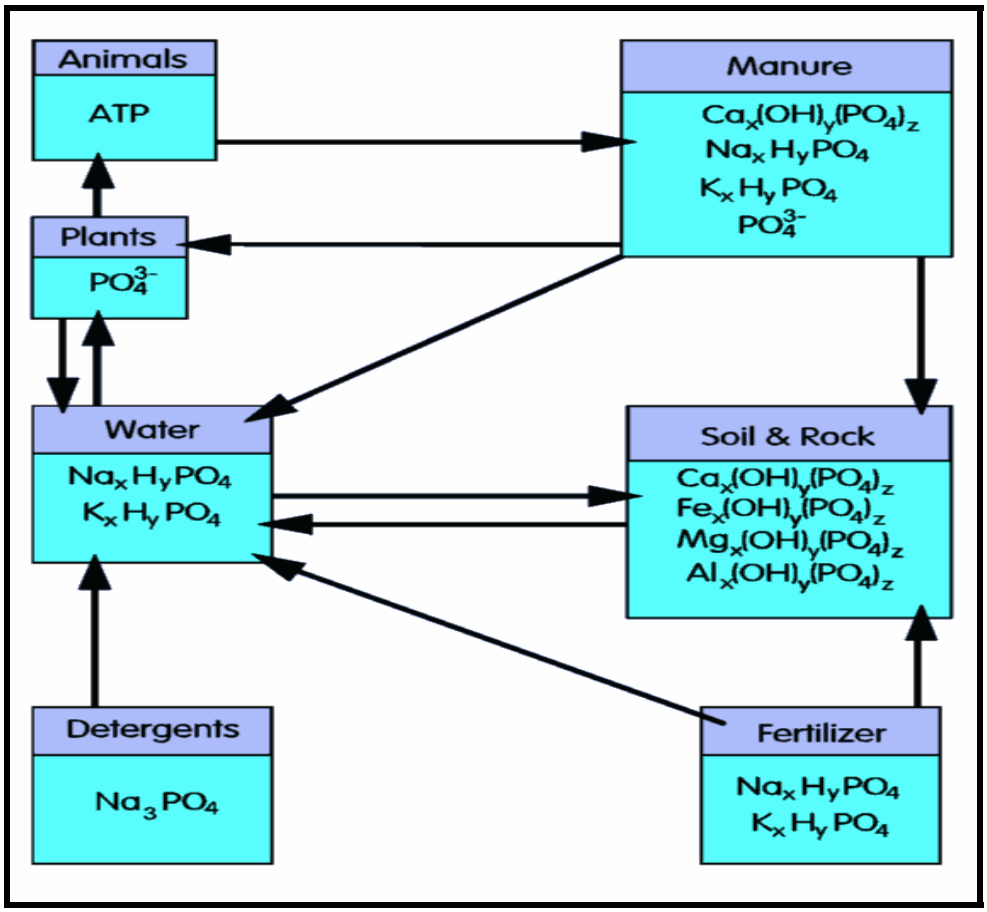


Figure 2.5: The association of phosphates with other chemicals in water (Edward, 2005).

Agricultural, sewage and industrial effluents contribute to the high level of phosphorus in natural water environments. The P from these sources emanate from animal dung and droppings in farms, household and industrial detergents respectively. Naturally rainfall could wash varying amounts of phosphates from farm soils into nearby water courses and thus increasing concentrations that exceed the ambient levels (Brisbin *et al.*, 1995, Sharpley *et al.*, 1994).

Much of the phosphorus runoff in South African urban areas occurs either in the spring or summer. During autumn, after the leaves have fallen, decaying organic matter becomes a significant source of phosphorus as streets, gutters, and roads act as conduits for bringing the material into nearby water courses.

2.5 Nitrogen in Aquatic Systems

Nitrogen is one of the most abundant elements and is found in the cells of all living organisms as a major component of proteins (Chapra 2000, Tappin, 1999). Its pathway through a water body is complex as it can enter and leave in the form of free nitrogen (N_2^-) (OECD, 1982). It may exist in water bodies, in gaseous form or as inorganic NO_3^-, NO_2^-, NH_3 or organic form as amino acids. These compounds act as nutrients and are regarded as pollutants causing eutrophication of waters. Figure 2.6 illustrate an existence and transformation of N in aquatic environment. It should be noted that some of these reactions occur as a result of both anaerobic and aerobic conditions in water.

In aerobic conditions the bacterial species which fix molecular nitrogen are *Azotobacter agile*, *Azotobacter chronococum, Nitrobacter winogradsky and Nitrosomonas europaea* and they are present in almost all rivers and dams (Rheinheimer, 1976).

It has been observed that the blue green algae of the species *Anabaena scheremetievi* fix N in dams and slow flowing rivers. These are chemo-autotrophic nitrifying bacteria that provide energy by oxidising N. The end products of this process are nitrates which are very soluble and can be easily used by living organisms. It has also been found that in eutrophic dams heterotrophic nitrification is more extensive than the autotrophic one (Prescott, 1992).

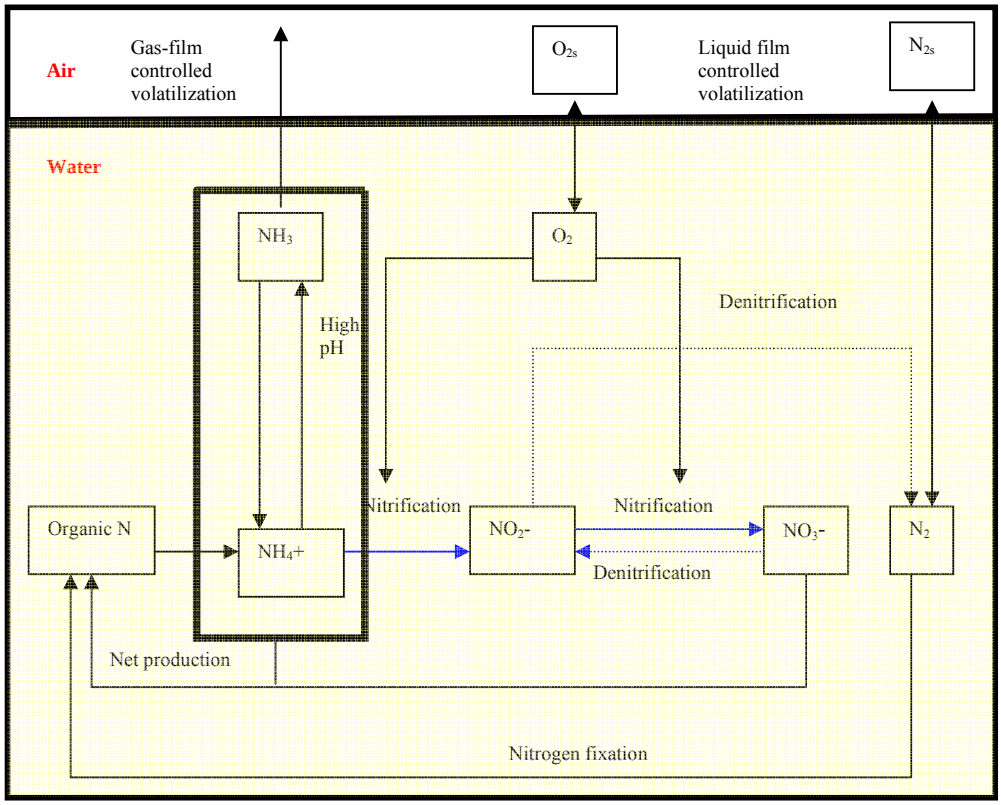


Figure 2.6: Nitrogen cycle in natural waters (Chapra, 1997).

According to Chapra, (1997) it is assumed that nitrification follows first-order kinetics and occurs through a series of reactions which are $NH_4 \rightarrow NO_2^- \rightarrow NO_3^-$ and the reverse reaction during denitrification is regarded as a feed forward. It is noteworthy that large part of N escapes from water in the denitrification process. This process is also used as a method to remove N from waste water.

2.5.1 Nitrates

As shown in Figure 2.6 above, nitrates result from the oxidation of NH_3 and NO_2^- through the nitrification process. In fresh water nitrification can cause oxygen depletion which can lead to death of aquatic organisms that depend on it for survival (Duguid *et al.*, 1978; Prescott, 1990). Under anaerobic conditions denitrification occurs and nitrate is converted to NO_2^- , gaseous nitrogen (N_2) and

ammonia.

The industrial wastewater, municipal wastewater, agricultural activities, septic tanks, animal waste and acid rain have been noted as the major sources of N compound that enter water systems (Brisbin *et al.,* 1995, Chapra, 1997, DEAT, 1990). From these sources, the autotrophic bacteria *(Nitrosomonas*) assimilate NH_3 to form NO_2^- then NO_3^- formed from NO_2^- by *Nitrobacter species.* The reactions below illustrate the oxidation of NH_3 to NO_2^- and NO_2^- to NO_3^- by *Nitrosomonas* and *Nitrobacter:*

$$NH + 2\,O_2 \Longrightarrow NO_2 + 2H_2O \quad (2.1)$$

$$NO^{2-} + 0.5O_2 \Longrightarrow NO_3 \quad (2.2)$$

For this reaction to occur rapidly in water there should be enough nitrifying bacteria with sufficient oxygen and substrate. The pH levels should be between 8 and 9. It has been observed that elevated nitrate levels are likely to occur in streams draining watersheds with high levels of nitrogen fertilizer application (Brisbin *et al*., 1995). In unpolluted water the nitrate concentrations are typically less than 2 mg/l (as N).

2.5.2 Nitrites

Nitrites are the first to be formed during nitrification process which strictly occurs under aerobic conditions. In natural waters NH_3 is oxidised to NO_2^- by action of *Nitrosomonas,* a bacterial species. The reaction bellow shows the process:

$$NH_4^+ + 1.5O_2 \Rightarrow 2H^+ + H_2O + NO_2 \quad (2.3)$$

The presence of NO_2^- in higher concentrations can lead to serious condition in fish called "brown blood disease." Their effect to humans especially to babies under the age of 3 months is manifested by condition called methemoglobinemia which may be fatal if not treated.

2.5.3 Ammonia nitrogen

Ammonia occurs naturally in water bodies and arises from the breakdown of nitrogen organic and inorganic matter in both soil and water (Gorham *et al*., 1985). A complicated process termed ammonification which includes hydrolysis of amino acids, bacterial decomposition, zooplankton excretion and direct autolysis after cell death result in formation of NH_3. Ammonification in water can be performed by putrefying bacteria and some fungal species and these differ from water to water.

It has been found that, although the optimal temperature for ammonification is generally from 30^0C to 35^0C, the quantity of putrefying bacteria in sewage polluted rivers is considerable greater in winter than in summer (Prescott *et al*., 1990, Rheinheimer, 1976). It should be noted that ammonia nitrogen exist in two forms, that is NH_3 which is toxic to fish and ammonium NH_4^+. The ratio of occurrence of these two species depends on temperature and pH variations as presented in Table 2.1.

Table 2.1 The fraction of toxic ammonia in aqueous solutions at different pH values and temperature (Tappin, 1999).

pH	Temperature (°C)					
	20	**22**	**24**	**26**	**28**	**30**
7.0	0.0039	0.0046	0.0052	0.0060	0.0069	0.0080
7.2	0.0062	0.0072	0.0083	0.0096	0.0110	0.0126
7.4	0.0098	0.0114	0.0131	0.0150	0.0173	0.0198
7.6	0.0155	0.0179	0.0206	0.0236	0.0271	0.0310
7.8	0.0244	0.0281	0.0322	0.0370	0.0423	0.0482
8.0	0.0381	0.0438	0.0502	0.0574	0.0654	0.0743
8.2	0.0590	0.0676	0.0772	0.0880	0.0998	0.1129
8.4	0.0904	0.1031	0.1171	0.1326	0.1495	0.1678
8.6	0.1361	0.1541	0.1737	0.1950	0.2178	0.2422
8.8	0.1998	0.2241	0.2500	0.2774	0.3062	0.3362
9.0	0.2836	0.3140	0.3456	0.3783	0.4116	0.4453

2.6 Other Parameters Associated with Eutrophication

2.6.1 Dissolved oxygen

Oxygen (O_2) is essential for the survival of all aquatic organisms. Fish require it to breath and bacteria require oxygen to oxidise wastes. It enters the water primarily through direct diffusion at the air-water interface and from aquatic plant photosynthesis (Tappin, 1999). Its levels can change dramatically over a 24-hour period and should be checked at various times of the day and night, with particular attention paid to times of known low O_2. Levels are usually lowest before sunrise and highest in late afternoon. Warm water is much less capable of holding O_2 in solution than cool water. Altitude also influences the level of saturated oxygen in water. At high altitude its saturation level is low.

It should be noted that total dissolved gas concentrations in water should range from 70 to 120 percent saturation as recommended by Water user Groups (Wates *et al*., 1995). Concentrations beyond this range could be harmful to aquatic life especially fish. Adequate dissolved O_2 is necessary for good water quality also a necessary element to all forms of life.

In shallow rivers with uneven rocky beds and rivers with falls, water is expected to be rich in dissolved oxygen when tested downstream, as contact with the atmosphere is intensified. This was observed in the most of the rivers in the study. Figure 2.7 overleaf shows these features of Crocodile River downstream of the Hartbeespoort Dam wall.



Figure 2.7: Natural aeration as observed in Crocodile River about 50 m downstream the outflow of the Hartbeespoort Dam.

2.6.2 Biochemical oxygen demand (BOD-5)

Biochemical oxygen demand is a measure of the presence of organics prone to bio-oxidation. When excess biodegradable organic material enters aquatic ecosystems and undergoes bacterial decomposition, large amounts of O_2 are consumed, causing an imbalance that can lead to severe damage to the ecosystem. Further impacts occur due to increased turbidity, reduced light penetration, and nutrient loading.

2.6.2 Temperature

Temperature generally impacts most chemical and biochemical reactions in aquatic environments either outside or inside living organisms. As aquatic conditions are naturally tuned to certain temperature levels, biological and chemical transformations leading to production of useful processes may be negatively or positively impacted. Temperature levels in aquatic environments are

influenced by natural and human activities. Natural impacts include solar radiation which causes seasonal temperatures changes of water (McCarey *et al*., 2004). These may not necessarily be harmful to living aquatic organisms but if they occur in the extreme their impact could be noticeable. In eutrophic dams the solar radiation has a direct influence on algal growth as it provides both heat and light (Imboden, 1992).

Human activities that impact water temperature include: industrial and municipal effluents which are released in aquatic environments. Of particular concern are cooling waters that can cause severe thermal pollution.

2.6.4 Turbidity

Turbidity is caused by presence of suspended solids in water. During rainy seasons clays, silt and soluble organic matter are washed into rivers and cause turbid waters (U.S. EPA, 2003). The main sources of turbidity are natural and agricultural land. Discharge of municipal sewage, industrial effluents and storm water could also contribute to turbid state of natural waters.

In the first instance, the impact of increased turbidity on aquatic ecosystems is a reduction in light penetration, and consequently lowers rates of photosynthesis. As light penetration is reduced, primary production decreases and food availability to organisms higher in the food chain diminishes. Since the bulk of aquatic ecosystems are supported by primary production, this impact may have serious, far-reaching consequences for aquatic fauna and flora.

Moreover, suspended solids may smother plants and animals, altering the community composition so that the food chain is further impacted. The impact may also have consequences on human populations who are dependent on the aquatic ecosystem.

2.6.5 Total dissolved solids

Total dissolved solids (TDS) are one of the most common descriptors of water quality. TDS are essentially measures the total quantity of dissolved material (organic and inorganic, ionised and un-ionised) in a water sample, and is therefore related to salinity and conductivity (Sholkovitz, 1985). Consequently, it is closely related to the pollution of water sources. The TDS in aquatic ecosystems could lead to increase or lowering of the pH as observed on bog waters (Gorham *et al*., 1985). Fluctuation of pH on a water course as influenced by TDS may either facilitate or hinder the release of P from sediments. Aquatic microorganisms including those involved in nitrification may be affected by the pH changes caused by TDS.

2.6.6 pH

pH is a measure of the acidic or basic nature of a solution. It is directly related to the concentration of the hydrogen ion [H^+] activity in a solution. The pH scale runs from 0 to 14 with 7 representing a neutral condition in most situations (Brady, 1990). pH is a critical determinant of many biological functions. Adverse pH conditions may therefore damage the organism by interfering with metabolic processes and biological integrity (Morgan *et al*., 1985). It is likely that the pH of surface water would be 7.0 but many environmental factors and processes such as geology, topsoil composition, vegetation decay, algal activities, etc. have an impact on the resulting surface water pH values.

The buffering system represented by: $H_2CO_3 \rightarrow HCO_3 \rightarrow CO_2$, controls the pH in natural waters. In most aquatic environments it ranges between 6.0 and 8.5, but slightly lower or higher values can be recorded in water with a high organic content or eutrophic water bodies respectively (Schoor *et al*., 1985).

Algae have an impact on pH levels in eutrophicated waters. During

photosynthesis they consume CO_2 and consequently increase pH. During respiration they release CO_2, thus decreasing pH. Research has shown that sudden variations in pH can have potentially catastrophic impacts on river ecosystems. In addition to its biological effects, pH also controls the chemical speciation of many metals, and thus controls their potential toxicity (DWAF, 1985).

For the protection of the aquatic environment, no general pH value can be adopted. However for ideal water quality range at any given site the pH should not vary by more than 0.5 pH units from the range of the background pH values for that specific site. Potential sources of pH change at the catchment are final effluents from wastewater plants, industries, mine drainage and effluents from informal settlements.

The most significant environmental impact of pH involves synergistic effects. Synergy involves the combination of two or more substances which produce effects greater than their sum.

2.6.7 Electrical conductivity

Conductivity is a measure of the ability of water to conduct an electric current. In other words the more salts in the water the greater the ability of water to conduct an electric current and hence an increase in the conductivity value (Jonnalagadda *et al.*, 2001). The conductivity of most fresh water bodies ranges between 10 and 100 mS/m. Salts can be released into the surface water on a natural basis during rainfall or unnaturally during an industrial spill or illegal release of effluent into a stream. A sudden increase or decrease in the conductivity at any given site is therefore a good indicator of a possible water quality change in a water body (Braddy, 1992).

In terms of protecting the natural aquatic environment it is recommended that the

conductivity should not exceed the ambient standard as set by the legislation. Fluctuations in conductivity values in a catchment may be experienced seasonally due to rainfall influences.

2.6.8 River flow rates

River flow rates are important because they are one of the variables used in mass balance computation. The mass load of pollutant in water environment is estimated as the product of the flow rate and measured concentration as shown in Equation 2.4.

$$M = Q \times C \qquad (2.4)$$

Where: Q is flow rate in m^3/s,

C is concentration in g/ m^3

M is mass load in g/s

The mass load in kg/d (or in other units) can be calculated from this basic equation by multiplying basic value with relevant factor. River flow rate in a point of a river course depends on many factors but is directly correlated by the precipitation and the surface runoff from upstream catchment. In some situations like the one that exist in Hartbeespoort Dam Catchment; effluent discharges could greatly contribute in river flow.

2.6.9 Total hardness

Hardness is measure of presence of Calcium (Ca^{2+}) and magnesium (Mg^{2+}) in water. Ca^{2+} and Mg^{2+} are the most common factor that comprises hardness and are termed as "total hardness" (Tappin, 1999).

Ca^{2+} and Mg^{2+} are essential in the biological processes of fish (bone and scale

formation, blood clotting, and other metabolic reactions). Fish can absorb calcium and magnesium directly from the water or food. The presence of Ca^{2+} in natural water helps reduce the loss of other salts; for example, sodium (Na^{+}) and potassium (K^{+}) from the fish's blood.

Research has shown that environmental calcium is also required to reabsorb these lost salts. Ca^{2+} and Mg^{2+} bind many anions that occur in water and thus decreasing their adverse impacts on the living organisms. They could also bind P in less soluble compounds taking it out of the biochemical cycles.

2.7 Phosphorus and Nitrogen Relationship in Water Sources

Phosphorus and nitrogen as main nutrients which cause eutrophication in water bodies are considerably presented as mean lake concentration/mean inflow concentration. This ratio emanate from the fact that the two are primary controllable nutrients (Chapra, 2002). It should be noted that their pathways through a water body are different as indicated previously. It is this difference that makes P the obvious choice for eutrophication control in water sources.

It has been found that both nutrients have a tendency of increasing concurrently in eutrophic waters which makes it difficult to determine which of the two might be a limiting nutrient (Chapra, 2002, OECD 1982). Most of eutrophication control measures are focused on phosphorus control because it is less soluble and was found to be the limiting nutrient in most of the reservoirs.

Both external and internal loading of nutrients may be the controlling factors in a dam (Gachter *et al*., 1985). In shallow reservoirs where flushing rate is high and the residence time is short, the external loading is usually the controlling factor. In deep reservoirs with long residence times the internal loading may be the controlling factor (Imboden *et al*., 1985). However their impact depends on

environmental factors, weather, topography, morphological characteristics of the reservoir, etc. (Imboden, 1992).

When a reservoir is fed by more than one river it may not be simple to conclude which is the main nutrient contributor unless adequate data on flow rates, nutrient concentrations and its morphology are known. It has been noted that the reduction of N input without a proportional reduction in P leads to low N/P ratio. This in turn promotes growth of nuisance algae and retards that of algal biomass (OECD, 1982).

2.8 The Measurement and Prediction of Eutrophication

There are a number of models which have been developed to predict the trophic state of a water body for given nutrient load and morphological characteristics (Harding *et al*., 2004). They are mostly based on P load which is seen as the nutrient crucial for eutrophication control (Reynolds, 1992). One of the most used is the model developed by Vollenweider (OECD, 1982). This is not a perfect model because it does not count the impact of environmental and biological factors but was chosen as a valuable simple tool to solve a complex problem like eutrophication.

The Vollenweider equation given bellow is used to relate the load of P and expected annual mean P concentration in a dam for given hydrologic and morphologic parameters of a stagnant water body (OECD, 1982).

$$\text{Total Load} = \frac{[P]}{T\,(W)} * z * A \qquad (2.5)$$

Where, [P] is the annual mean concentration of the phosphorous (mg/m^3)

T (W) is average residence time (year).

z is the mean depth of the lake (m)

A is surface area of the dam (m^2)

This formula is widely used in estimating the required TP loading into a water body to maintain the likely conditions before constructing a new dam and after constructing the dam. The flow rate and concentration of P in a tributary could be obtained from monitoring data. The data is subsequently used in estimating P loading and calculation of an annual mean P concentration in a dam using Equation 2.5.

The OECD also proposed a qualitative prediction model for the trophic status of a water body. Figure 2.8 shows a graph in which the concentration of phosphorus is correlated with probability of the given trophic status of a stagnant water body. This could assist in estimating the phosphorus load which could be allowed to maintain the desired trophic status of a stagnant water body.

This concept is further developed to predict chlorophyll-a (Chl-a) concentration (i.e. algal biomass) for given phosphorous concentration and water retention time in a water body. As presented on the Figure 2.9, (page 34) the average annual P concentration of 350 mg/m^3 in a dam of retention time of 0.8 year will cause hypertrophic conditions and average annual chlorophyll-a concentration over 25 mg/m^3.

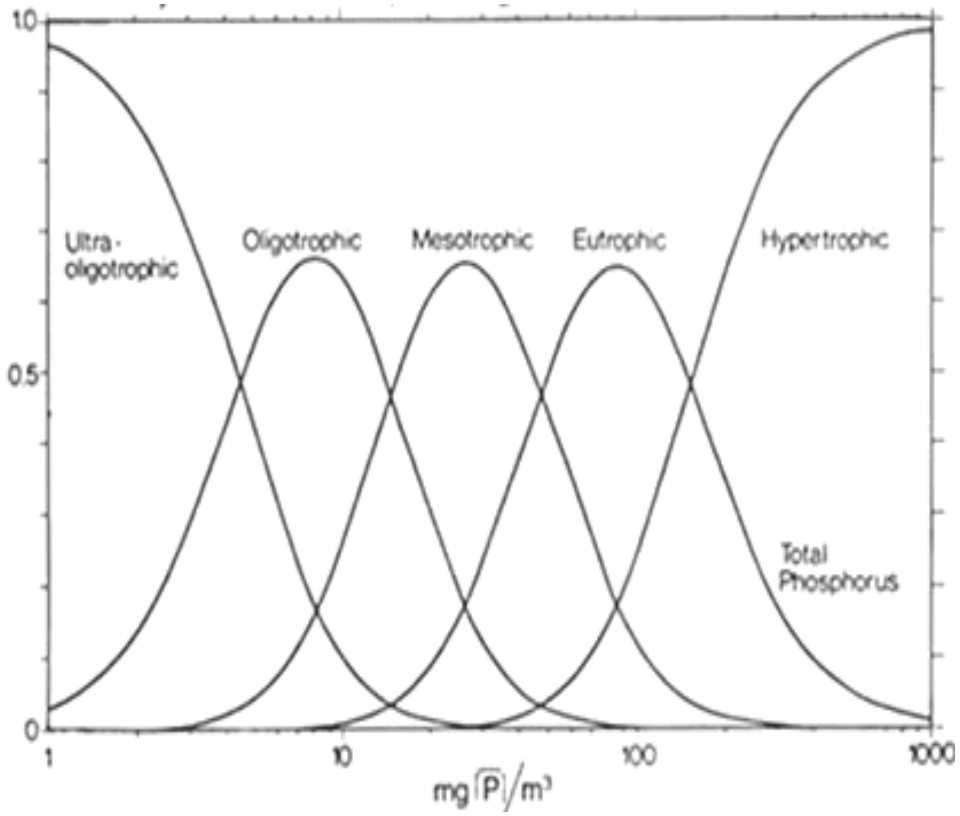


Figure 2.8: Relationship between the phosphorous concentration in a dam and probability of the occurrence of given trophic state (OECD, 1982)

For the selection of the best pollution abatement strategy it is recommended that the pollution be measured and quantified considering all factors. For the estimation of nutrient loading to a water source, the most important parameters to be critically considered are, the flow rates in the relevant gauging stations and the concentration of the nutrients.

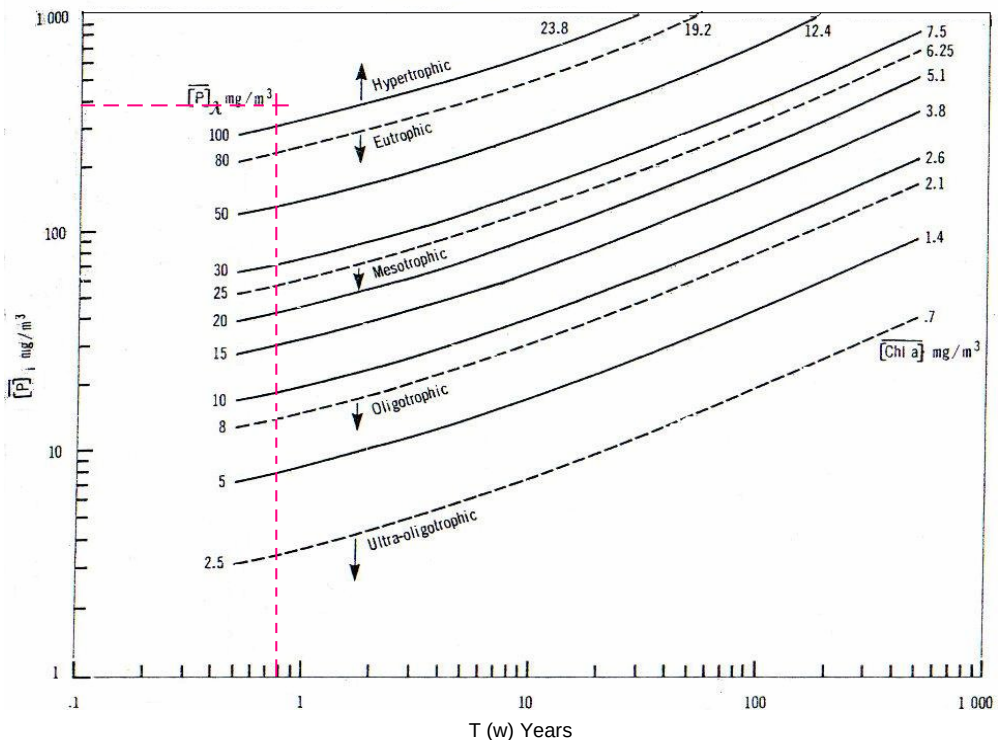


Figure 2.9: Relationships amoung retention time, P concentration, trophic state and chlorophyll-a concentration (OECD, 1982).

When considering environmental performance indicator goals for a lake management programme, nutrient loading from river tributaries that are in that specific catchment indicates which abatement strategy can be implemented to achieve the best results. Formula 2.6 below is used in calculating the mass flows of pollutants in a given river point.

$$Mi = Qi * Ci * 86.4 \qquad (2.6)$$

Where,

Mi = Measured pollutant mass flow (kg/d)

Ci = Pollutant Concentration (g/m^3)

Qi = Flow rate (m^3/s)

i = single sample collection

The sum of daily mass flows estimated from measured data could then be used to estimate yearly load but careful analysis of hydrological data is of great importance. Imboden *et al.,* (1985) stated that transport of nutrients into a lake is driven by the rate of water renewal by river, transport through molecular diffusion, water currents, particle movement and mass transfer at boundaries. It has also been proven that P budget from large catchments could be used to predict the river P export (Baker & Richards, 2002).

2.9 Abatement of Eutrophication

Abatement of eutrophication is internationally considered as the most important strategy to be implemented to maintain water bodies in desired conditions (Sharpley *et al*., 1994). It is therefore this strategy that has led to development of policies that specifically deal with control of eutrophication. These policies have been developed in consideration of the type of water bodies involved and the activities leading to their enrichment by nutrients (Walmsley, 2003; OECD, 1982).

It has been observed that under environmental conditions in a dam; coagulation, sedimentation and hydraulic loading exert controlling effects on the transport and fate of nutrients (O'melia, 1985, Reynolds, 1978). In dam coagulation increase the deposition of P in the sediments thus reducing the concentration when water is flushed out of the dam.

Nutrients control in a catchment is a serious long term objective which asks for the comprehensive administrative and technical measures. When initiating eutrophication control strategy it is imperative that one considers nutrient load and sources of nutrient pollution, the current trophic state of water body under consideration, its hydrology, climate conditions, morphology, etc. Once information on these is available the strategy should be precisely considered and proper decisions be made.

The following general measures are considered as useful in controlling eutrophication (Cullen et al., 1978; OECD, 1982, Reynolds, 1978)

- Strict control of the application of fertilisers in agricultural activities and landscaping;
- Phasing out of phosphorus containing detergents;
- Control on handling of animal wastes;
- Control of landfills and dumps;
- Implementing of stricter effluent discharge standards for wastewater treatment works including serious monitoring of effluent discharges and legal proceedings for violators; and
- Intervention on water bodies that are already impacted by eutrophication (such as management of in-out flow, hypolimnetic aeration, dredging of sediments, bio-manipulation, etc.).

Although the above measures are regarded as efficient for the control of eutrophication it should be noted that there are financial and political implications associated with their implementations. For success of the eutrophication control programme it is advisable that governmental as well as private technical structures and research are engaged in planning and implementation of such a programme.

2.10 Water Pollution and Eutrophication in South African Conditions

Preservation of quantity, quality and reliability of natural waters is required to maintain their ecosystems in which humans benefit (DWAF, 1997). It has been suggested that the maintenance and management of water courses in South Africa should be the responsibility of the users and government authorities (World Commission on Dams, 2004; Business day, 2003). The international community had been urged by Supply and Sanitation Collaborative Council to pay more attention to the ignored public health problems emanating from polluted water, sanitation and unhygienic practices (Fourways Review, 2003).

Availability of fresh water for humans, animals and plants should not be compromised at any cost as it is a basic need (DWAF, 1999). South Africa's natural water systems have been altered by developmental activities such as urbanisation, housing, mining, industrialisation, development of intensive agricultural land use and farming, and recreational activities. This has resulted in increased salinity which has detrimental effects on the aquatic ecosystem (Bredenkamp *et al*., (1995).

Although water quality problems have been addressed and action plans proposed in the national legislature, most of these plans have not been fully implemented for various reasons. Illegal dumping of waste, effluent discharge into rivers, direct discharge of storm water and releases of polluted mine drainage are common in South Africa (Whittington-Jones *et al.,* 2002, Freeman *et a.,*. 1996*)*. It has been recorded in many areas around South Africa that the quality of water sources is declining, and is primarily as a result of saltification, eutrophication, and pollution by trace metals and micro-pollutants (Fuggle *et al.*, 1996).

South African rivers are polluted by natural and human activities (Fuggle and Rabie, 1996) in spite of the efforts to keep them in desired conditions. Large developments, urbanization and lack of comprehensive and strict pollution prevention measures combined with low receiving capacities of national waters and specific climate, caused the deterioration in quality of national waters and aquatic ecosystems. Saltification, microbial pollution and eutrophication of natural waters are the processes of main concern in South Africa. Among recipients, dams that were built to balance an uneven seasonal distribution of runoff and to provide for water supply during dry seasons are particularly attacked. These accumulate historical pollution and are particularly sensitive to nutrient input which accelerates eutrophication processes, alter the aquatic ecosystems and interfere with the use of water.

South African dams and lakes provide drinking, industrial and irrigation water and serve as recreational attractions (Freeman *et al*,. 1996) contributing to the tourism industry. Most of them were built without comprehensive analyses of long term impact of the catchments and without consultation with the affected surrounding communities. This has raised serious political debates (DWAF, 2002) that are centred around their construction and benefits to the affected communities. Negative health effects like, toxins released by algae, fish kills and gastrointestinal disease outbreaks had been encountered in some (World Commission on Dams, 2004, Duguid *et al*., 1978).

Because of natural processes and pollution caused by human activities, some dams have been closed for recreational and irrigation purposes because of health related problems (Pearson *et al.,* 2002). An example is Pardenkraal Dam built at Hex River downstream of Rustenburg. As noticed many other dams (i.e. Bluemhof, Roodeplaat) around South Africa are threatened by nutrients discharge and acceleration of eutrophication processes (Harding *et al*., 2004a).

One can conclude that the consequences of the damming of rivers and eutrophication phenomena were not considered or understood at the time of the construction of these dams. It is to be emphasized that the long term impact of eutrophication processes on the water bodies and their link with the activities in the catchment were not recognized internationally by the 1970s. The consequence is that many dams worldwide (as well as in South Africa) suffer from the so-called historical pollution accumulated during longer periods as is the case with the HBS Dam.

Eutrophication in dams has been recognised as the major issue and has long been recorded in some of our dams especially those whose waters are from heavily industrialised and densely populated regions with squatter camps (Freeman *et al.,* 1996). An excessive nutrient load from wastewater treatment plants, agricultural and urban runoff, farming and other non-point source polluters (Wates *et al.,*

1995) cause the following:

- The deterioration of water quality in dams;
- The alteration of dams' ecosystems;
- Uncontrolled blooms of blue green algae; and
- Frequent fish kills.

It seems that authorities' main focus in the past was on the seasonal bad conditions in the dams neglecting the causes of the problem. The protection measures were mostly directed on the cleanup of the dams every year forgetting that the catchment area activities lead to such conditions. The impacts of nutrient load from a catchment were fully recognized in the 1990s when a new, environmentally sound approach to the catchment management was proposed and finally implemented (Water Act, 1998), including the new effluent standards for nutrients (Total P < 1 mgP/l and Total N < 2 mgN/l).

The improper management of South Africa's catchments in the past has resulted in eutrophication and salinisation problems in the dams and in other water bodies (CSIR, 1985; Fuggle *et al*., 1996). Hypertrophic Hartbeespoort dam which is the main subject of this study is one of the "victims" of such a situation. It is regarded as one of the most polluted water bodies in South Africa (as well as worldwide) and has been cited for a long period as the prime example of the consequences of poor catchment and impoundment management practices [DWAF, 1998].

The environment within which Hartbeespoort dam is located is valuable in both, an ecological and an economic sense. It is located within a broader area that is largely pristine (i.e. Magaliesburg Mountains) and provides good soil for organic agriculture. This dam was constructed by the damming of the Crocodile River which drains a densely populated, highly urbanized and industrialized area. The combination of urban and agricultural runoffs makes it difficult to implement the pollution control measures in the area, particularly those concerned with nutrient

pollution control. It seems reasonable not to expect blue "oligotrophic" water in the Dam but once constructed it has to be kept in likely mesotrophic or meso - eutrophic environmental conditions.

The South African mild climate combined with high solar radiation is suitable for the development of intensive eutrophication processes. Urbanization, mining operations, industry and agriculture had accelerated these processes over several decades of uncontrolled nutrient discharge into national water bodies.

As stated, human activities have accelerated eutrophication processes in many national water bodies (Fuggle *et al*., 1996; Walmsley, 2003). According to Fuggle *et al*., (1996) the condition of the HBS Dam has deteriorated from mesotrophic to eutrophic and lastly to hypertrophic under the pressure from upstream catchment. Many years after the problem was identified, strategies were devised and implemented in order to control nutrient discharges upstream. In the 1990s, a 1 mgP/l Phosphorous and 2 mgN/l Nitrogen effluent discharge standards (EDS) were established and implemented at most of sewage works operating in this Dam's catchment.

Although it has been found that the phosphorus level in the dam has dropped from 0.5 mg/l to 0.13 mg/l (Harding *et al*., 2004a) the dam is still eutrophic / hypertrophic because of historical pollution accumulated in the Dam. It has also been observed that external nutrient loading is still high. Even though the sustainable use of South African aquatic resources and protection of water quality have been noted as priority issues which need to be attended, it seems that the majority of South African Water Management Areas do not take the eutrophication as a serious problem.

As matter of concern the Crocodile/Marico area which is the research polygon of this study is among those regarded as having hypertrophic waters. There is further no consistent policy in the Department of Water Affairs and Forestry that

addresses the problem of eutrophication in a comprehensive manner (DWAF, 2003). Presently in the Hartbeespoort Dam the DWAF has opted on intervening only when there are visible signs of algal blooms in that dam. An Action Plan (Action Plan I and II) to combat eutrophication of the HBS Dam has been produced. This action plan mainly focus on the treatment of Crocodile River upstream of the inlet to the dam and implementation of bio-manipulation in the Dam's ecosystem.

3 THE STUDY AREA

The study focus is on the Hartbeespoort Dam Catchment which extends from the north western section of Gauteng to the southern part of the North West Province. This catchment falls under the Crocodile/Marico Water Management Board.

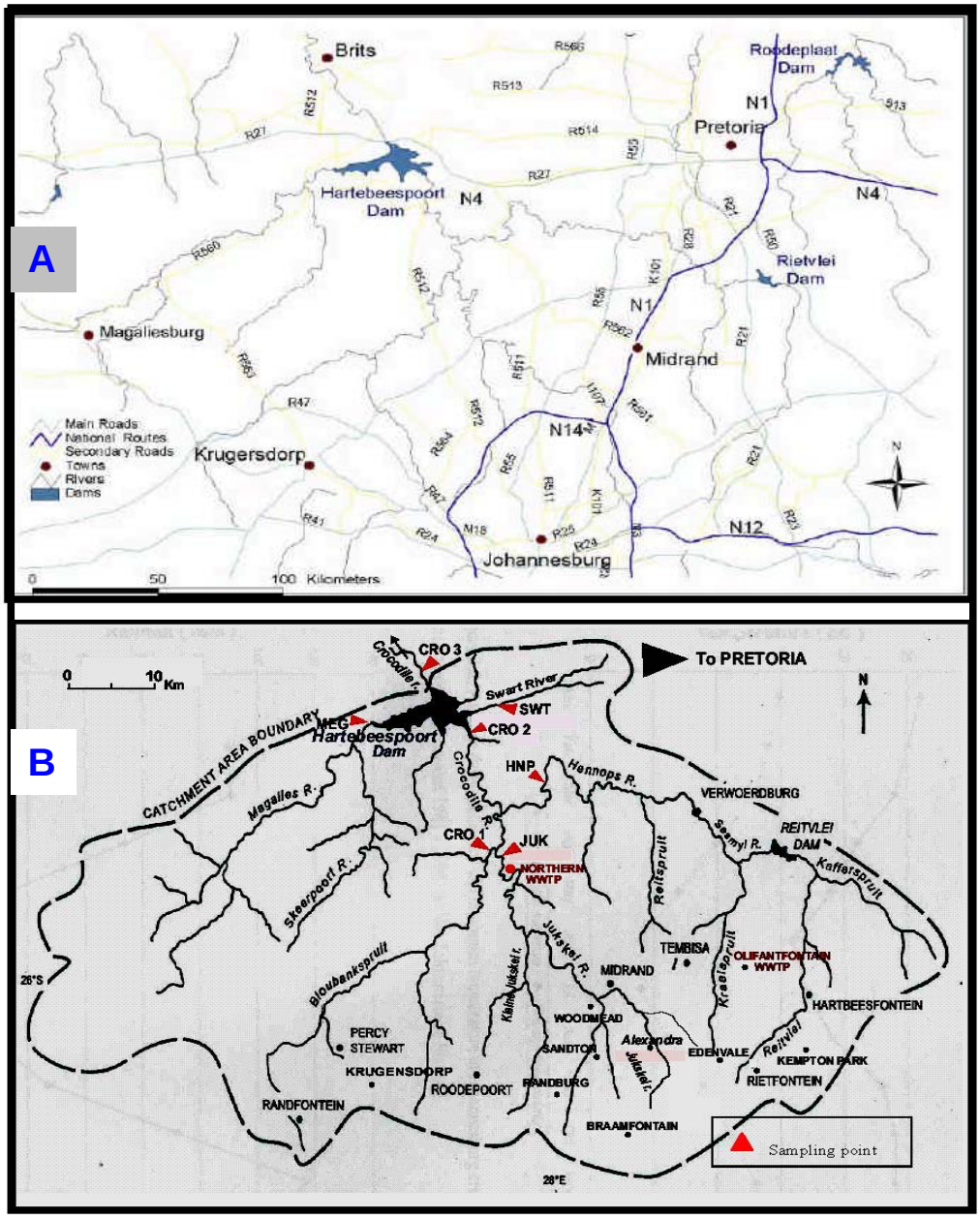


Figure 3.1: The regional setup (A) and the river networks (B) at the HBS Dam Catchment.

The subcatchments of interest are Crocodile River, Magalies Rivers and Swartspruit. Crocodile River is the main tributary that brings more than 95% of water and pollution load into the Hartbeespoort Dam. Its catchment is composed of the following three sub-catchments:

- Upper Crocodile River;
- Jukskei River; and
- Hennops River.

In addition, a small riparian catchment exists downstream of Jukskei and Hennops river confluences. This is the zone that includes lodges and Pelindaba research centre. According to FRD, (1985) and Harding *et al.,* (2003a) the characteristics of the Hartbeespoort Dam are as follows:

Table 3.1 The measurable changes of certain parameters in the HBS Dam between 1985 and 2003.

Character	FRD, (1985) (*as in 1971)*	Harding *et al.,* 2003a
Altitude m a.s.l.	1135 - 1165	1135 – 1165
Max. Depth	32.5	32.6 m
Full supply surface area	20 km^2	20.7 km^2
Mean depth of the dam	9.6 m	8.23 m
Mean annual water residence time	0.87 year	0.81year
Catchment area	4 144 km^2	4 144 km^2
Lake volume	195 x 10^6 m^3	195 x 10^6 m^3
Hydraulic loading	No data	216 x 10^6 m^3/y
Aerial water load	No data	10.1 m/y
Flushing rate	No data	1.24 times/yr
Mean annual abstraction	No data	127 x 10^6 m^3/y

The dam water is used for the irrigation of surrounding agricultural area, gardening and, to some extent for water supply.

3.1 Climate

The importance of climate in this research is its contribution in nutrient cycling that had also lead to eutrophication in the Dam. The catchment is located in the Highveld Region which is characterised by dry and wet seasons. The climatic conditions of the catchment differ and varies considerable. The Dam itself is situated in well-watered Magaliesburg Mountains. The precipitation range from 450 -750 mm/y, in average of 650 mm/y (South African Weather Bureau). Table 3.2 below shows the mean annual rainfall for Zuurbekom in the period 1999 - 2003.

Table 3.2: Mean annual rainfall at Zuurbekom (1999-2003).

Month	Jan	Feb	Ma	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av Rainfall (mm)	98.2	107.3	71.9	17.7	26	7.3	0.1	12	32.2	19.8	70.4	72.3

Evaporation from an open water surface ranges from 1250 – 1800 mm/y. It is at its highest during the summer months and at its lowest during the winter months. Warmer weather and windy conditions during August and September result in the highest monthly evaporation. Cloud cover is very low during the winter months and increases to a maximum of more than 50% during December and January. The information on climatic conditions at Jukskei Upper Crocodile and Upper Hennops was taken from the relevant weather station representing the catchments namely: Irene, Jan Smuts and Zuurbekom. Mean annual precipitation in the dam is 650 mm per annum with peak rainfall occurring in December. The mean annual air temperature is about 19,5^{o}C.

Generally these areas experience a sub humid warm climate with mean daily maximum of 24,1^{o}C and mean daily minimum of 7.6^{o}C. The summers are warm and winters cool with moderate to severe frost. Mean annual rainfall is 700mm mostly in summer in the form of thunderstorms during November and March.

Table 3.3 below shows the mean maximum and minimum monthly temperatures for Zuurbekom over the past five years.

Table 3.3: Average mean of daily maximum and minimum temperatures (1999 - 2003).

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**D ec**
D.Max (^{o}C)	27.2	26.4	26.1	23.9	20.9	19.3	18.8	22.3	23.8	25.7	20.8	25.1
D. Min (^{o}C)	13.3	14.6	12.9	8.4	3.68	0.9	0.2	0.3	7.32	10.8	10.2	11.1
Max + Min (^{o}C)	20.3	20.6	19.5	16.2	12.3	10.1	9.53	11.3	15.5	18.3	15.5	18.1

The mean wind speed on the surface of the dam is generally low. The mean monthly wind speed varies seasonally between 1m/s in June and 2.5m/s in October. This applies to Swartspruit, the dam area and Magalies River although the river canopy interferes.

A consistent pattern of wind, mainly from the northwest to southeast can be identified, with lesser contributions from the east during summer and from southwest during autumn and winter. Strong winds are normally experienced during August and September. Up to 25 % of calm conditions occur during February and March, decreasing to 20% in mid winter and to 10% in October.

3.2 General Geology of the Catchment

As the geology of the entire HBS Dam Catchment is not the same it was suggested that only the areas where the Catchment Rivers are located should be discussed.

The Jukskei River with its tributaries and the main Crocodile River are located in the Johannesburg Granite Dome. This area is composed of granitoid gneisses and migmatites of Archean age (Anhaeusser, 1999). One portion of the Bloubank

River which is a tributary of the main Crocodile River is located on dolomite of the Transvaal Supergroup and the area at the confluence tributary with Crocodile River is on basic intrusives of the Archean Complex. The Hennops River and its tributaries are on dolomite, quartzite, shale and conglomerate of the Transvaal Supergroup (Wates *et al.,* 1994 and Anhaeusser, 1999).

The HBS Dam area, Magalies River and Swartspruit are on quartzite, conglomerates, shale and hornfels of the Transvaal Supergroup and Karoo Group. A portion of the Skeerpoort River which is a tributary of Magalies River is on dolomite, quartzite and shale also of the Transvaal Supergroup. A portion of the Swartspruit is on shale and diabase of the Pretoria series (National Institute for Water Research, 1985).

Water in the HBS Dam Catchment is expected to contain Na^{+}, Ca^{++}, K^{+} Mg^{++} and HCO_3^{-} as chemical weathering of the rocks mentioned above result in release of these ions.

3.3 Catchment Description

The Crocodile River is the back bone of water supply of the North West Province and the north west part of Gauteng Province. Its catchment to the confluence with Limpopo River covers an area of about 10 450 km^2. The part of the catchment which drains into the HBS Dam is 4 144 km^2 in extent (Harding *et al*., 2004b). The mean annual natural runoff from this catchment is estimated at 150 x 10^6 m^3/y. The total mean annual runoff of Crocodile River to the HBS Dam is estimated at 305 x 10^6 m^3 /y.

The physical environment of the larger Hartbeespoort Dam Catchment is composed of the urban, rural and pristine natural areas of Magaliesburg. The urban area constitutes 13 to 15% of the total catchment area.

The main sources of pollutants that are found in the catchment are from sewage treatment plants, illegal dumping both in the rivers and on land, agricultural activities upstream, construction activities, heavily polluted water from informal settlements, runoff from parks and golf courses and effluents from mining and industrial activities. In all the four subcatchment, it is believed that there are existing organisations which are involved in monitoring of water quality in the catchment. Although DWAF is presently monitoring the catchment, Johannesburg Water is also actively involved in monitoring of the Jukskei and Crocodile Rivers upstream.

As mentioned above the Catchment Rivers originate from areas with varied geological formations which could have a major influence on the quality of water. The interference of these formations on water quality could be confused with pollution from human activities in the catchment area. Water originating from dolomitic formations is regarded as the best but this could be negatively impacted by underground mining and other activities as it is the case in the Gauteng Province from where these catchment rivers originate.

As shown in Figure 3.1 (B) the sampling points were selected on strategic positions to represent the subcatchment of interest during study period. Worth mentioning is a network of tributaries which join the Crocodile and Magalies Rivers. Most of them originate from the areas believed to be the main contributors to the eutrophication of the Dam. As shown in Figure 3.1 (B) the Crocodile River Catchment upstream of the HBS Dam could be divided into three subcatchment i.e. the Upper Crocodile, Jukskei and Hennops.

3.3.1 Jukskei River catchment

The Jukskei River is one of the prime tributaries of the Crocodile River, and its catchment is located within the Witwatersrand area. Its source is situated within the Eastern Metropolitan Local Council (EMLC) upstream of Bruma Lake. Its

catchment area drains a large portion of the Witwatersrand where watersheds between the two oceans (i.e. Indian Ocean through Limpopo River and Atlantic Ocean through Orange River) drainage areas exist.

The Jukskei catchment embraces a number of areas from which considerable amount of pollution is generated and dumped into the Jukskei River. The areas include a portion which originates from densely populated and busy sections of the east and north of Edenvale, Bedfondview, Modderfontein, Greater Johannesburg, Johannesburg, Randburg, Alexandra, Diepsloot and Midrand. It is not easy to accurately estimate the population in this subcatchment because of the increased rate of residential developments and new informal settlements. It is composed of Great Jukskei River and three tributaries which are:

- Modderfonteinspruit;
- Braamfonteinspruit; and
- Klein Jukskei River.

Modderfonteinspruit

This tributary originates from Kempton Park West and Thorn Hill. Water drained from these areas pass via Modderfontein Golf course to the Jukskei River. The Klipfontein Organic Product Manufacturing Corporation is situated within this subcatchment. Four catchment dams which act as attenuation barriers have been constructed on Modderfonteinspruit. High levels of total dissolved solids, sodium, chlorides and nitrates had been detected on this tributary.

Braamfontein spruit

It originates from Wesdene, North Cliff, a portion of the west of Braamfontein including The University of Witwatersrand and Auckland Park. Several Golf Courses are situated in this subcatchment and are: River Club, Johannesburg,

Brynston and Pine Park. It also has seven catchment dams which act as attenuation barriers before joining the Jukskei River.

Klein Jukskei

The Klein Jukskei is the largest tributary of the Jukskei River. It originates from Florida Hills. Several weirs had been constructed on Klein Jukskei including one at Jukskei Park. It traverses through a flat area before joining the greater Jukskei at Chatwell.

Great Jukskei River

The main Jukskei River originates at Bezuidenhout Valley west of the East Gate Shopping Mall. East Hillbrow, Johannesburg Stadium and Observatory surround the source point of this river. Another original point is at Sandringham south east of Alexandra Township. Bruma Lake is the only catchment dam identified before the river reaches the Alexandra Township. Although this township is regarded as the main source of pollution of this river, high nutrient values have been recorded upstream. This gives an indication that the identified activities above also contribute to this situation. The closed landfill situated north of this township also contributes to the pollution of the river. It is anticipated that heavy metals and other organic pollutants may be washed out from the landfill to the river.

Further downstream of Alexandra Township in Midrand and Kayalami area, there are quarrying and massive construction activities. It is anticipated that the construction activities are developmental and will be completed within a short period but the quarrying one has been there for many years. There are also some farming activities within the Jukskei catchment that through use of fertilisers and production of animal manure produce nutrients that are drained into the Jukskei River.

There are many activities taking place in the Diepsloot area and are suspected to contribute to the pollution of the river. The following occur in the area: massive developments at Dainfern and Fourways, Diepsloot Township and the informal settlements, the compost heaps next to the river, the old dried sludge beds at Northern Johannesburg Water Works, sewage treatment plant and horse stalls. Downstream of the Diepsloot area are farming activities which include chicken, sheep, and horse and unidentified small farm holdings. Lodges and resorts are also found along the river.

Informal settlement such as those in Alexandra, and Diepsloot etc., do not have adequate stormwater drainage systems, sewer systems, and solid waste management systems in place. Overflowing of storm and grey water over bar racks is the problem as it mixes with sewer to the river. Presently Jukskei River in which the storm water from Alexandra Township is deposited was monitored by Wits and results have indicated high nutrients level down stream of Alexandra (Cukic *et al*., 2004).

The unacceptable levels emanate from storm water drainage pipes carrying grey water from different sections of the township. In the same township, sewer lines bursts and leakages are a daily problem. Of particular interest is the Modderfontein spruit where high TDS and NO_3^- concentrations were observed (Cukic, *pers, comm,* 2005).

In areas where there are no stormwater drainage and sewer systems, residents dispose their wastewater on the roads and by their houses/shacks sides. Wastewater from domestic use of water includes wastewater from washing and bathing and contains phosphate from soaps and washing detergents. The effluent from the Johannesburg Northern Wastewater Treatment Works (JNWTW) is the main source of nutrients in the catchment even though it fully complies with the strict discharge standards laid down.

Table 3.4: Point sources in the Jukskei River sub-catchment.

Works	P loading (tons P/annum)	Reference
Johannesburg NWTW	66	(Harding *et al*.,2004a)
Esther Park	0.2	(Harding *et al*.,2004a)

3.3.2 Hennops River Catchment

The Hennops River Catchment covers southern Pretoria and eastern Johannesburg. It stretches from Kempton Park to Scurweberg where it joins the Crocodile River. It traverses through an agricultural area which contributes in nutrient load during the rainy season.
The main point sources in this subcatchment are:

- Olifantsfontein Waste Water Treatment Works;
- Kempton Park Waste Water Works;
- Kelvin Eskom Power Plant which utilizes a part of the final effluent from the Johannesburg Northern Waste Water Works as a coolant; and
- Several Dairy Farms; and

The non point sources are:

- Industrial areas
- Agricultural Holdings such as Glen Austin Extension, Randjiesfontein and others;
- Wetlands at Rietfontein which release pollutants during flood conditions;
- Irene Golf Course; and
- Tembisa Township and informal settlements in the vicinity of the township.

The Midrand Metropolitan Local Council (MMLC) area alone consist of parts of three surface water catchments, namely Rietspruit, Olifantspruit and which include small and local dams that drains into the Crocodile River.

Hennops River had also been identified as a source of nutrients into the Crocodile River. The extensive construction activities in progress at Centurion, Tembisa and south of Pretoria contribute to the turbid water in this river. During the sampling period some illegal dumping of waste was observed along the river valleys next to the small farm holdings. Runoff and leakage from such dumping sites could contribute to the high level of nutrients.

Several dense informal settlements like, Ivory Park, Rabie Ridge and others experience the same problem of overflowing of stormwater drainage, blocked sewer pipes and illegal dumping of waste at the banks of the river. The nutrient rich runoff is deposited into the Olifantspruit, a tributary of the Hennops River, which eventually reach the Hartbeespoort dam. Informal settlements such as Rabie Ridge, Ivory Park, Olivenhoutbosch and others in Tembisa also do not have adequate drainage systems, sewer systems, and solid waste management systems in place. As a result polluted stormwater from these areas is drained via stormwater canals to the river and lastly to the overflow of the dam. There are several in stream reservoirs that attenuate some of the pollutants originating upstream. Amoung these are the Rietvlei Dam constructed for water supply and the Centurion Lake at Centurion.

3.3.3 The Upper Crocodile River catchment

The Upper Crocodile River catchment receives runoff from Randfontein, Krugersdorp and northern part of Roodepoort. This part of the catchment includes gold mining activities, food processing industries, retail industries, farming activities, residential, recreational and tourist resorts. The main sources of pollution in the Upper Crocodile are mine drainage, sewage treatment works and

several oxidation ponds located on farm holdings west of the N24 freeway to Pretoria. It is anticipated that nutrients analysed in this catchment could have emanated from these sewer plants.

Table 3.5: Point sources upstream of the Crocodile River.

Works	P loading (tons P/annum)	Reference
Randfontein Works	12.5	(Harding *et al.*,2004a)
Percy Stewart	30.5	(Harding *et al.*,2004a)

Major activities along the Crocodile River before the dam are the Pelindaba Nuclear Research Center, the Alpha Conference Centre, the Art Exhibition Centre and the Lesedi Cultural Village. According to DWAF the Pelindaba plant has a small wastewater treatment plant which is well monitored.

3.3.4 Magalies River catchment

The Magalies River catchment is around the Magaliesburg Mountains and is dominated by farm activities. The water quality in this catchment has not been identified as a problem, even though increased nutrient loads have been recorded in the past as well as in this study.

The Catchment comprises of the following areas: Vlakdrif, Hartebeesfontein, Bultfontein, Hartebeeshook Game Reserve, Rietfontein, Magaliesburg and Doornkloof. There are several farm holdings along the river which may be using septic tanks and French drains but there is no indication of mismanagement of these drains. The Magalies Sewage Works which has a capacity of 2Ml/day is the main point source in this catchment.

3.3.5 Swartspruit catchment

The flow rate in the Swartspruit is low but the nutrients consistently keep alarming high concentrations. This catchment is dominated by both new development and farming activities. Construction activities are rife in this area and they contribute to the deteriorating quality of water in the stream including extremely high levels of P. The main point source of pollution is Rietfontein Sewage Treatment plant and P loading is 3.3 tons per annum (Harding *et al*., 2004). The catchment comprises of: Rietfontein, Kameldrif, Uitsig and Rietfontein Sewage Works etc.

3.4 Erosion Potential of the Soil

In the catchment urban, residential and industrial areas soil is completely paved and landscaped with evergreen lawns and as result of that erosion is unlikely to occur except in informal settlement areas. In informal settlement areas storm water is not properly channelled and roads are not tarred and in this case soil erosion occurs.

The rural areas land is mostly covered with vegetation throughout the year. Due to the high turbidity of water during wet season it is possible that erosion occur along the river banks (Fatoki *et al*., 2001). The period the land is more prone to erosion is during cultivation and harvest time but during these periods precipitation is low. Most of the catchment is not prone to erosion because of grassland and nature reserves which dominate the area.

3.5 Land Use and other Activities

Considering the sub catchments, the Jukskei, lower Hennops and lower Crocodile are mostly urban and composed of the following areas: commercial, formal

residential, informal residential, small agricultural holdings and sewage treatment plants. The upper Hennops, upper Crocodile and Magalies are mostly rural with large patches of land cultivated and with nature reserves. In these areas septic tanks or French drains are use as mode of disposing sewage and their efficiency is unknown at the moment.

The Hartbeespoort dam area and the Swartspruit area are peri-urban. There are quite a number of developments taking place along these areas. A large agricultural land exists towards northern side of the dam. Surrounding the dam is quite a number of lodges and restaurants for tourists and local residences.

3.6 Water Use

Hartbeespoort Dam was constructed from 1923 to 1925 for agricultural purposes. It quickly translated into a water source for primary consumption and also as an attractive recreational destination (CSIR, 1985). It is now a major recreational (i.e. water sports, including fishing, boating and water skiing) and tourist attraction centre in the North West Province. Water from HBS Dam is also used for domestic purposes by Magalies Water Board and for irrigation purposes by the farmers along the area.

3.7 Water Quality in the Catchment

According to DWAF, pollutant monitoring programme at the main gauging stations for the Hartbeespoort Dam catchment exhibited mixed trends in relation to the pollutants. This is clearly indicated in Table 3.1 and 3.2.

Over the years Jukskei River downstream of Alexandra has been reported as the most polluted river in South Africa with high levels of pathogens, consistently generating high risk of outbreaks (i.e. cholera). The Alexandra Township

Community and Soul Foundation have been involved in cleaning up of solid waste including plastics, metal plates and papers along the river banks. Grey water from the 18th Avenue and Swjetla informal settlements was noted on the outfall of the storm water culvert mixing with water in the river. This indicated that sewage and grey water was being disposed directly into the stormwater system to the river.

Water samples analysed downstream, measured high concentrations of nutrients and faecal coliforms. Similar situations were also observed at Tembisa, Diepsloot and Olivenhoutbosch. Solid waste removal in these areas has improved but water courses are still polluted.

The Johannesburg Northern Waste Water Treatment Plant monitors its final effluent and according to their reports all parameters measured do not exceed the limits (Johannesburg Water, 2001). The final effluent that is discharge into the Jukskei River from this Plant does not exceed 0, 8 mgP/L of total P, but the load into it is high because of large volumes. According to Wates *et al*, (1994), the Hennops River is also severely polluted as a result of runoff from the formal and informal settlements.

The Swartspruit is also highly polluted as a result of construction and other activities within the catchment area. The main source of pollution is the Rietvlei Sewage Treatment Works Plant which does not comply with DWAF Effluent Discharge standards. There is no record of high nutrient load from the Upper Crocodile River Catchment.

Table 3.6: Average mean annual concentrations of water parameters during wet season of the year 2003 (DWAF, 2003).

Parameter	DWAF Monitoring Stations						
	A2H045	**A2H012**	**A2R001**	**A2H044**	**A2H014**	**A2H074**	**A2H058**
PO_4 (mg/l)	0.13	0.46	0.07	0.46	0.03	0.58	3.19
P-tot mg/l			0.19		0.05	0.85	
NO_3^- (mg/l	2.72	3.56	0.4	4.04	0.70	5.25	1.31
NH_4 (mg/l)	0.04	0.013	0.3	0.06	0.03	0.02	2.34
SO_4 (mg/l)	61.7	48.6	53.4	46.4	12.0	51.7	48.6
Cl^- (mg/l)	40.9	57.4	53.5	51.2	5.1	79.6	92.3
pH	8.1	7.9	8.6	8.0	8.41	8.2	8.0
K^+	4.96	9.95	9.6	10.1	0.9	11.3	13.5
Ca^{2+}	41.14	37.3	24.4	33.5	38.5	44.9	39.7
Mg^{2+}	21.7	13.1	15.6	9.3	26.1	17.4	23.4
Na^+ (mg/l)	29.1	47	46.3	44.6	6.8	61.9	81.9
Hardness	192	146..7	125.4	121.3	204.7	183.9	195.0
EC (mS/m)	57.3	56.6	51.0	51.3	41.6	70.1	79.2

A2H045 = CROC 1, A2H0 = CROC 2, A2R001 = CROC 3, A2H044 = JUKS, A2H074 = MAG A2H014 = HNPS and A2H058 = SWRT

Table 3.7: Average mean annual concentrations of water parameters during dry season of the year 2003 (DWAF, 2003).

Parameter	DWAF Monitoring Stations						
	A2H045	**A2H012**	**A2R001**	**A2H044**	**A2H014**	**A2H074**	**A2H058**
PO_4 (mg/l)	0.09	0.50	0.13	0.58	0.02	0.63	3.2
P-tot mg/l		0.87	0.22		0.04	0.94	
NO_3^- (mg/l	3.38	4.76	0.85	4.04	0.97	6.33	1.7
NH_4 (mg/l)	0.05	0.03	0.25	0.15	0.03	0.05	2.34
SO_4 (mg/l)	68.4	57.7	55.4	52.4	11.1	56.3	70.4
Cl^- (mg/l)	44.37	65.1	54.3	60.2	2.01	86.3	99.6
pH	8.14	7.8	8.15	7.9	8.5	8.4	8.0
K^+	4.29	11.9	9.49	12.13	0.54	12.3	16.5
Ca^{2+}	48.9	39.9	27.89	33.66	39.4	45.3	41.6
Mg^{2+}	27.0	15.9	16.32	10.9	27.6	20.4	22.17
Na^+ (mg/l)	31.9	59.9	46.55	59.9	6.6	71.5	89.69
Hardness	233	165.4	136.4	129.0	212	197.3	195.3
EC (mS/m)	62.3	64.5	53.3	59.4	42.75	79.6	82.5

3.8 Historical Nutrient Loading in the HBS Dam

The first signs of eutrophication in HBS Dam were observed in 1928. Industrial developments, farming and residential developments increased the volume of water and concentration of nutrients (phosphate and nitrogen) in HBS Dam Catchment. Treatment plants that were designed to receive limited volumes of waste water could not thoroughly treat it; as a result, partially treated effluents were discharged into the Catchment Rivers. For many years the P and N compound rich effluents had been discharged to the Catchment Rivers. The amount of nutrients reaching the HBS Dam had risen and caused severe eutrophication.

Over the years these nutrients reached the dam and accumulated with sediments which over a long time causing severe eutrophication. This has also resulted in massive development of blue green algae in the dam water. Presently it is estimated that N to P in the Dam occurs at a ratio of N: P =25:1 (Harding *et al*., 2003).

Although nutrients had been implicated as the main cause of eutrophication in the HBS Dam there are other complex biophysical and chemical activities which have contributed. Following the findings that P was the limiting nutrient to algal growth; DWAF introduced the special P standard of 1mgP/L to effluent dischargers. The implementation of this special standard took some time but has contributed in a decrease of P load to the Dam (refer to Table 3.3 below).

Table 3.8 The historical total-P load of the HBS Dam (NIWR, 1985 & Harding *et al*, 2003)

Year	Tot. –P (t/y)	Tot. stream inflow	Reference
1973	260	No data available	Osborn and Halliday (1976)
1974	336	No data available	Osborn and Halliday (1976)
1975	350	No data available	Toerien and Walmsley (1976)
1977	418	No data available	Scott *et al*. (1980)
1981	283	No data available	National Institute for Water Research, (1985)
1982	323	No data available	National Institute for Water Research, (1985)
1983	206	No data available	National Institute for Water Research, (1985)
1986	161	132.1	DWAF (2003)
1987	297	251.2	DWAF (2003)
1988	263	203.2	DWAF (2003)
1989	199	202.6	DWAF (2003)
1990	211	184.7	DWAF (2003)
1991	155	192.8	DWAF (2003)
1992	162	116.8	DWAF (2003)
1993	169	149.3	DWAF (2003)
1994	134	246.8	DWAF (2003)
1995	148	215.5	DWAF (2003)
1996	241	611.9	DWAF (2003)
1997	179	641.5	DWAF (2003)
1998	122	308.3	DWAF (2003)
1999	122	336.3	DWAF (2003)
2000	251	702.4	DWAF (2003)
2001	117	434.8	DWAF (2003)
2002	81	251.0	DWAF (2003)

4 MATERIALS AND METHODS

As mentioned in Chapter 1, one of the objectives of this study was to examine water quality at selected points of HBS Dam catchment focusing mainly on the nutrients (i.e. N and P). This was performed through sampling campaigns scheduled to cover wet and dry season (eight months in total). The frequency and extent of sampling schedule was adjusted in accordance with time, available funds and available resources.

Sampling was done in the first half of the day once a month from January 2004 to July 2004. The schedule during wet season was adjusted and the decision was to sample as soon as the rain fell. In each sampling campaign carried out, an observation of the surrounding environment was done in order to provide information for the analysis of the results obtained. These include weather conditions, riparian conditions, and visual appearance (Rodier, 1975).

Measurements of air and water temperature were performed on site. The photographs on sampling sites were taken and are presented in Figure 4.1 to 4.7. The sampling of water from the rivers that directly feed the HBS Dam (i.e. Crocodile River, Magalies River and Swartspruit) was done at the lowest sections where there is no Dam impact. The sampling points in the Crocodile River catchment were selected at strategic positions to represent the three sub-catchments, i.e. Upper Crocodile river, Jukskei and Hennops River. This was done in order to quantify the contribution of each of these catchments to the overall pollution load entering the Dam. In addition, an outlet of HBS Dam was also monitored in order to gather information on water quality in the dam and to assess the outflow of nutrients of interest during the study period.

Situational analysis of the catchment as well as sub-catchments was done in order to link data produced with activities identified from these areas. The procedures for sampling, preservation and majority of analytical methods were performed following the instructions given in the Standard Methods for the examination of

water and wastewater (Standard Methods, 1995). All samples were analysed in the laboratory at the University of the Witwatersrand, Water Quality Laboratory of the School of Civil & Environmental Engineering.

Daily flow rates data for mass flow calculation of relevant parameters at selected points was obtained from DWAF (www.dwaf.gov.za/hydrology) and some were provided on request from their offices. Data from DWAF Gauging Stations corresponding to each sampling point established for the purposes of this study were used.

4.1 Description of Sampling Points

The criterion applied in selection of sampling points was:

- Representing the contribution of the entire catchment as well as sub-catchments of interest to the nutrient load of the HBS Dam; and
- Providing link with corresponding DWAF gauging stations where daily flow rates are recorded.

Table 4.1 shows some details of the sampling stations and of the towns and townships which form part of these catchments. The coordinates of each sampling point were taken from the 1: 50 000 topographical maps:

Table 4.1 The description of sampling stations and associated catchment areas.

Station	River	Co-ordinates	Catchment representation	Description
CROC 1	Crocodile	270 55' E 250 42.2' S	Upper Crocodile; Randfontein; Krugersdorp; Part of Roodepoort, Zwartkop; Kromdraai; Nooitgedacht; Rhenosterspruit; Tweefontein: Rietfontein;	Crocodile River 3 km upstream of the confluence with Jukskei River.
CROC 2	Crocodile	270 53.5' E 250 53.7' S	Upper Crocodile plus Jukskei and Hennops catchments; Pelindaba; and Broedestroom	Crocodile River 1 km upstream of HBS Dam.
CROC 3	Crocodile	270 50.1' E 250 43.2' S	The dam	Crocodile River at the outlet of the dam
JUKS	Jukskei	270 53.5' E 250 56' S	Johannesburg Northern suburbs; Randburg, Alexandra Township; Diepsloot; Lanceria; and Midrand	The bridge to Vlakfontein. Close to DWAF gauging station.
MAG	Magalies	270 46.1' E 250 46.5' S	Magalies, Vlakdrif, Hartebeesfontein, Bultfontein Hartebeeshook game Reserve Rietfontein, Doornkloof	Down the bridge at Paradise Place 2 km upstream of HBS Dam
HNPS	Hennops	270 58.8' E 250 50.3' S	Kempton Park, Edenvale; Claville Tembisa; Part of Pretoria; Centurion	100m upstream of the R511 bridge.
SWRT	Swart	270 45' E 250 54.3' S	Rietfontein; Kameldrif; Uitsig, Rietfontein Sewage Works	Down the bridge at Rustenburg Road

Photographs of each sampling station are presented in Figures 4.1 to 4.7 overleaf. These photographs were taken during the wet season which has high P and N load to the Dam.



Figure 4.1: CROC 1 sampling point.



Figure 4.2: CROC 2 sampling point.

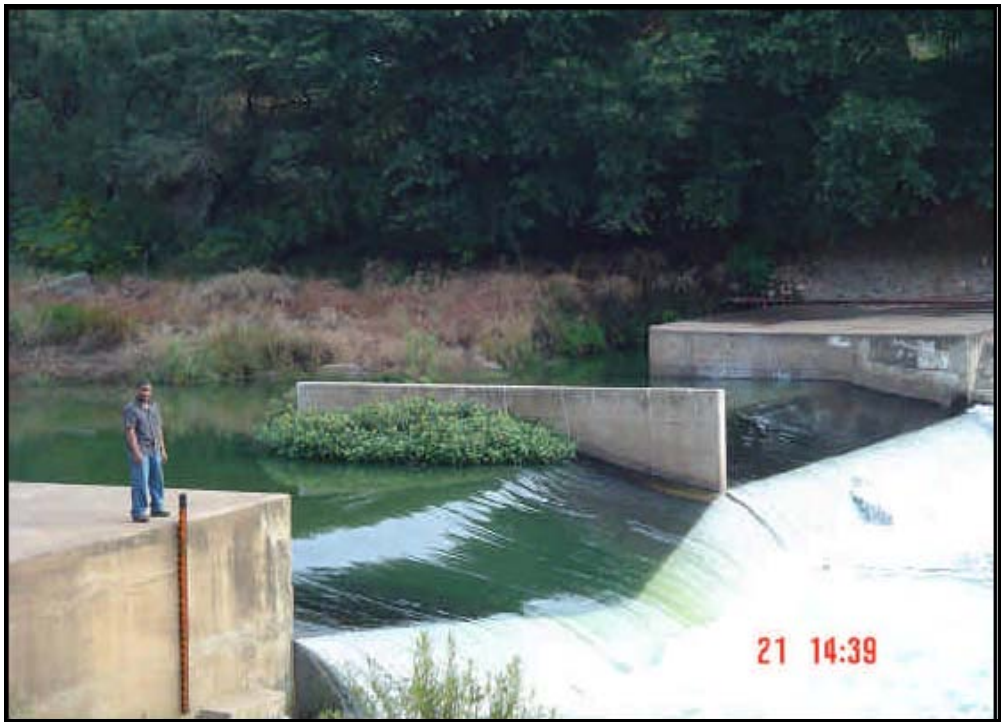


Figure 4.3: CROC 3 sampling point.



Figure 4.4: JUKS sampling point.



Figure 4.5: HNPS sampling point.



Figure 4.6: MAG sampling point.



Figure 4.7: SWRT sampling point.

4.2 Analytical Methods

Analytical methods used in the analysis of WQ parameters were those stipulated in the Standard Methods except the atomic absorption spectrophotometric (AAS) analysis and dissolved organic carbon (DOC) determinations (performed following the instructions given by the manufacturer i.e. Shimazu Co.) and chloride (Cl^-) (performed following the instructions given by the manufacturer i.e. Merck).

In the laboratory priority was given to phosphorus and nitrogen analysis on fresh samples, then other parameters were analysed either on fresh or preserve samples following Standard Methods. Quality control was performed by running replicates and/or blind samples and spikes (Wilson, 1974). A detailed explanation of methods applied to analyse both N and P species is presented. Other parameters

whose results are appended in this report were analysed using the Standard Method (STD Methods, 1994).

4.2.1 Inorganic nitrogen compounds

Figure 4.8 below shows the summary of analytical methods applied.

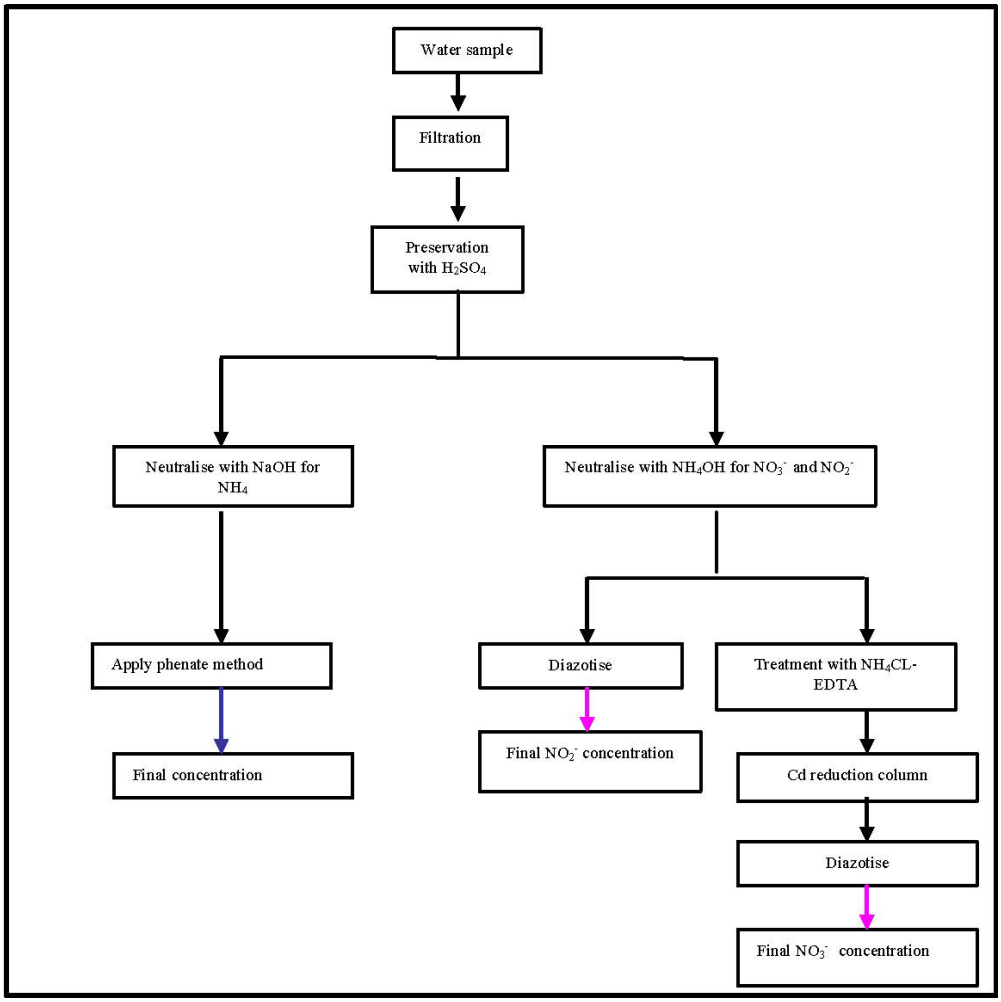


Figure 4.8: Flow chart of the procedure for nitrogen compounds measurements (*Author*).

Ammonia Nitrogen

Preserved (by sulphuric acid) and filtered (0.46 µm) samples were analysed. Each sample was neutralized by sodium hydroxide (NaOH) to pH 5 - 9 before

processed. The phenate method was used in ammonia nitrogen analysis. This method is based on the reaction of ammonia nitrogen with hypochlorite, and phenol which is catalyzed by sodium nitroprusside. The intensity of the blue colour of Indophenol developed in the reaction is the measure of Ammonia nitrogen concentration. Ammonia-free water was used to prepare all reagents and calibration standards. Concentration of ammonia was red directly on the spectrophotometer (wavelength 640 nm) against the calibration curve freshly prepared with each series of samples.

Nitrite Nitrogen analysis

Preserved (by sulphuric acid) and filtered (0.46 μm) samples were analysed. Each sample was neutralized by NaOH to pH 5 - 9 before being processed. The method applied is based on the reaction of nitrite with reduction of nitrates sulphanilamide and complexing with N-(naphthyl)-ethylenediamine dihydrochloride to form a pink azo-dye. The final concentration was red directly on the spectrophotometer (wavelength 543 nm) against the calibration curve freshly prepared with each series of samples.

Nitrate Nitrogen analysis

Preserved (by Sulphuric acid) and filtered (0.46 μm) samples were analysed. Each sample was neutralized by NaOH to pH 5 - 9 before processed. The cadmium reduction method was used in the determination of nitrate nitrogen. Figure 4.9 shows the reduction column similar to the one illustrated in the Standard Methods (1995). The reduction column, preparation of cadmium granules, loading the reduction column and the procedure for colour development were done following the same guidelines.

This Cadmium reduction method is based on reduction of nitrates to nitrites in the presence of cadmium coated by $CuSO_4$. The concentration of nitrite produced is determined by diazotizing with sulphanilamide and complexing with N-

(naphthyl)-ethylenediamine dihydrochloride to form a highly coloured azo-dye.

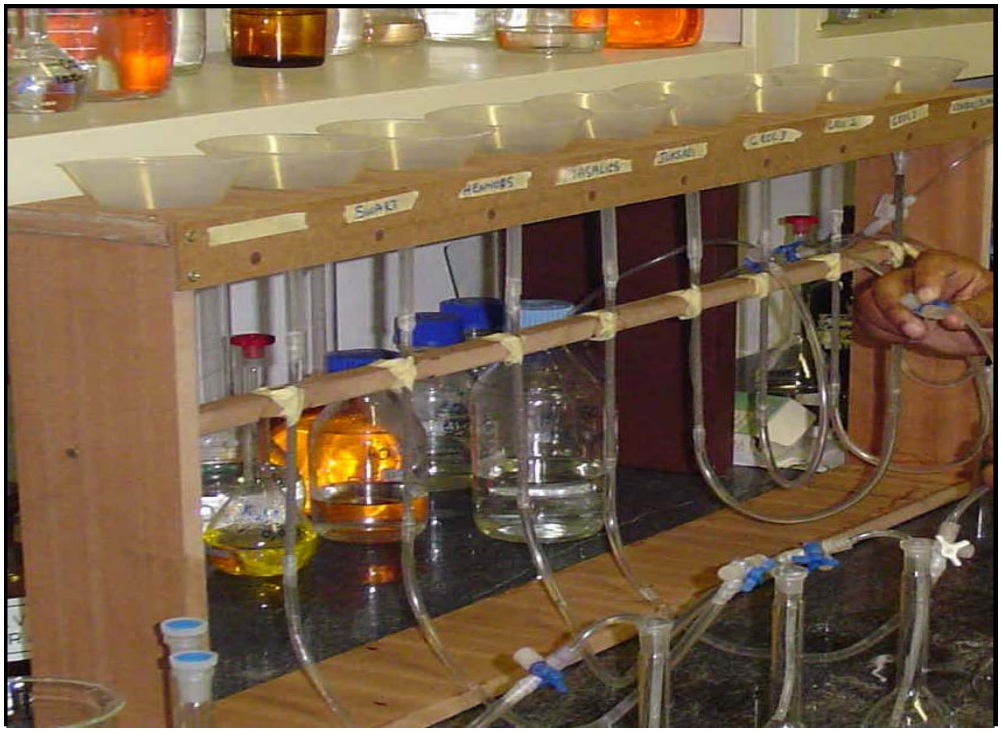


Figure 4.9: The nitrate cadmium reduction columns assembled in the laboratory by the author of this report (*Author*).

The final concentration was read directly on the spectrophotometer (wavelength 543 nm) against the calibration curve freshly prepared with each series of samples.

4.2.2 Phosphorus analysis

As mentioned above four P species (i.e. ortho-phosphorus (OP), acid hydrolysable P (AHP), Total dissolved P (TDP) and Total P (TP) were analysed. Fresh filtered (0.46 µm) samples were used to determine OP and preserved (by sulphuric acid) and filtered (0.46 µm) samples were analysed to determine other P species. Proposed pre-treatment of samples was done depending of the species to be

determined. Each sample was neutralized to pH 7 before the final determination. A schematic representation of samples processing is shown in Figure 4.10 below.

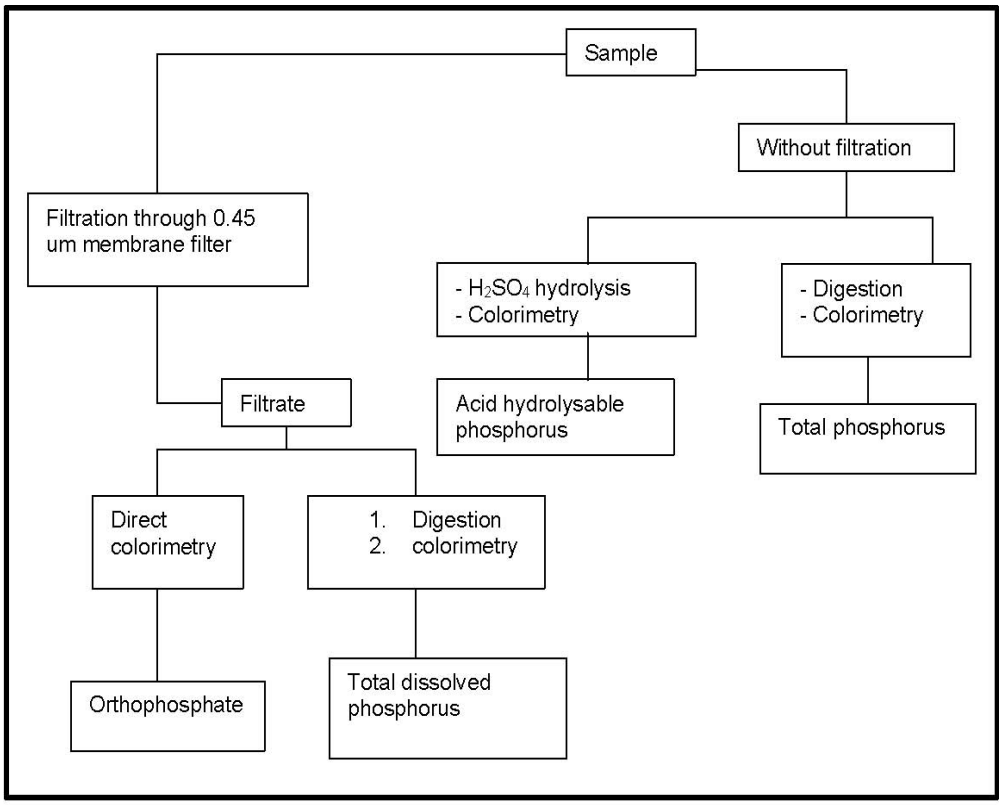


Figure 4.10: Flow chart of the procedure for phosphorous species measurements (STD Methods, 1994).

Ascorbic acid method was used in final determination of all P species. This method is based on reaction of orthophosphate with ammonium molybdate and potassium antymonyl tartrate in acidic conditions. The product is the heterpoly phosphomolybdic acid which is further reduced to the blue colour of molybdenum by ascorbic acid.

Orthophosphorus (OP)

Samples were analysed from fresh filtered (0.46 μm) non-preserved samples. Filtration was performed in all samples to remove turbidity before adding colour

development reagents. The final concentration was red directly on the spectrophotometer (wavelength 880 nm) against the calibration curve freshly prepared with each series of samples.

Acid hydrolysable phosphorus (AHP)

Preserved (with sulphuric acid) samples were filtered (0.46 μm) and reagents were added to neutralised samples for colour development as explained above in the text.

Total dissolved phosphorus (TDP)

Non-preserved samples were filtered as above and digested by ammonium persulphate in acidic conditions following the guidelines in the Standard Methods. Samples and a blank were run in each series of samples. After the digestion was completed one drop of phenolphthalein was added into each flask and was neutralized to a pink colour with sodium hydroxide.

The digested solution was transferred to 100 ml volumetric flasks and made to the mark. After the addition of colour development reagents and time required for colour development the final concentration was red directly on the spectrophotometer (wavelength 880 nm) against the calibration curve freshly prepared with each series of samples.

Total phosphorus (TP)

The same procedure was done for this species but non-filtered homogenized samples were digested. The digestion was performed by ammonium persulphate in acidic conditions following the guidelines in the Standard Methods. Samples and a Blank were run in each series of samples. After the digestion was completed one drop of phenolphthalein was added into each flask and was neutralized to a

pink colour with sodium hydroxide. The digested solution was than filtered and transferred to 100 ml volumetric flasks and made to the mark.

After the addition of colour development reagents and time required for colour development the final concentration was red directly on the spectrophotometer (wavelength 880 nm) against the calibration curve freshly prepared with each series of samples.

5 RESULTS AND DISCUSSION

As the main objective of the study was to analyse the situation in the Catchment, the preferred logical presentation of the results was firstly in the form of concentration (mg/L) versus time (sampling dates) graphs, followed by mass flow (g/day) versus time (sampling day) graphs specifically for P and N compounds. Nutrient loading was then converted to tonnes/year (t/y) in order to apply Equation 2.6 in Chapter 2.

Considering the number of sampling stations it was decided that the results should be in the form of:

- Bar, line and pie graphs for each sampling station;
- Tables showing the results of each station (refer to Appendix B); and
- Tables showing mass flow balance into the rivers and dam (refer to Appendix B).

This was done to observe trends of the parameters. Some tables were derived on data obtained from the Department of Water Affairs and Forestry.

5.1 Phosphorus in Selected Sampling Points

As stated, P in water occurs in different species, it was therefore decided that all of these be analysed separately using the prescribed methods. In order to easily compare their concentrations, all were combined in one line graph as shown in Figure 5.1. Mass loading in grams/day is also presented graphically for Jukskei (JUKS), Hennops (HNPS), Upper Crocodile Rivers (CROC 1) as well as the Main Crocodile River (CROC 2) entering the Dam. The Swartspruit (SWRT) and Magalies (MAG) were not presented as their daily flow rates could not be obtained from DWAF. The annual mass loading (t/y) of all the species was estimated and presented in the form of a bar graph. The relevant information about the dam (Table 3.1) was used to calculate P load into the Dam required to maintain desired mesotrophic conditions.

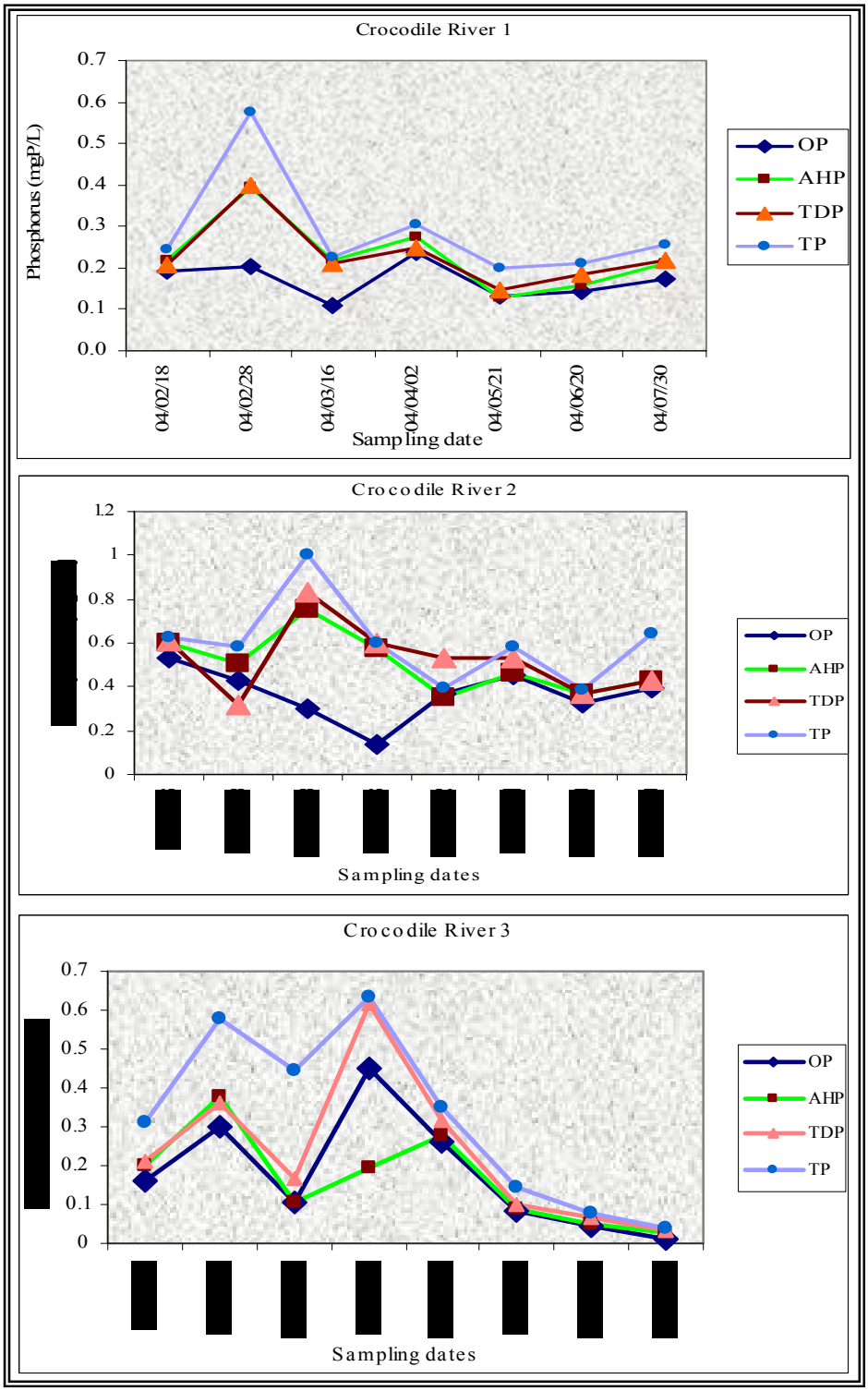


Figure 5.1(a): The concentrations of P species at CROC 1, CROC 2 and CROC 3.

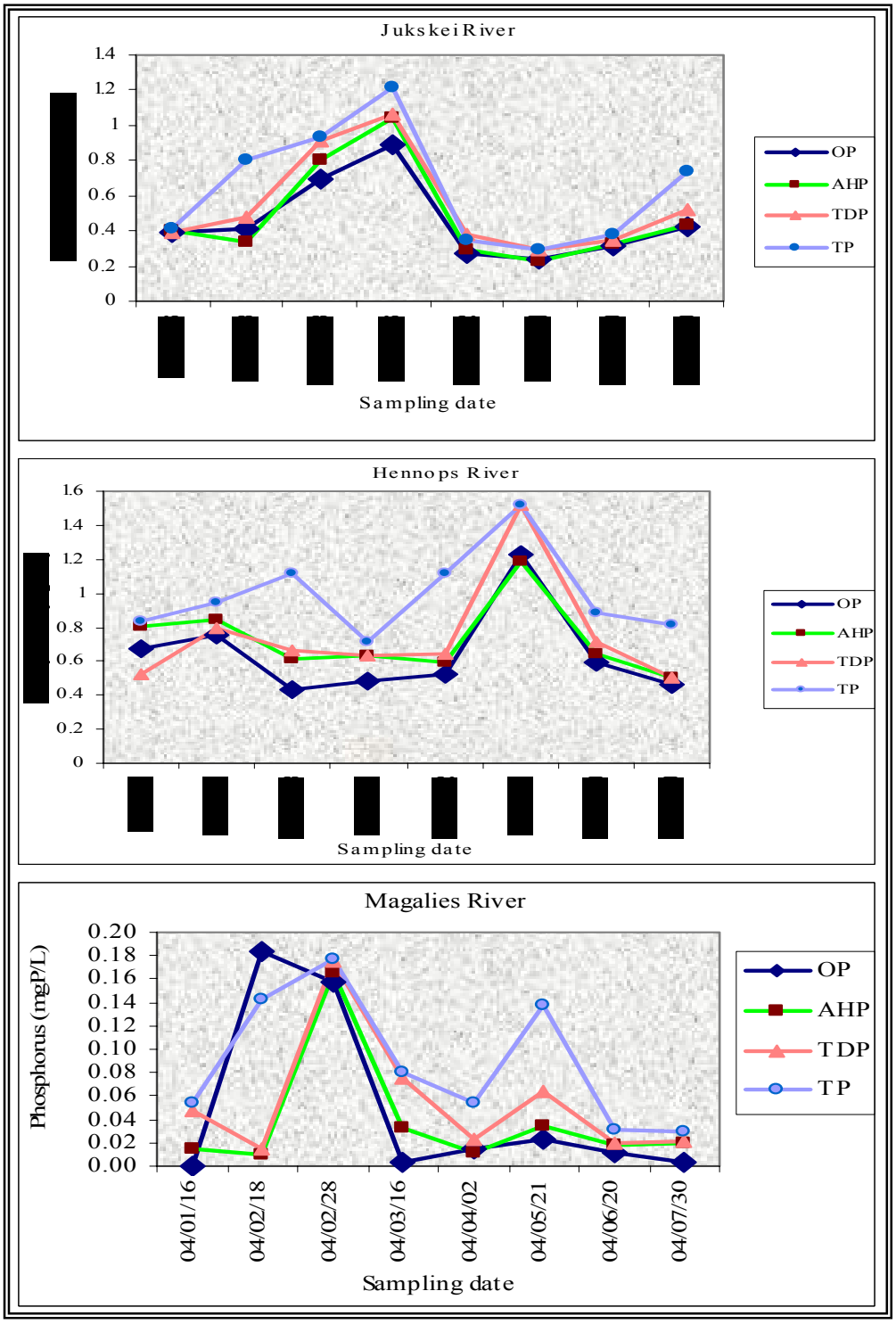


Figure 5.1(b): The concentrations of P species at JUKS, HNPS and MAG.

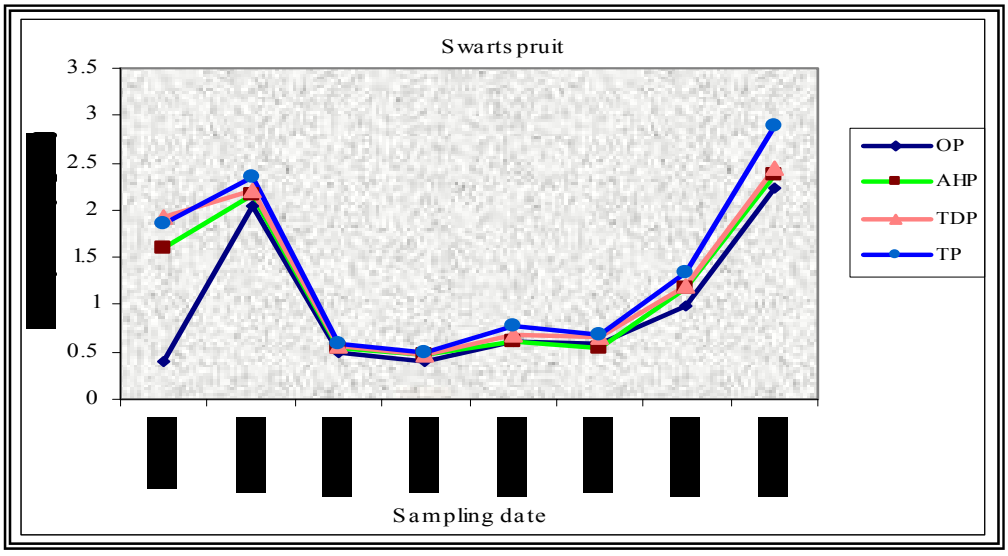


Figure 5.1(c): The concentrations of P species at SWRT.

As shown in Figure 5.1(a) to (c) the sampling points which did not exceed 1mg/l TP during both the wet and dry seasons were MAG, CROC 1 and Crocodile River at the outflow (CROC 3). In case of CROC 3 status it was anticipated that the bulk of P was utilised by algae or was settled with suspended solids at the bottom of the dam.

Very low values of P were measured at MAG station as compared to others. High TP values (i.e. 0.18mg/l) in this river were observed during the wet seasons. This could be from non point sources like agricultural activities or runoff from burnt natural pastures (Lamontagne *et al.*, 2000).

In the CROC 1 station, low P concentration values were measured as compared with the other tributaries of the Crocodile River (i.e. JUKS and HNPS). The CROC 1 sampling point was selected several kilometres away from point sources identified in this subcatchment. The possibility is therefore that by the time the water reached this sampling point, P had precipitated, settled with suspended solids or utilised by algae and other aquatic plants.

In JUKS, HNPS and the CROC 2, TP concentration ranged from 0.3 – 1.25 mgP/L, 0.7 – 1.55mgp/L and 0.35 -1mgP/L respectively. The high values at CROC 2 were the influence of Jukskei and Hennops Rivers not the Upper Crocodile River.

The SWRT had highest P values as compared to all other stations. Even though the observed P values were high, the river flow rates at this point were small and as a result of that, the Swartspruit P loading into the Dam has a negligible influence on the current nutrient status. Noteworthy were the P species graphs that showed highest values during the wet season months and July. These high values corresponded with high turbidity values that were observed on the same water samples. It is anticipated that the high P species values observed were a combination of P in aqueous and solid phases (i.e. P adsorbed to the soil particles surfaces). When comparing the P results observed from all the stations, the JUKS had the highest. It is believed to be the main contributor of the P loading in the HBS Dam Catchment. The Jukskei and Hennops River contributed the bulk of P into the Crocodile River and into the HBS Dam.

The Jukskei River catchment is highly urbanised and release of P (as well as other pollutants) is high and are not easy to control. The Johannesburg Northern Water Works is the main contributor in P load in spite of the fact that it does not violate P standard of 1mg/L. The high P concentration values at Jukskei River were expected as this has been recorded over the years.

As it has been stated, in some of the investigations undertaken in the Jukskei subcatchment, the problem of informal settlements in Alexandra and Diepsloot Townships still exists. Grey water with high concentrations of P from these informal settlements still pollutes the Jukskei River. Besides presence of these townships, there are eight golf courses which could also contribute a certain portion of P in the rivers especially during wet seasons.

Contrary to the high values of P upstream of the dam, the outflow of the HBS Dam had lower P values during both the dry and wet season. Although this was a case, when water was released from the dam due to flooding caused by overflowing Catchment Rivers, P concentration on this point, sometimes matched the upstream values. This indicated that during flood days a certain part of external P was mixed with internal P and sluiced off the Dam. During the dry season less P concentration values were measured at CROC 3. It is likely that P had been utilised by the phytoplankton and some had settled in the Dam during this time.

It is to be emphasised that P load of the Hennops River was high. This river also has a history of exceedingly high concentration of P which emanate from various activities in this subcatchment. It has many impoundments like the Centurion Lake and the Rietvlei Dam that retain a part of P, but downstream of these are several informal settlements including the Olivenhoutbosch which discharges grey water into this river. Sewage water works in this catchment currently do not violate the 1mg/l phosphorus rule. The very high P concentrations observed in wet season indicate large contribution of non-point sources in the P load from Hennops River.

The high concentrations of P observed in this river could be from the informal settlements, the runoff from the densely populated residential areas and a small quantity from the natural environment.

5.2 Nitrogenous Compounds and Associated Parameters

It was proposed that a different approach be applied on Nitrogen (N) species since they undergo transformations. In order to observe the relationship between these species it was suggested that all be presented separately from P. The same procedure as applied with P for mass flow estimate was applied to the N compounds. The tonnage was only applied to total nitrogen (TN) which was

obtained by adding the concentrations of ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) (OECD, 1982).

5.2.1 Ammonia

The concentrations of NH_3 on both wet and dry seasons in all the rivers exceeded the recommended in-stream limit of 0.4 mg/l for aquatic life support. During May to July the concentrations were exceedingly high at Jukskei, Hennops, Crocodile and Swartspruit. The low concentrations encountered in other periods could be the result of oxidation of NO_2^- and NO_3^- (Tappin, 1999).

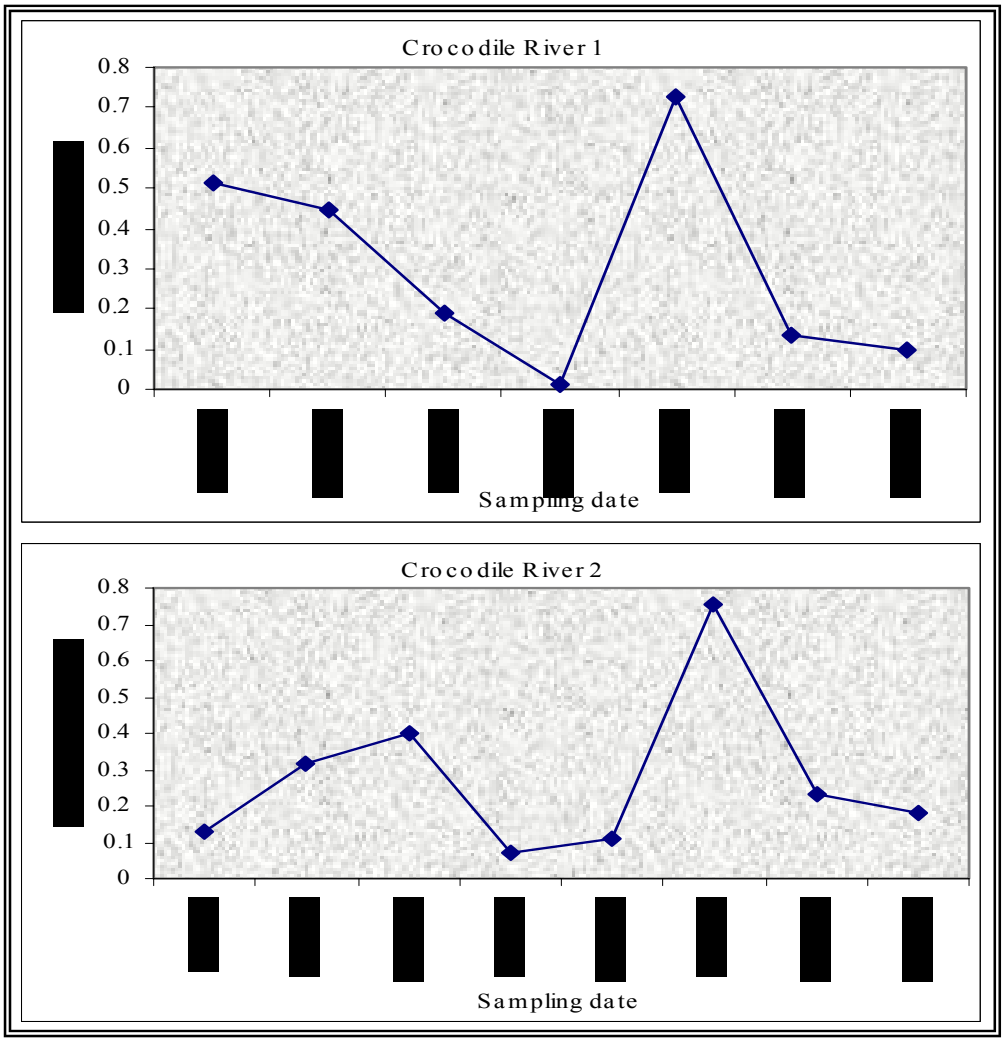


Figure 5.2 (a): Ammonia concentrations observed at CROC 1 and CROC 2.

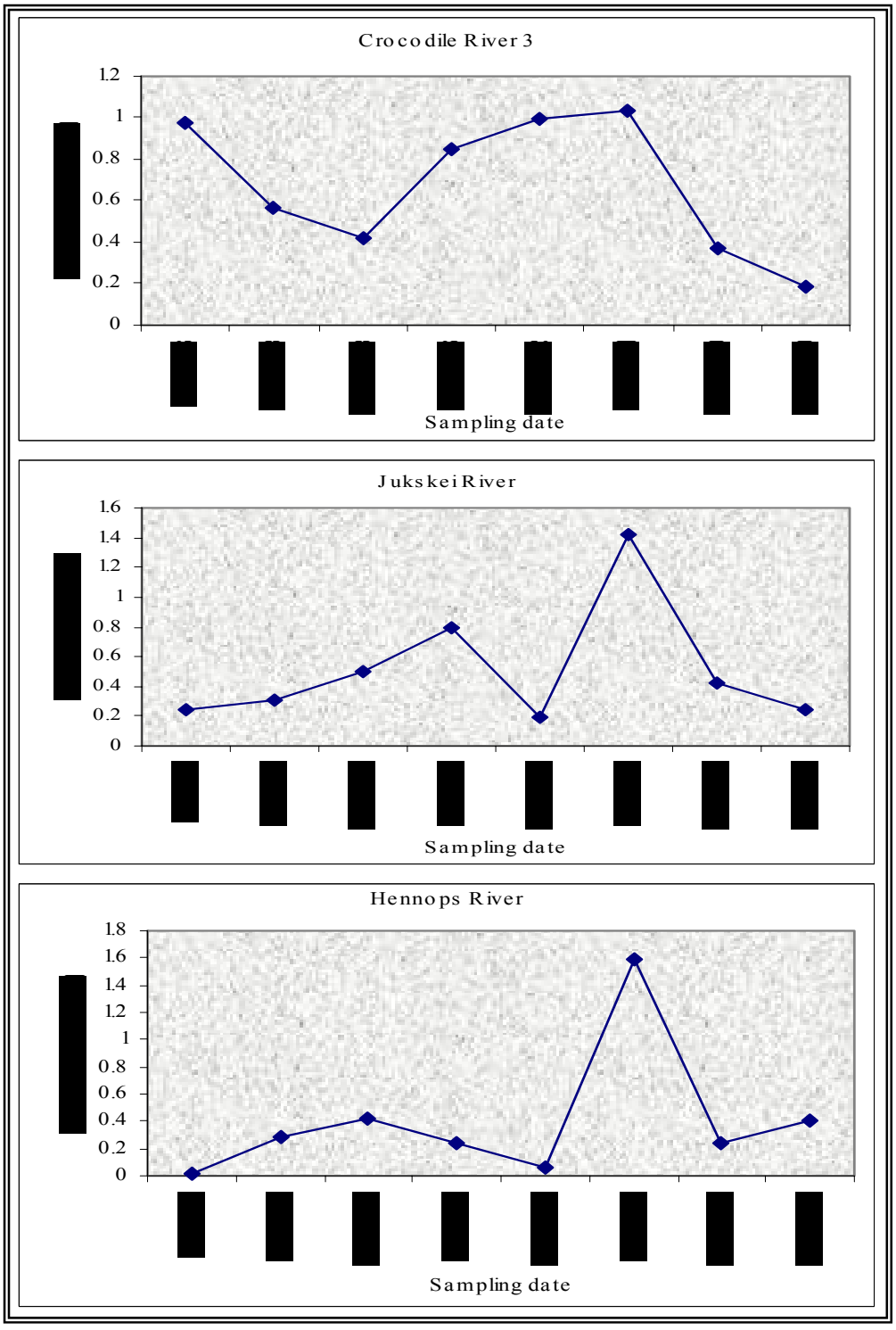


Figure 5.2(b): Ammonia concentrations observed at CROC 3, JUKS and HNPS.

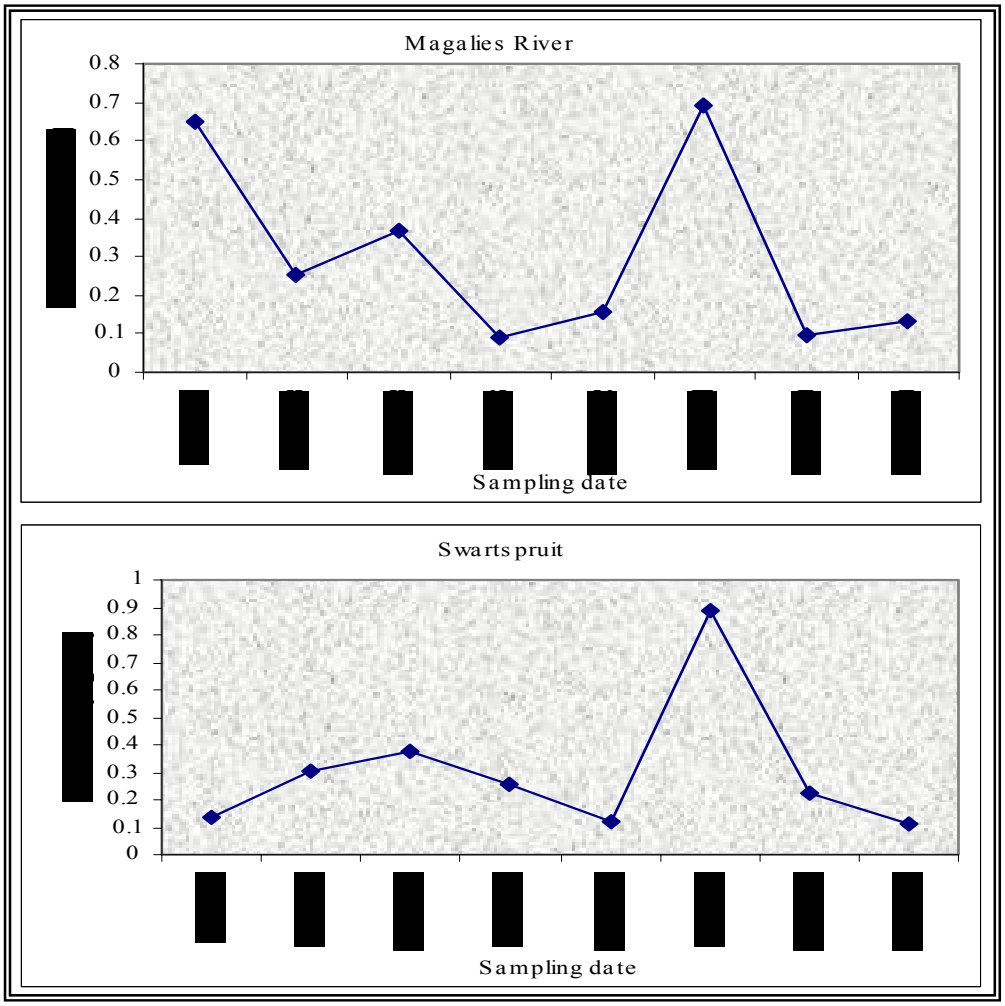


Figure 5.2(c): Ammonia concentrations observed at MAG and SWRT.

It is anticipated that anaerobic condition could occur during dry season in the CROC 2 (Kalhuiwel) as the consequences of slow flow and less aeration so that both aerobes and anaerobes play their role in N processing. In anoxic conditions, micro-organisms could have reduced NO_3^- to nitrogen gas and by the time water reaches the dam there is less total nitrates.

5.2.2 Nitrites

Nitrite is a product of N transformation. It is intermediate of the two compounds namely, NH_3 and nitrate. Concentrations as low as 0.5mg/l could cause fatal

consequences on fishes in water. Figure 5.6 shows the trends on NO_2^- in all the rivers of the catchment during the sampling period. During the wet season the concentration was lower than during dry season. It is anticipated that this could be as a result of the intensive oxidation reduction process of N compounds during the periods of high temperature.

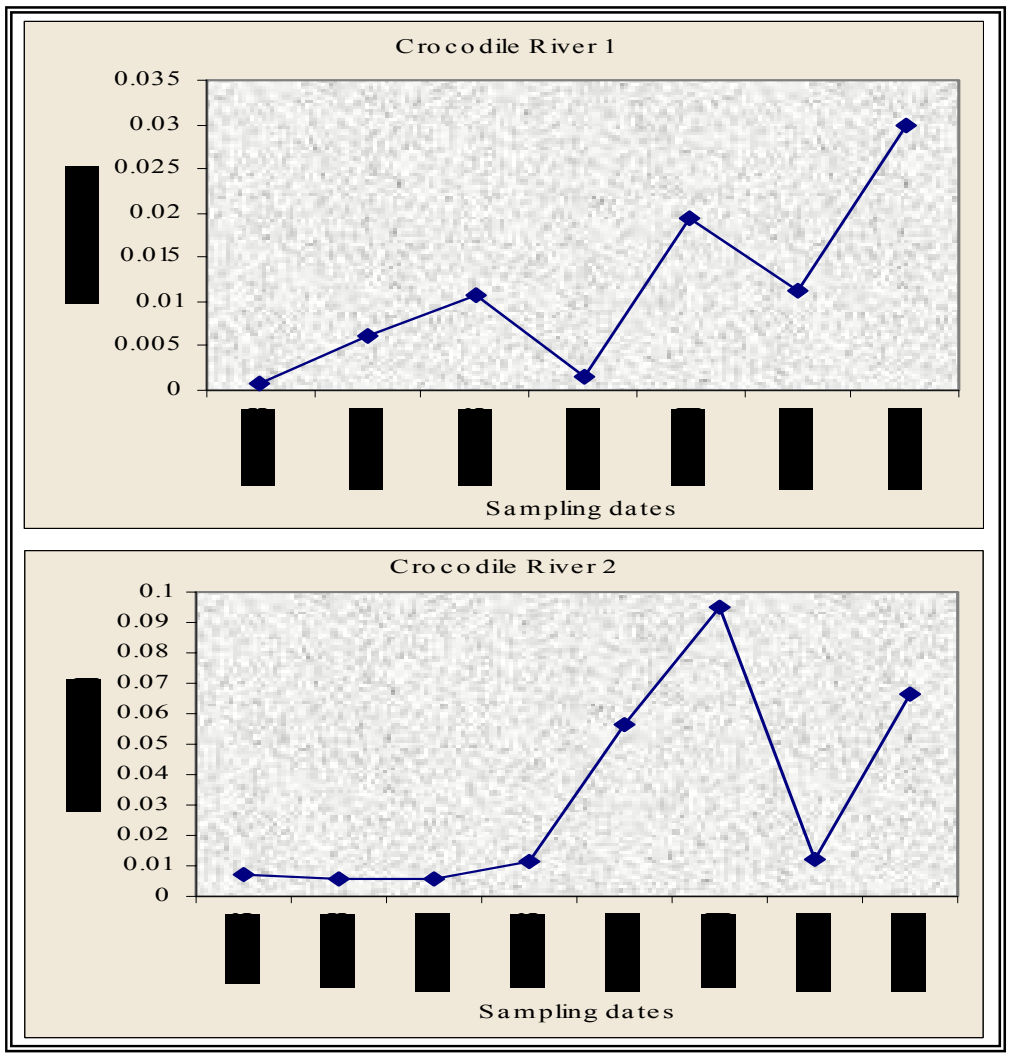


Figure 5.3 (a): The nitrite concentrations measured at CROC 1 and CROC 2.

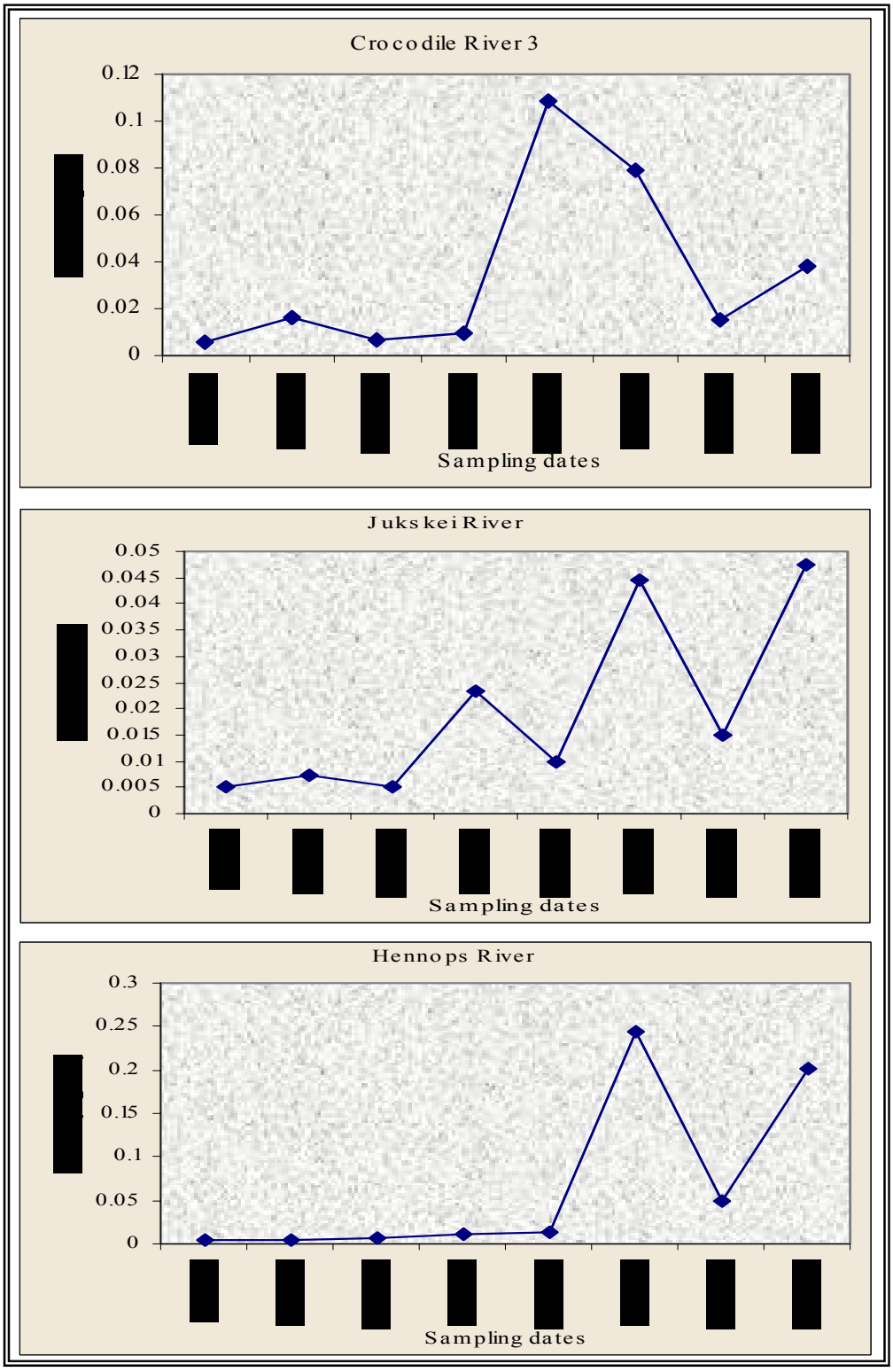


Figure 5.3 (b): The nitrite concentrations measured at CROC 3, JUKS and HNPS

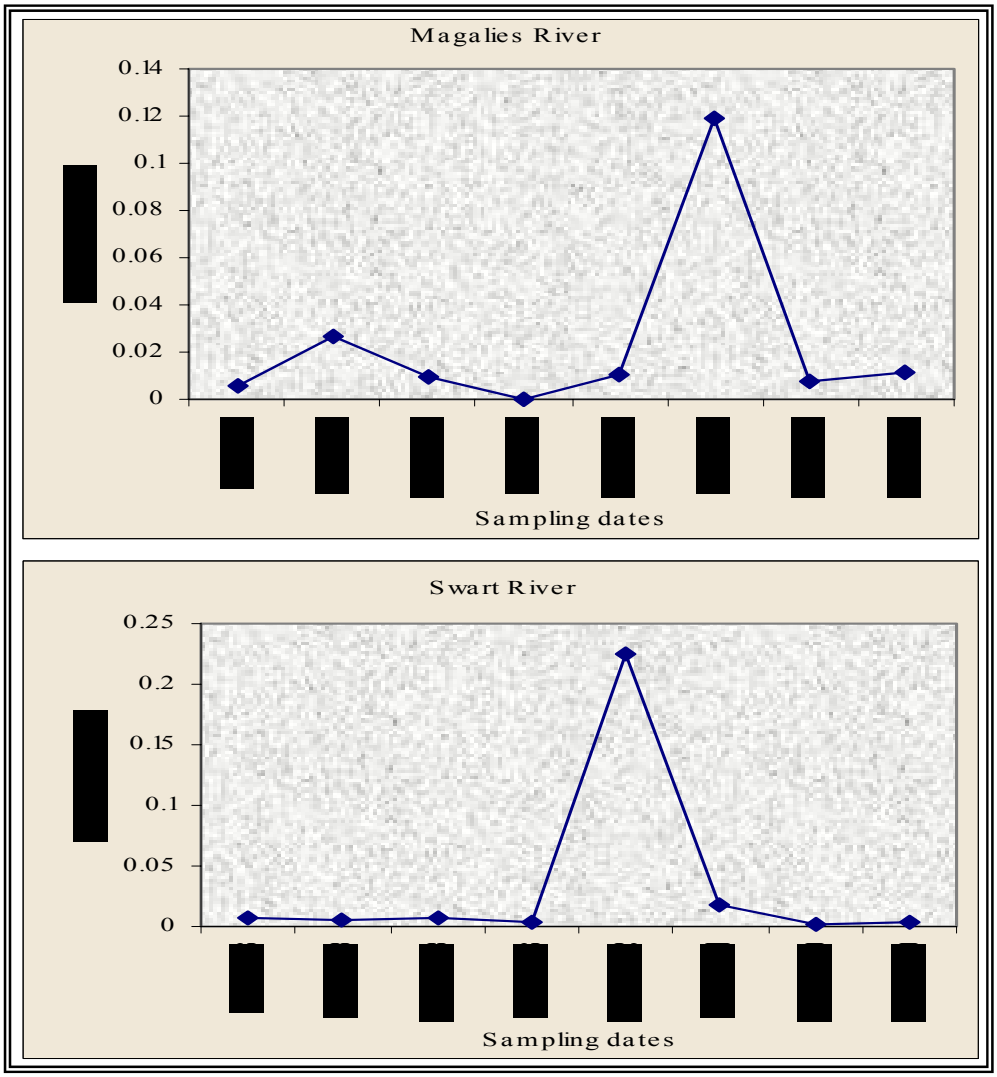


Figure 5.3 (c): The nitrite concentrations measured at MAG and SWRT.

5.2.3 Nitrates

From Figure 5.4 it is clear that the rate of nitrification was high at CROC 2 since the values were higher than at other stations. The explanation for this can be two fold, the first being the contribution from the already processed NO_3^- from the tributaries, secondly it might be that the process of nitrification was taking place upstream of this sampling point.

Although it is recorded that the main rivers from which the NO_3^- emanate are the Jukskei and the Hennops one could not solely rely on that kind of information as there are developments along the banks of the Crocodile River, which use septic tank systems as method of disposing sewage. The overflow of such operations during floods could have been discharged to this river thus increasing the concentration of nitrates in them. There are quite a number of fertilizers processing activities as previously stated along the banks of this river, and these could contribute a large percentage of NO_3^- observed.

As nitrification in the river is also associated with decomposition of organic matter, this process also occurred in these rivers. This is supported by the total organic carbon, the turbidity and suspended solids which were measured during the study. The process anticipated to have occurred is as shown in Equation 2.1 in Chapter 2.

There is a trend of decreasing NO_3^- during dry season and the possible reasons for that are:

- Less runoff from agricultural land and urban areas;
- High temperatures and longer travel time i.e. time for reaction to occur;
- Slow flow and slow aeration causing anoxic conditions; and
- Consequently reduction of NO_3^-.

From the data presented it is clear that the greatest load of N into the dam is discharged during wet season. It means that control of N release from the catchment should be directed to storm water and agricultural use.

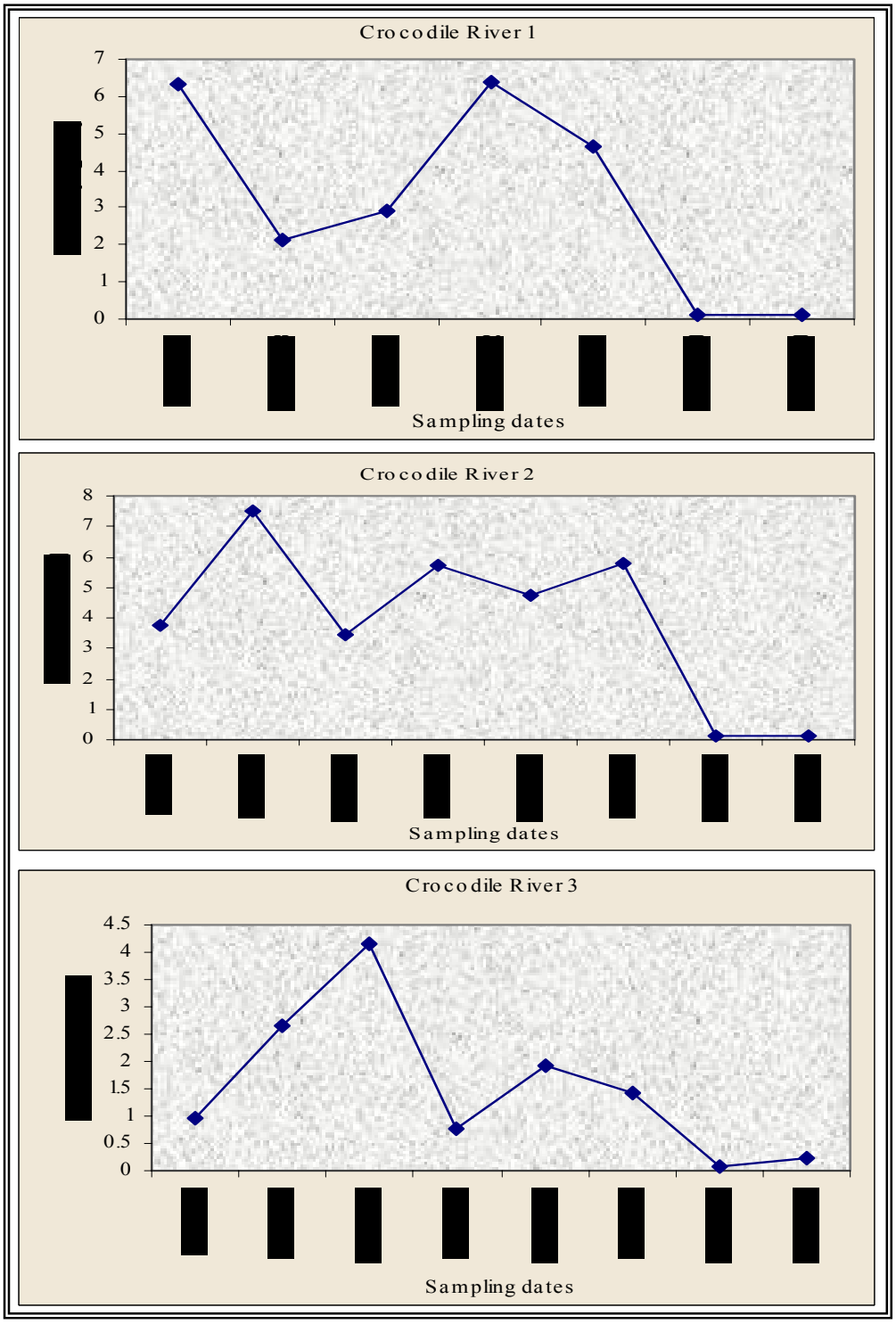


Figure 5.4(a): The concentrations of nitrate measured CROC 1, CROC 2 and CROC 3.

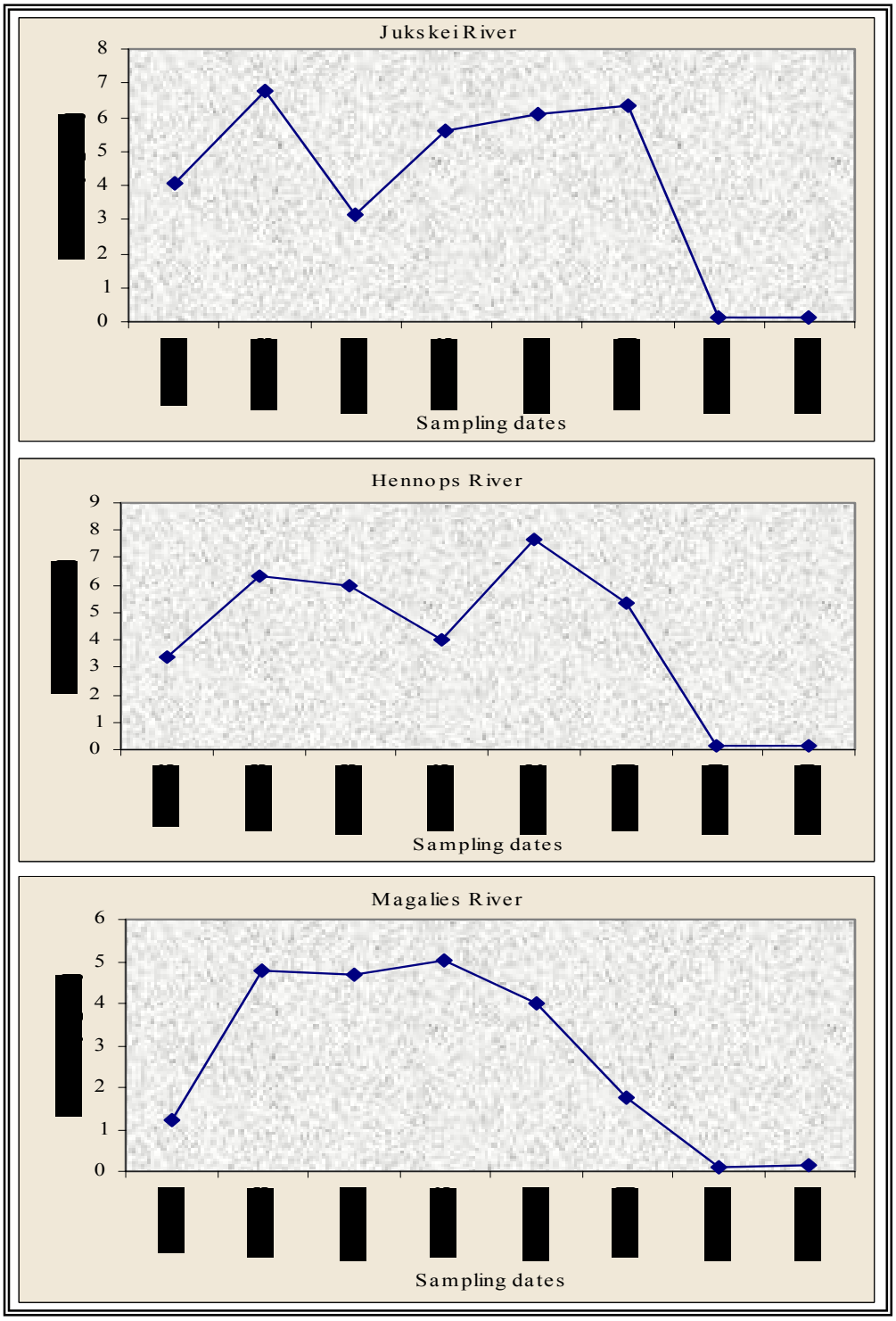


Figure 5.4 (b): The concentration of nitrate measured at JUKS, HNPS and MAG.

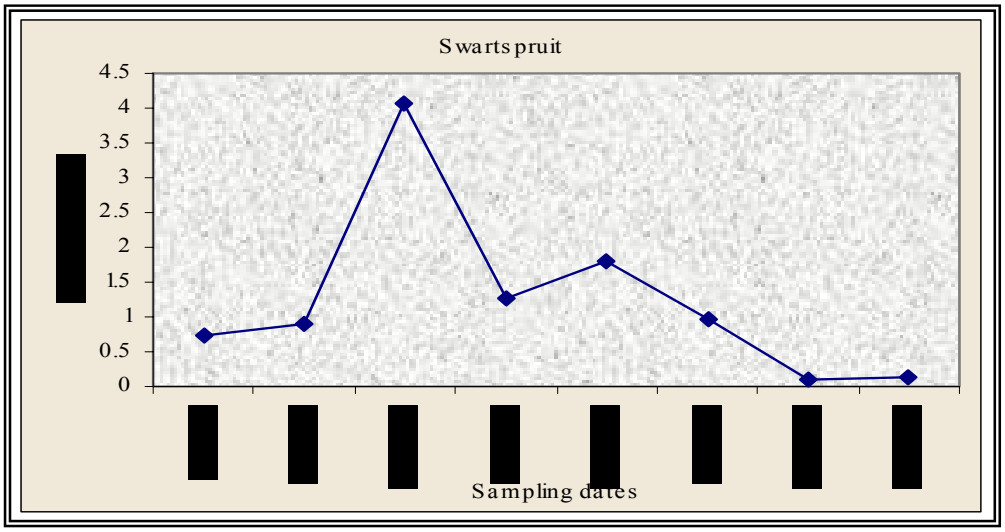


Figure 5.4 (c): The concentration of nitrate measured at SWRT.

3.2.4 Total nitrogen

The Total Nitrogen (TN) concentration (i.e. sum of all N species) is calculated and graphically presented in Figure 5.5 below.

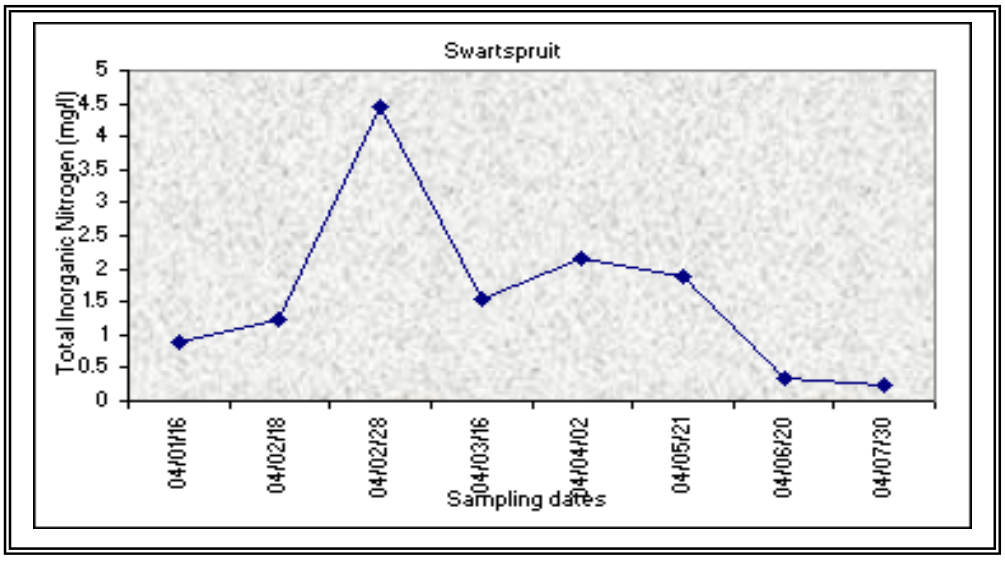


Figure 5.5 (a): The total inorganic nitrogen measured at SWRT.

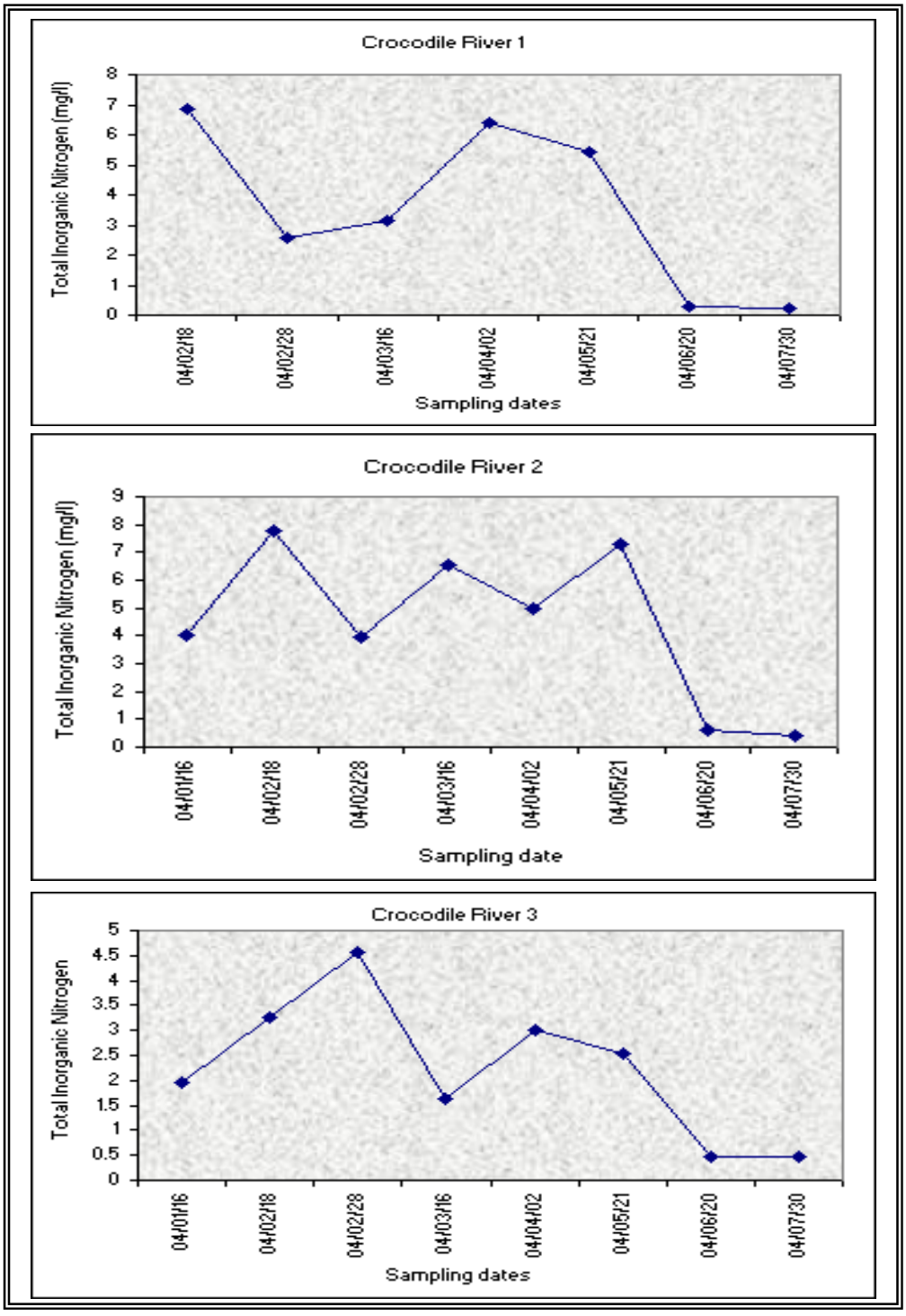


Figure 5.5 (b): The total inorganic nitrogen measured at CROC 1, CROC 2 and CROC 3.

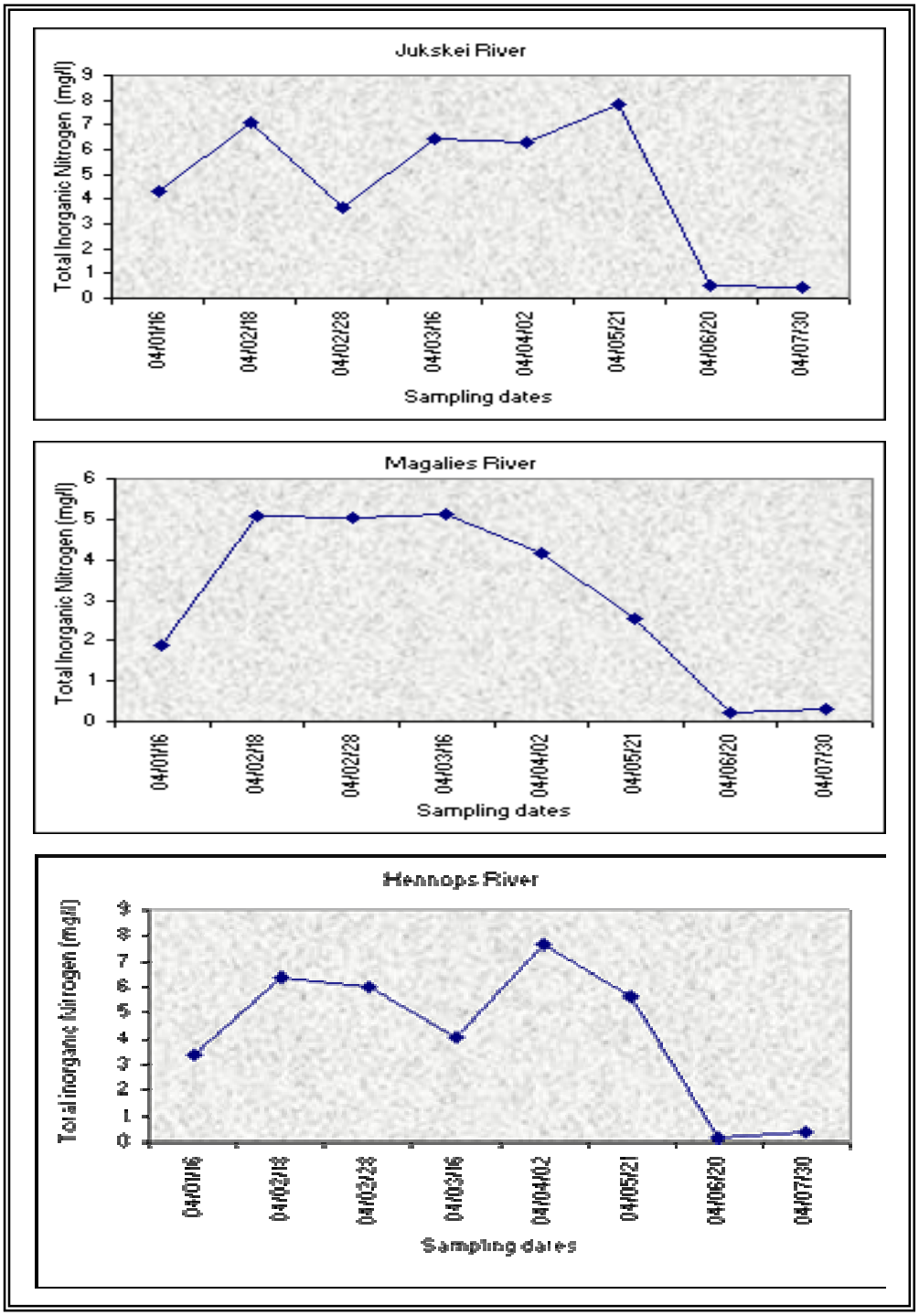


Figure 5.5 (c): The total inorganic nitrogen measured at JUKS, MAG and HNPS.

When comparing the data from Figures 5.2, 5.3 and 5.4 with data presented in Figure 5.5 it could be concluded that anoxic processes prevail in all the rivers during dry and wet seasons.

5.3 Observed Concentrations on other Parameters

5.3.1 Dissolved oxygen

From Appendix B and Ciii, the Hennops River showed the highest dissolved oxygen values during the winter season followed by the Jukskei, the Swartspruit, the Crocodile River and the Magalies River with the lowest values. The Swartspruit has a combination of low dissolved oxygen and low stream flow. The low dissolved oxygen is associated with effluent which is discharged into this stream from the Rietfontein Sewage Treatment Works.

The Crocodile River after the dam wall also had high values of dissolved oxygen and this could be as a result of aeration from falls after the outflow and photosynthesis which is taking place in the dam. It is accepted that a dam discharging water with low dissolved oxygen from the hypolimion has effects downstream but with this dam that was not the case. The falls located upstream of the sampling point contributed to the immediate reintroduction of oxygen in water.

5.3.2 Chloride

According to the Quality of Domestic Water Supplies – Assessment Guide report (DWAF, 1998) adverse health effects from chloride (Cl^-) only start to occur at > 600 mg/L. The results obtained clearly indicate that the Cl^- content in the catchment is generally bellow 100 mg/L irrespective of dry and wet season's conditions.

Although the Cl^- concentrations in the catchment at other stations were significantly lower than those mentioned above, the relatively high chloride concentration at CROC 2 in relation to the Cl^- concentrations at CROC 1 could be the combined effects of the concentration from the Jukskei and the Hennops Rivers.

The Cl^- concentration graph follow the same pattern as that of electrical conductivity with slight decrease during wet season i.e. from January to April. This indicates that one of the major contributors to the conductivity values in the catchment is Cl^-. In other words Cl^- concentration changes have a major influence on the conductivity readings at any of the selected stations.

5.3.3 Conductivity

Besides the normal seasonal and monthly climatic fluctuations in the catchment region, no noteworthy changes on conductivity took place during both wet and dry seasons (refer to Appendix B and C (vi)). There was however a slight decrease in conductivity at most points during February. This decrease could possibly be related to rainfall that occurred in the catchment. The major observation on conductivity at the sampling stations was the significant difference between the SWRT and other stations. This difference could be due to the location of the Swartspruit catchment on which ongoing construction activities, farming, and a historically nonconforming sewage treatment plant are found. It is therefore not uncommon to have elevated conductivity values in the catchment. Other water quality parameters like sodium, calcium, magnesium, biochemical oxygen demand, total dissolved solids total hardness and turbidity were analysed in this study (refer to Appendices B and C for graphical presentation of their results).

5.4 Phosphorus Loading from the Catchment Rivers to the Dam

Several research studies conducted in the study area have concluded that the major part of nutrients (i.e. > 95%) into the dam is discharged by the Crocodile River into which the Jukskei and Hennops Rivers discharge their highly polluted waters. Because of the stated conclusions, it was worthwhile to monitor these subcatchments to determine the main sources of nutrients and their locations. This decision was also influenced by the high flow rates and elevated nutrient concentrations recorded in their sampling stations as compared with other rivers in the study.

As stated previously, the flow rates for all the station were obtained from DWAF as it was difficult to measure them during sampling. Although the recording times of DWAF flow rate measurements did not correspond with this analysis time of sampling, it was assumed that the flows would be constant for each day as it is normally the case with big rivers. Figure 5.6 (a) to (c) below and overleaf show graphical representation of the phosphorus species mass loading at CROC 1 sampling station.

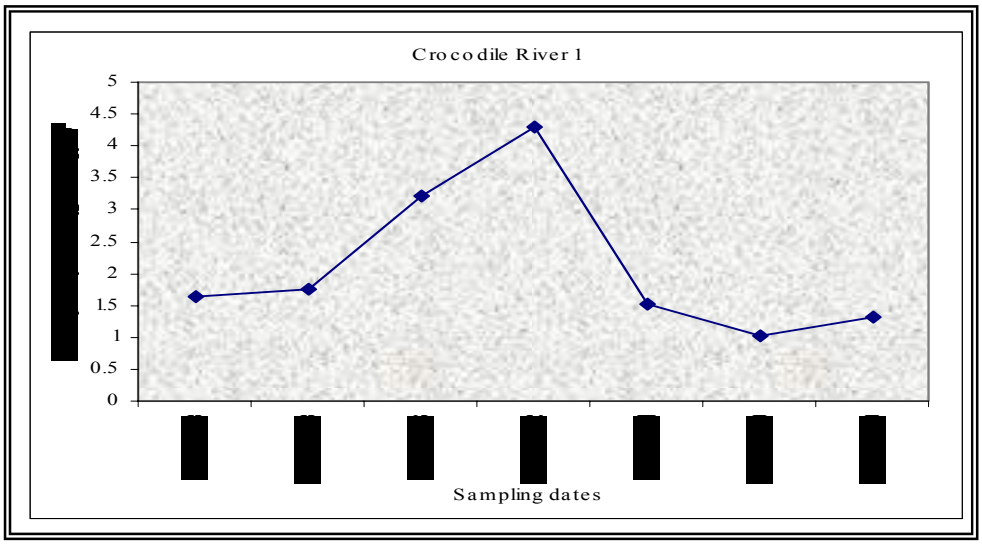


Figure 5.6 (a): OP mass loading from the CROC 1.

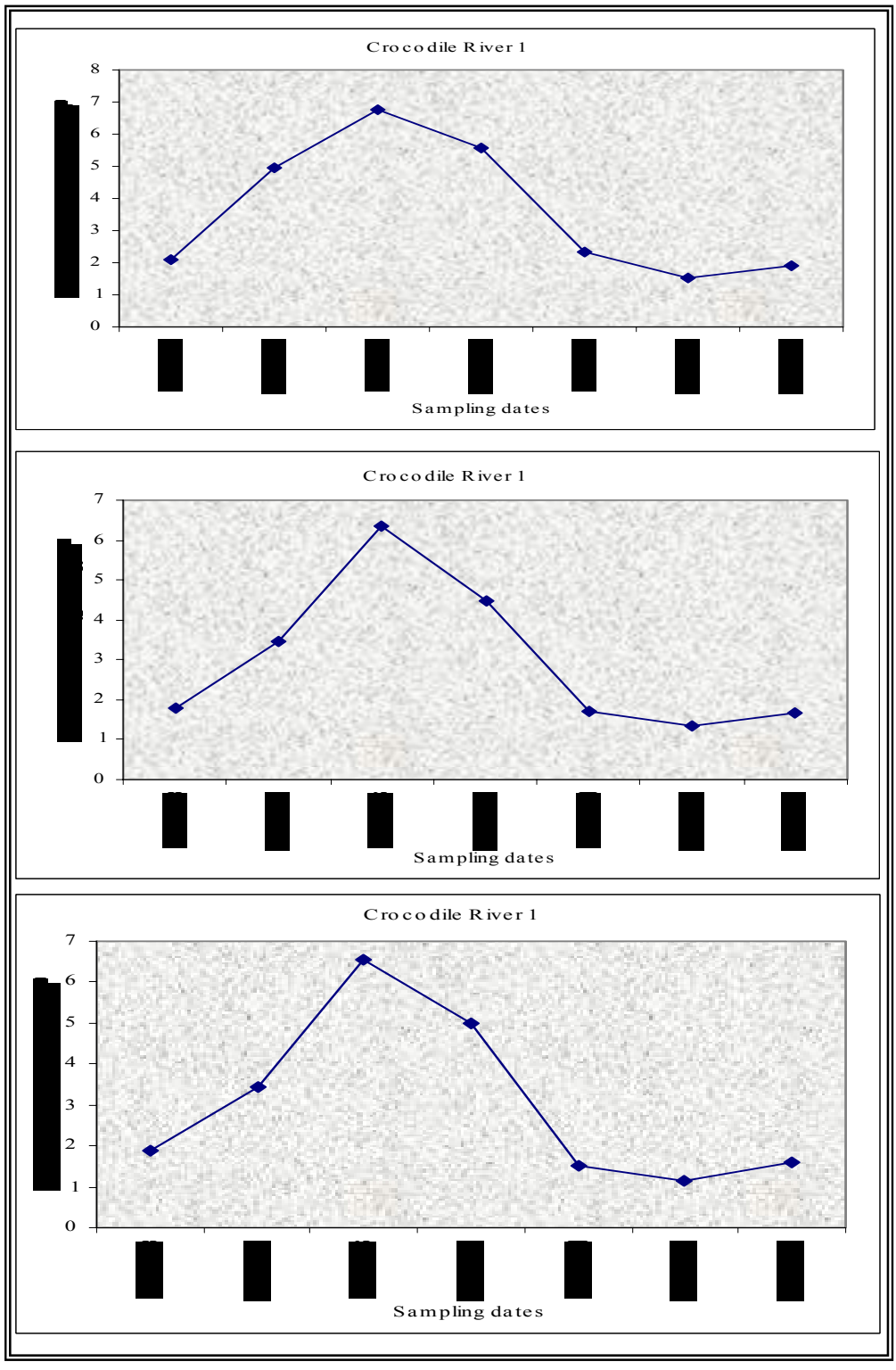


Figure 5.6 (b): The TP, TDP and AHP mass loading from the CROC 1.

Figure 5.7 (a) to (d) overleaf shows a graphical representation of the phosphorus species mass loading at HNPS and JUKS sampling stations.

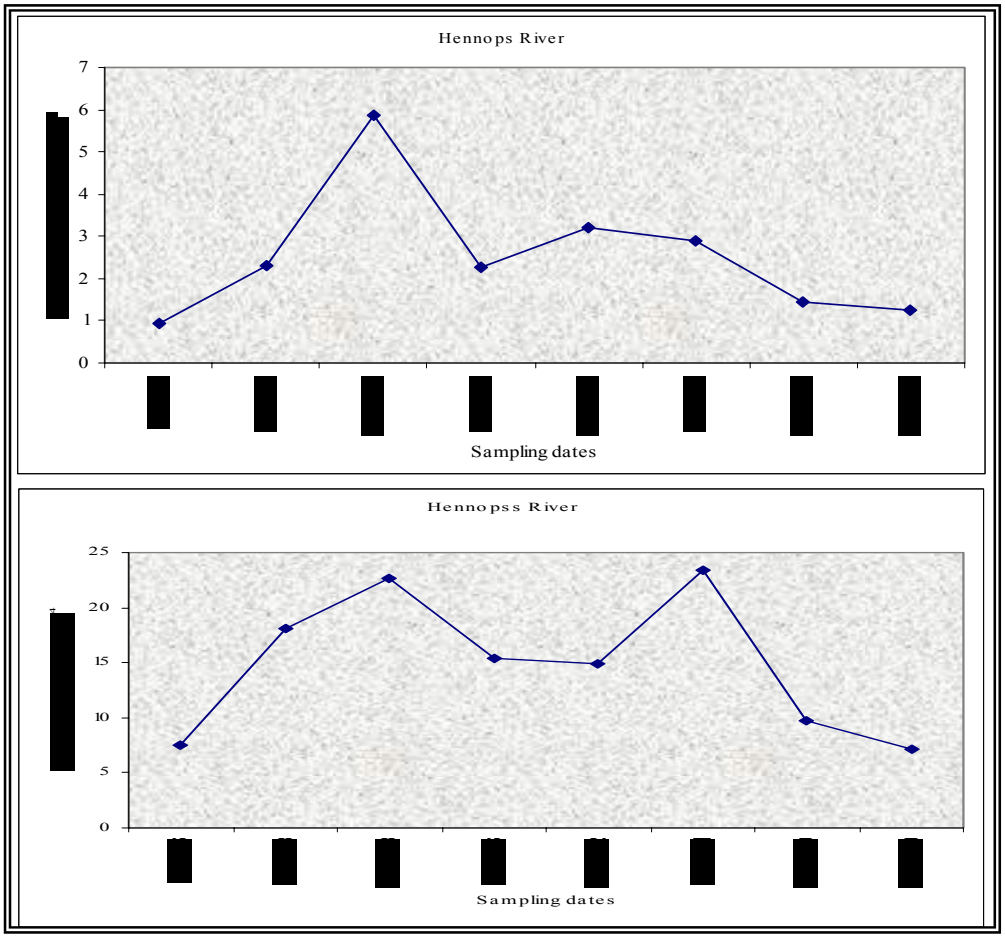


Figure 5.7(a): The TP and OP mass loading at HNPS.

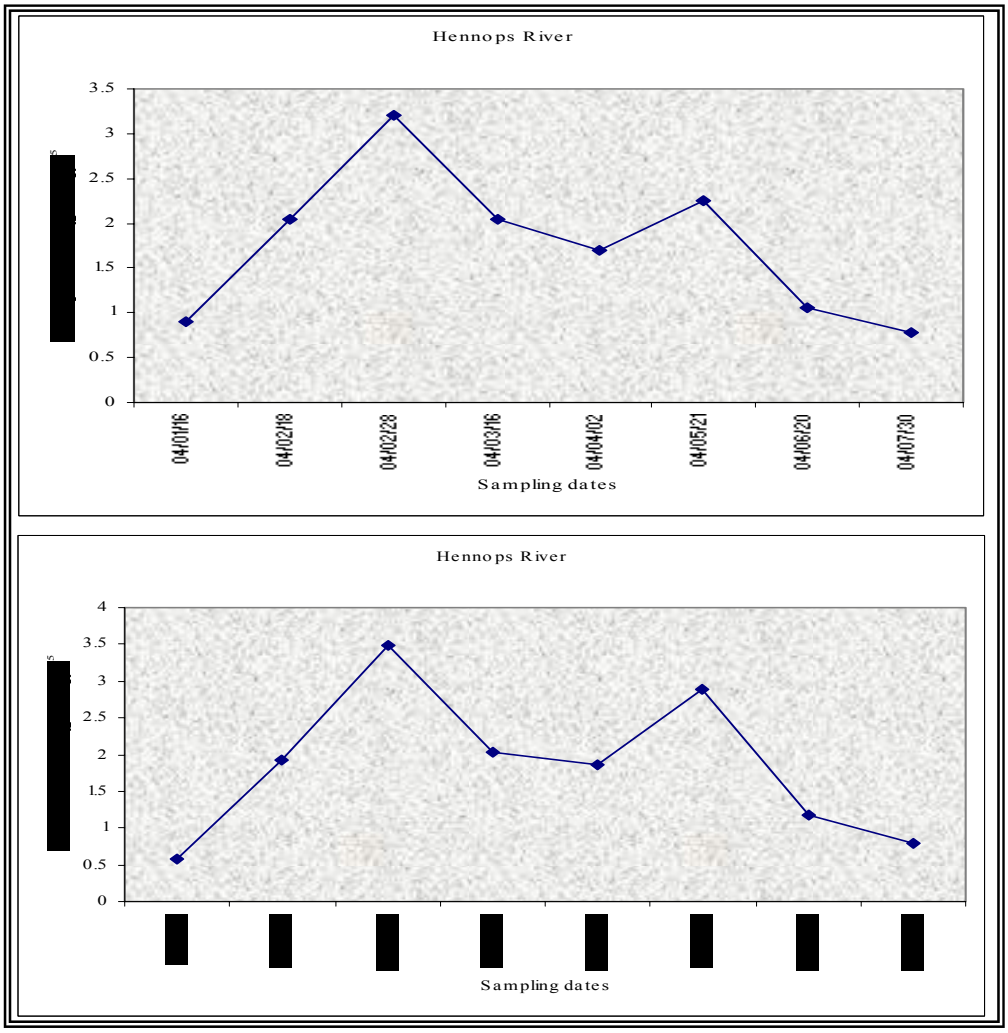


Figure 5.7(b): The AHP and TDP mass loading at HNPS.

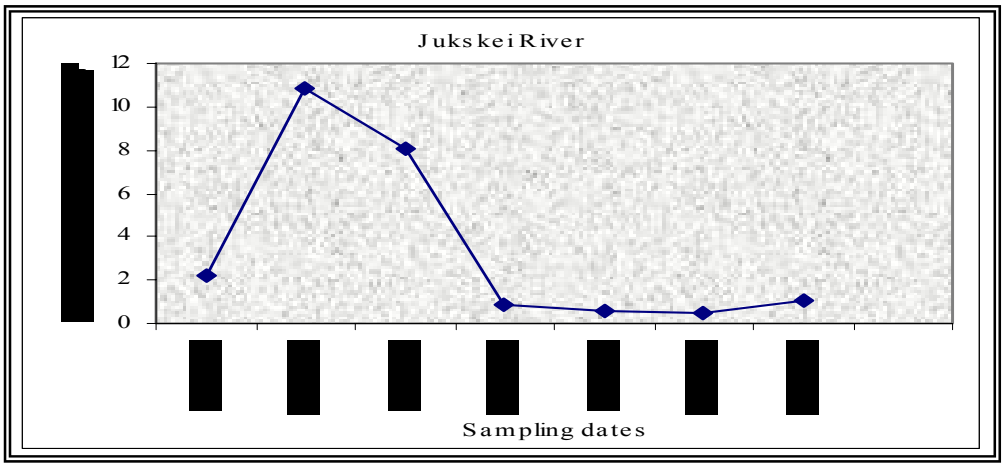


Figure 5.7(c): TP mass loading at JUKS.

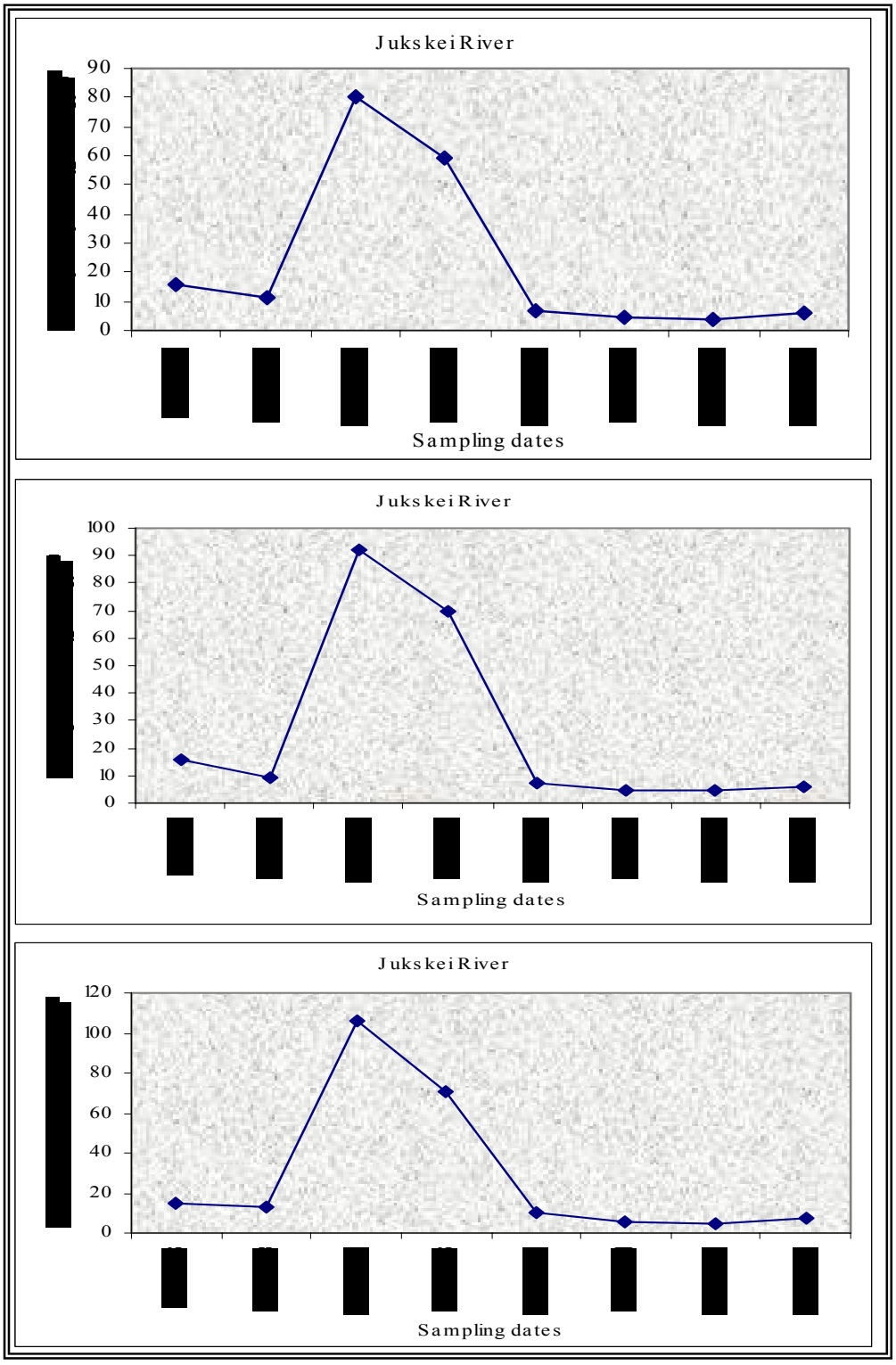


Figure 5.7(d): The TDP, OP and AHP mass loading at JUKS

The P species tonnage in all the sampling stations is presented in Figure 5.12 and is according to the order of nutrient contribution to the Main Crocodile River. TP species in all the stations dominated with the highest grams per day loaded into the CROC 2 on both seasons.

The turbidity and the suspended solids as in Appendices C (iv) and C (v) during the wet season indicate that a reasonable amount of the nutrients could have adsorbed on the surfaces of the fine soil particles (O'melia, 1985). In Appendices C (iv) and C (v) these parameters are shown graphically. Baccini, (1985) had shown that some other inorganic elements (e.g. Fe^{++}) that are components of the suspended solids have high affinity for P adsorption in water.

At these stations the pH ranged between 8.1 -8.6 which lie on the alkaline region in the pH scale. That indicated that P adsorbed on the surface of the particles could not be released to aqueous form as alkaline or neutral conditions can not accelerate its release. Because of such influences low P concentration and mass loading during analysis could be expected. In Figure 5.8(a) and (b) together with Figure 5.9 the same trend of high mass loading in summer and low mass loading in winter is observed in CROC 2.

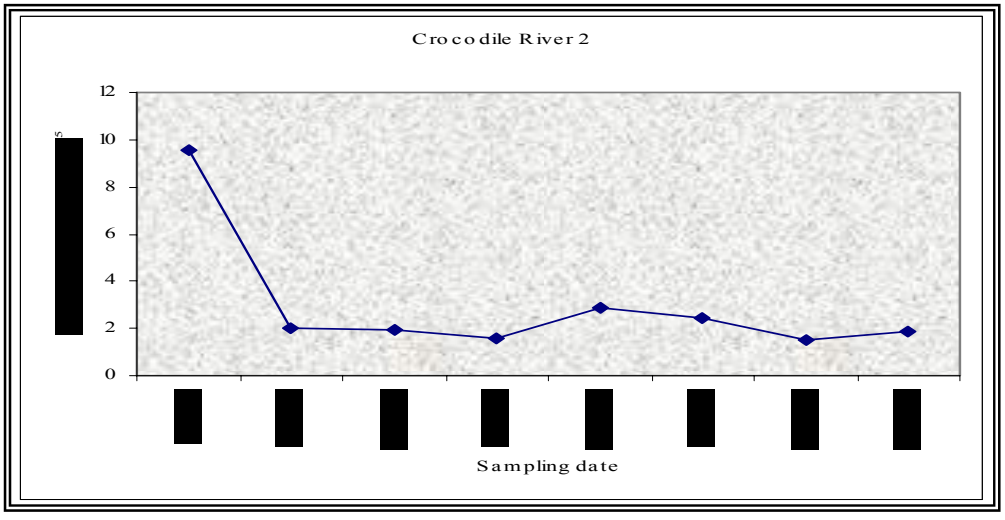


Figure 5.8 (a): The OP mass load in CROC 2.

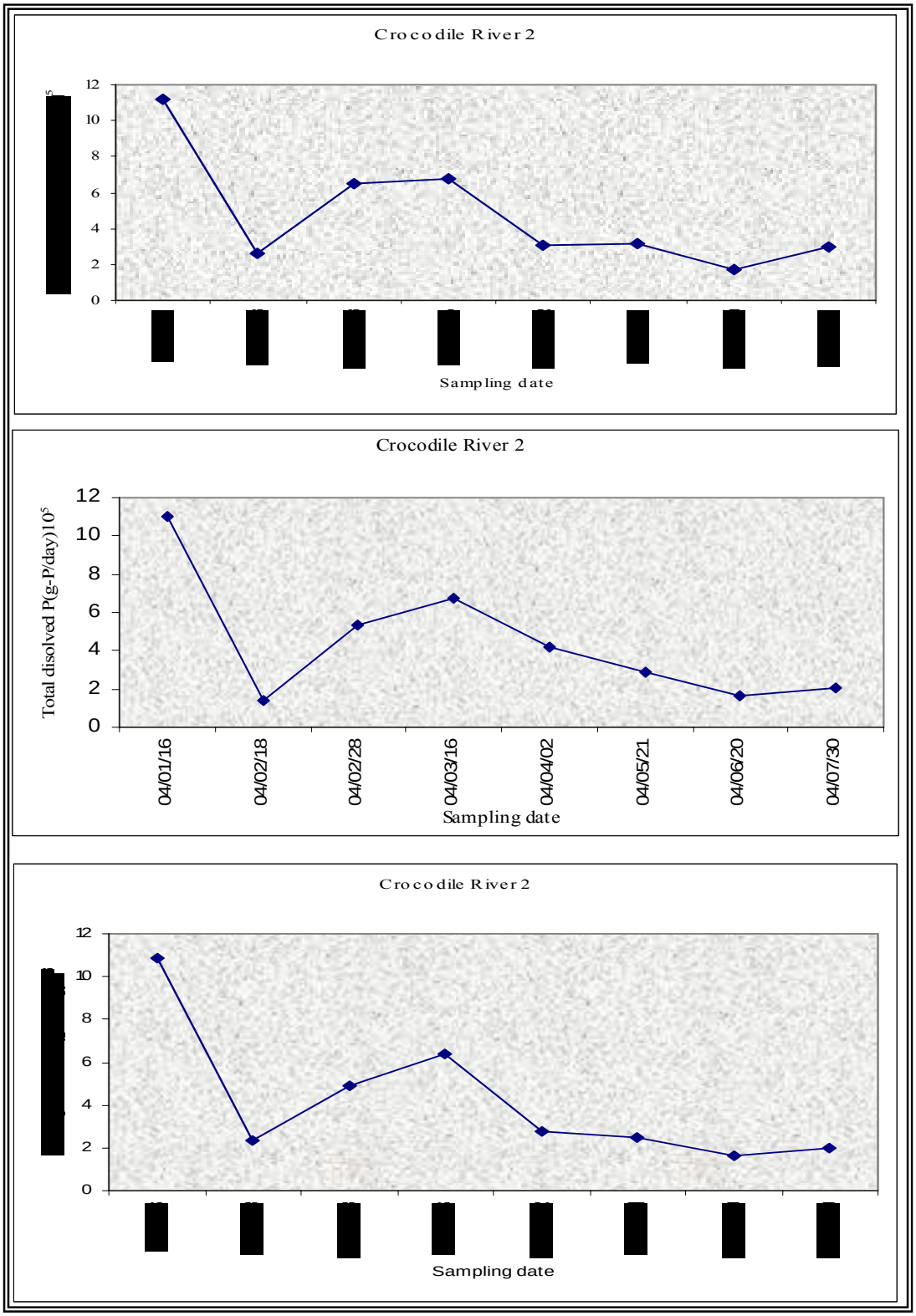


Figure 5.8 (b): The T P, TDP and AHP mass loading at CROC 2.

In Figure 5.9 below, the P species mass loadings are separated into wet and dry seasons. During the wet season, CROC 2 measured an average of 220.81 t/y of TP. From this load a certain percentage was in the dissolved form as TDP, AHP and OP. When observing Figures 5.9 and 5.10 the P mass loading into CROC 2 can be arranged the following order (i.e. from high to low contribution):

Jukskei River > Hennops River > Crocodile River 1

During the wet season the highest mass loading value in grams per day (g/d) measured at JUKS was 9x 10^5 g/d and the lowest was 0.8 x 10^5 g/d. During the dry season mass loading at JUKS was at its lowest, measuring at 1x 10^5 g/d.

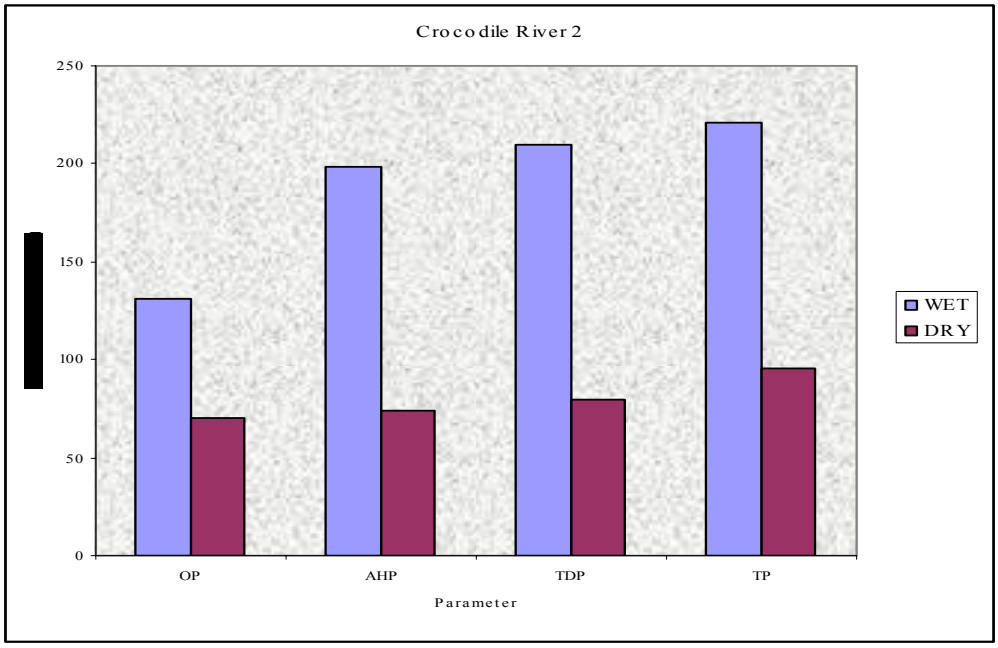


Figure 5.9: The estimated average inflow of phosphorus into the dam.

During the dry season, an average of 95.5 t/y of TP, a certain percentage of which is in dissolved form was measured. This estimation could not be taken as the actual mass load contribution from the tributaries as there are some streams after the confluences which join the Crocodile River to the dam. Along these streams are human activities including small agricultural holdings which utilise septic

tanks as options for sewage waste disposal. Their contribution to phosphorus loading to the dam could be small but during heavy rains these may overflow and increase the load.

Through the observed annual P mass loading in Figure 5.10 one could conclude that the bulk of it is from the identified wastewater treatment plants which discharge effluents into these rivers. Amoungst them are those which have been identified as non-compliant with 1mg/l effluent discharge standard.

When associating the observed annual P mass loading from the Crocodile River with the surface area of the dam, the resident time in the dam, mean flushing rate (Harding *et al*., 2003) and the environmental factors, one could roughly anticipate a high rate of algal growth in the dam. According to OECD, (1985) such an inflow of phosphorus could result in hypertrophic state of the dam which is the case in HBS Dam. As the dam is utilised for many purposes including drinking, the P concentration in it is expected to be bellow 10mg/m^3.

In view of the numerical values assigned on each character in the HBS Dam morphological table (Table 3.1), one could observe on the mean depth and resident time differences as observed by the two authors, that sedimentation into the dam had occurred at high rate over the years. As observed on the Catchment Rivers, high values were obtained on suspended solids and turbidity during the wet season. This indicated that P had been buried with sediments over many years in both the Catchment Rivers and HBS Dam.

It is estimated that 80 000 to 300 000kg/y (i.e. 80 to300 t/y) of P is loaded by the Crocodile and Magalies Rivers into the dam Crocodile and Magalies Rivers (Harding *et al.,* 2003). MAG and SWRT sampling stations mass loading are not presented in Figure 5.10 because of the unavailability of data on daily flow rates.

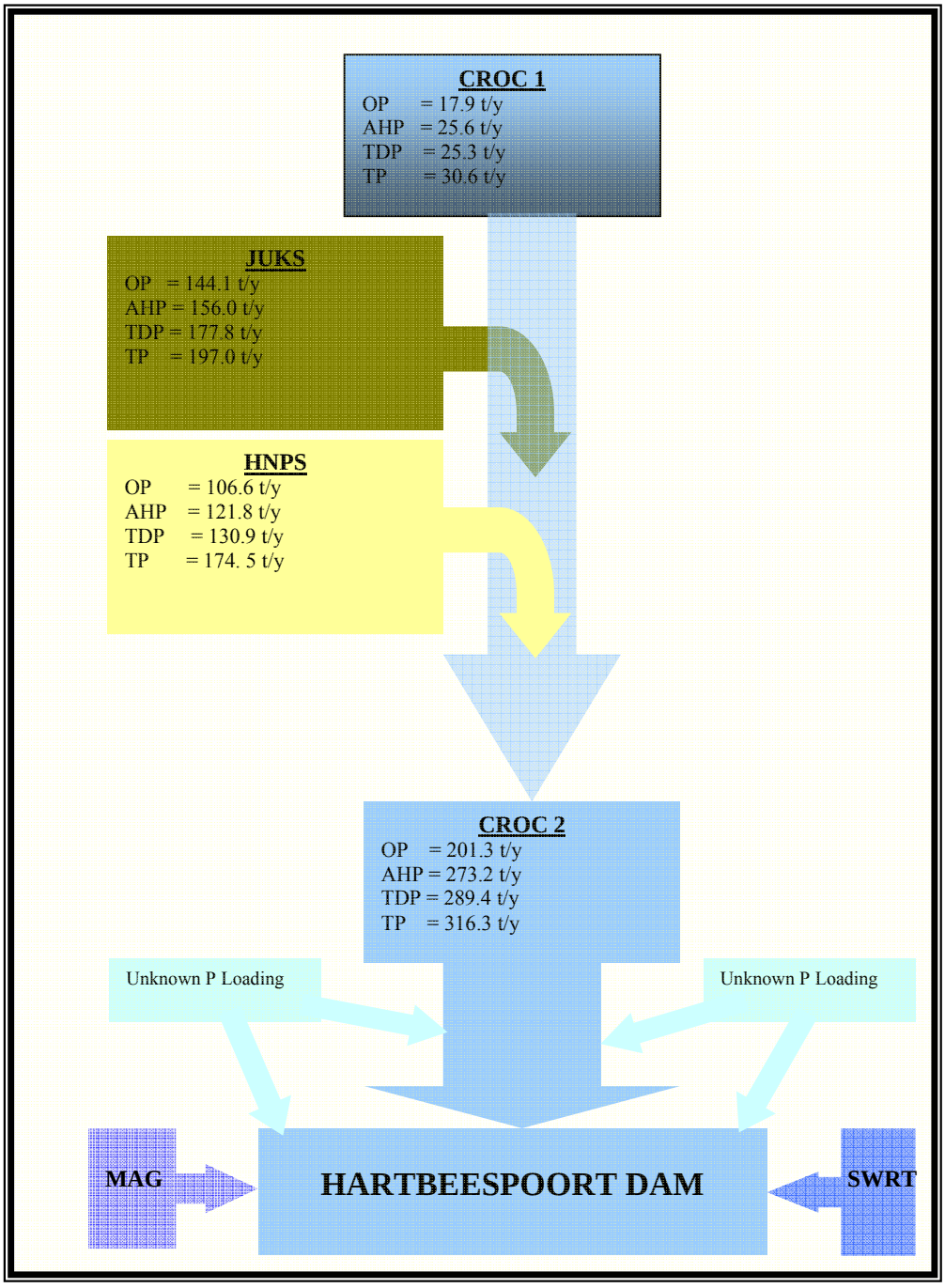


Figure 5.10: The flow of P species per year from the Crocodile River Catchment into the Dam.

The Crocodile River contributes most of the P load which is from its tributaries. As shown in figure 5.11 below, the Jukskei River has the highest load into Crocodile. From DWAF reports the average P mass loading from Magalies River is approximately 1.047 t/y.

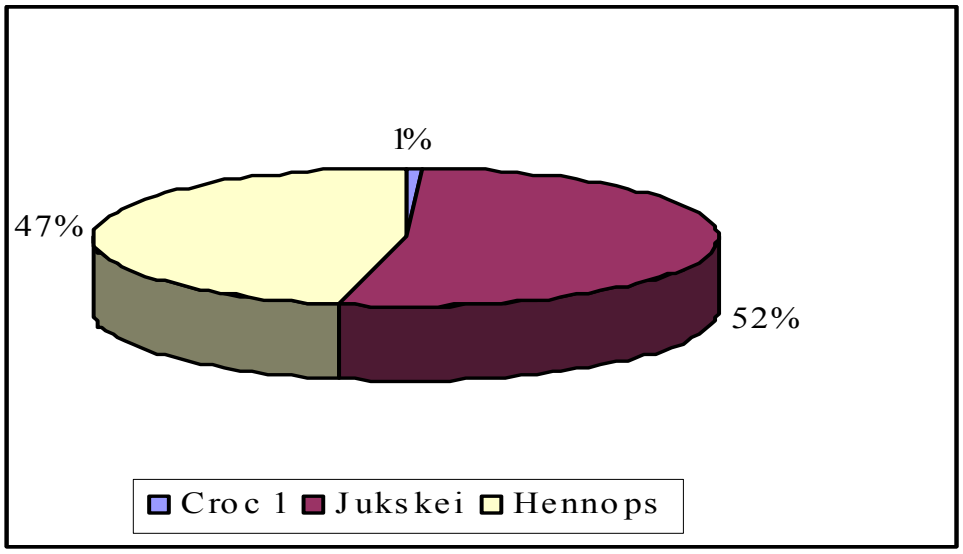


Figure 5.11: The TP contribution of the tributaries into the Crocodile River

When matching the resident time and phosphorus load in the dam, it can be classified under hypertrophic state as per OECD method of assessment. As the Hartbeespoort Dam had been in the hypertrophic state for many years it would be costly to abate it to the oligotrophic state, therefore maintaining it in the mesotrophic state is preferred. This is because of the internal loading which has not yet been accurately estimated and the continuous inflow of nutrients from the point and non-point sources in the catchment.

The observed average annual concentration of total phosphorus at Crocodile River was 0.6 mg/l and 0.21mg/l at Magalies River. When applying the Vollenweider's model formula, a value of 0.33mg/l as an average in-dam concentration was obtained. When extrapolating this value in Figure 5.12, the Hartbeespoort Dam is in the region of the hypertrophic state. In terms of qualitative prediction of the

trophic category as in the same figure, the 0.33 mg/l P has a probability distribution of 0% for mesotrophic, 10% eutrophic and 90% hypertrophic.

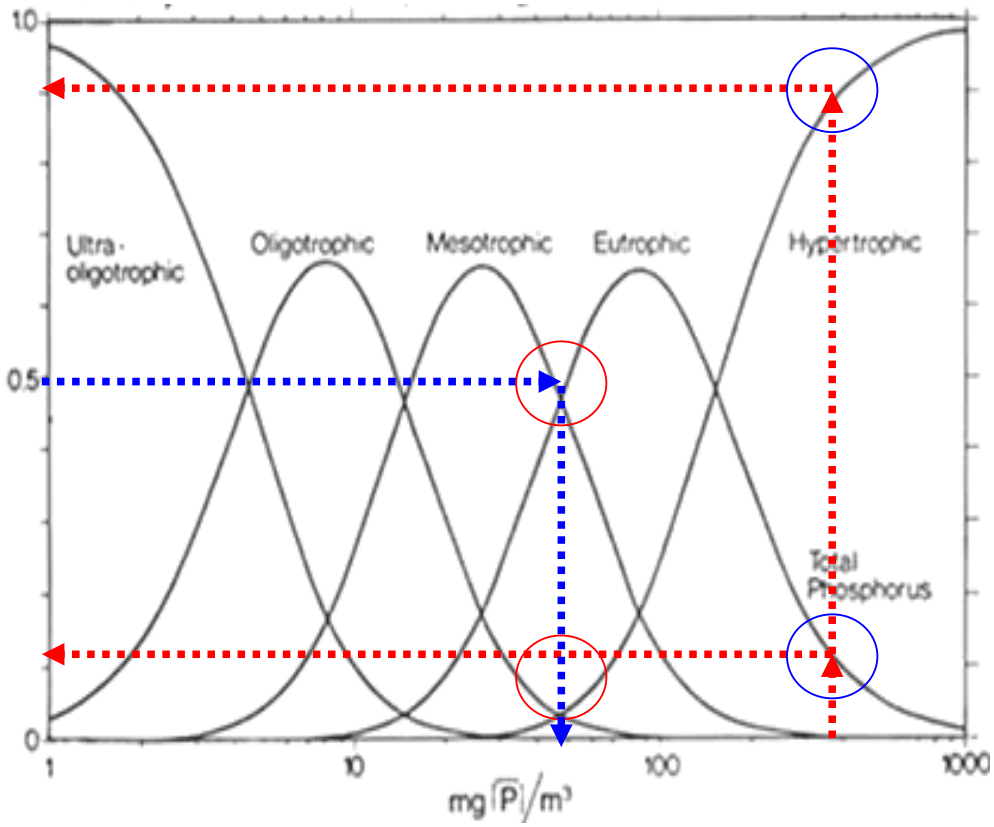


Figure 5.12: The P level prediction into the HBS Dam (OECD, 1982 graph modified).

The condition in the Dam can be improved by attenuating the TP concentration to a level of 50 %. As shown in Figure 5.12 above, this level correspond with 50 mgP/m^3. The Effluent Discharge Standard set by the authorities for point sources is above this level and falls under hypertrophic state. In order to keep the dam at 50 % mesotrophic, an average TP mass loading into the dam should be between 10 to 15 t/y. As an average of 0.6 mg/l of TP has been measured in this analysis more advanced methods should be applied to reduce it in the Subcatchment Rivers.

5.5 Nitrogen Compounds Mass Loading

During sampling period about 1 650.9 and 392.5 t/y of nitrates were measured during wet and dry seasons respectively. This gave indication that approximately 2 043 t/y of NO_3^- and 2 330 t/y of TN flow into the Hartbeespoort Dam every year. The TN is from the summation of t/y of NH_3, NO_3^- and NO_2^- measured during sampling period.

In Figure 5.13 bellow, the average yearly inflow of N compounds into the dam from the Crocodile River is shown.

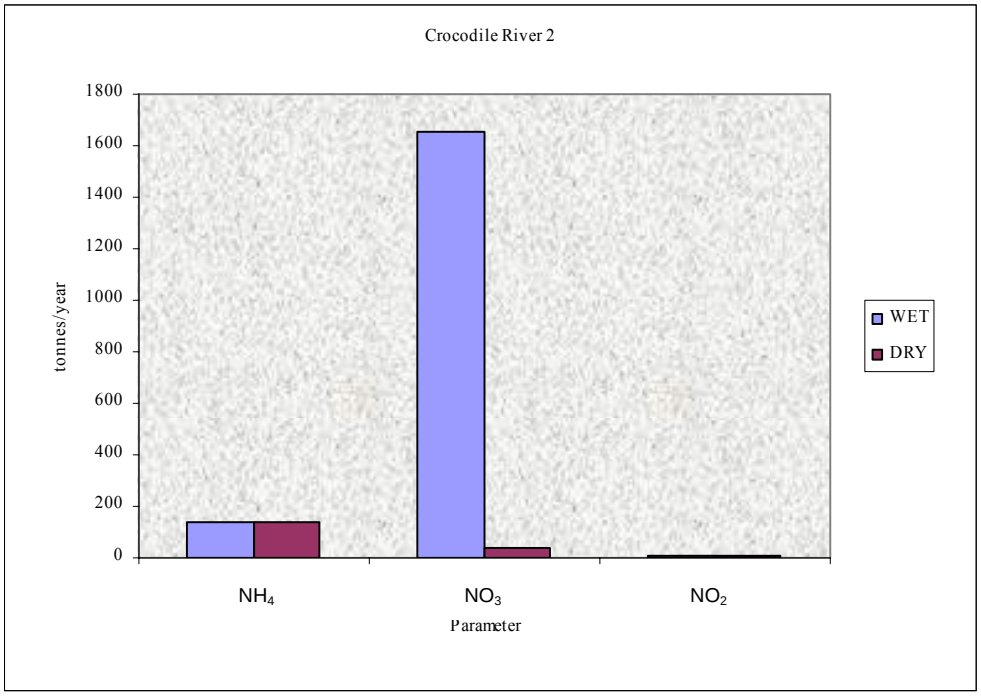


Figure 5.13: The yearly inflow of the N compounds into the Dam from the Crocodile River.

The N compounds loading to the Crocodile River from other rivers is shown in Figure 5.13. Both Figures 5.13 and 5.14 indicate that the Jukskei River is the major contributor of total inorganic nitrogen. Although the observed tonnage is high for these compounds, the same trend observed on P mass loading to CROC 2 have been observed on TN.

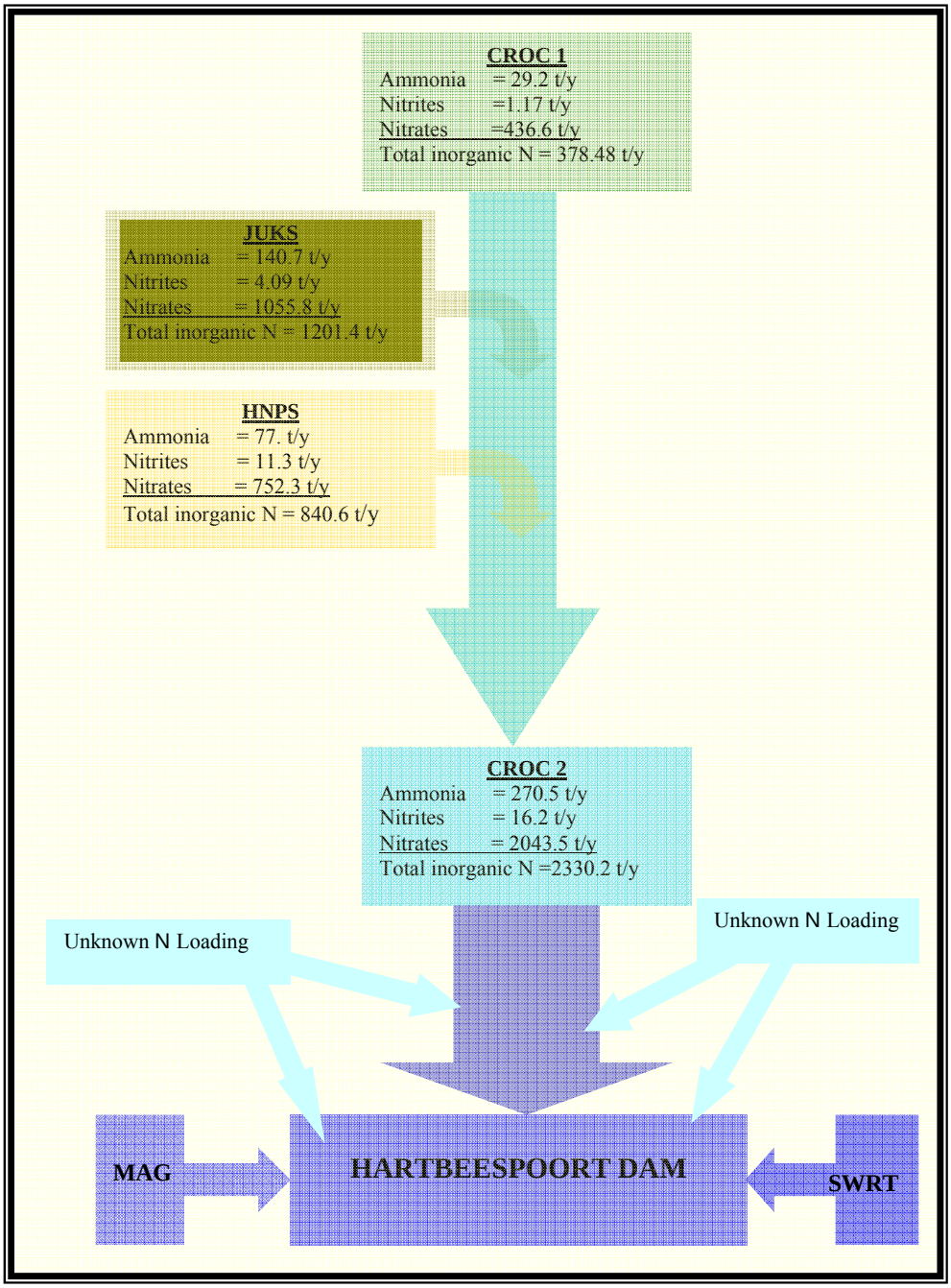


Figure 5.14: The flow of N compounds from the Catchment into the Dam.

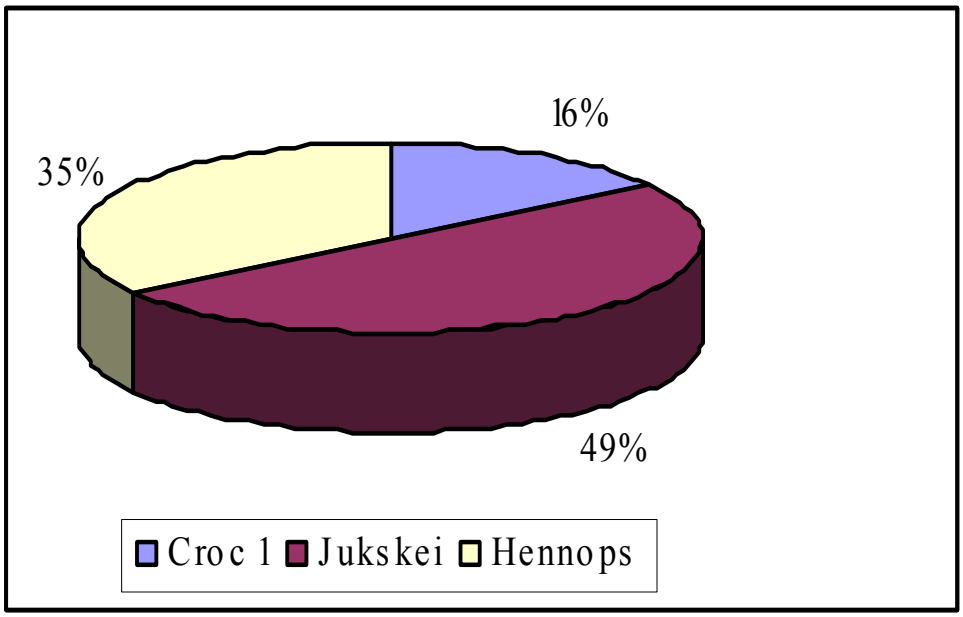


Figure 5.15: The yearly total inorganic N mass loading from the tributaries into the Crocodile River.

5.4 Mass Loading of other Parameters

The parameters which were also selected for the loading analysis were total organic carbon (TOC) and potassium (K^+) and these are shown in Figure 5.16 below. The TOC measured in this catchment is associated with various activities as identified in Chapter 3 of this report. However, a certain percentage emanates from natural organic content (i.e. from plants and soil) in the catchment.

It should be noted that the TOC measured from the stations play a role in algal and microbial activities in the HBS Dam. Generally, carbonaceous compounds are good substrates for microbial enzymatic reactions. Both the TOC and K^+ could be associated with the amount of suspended solids (SS) and electrical conductivity, measured in the catchment.

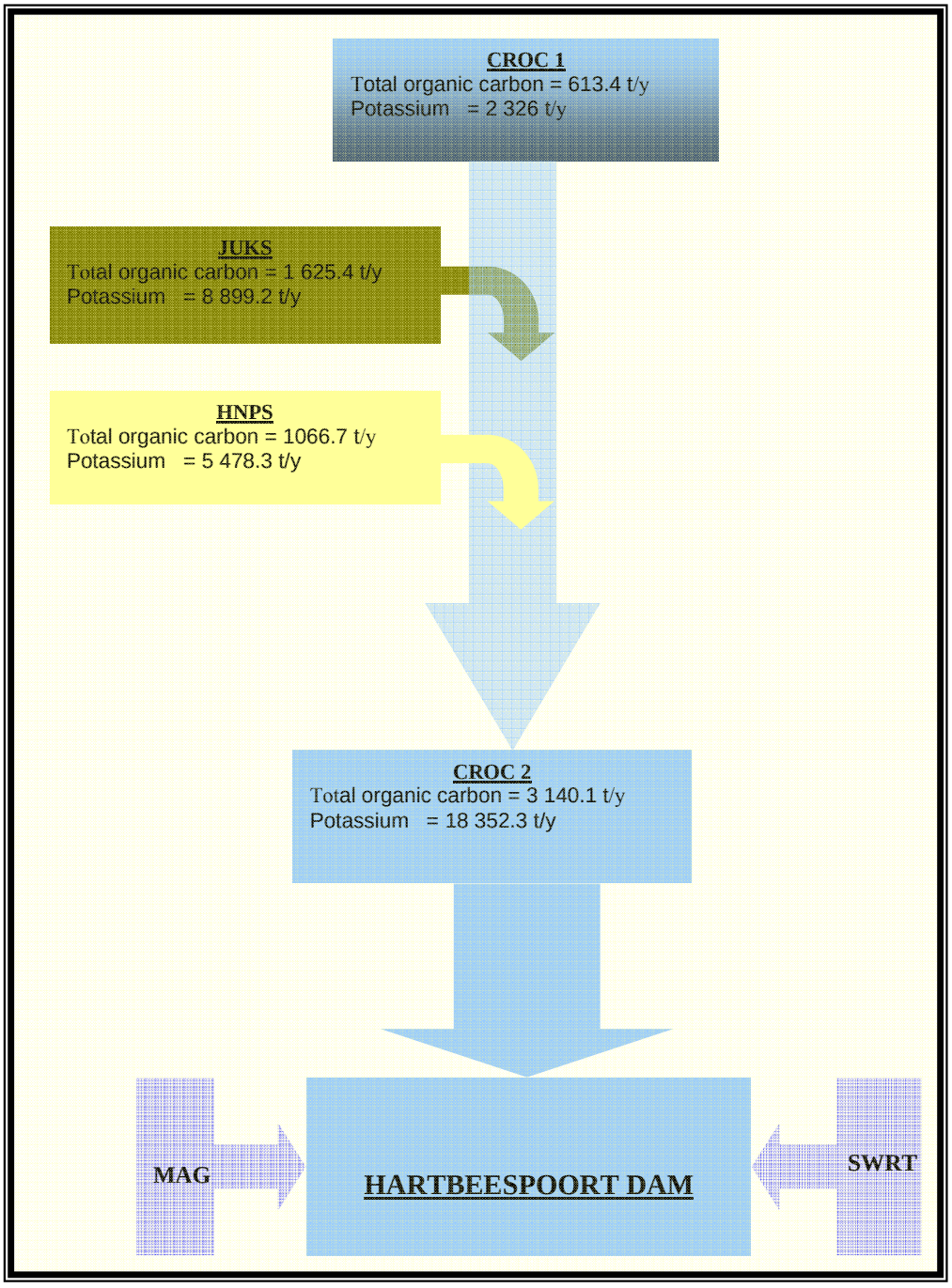


Figure 5.16: The total organic carbon and potassium mass loading into the Dam.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The situational analysis of the Hartbeespoort Dam catchment has been conducted over a period of six months with successful laboratory analysis of the selected water quality parameters. Waste water works (WWW) identified on this catchment are the main sources of nutrients which led to the eutrophication state of the HBS Dam. Several townships and informal settlements with lack of proper sanitation services and stormwater management systems have been identified in the catchment. The lack of proper stormwater management in these settlements directly contributes to pollution of the subcatchment rivers. It is clear that the polluted stormwaters from the identified townships are also nutrient sources and are health hazards that need attention from the authorities. Water in the rivers from these areas cannot be considered safe for human contact and for consumption because of the high level of pollution.

Although the current situation in these townships is being attended to, from the author's perspective, the environmental consequences of an ineffective bucket system which is practiced in some and the pollution caused by deposition of gray water in the open space or streets could accelerate the enrichment of river waters in the catchment. It has been reported that, at times, raw sewage flows in the internal roads of Alexander, Diepsloot, Olivenhoutbosch and Tembisa informal settlements and that these roads act as stormwater drains.

Besides efforts undertaken by government and non-governmental organizations to improve the Jukskei River in Alexandra, solid and liquid waste is still being illegally dumped in the river banks by residents and the water nutrient levels are still high. It has also been observed that the extensive construction activities, the townships, industries, agricultural activities, golf courses and parks, burnt pastures and sewage treatment plants in the catchment contribute to the pollution of the HBS Dam presently. It has been found that in addition to the well known sewage

treatment works which discharge their effluent in the Catchment Rivers; there are few sources of pollution including Kelvin Eskom Power Plant, Chloorkop Industrial Operations etc. whose nutrient contributions to the catchment are underestimated. Generally in all the subcatchments there are agricultural activities some occupying areas which could be reserved as riparian buffer strips. During the wet season fertilized soil is freely washed into the river thus increasing the loading of nutrients.

The quality of water in the Catchment Rivers is in a bad state and will continue to pollute and enrich the HBS Dam unless abatement strategies are planned and implemented. It has been proven that the Crocodile River loads the highest concentration of nutrients than any other river in the HBS Dam catchment every year. The bulk of the nutrients emanate from point and nonpoint sources located in the subcatchments to the Dam. Magalies River which has low concentrations is also regarded as another river which is contributing a certain percentage of nutrients but mostly from non-point sources. The analytical results have revealed that the order of phosphorus loading into the Crocodile River is as follows: Jukskei River > Hennops River > Crocodile River 1 whilst the nutrient mass loading order into the dam is as follows: Crocodile River> Magalies River > Swartspruit > activities surrounding the dam.

Although the daily nutrient concentration values in the Swartspruit were the highest compared to others it was concluded that these values could be negligible because of the observable small flow rates. Data on flow rates for Swartspruit was not available at DWAF as the gauging station was closed sometimes ago. It was also noted that the same river has massive growth of duck weeds which thrive in nutrient rich slow moving waters or dams. The Rietfontein Sewage Works which discharge its final effluent in this river is believed to be the only point source which could cause the high nutrient concentration levels.

At this point in time, the information with regard to internal loading in HBS Dam has not been obtained and is anticipated that it contributes to the trophic state. The

observed turbidity and suspended solids from the inflowing rivers and the outflow from the dam indicate that sedimentation rate could be high in the Dam (i.e. high turbidity at CROC2 and very low turbidity at CROC 3).

The current 1mg/l phosphorus standard for point sources effluent discharge in the catchment could only reduce the extent of the trophic state in the dam. According to the OECD the 0.4 mg/l P a year (average obtained from the laboratory analysis) still put the dam under hypertrophic state as algae need less than that for optimal growth. It is anticipated that the dam could be impossible to return it to the oligotrophic state because of the external and the unknown internal loading. For this reason all programmes aimed at abatement of eutrophication in the Dam should be based on maintaining it in the mesotrophic state. Based on the OECD strategies, it has been concluded that 10 to 15 t/y of TP load into the dam from the external sources would enable its survival on 50 % mesotrophic and eutrophic states.

6.2 Recommendations

1. For the establishment of an effective plan for the abatement of eutrophication it is advisable that the long and short term abatement options be considered. Both options should be implemented concurrently so that they do not interfere with daily activities which are presently underway around the Dam. This means that while the physical removal of the scum and chemical dosing as proposed are underway, natural abatement strategies, community consultation and education upstream are also undertaken.
2. In view of the fact that the Dam and the Catchment are already the focal points with regard to alleviation of problem by North West, Gauteng Province and National DWAF, it is recommended that the existing programme proposed by other previous researchers be implemented and optimized when necessary. The measures include but are not limited to:
    - Existing constructed wetlands in the Hennops River subcatchment;

- The Swartspruit constructed wetland; and
- The in-stream detention ponds.

3. It has been confirmed that the effluent from Rietfontein Sewerage Works contains high concentration of P. The abatement strategy in the form of a wetland down stream of these works has not improved the nutrient status of the Swartspruit; therefore it should be attended to as a matter of urgency. It is recommended that small subcatchment reservoirs be constructed on both the Hennops and Jukskei Rivers as forms of natural abatement.
4. The buyback centres for waste recycling identified within the catchment should be regulated and each should have a policy on watercourse pollution prevention. This should be done in conjunction with participation of the local people within which the center is located.
5. It is recommended that the main stakeholders which are the two provinces and DWAF engage together to formulate a strategy leading to provision of better sanitation for the informal settlements. If this is not done, pollution of the Catchment Rivers will continue.
6. It should be noted that it is the responsibility of catchment management forums and water user associations to decide what water quality objectives are for this specific area then a nutrient load strategy could be developed. Regarding this issue, the Magalies River subcatchment will be totally different from the rest as its water quality is far better than others.
7. As it has been identified that the main source of nutrients in the catchment are from point sources and most of them claim to be compliant with the effluent discharge standards as set by DWAF, it is recommended that independent organisations be legally included in the monitoring. The purpose of such an undertaking will be verification of any loophole within their monitoring programme by which companies may avoid to prevent penalties.
8. With regard to the crop cultivators along the rivers it is recommended that the department negotiate with them so that few metres are awarded for land-water interface. These riparian buffer strips should be managed and should aim at protecting the riparian ecosystems, terrestrial riparian interfaces, and surface

waters from unwanted inputs (sediments, logging slash) from harvested cultivated land.

9. It is recommended that a permanent monitoring station be built at Hartbeespoort Dam and should avail the information on status of the dam to the public.
10. Recommended studies include:
    - The estimation of existing nonpoint source loads for the entire Hartbeespoort Dam Catchment;
    - Estimation of N and P loading rates for different land uses during the dry, and the wet seasons conditions which will include farm lands, burnt pastures and golf courses;
    - River sediment quality analysis in the catchment;
    - Microbial availability in the Catchment Rivers for nitrification and other related processes; and
    - Detailed study on suspended solids in the catchment during wet and dry seasons.
11. Detailed study of internal loading and its contribution to the trophic state of HBS Dam.

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APPENDIX A: CATCHMENT SAMPLING POINT DATA

i. Crocodile River 1

Date	16/01/04	18/02/04	28/02/04	16/03/04	02/4/04	21/5/04	30/6/04	30/7/04
Time	09:45	11:00	08:57	06:25	07:19	16:18	09:00	
Weather	Cloudy	Cloudy	Cloudy	Misty	Slightly Cloudy	Clear	Misty	Clear
Water Colour	Turbid	Turbid	Turbid	Turbid	Slightly Turbid	Clear	Clear	Clear
Soil Status	Wet	Wet	Wet	Wet	Wet	Dry	Dry	Dry
H_2O Temp ^0C		25	18	18	18	16	11	
Air Temp ^0C		30	25	15	10..9	21.5	15	

ii. Crocodile River 2

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/04	30/7/04
Time	14:00	12:00	09:47	07:13	08:42	15:50	10:00	
Weather	Cloudy	Cloudy	Cloudy	Clear	Slightly Cloudy	Clear	Partly Cloudy	Clear
Water Colour	Turbid	Turbid	Turbid	Turbid	Turbid	Turbid	Dirty	Clear
Soil Status	Wet	Wet	Wet	Wet	Wet	Dry	Dry	Dry
Water Temp ^0C	28	28	20	20	20	16	12	
Air Temp^0C	31	30	22	18	15	22	16	

iii. Crocodile River 3

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/04	30/7/04
Time		13:30	10:55	08:09	09:56	14:15	11:24	
Weather	Windy Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy	Clear
Water Colour	Greenis/ Macroph.	Greenish	Turbid/ Macroph	Greenish/ Macroph./ Water Released From Dam	Greenish	Greenish/ Macroph	Greenish	
Soil Status	Wet	Wet	Wet	Wet	Wet	Dry	Dry	Dry
Water Temp ^0C	22	26	20	21	20	19.5	14	
Air Temp^0C	30	30	23	17	19	22	15	

iv. Jukskei River

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/2004	30/7/04
Time	09:45	11:30	09:30	06:37	07:47	16:40	09:11	
Weather	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Cloudy /Misty	Clear
Water Colour	Turbid	Turbid	Turbid	Grayish	Grayish	Clear	Greyish	
Soil Status	Wet	Wet	Wet	Wet	Wet	Dry	Dry	Dry
Water Temp ^0C	23	25	19	18	18.5	17	13	
Air Temp ^0C	25	30	20	15	16	21	12	

APPENDIX A: CATCHMENT SAMPLING POINT DATA CONT.

v. Magalies River

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/04	30/7/04
Time	11:10	12:30	10:20	07:35	09:30	15:00	10:55	
Weather	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear	Partly Cloudy	Clear
Water Colour	Turbid	Turbid	Turbid	Turbid	Clear	Slightly Turbid	Clear	Clear
Soil Status	Wet	Wet	Wet	Wet	Dry	Dry	Dry	Dry
Water Temp ^{0}C	24	25	20	20	19	14.5	12	
Air Temp ^{0}C	28	28	23	15	16	22	15	

vi. Hennops River

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/04	30/7/04
Time	14:45	14:30	11:57	09:00	11:38	13:00	12:50	
Weather	Cloudy	Cloudy	Cloudy	Cloudy	Clear	Clear Cold	Cloudy	Clear
Water Colour	Turbid	Turbid	Turbid	Turbid	Dirty	Milky/Dirty	Dirty	
Soil Status	Wet	Wet	Wet	Wet	Wet	Dry	Dry	Dry
Water Temp ^{0}C	25	24	18	20	20	14	14	
Air Temp ^{0}C	27	28	20	20	21	21	16	

vii. Swartspruit

Date	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	30/6/04	30/7/04
Time	13:13	14:00	11:27	08:38	11:06	13:30	12:55	
Weather	Cloudy, Windy	Cloudy	Cloudy	Cloudy	Clear	Clear /Cold	Cloudy	Clear
Water Colour	Turbid	Turbid	Turbid	Turbid	Clear	Clear	Clear	Clear
Soil Status	Wet	Dry	Wet	Wet	Dry	Dry	Dry	Dry
Water Temp ^{0}C	27	27	22	18	20	22.5	14	
Air Temp ^{0}C	32	29	28	18	21	23.2	16	

APPENDIX B: WATER QUALITY DATA IN SAMPLING POINTS

i. Crocodile River 1

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	NM	0.51	0.44	0.19	0.01	0.73	0.14	0.1
NO_2 (mgN/l)	NM	0.001	0.006	0.011	0.002	0.019	0.011	0.03
NO_3 (mgN/l)	NM	6.35	2.11	2.93	6.38	4.66	0.11	0.08
OP (mgP/l)	NM	0.191	0.203	0.107	0.236	0.13	0.143	0.174
AH P (mgP/l)	NM	0.218	0.397	0.217	0.274	0.13	0.158	0.209
TDP (mgP/l)	NM	0.206	0.401	0.211	0.247	0.146	0.183	0.22
TP (mgP/l)	NM	0.243	0.575	0.225	0.307	0.198	0.21	0.254
SO_4 (mg/l)	NM	40.8	64	63.7	64	74.9	64.4	58.2
DO (mg/l)	NM	6.893	7.294	7.535	7.037	9.046	8.853	9.962
TOC (mg/l)	NM	4.45	4.7	5.61	7.61	3.45	8.4	6.4
pH	NM	8.18	8.18	8.1	8.1	8.4	8.2	8.6
Elec. Cond. (mS/m)	NM	47	35	46	58	64.3	43	43
Turbidity (NTU)	NM	22	135	30	21	3.6	2.4	2.3
Hard. ($mgCaCO_3$ /l)	NM	143.4	128.3	169.8	218.9	207.5	196.2	207.5
Ca ($mgCaCO_3$ /l)	NM	94.3	71.7	83	120.8	113.2	120.8	132.1
Alkal.($mgCaCO_3$ /l)	NM	120	80	140	92	140	160	160
SS (mg/l)	NM	102	260	45.5	60	7.5	4	3
Cl (mg/l)	NM	99.3	85.1	37.5	48.7	59	54.2	51.9
Na (mg/l)	NM	5.5	6.3	5.2	4.7	3.4	35	39.3
K (mg/l)	NM	26	21.1	24	33	22.6	4.4	4.4

ii. Crocodile River 2

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	0.13	0.32	0.4	0.07	0.11	0.75	0.24	0.18
NO_2 (mgN/l)	0.007	0.006	0.006	0.012	0.056	0.095	0.012	0.066
NO_3 (mgN/l)	3.75	7.49	3.44	5.75	4.74	5.81	0.15	0.1
OP (mgP/l)	0.531	0.432	0.296	0.139	0.37	0.457	0.33	0.395
AH P (mgP/l)	0.601	0.507	0.756	0.572	0.348	0.464	0.366	0.426
TDP (mgP/l)	0.61	0.314	0.828	0.599	0.532	0.534	0.372	0.432
TP (mgP/l)	0.622	0.581	1.002	0.603	0.393	0.582	0.384	0.644
SO_4 (mg/l)	44.48	44.5	51.1	64	66.5	47.6	51.4	53
DO (mg/l)	NM	6.78	7.664	7.873	7.359	8.451	8.274	10.444
TOC (mg/l)	5.45	4.43	3.76	6.52	8.84	6.21	5.58	6.06
pH	8.46	8.12	8.12	8.16	8.16	8.1	8.2	8.4
Elec. Cond. (mS/m)	47	48	28	50	59	59	48	49
Turbidity (NTU)	34	26	180	22	42	29	7.9	6.5
Hard. ($mgCaCO_3$ /l)	113.2	128.3	75.5	154.7	169.8	169.8	150.9	169.8
Ca ($mgCaCO_3$ /l)	48	79.2	79.2	86.8	113.2	113.2	113.2	105.7
Alkal.($mgCaCO_3$ /l)	120	104	60	124	104	120	132	140
SS (mg/l)	86	84	226.7	80.5	46.5	5.25	4.8	4.2
Cl (mg/l)	52.26	102.4	84.7	55.4	65.6	65.1	62.8	71.6
Na (mg/l)	15.8	8.8	6.2	7.7	8.2	9.5	40	65
K (mg/l)	50	39	19.8	38	49	40	11.7	9.1

APPENDIX B: WATER QUALITY DATA IN SAMPLING POINTS CONT.

iii. Crocodile River 3

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/5/04	30/7/04
NH_4 (mgN/l)	0.98	0.57	0.41	0.85	0.99	1.03	0.37	0.19
NO_2 (mgN/l)	0.006	0.016	0.007	0.009	0.109	0.079	0.015	0.038
NO_3 (mgN/l)	0.97	2.66	4.15	0.77	1.91	1.44	0.09	0.25
OP (mgP/l)	0.163	0.302	0.107	0.448	0.259	0.085	0.044	0.011
AH P (mgP/l)	0.199	0.38	0.106	0.197	0.276	0.089	0.051	0.028
TDP (mgP/l)	0.211	0.362	0.165	0.619	0.318	0.1	0.068	0.032
TP (mgP/l)	0.312	0.579	0.446	0.632	0.351	0.145	0.079	0.041
SO_4 (mg/l)	55.45	55.4	39.6	42.5	38.2	48.1	49.4	43.8
DO (mg/l)	NM	5.479	8.114	7.23	5.864	7.696	10.122	9.046
TOC (mg/l)	6.47	5.05	6.42	5.97	8.78	5.8	5.15	5.26
pH	8.1	7.57	7.57	8.11	8.11	8.5	8.6	8.6
Elec. Cond. (mS/m)	48	48	47	45	46	51.7	43	42
Turbidity (NTU)	2	12.1	8.4	4.2	3.5	4	3.5	2.3
Hard. ($mgCaCO_3$ /l)	120.8	132.1	101.9	132.1	135.8	132.1	147.2	150.9
Ca ($mgCaCO_3$ /l)	48	86.8	71.7	75.5	83	86.8	109.4	79.2
Alkal.($mgCaCO_3$ /l)	132	92	100	112	96	100	136	120
SS (mg/l)	3	2	36.7	59.5	68	3.75	6.4	7.5
Cl (mg/l)	98.29	85.7	142.2	56.2	52.3	68.4	58.9	60.7
Na (mg/l)	10.7	14.7	10.3	8.6	8.3	8.7	59.1	151
K (mg/l)	50	42	46	40	40	39	11.1	27.6

iv. Jukskei River

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	0.24	0.31	0.5	0.79	0.19	1.42	0.42	0.24
NO_2 (mgN/l)	0.005	0.007	0.005	0.023	0.01	0.045	0.015	0.048
NO_3 (mgN/l)	4.06	6.75	3.16	5.61	6.11	6.35	0.11	0.14
OP (mgP/l)	0.389	0.417	0.691	0.894	0.27	0.243	0.312	0.426
AH P (mgP/l)	0.397	0.337	0.798	1.046	0.289	0.23	0.33	0.432
TDP (mgP/l)	0.386	0.481	0.917	1.062	0.385	0.289	0.342	0.523
TP (mgP/l)	0.411	0.808	0.933	1.21	0.348	0.293	0.375	0.739
SO_4 (mg/l)	52.27	52.3	48.4	67.5	67.5	57	52	49.2
DO (mg/l)	NM	7.198	8.323	7.712	7.584	7.953	8.885	10.411
TOC (mg/l)	6.8	5.91	4.92	5.89	9.94	6.85	9.46	6.84
pH	8.19	8.3	8.3	7.91	7.91	8.6	8.2	8.8
Elec. Cond. (mS/m)	40	47	35	54	55	51.8	36	44
Turbidity (NTU)	58	26	110	7	17	7.8	24	15
Hard. ($mgCaCO_3$ /l)	94.3	120.8	94.3	149.1	154.7	124.5	32.1	132.1
Ca ($mgCaCO_3$ /l)	40.1	90.6	75.5	113.2	83	94.3	94.3	94.3
Alkal.($mgCaCO_3$ /l)	112	80	78	118	88	100	120	120
SS (mg/l)	598	72	133.3	56.5	73	4.25	9.6	8.5
Cl (mg/l)	56.24	107.2	76	54.5	57.9	68.3	60.5	59.9
Na (mg/l)	13.3	10.2	7.2	9.8	11.1	12.6	64	67
K (mg/l)	55	41	24	43	51	45	11.2	12

APPENDIX B: WATER QUALITY DATA IN SAMPLING POINTS CONT.

v. Hennops River

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	0.01	0.29	0.43	0.24	0.06	1.59	0.24	0.41
NO_2 (mgN/l)	0.005	0.006	0.006	0.01	0.015	0.244	0.049	0.2
NO_3 (mgN/l)	3.37	6.36	5.99	4.01	7.63	5.35	0.13	0.17
OP (mgP/l)	0.672	0.75	0.43	0.483	0.521	1.231	0.594	0.462
AH P (mgP/l)	0.804	0.845	0.609	0.637	0.594	1.186	0.64	0.498
TDP (mgP/l)	0.522	0.794	0.661	0.638	0.649	1.517	0.712	0.504
TP (mgP/l)	0.836	0.947	1.112	0.715	1.121	1.52	0.882	0.811
SO_4 (mg/l)	39.9	39.9	44.9	52	44.9	59	46.4	51.2
DO (mg/l)	NM	6.941	8.564	8.339	8.066	7.857	8.885	11.488
TOC (mg/l)	4.43	1.72	3.86	8.12	8.76	5.74	5.53	5.55
pH	8.27	8.07	8.07	8.31	8.31	7.9	7.9	8.2
Elec. Cond. (mS/m)	35	38	33	56	53	66.4	54	62
Turbidity (NTU)	3	21	190	58	89	36	6.2	4.5
Hard. ($mgCaCO_3$ /l)	150.9	150.9	86.8	207.5	154.7	203.8	169.8	200
Ca ($mgCaCO_3$ /l)	64.1	75.5	56.6	124.5	90.6	113.2	124.5	143.4
Alkal.($mgCaCO_3$ /l)	160	80	80	142	96	140	200	156
SS (mg/l)	132	82	396.7	97	224	11.5	20.4	11.5
Cl (mg/l)	75.99	68.1	68.8	39.5	68.1	42.7	69.2	109.96
Na (mg/l)	51	44	27	48	44	33	65.1	76.6
K (mg/l)	13.1	9.6	9.8	6.8	8.4	10.1	11.3	11.6

vi. Magalies River

DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	0.65	0.25	0.36	0.09	0.16	0.69	0.1	0.13
NO_2 (mgN/l)	0.006	0.027	0.01	0.0003	0.01	0.119	0.007	0.011
NO_3 (mgN/l)	1.22	4.78	4.68	5.04	3.98	1.74	0.11	0.14
OP (mgP/l)	0.001	0.183	0.157	0.003	0.015	0.022	0.012	0.003
AH P (mgP/l)	0.014	0.009	0.166	0.033	0.012	0.035	0.019	0.019
TDP (mgP/l)	0.047	0.015	0.175	0.075	0.023	0.064	0.02	0.021
TP (mgP/l)	0.054	0.143	0.178	0.08	0.054	0.137	0.032	0.029
SO_4 (mg/l)	11.44	11.4	30.6	28.3	24.6	21.4	18.6	18.2
DO (mg/l)	NM	6.427	7.246	8.499	7.198	8.66	8.066	9.512
TOC (mg/l)	1.69	5.53	4.76	6.78	6.21	1.3	0.89	0.71
pH	8.34	8.12	8.12	7.81	7.81	8.1	8.1	8.1
Elec. Cond. (mS/m)	52	50	36	36	42	49.3	45	34
Turbidity (NTU)	39	68	100	36	19	6.1	3.6	3.8
Hard. ($mgCaCO_3$ /l)	218.9	162.3	166	196.2	207.5	226.4	211.3	207.5
Ca ($mgCaCO_3$ /l)	92.9	94.3	83	79.3	94.3	113.2	124.5	94.3
Alkal.($mgCaCO_3$ /l)	220	168	162	162	100	200	160	232
SS (mg/l)	8	42	266.7	35	33.5	2.25	3.2	2.9
Cl (mg/l)	56.24	54.5	51.5	22.7	17.9	46.7	18.2	16.7
Na (mg/l)	9.5	6.1	12.9	11.8	12.3	11.1	12.6	11.2
K (mg/l)	0.8	4.2	3.3	1.8	1.6	0.88	0.53	0.14

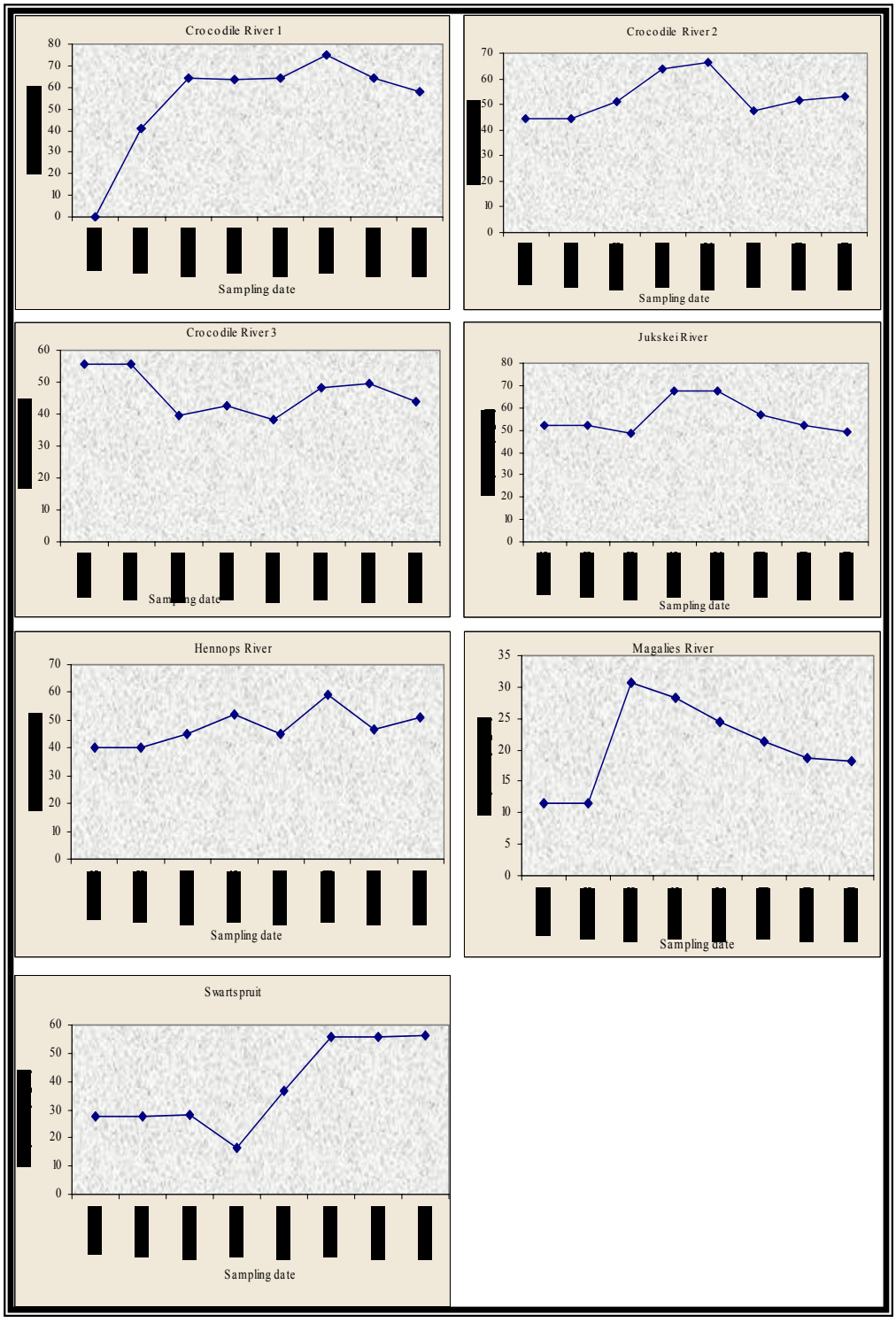
APPENDIX B: WATER QUALITY DATA IN SAMPLING POINTS CONT.

vi. Swartspruit

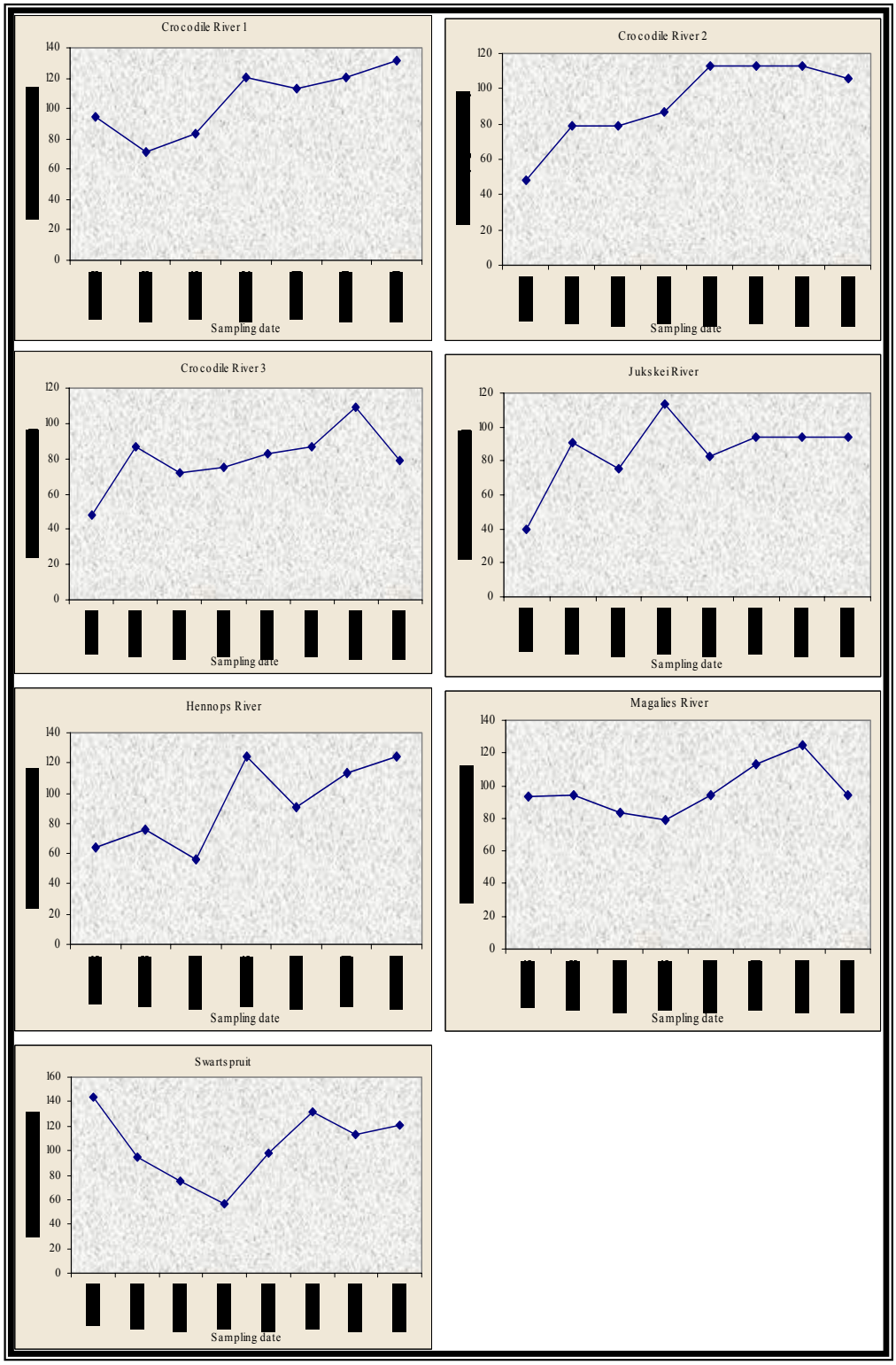
DATE	16/1/04	18/2/04	28/2/04	16/3/04	02/4/04	21/5/04	20/6/04	30/7/04
NH_4 (mgN/l)	0.14	0.3	0.38	0.26	0.12	0.89	0.23	0.11
NO_2 (mgN/l)	0.008	0.006	0.008	0.003	0.225	0.018	0.003	0.004
NO_3 (mgN/l)	0.75	0.92	4.05	1.28	1.81	0.97	0.11	0.13
OP (mgP/l)	0.4	2.05	0.494	0.4	0.615	0.578	0.985	2.223
AH P (mgP/l)	1.589	2.161	0.547	0.463	0.616	0.541	1.186	2.363
TDP (mgP/l)	1.917	2.21	0.567	0.473	0.678	0.664	1.197	2.432
TP (mgP/l)	1.848	2.348	0.583	0.5	0.771	0.671	1.329	2.89
SO_4 (mg/l)	27.82	27.8	28.3	16.2	36.8	55.5	55.6	56.1
DO (mg/l)	NM	6.395	7.439	6.941	7.487	7.584	9.656	10.283
TOC (mg/l)	6.77	8.75	4.62	4.47	12.58	8.61	9.42	9.92
pH	8.42	8.1	8.1	7.71	7.71	8.8	8.4	8.5
Elec. Cond. (mS/m)	95	59	30	22	57	85.7	66	64
Turbidity (NTU)	3	16	120	85	10	1.8	1.3	1.5
Hard. ($mgCaCO_3$ /l)	339.6	166	132.1	113.2	200	249.1	211.3	226.4
Ca ($mgCaCO_3$ /l)	144.2	94.3	75.5	56.6	98.1	132.1	113.2	120.8
Alkal.($mgCaCO_3$ /l)	410	180	80	96	104	240	200	240
SS (mg/l)	8	28	36.7	35.5	36.5	4	5.2	5.7
Cl (mg/l)	84.56	128.4	62.5	35.6	52.3	49.9	85.7	83.7
Na (mg/l)	80	55	16.4	11.1	39	63	92	91
K (mg/l)	10.5	12.9	7.3	9.7	10.2	11.3	15.1	14.6

APPENDIX C: GRAPHS OF OTHER WATER QUALITY PARAMETERS

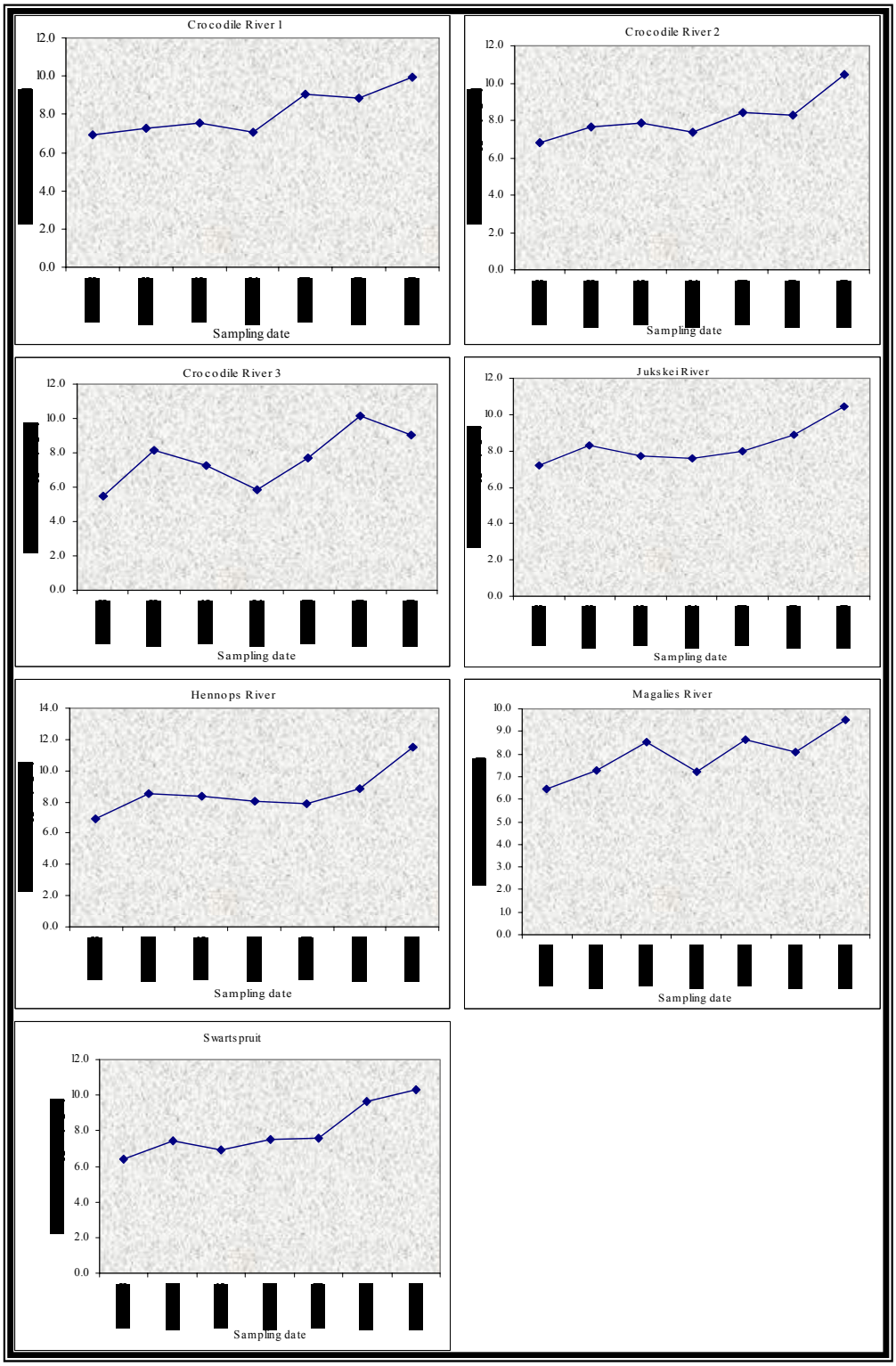
C1. Sulphate concentrations



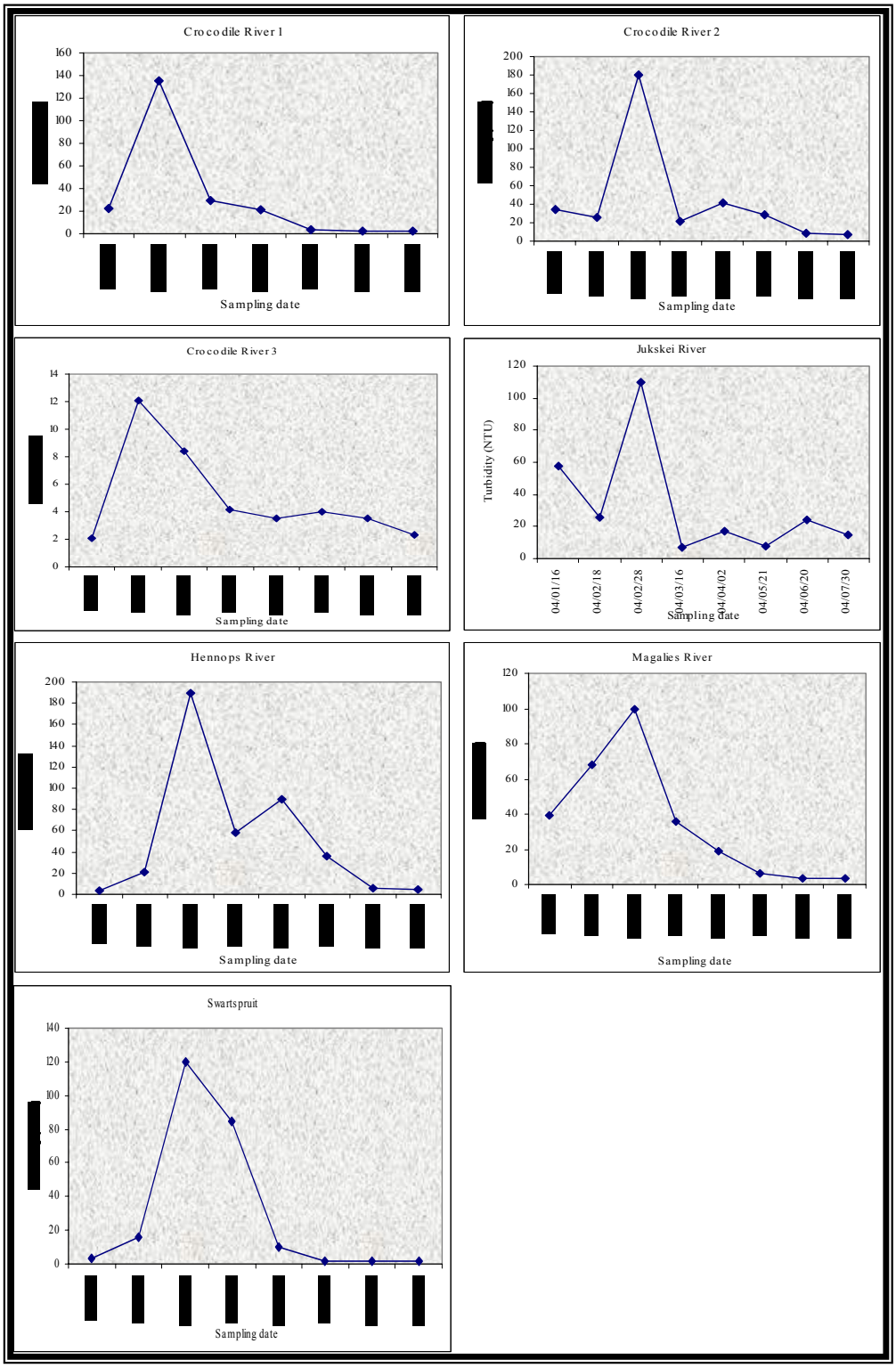
C2. Calcium concentrations



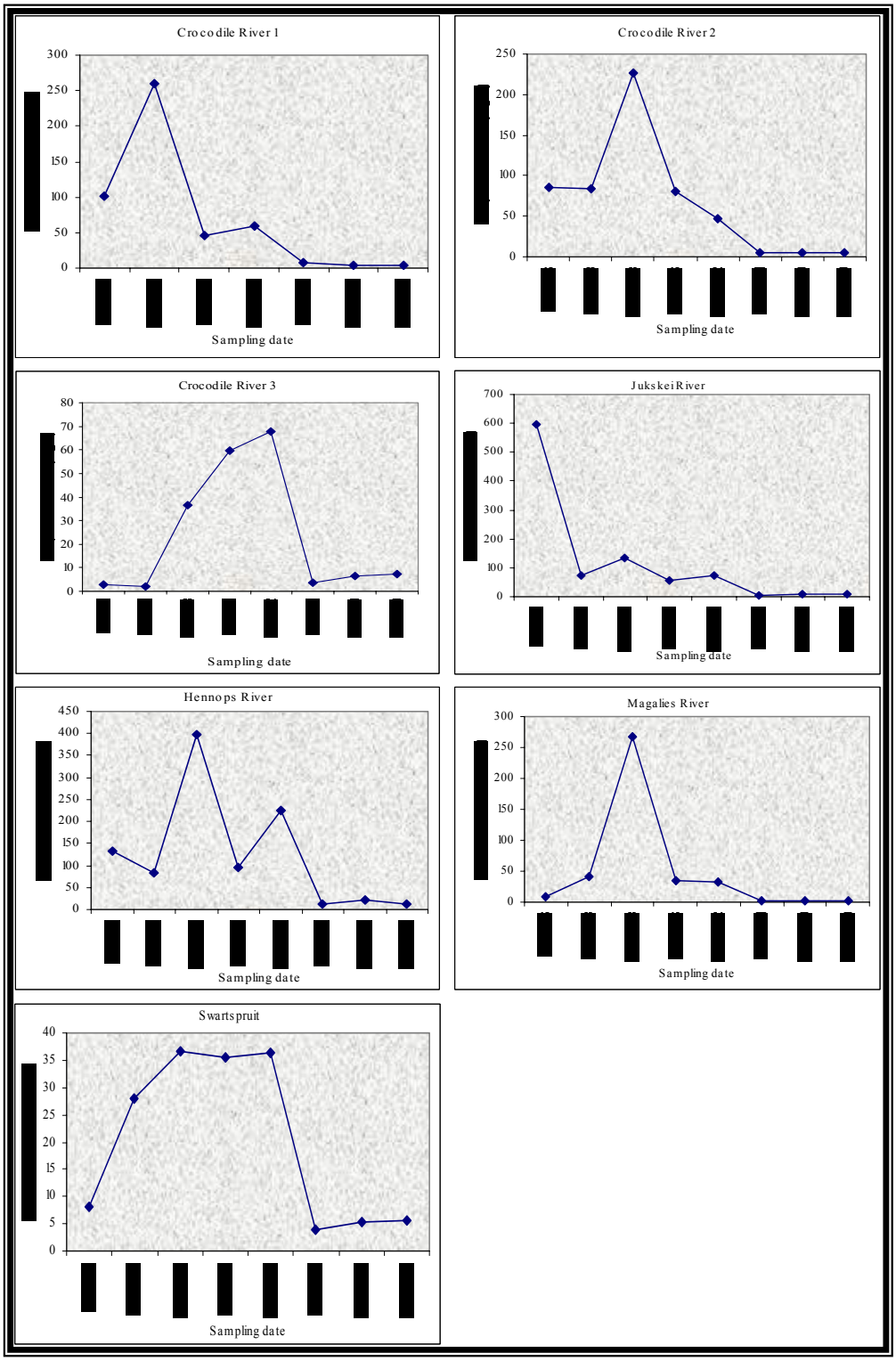
C3. Dissolved oxygen concentrations



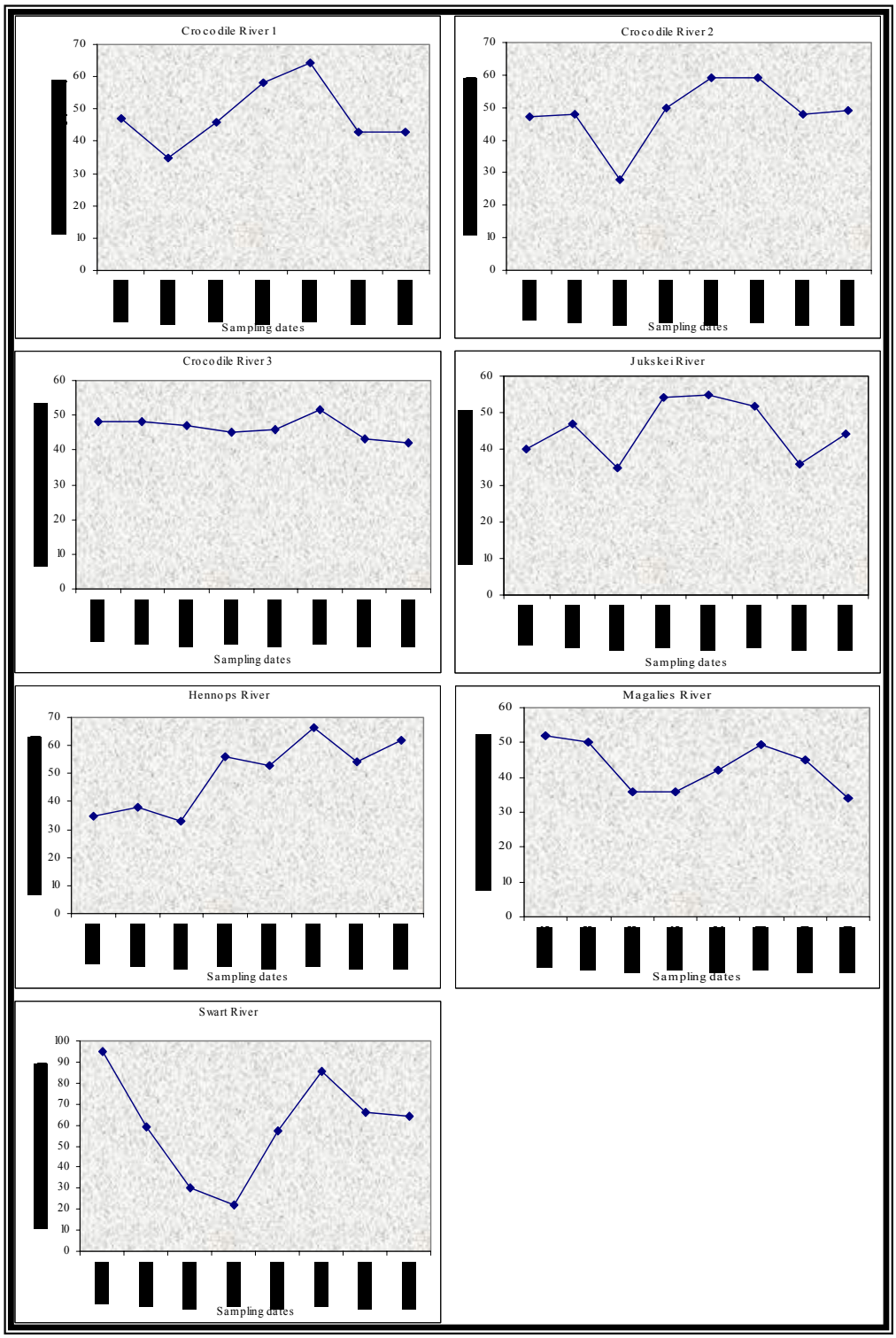
C4. Turbidity



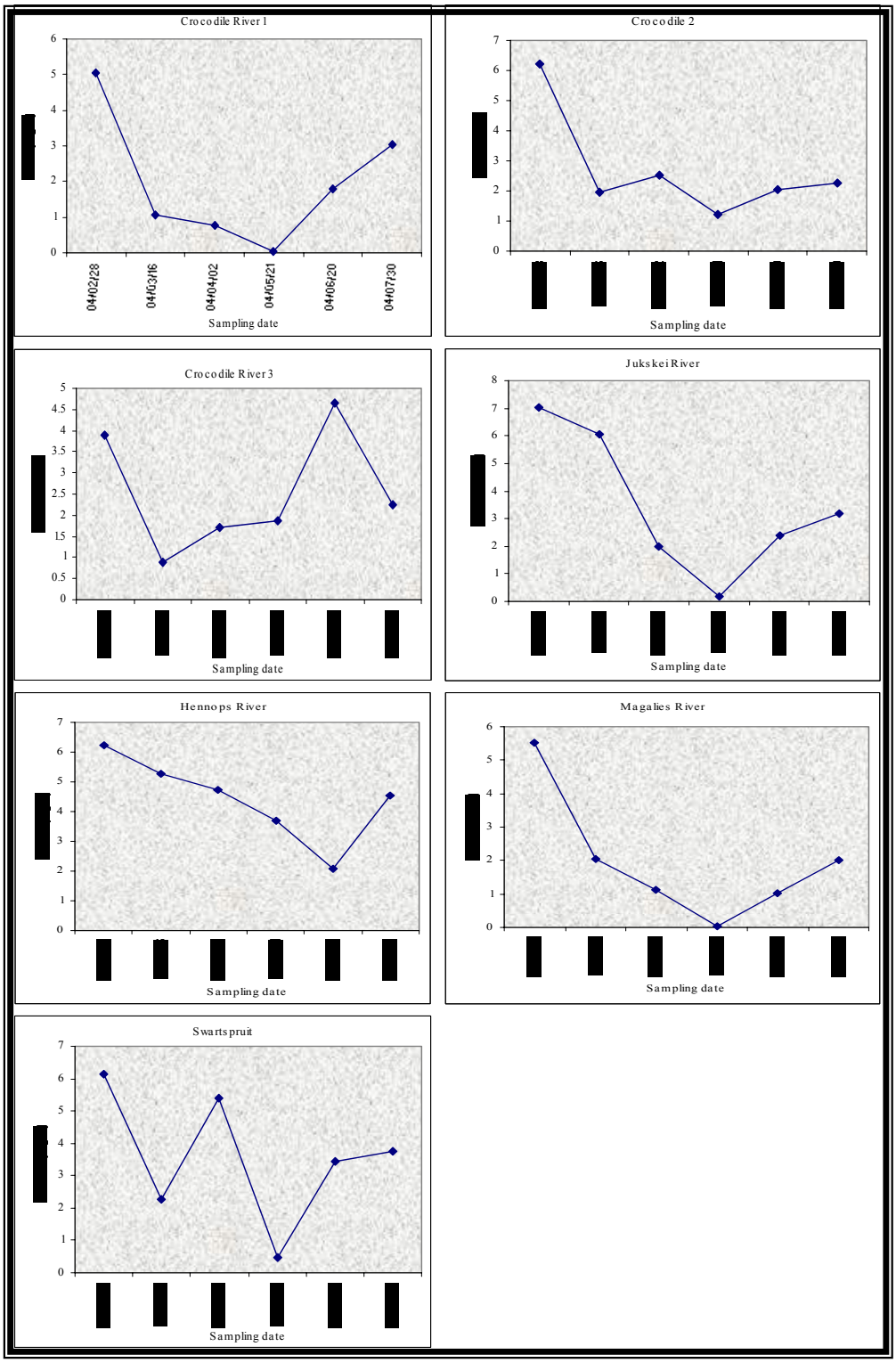
C5. Suspended solids



C6. Electrical conductivity



C7. Biochemical oxygen demand (BOD_5)



C8. Chloride concentrations

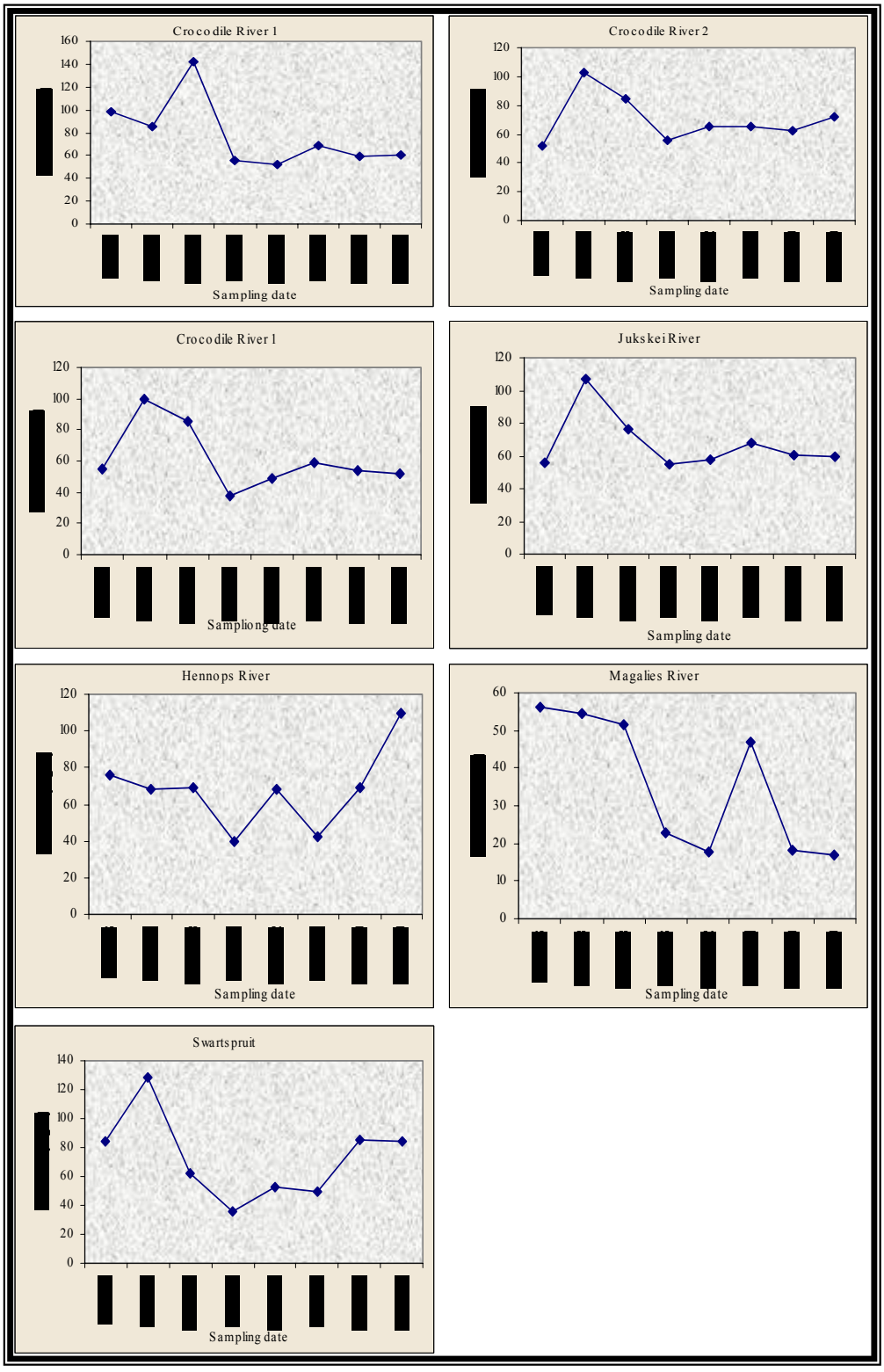


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