POLLUTION INCIDENT IN THE ROODEPLAAT DAM,

May 2000

by

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IWQS

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EXECUTIVE SUMMARY

This report was written as a result of a pollution incident in the Pienaars River, flowing into the Roodeplaat Dam that was reported to the IWQS by Prof. Cock from Wits University. This initiated, in addition to the regular monitoring, an *ad hoc* investigation to determine the cause and extent of the incident.

The Roodeplaat Dam is situated north-east of Pretoria at the confluence of the Pienaars River, the Moreleta/Hartbees- and the Edendalespruit. The Roodeplaat Dam is hyper-eutrophic due to various nutrient inputs from the catchment, especially two Water Care Works (servicing formal residential areas and industries), diffuse sources (including extensive agricultural feedlots and informal settlements) and the re-circulation of nutrients from the bottom sediments in the impoundment.

The report discusses the historical trends of eutrophication related variables in the impoundment and highlights the increasing deterioration of the water quality in the Roodeplaat Dam that led to the incident.

Conclusions

- The deteriorating water quality (the Roodeplaat Dam is a hyper-eutrophic impoundment) led to the eutrophication symptoms, in the form of a large toxic cyanobacterial bloom in the south-western inlets, and led to the reported pollution incident investigation. The results indicated that there was slight microbiological pollution present in the Pienaars River and the Moreleta/Hartbees Spruit tributaries that flow into the Roodeplaat Dam. The origin of this pollution is probably human wastes in the Pienaars River and animal wastes in the Moreleta/Hartbees Spruit and is usually associated with nutrient influxes.

- To manage the eutrophication related water quality problems in the Roodeplaat Dam, the actual sources of the high nutrient concentrations and the microbiological pollution need to be determined and controlled.

- The incidence of cyanobacterial toxin production in the Roodeplaat Dam should also be determined.

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1. INTRODUCTION

This report was written as a result of a pollution incident in the Pienaars River, flowing into the Roodeplaat Dam. Prof. Cock, from the University of the Witwatersrand, reported the incident to the IWQS on 25 May 2000 after she used the impoundment for recreational purposes over the weekend of 20-21 May 2000. She noticed a foul smelling patch (Site A in Figure 1) in the Pienaars River upstream of the confluence with the Moreleta/Hartbees Spruit in the Roodeplaat Dam. Many complaints about the state of the water quality of the Roodeplaat Dam were received by DWAF, especially during the summer of 1998 – 1999 (Van Ginkel, unpublished).

In addition to the regular sampling being conducted on the Roodeplaat Dam, the IWQS conducted an *ad hoc* survey to investigate the reported pollution incident. This survey took place on the 26th May 2000. Both the Pienaars River and the Moreleta/Hartbees Spruit were visited and samples were taken. The first sampling event was followed up by a second sampling trip on the 26th June 2000.

Due to the belief of the authors that this pollution incident is merely a symptom of long-term pollution resulting in a water quality problem in the Roodeplaat Dam the report is structured to:

- Initially outline the historical and general water quality situation in the Roodeplaat Dam, and
- To detail the sample results from the *ad hoc* investigation conducted to ascertain the extent of the pollution problem.

The historical overview details the chemical, biological, microbiological and physical properties of the Roodeplaat Dam are given. The historical water quality assessment gives the background to the development of the pollution incident. Eutrophication in the Roodeplaat Dam is discussed in detail as it can be directly linked to the 'pollution incident'.

2. SAMPLING METHODS AND ANALYSES

The water quality of the Roodeplaat Dam is monitored on a regular weekly basis at five sites of which only two (Sites 1 and 7) will be discussed in this report. Site 1 was chosen because it is near the dam wall, at the deepest site in the impoundment and when compared to Site 7 will give a spatial view of water quality change, if any, in the impoundment. Site 7 was chosen because it is the closest regular site to the impacted areas and would give a good background to the historical water quality in this area of the impoundment. The additional *ad hoc* sites (Sites A and B) were visited twice during the period of a month to determine the cause and extent of the pollution incident.

2.1 Sampling methods

Routine water quality samples were taken with a 5 m hose-pipe at Site 1 and 7 (Figure 1). This method of sampling provides an integrated sample representative of the top 5 meters of the water column. These samples were then poured into separate sampling bottles for macro-chemical analyses and biological sampling analyses. The macro (major inorganic chemical constituent) samples were preserved with $HgCl_2$ and the algal identification samples were preserved in 1 mℓ Lugol's solution.

The *ad hoc* sampling was done by taking grab samples as the sites were too shallow for hose-pipe sampling. These water samples were then poured into the appropriate sampling bottles, preserved and transferred to the laboratories within an hour. As the origin of the pollution incidents was not known samples were collected to do macro-, trace metal and biological analyses. The microbiological samples were taken separately by submersion of the sterilised bottles in the water.

Physical measurements were taken *in situ* with the exception of pH. The temperature and oxygen readings were taken with a YSI 95 oxygen and temperature meter and the pH reading was determined in the Macro Elements Laboratory at the IWQS.

2.2 Analysis methods for routine and *ad hoc* sampling

2.2.1 Macro chemical samples including Kjeldahl nitrogen (KN) and total phosphorus (TP) analysis are taken on a weekly basis at the five regular sites within the Roodeplaat Dam. The analyses included are pH, ammonium (NH_4-N), nitrate and nitrite (NO_3 + NO_2 as N), fluoride (F), alkalinity as calcium carbonate (ALK), sodium (Na), magnesium (Mg), silicon (Si), ortho-phosphorus (PO_4-P), sulphate (SO_4), chloride (Cl), potassium (K), calcium (Ca), electrical conductivity (EC), and total dissolved salts (TDS). The methods used to determine these variables are discussed in detail in the IWQS (1999) document.

2.2.2 Biological samples were analysed by the biological laboratory of the IWQS. Samples were tested for chlorophyll-*a*, phaeophytin-*a*, total suspended solids (TSS) and algal identifications. The methods used to determine the results are discussed in detail in the IWQS (2000a) document.

2.2.3 The microbiological samples were analysed by the microbiological laboratory of the IWQS. The variables determined are faecal coliforms, faecal streptococci and *Escherichia coli*. The analytical methods are discussed in detail in the IWQS (2000a) document.

2.2.4 The Trace Metal Laboratory of the IWQS conducted the trace metal analyses. The analyses included are dissolved beryllium (Be), boron (B), aluminium (Al), titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), strontium (Sr), zirconium (Zr), molybdenum (Mo), cadmium (Cd), barium (Ba), mercury (Hg), and lead (Pb). The standard methods used to determine these variables are discussed in detail in the IWQS (2000b) document.

2.2.5 The microcystin analyses to determine algal toxins were done by the Organic Laboratory of the IWQS, using two methods. Firstly, the ELISA screening method was used. This method is a quick screening method to test for microcystins-LR, YR, RR and nodularin. Secondly, the determination of the specific cyanobacterial toxin was done on a High Pressure Liquid Chromatograph (HPLC).

3. STUDY AREA

The Roodeplaat Dam is situated at the confluence of the Pienaars River, the Moreleta/Hartbees Spruit, and the Edendalespruit, 20 km north-east of Pretoria. These rivers drain the highly populated areas of northern and eastern Pretoria. The catchment includes two point sources, namely, a) the Baviaanspoort Water Care Works (WCW) situated on the Pienaars River, and b) the Zeekoegat WCW that discharges directly into the Roodeplaat Dam at the Canoe Club. Diffuse sources include formal and informal settlements, as well as agricultural activities along the banks of the tributaries (Hohls *et al.* 1998). The impoundment is used extensively for recreational purposes. A recent publication stated that the Roodeplaat Dam is highly eutrophic (Hohls, *et al.* 1999).

The impoundment is an important recreational resource (fishing, canoeing, and other water related uses) for the greater Gauteng area. The water is, therefore, used for direct contact - and semi-contact recreation.

Routine sampling is done at 5 sites on the Roodeplaat Dam. Only two of the routine sites (Site 1 and 7) will be discussed in this report to show the variation between Sites 1 and 7. Site 1 is at the dam wall and is, therefore, the site at which the water depth is the greater of the two sites. It has a maximum depth of 40 m. Site 7 is a shallow site with a maximum depth of 7 m and is situated at the confluence of the Pienaars River and the Moreleta/Hartbees Spruit on the Roodeplaat Dam. Site 7 is, therefore, comparable to the affected sites.

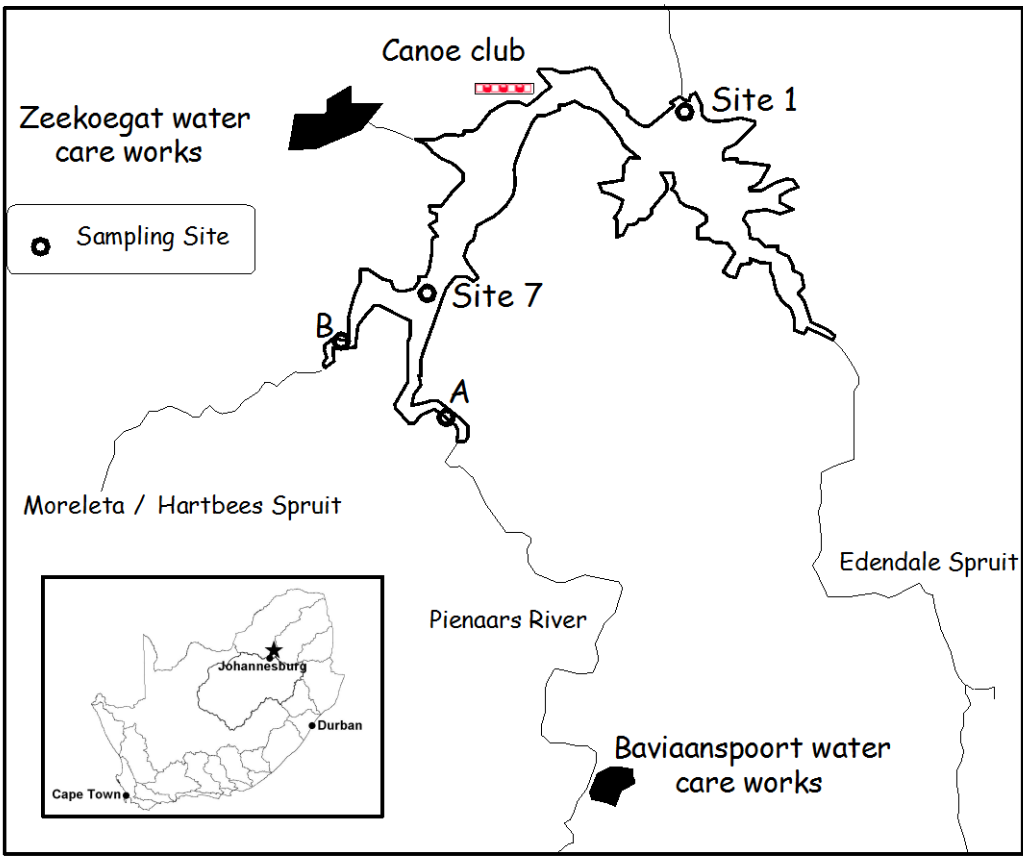

Figure 1. Sampling sites on the Roodeplaat Dam.

4. RESULTS AND DISCUSSION

The results are discussed under chemical characteristics, biological characteristics, physical characteristics, the trophic status of the impoundment, with the reported 'pollution incident' being discussed lastly. The results indicate clearly that the main cause of the 'pollution incident' is caused by the enhanced eutrophication due to the various inputs of nutrients into the impoundment. Therefore, the historical trends in nutrient concentrations and the trophic status of the impoundment are also discussed.

4.1 <u>Historical water quality properties of the Roodeplaat Dam</u>

4.1.1 Chemical characteristics

The chemical results are subdivided into nutrients and salinity as these two chemical groups pose two of the major threats to the water quality of South Africa's fresh water resources.

Nutrients

a) Phosphorus

The historical data of the Roodeplaat Dam at Site 1 (Figure 2) has shown a gradual increase in the mean annual TP and PO_4-P concentrations since 1991. The mean annual TP concentrations have also been above the total phosphorus management objective (PMO) value of 130 µg/ℓ (DWA 1988, ANON 1988a, ANON 1988b) since 1991 (Figure 2). This places the Roodeplaat Dam in the hyper-eutrophic class. This, in view of the fact that both the WCW's are required to comply with the 1 mg/ℓ P Standard, should be a serious concern to the managers of the impoundment. The Zeekoegat WCW was constructed and started to operate in late 1991, while the Baviaanspoort WCW was in operation prior to 1991.

The trends in the TP and the PO_4-P concentrations at Sites 1 and 7 (Figures 3) clearly show the general increases in concentrations of both variables since 1991. What is alarming about this is the fact that the TP concentration is increasingly dominated by PO_4-P (Figure 4). This increase is in such a manner that PO_4-P now forms the major component of the TP concentration. This phenomenon indicates that most of the phosphorus in the system is directly available for primary growth of algae and macrophytes within the impoundment and is most probably the main cause for the reported 'pollution incident'.

The minimum, maximum and mean TP concentrations at Site 1 are 0.012, 3.207 and 0.288 mg/ℓ respectively, for the period 1989 to 2000. The minimum, maximum and mean TP concentrations at Site 7 are 0.046, 1.046 and 0.354 mg/ℓ respectively, for the same period. This indicates that although the maximum TP concentrations at Site 1 is higher than that at Site 7, the mean TP concentration at Site 7 is much higher. Site 7 is, therefore, more subject to eutrophication symptoms.

The minimum, maximum and mean PO_4-P concentrations at Sites 1 are 0.005, 1.294 and 0.177 mg/ℓ respectively, for the period 1989 to 2000. The minimum, maximum and mean PO_4-P concentrations at Site 7 are 0.005, 0.708 and 0.226 mg/ℓ respectively, for the same period. This indicates the same tendency as was evident for TP. There is, therefore, more inorganic phosphorus directly available for algal or macrophyte growth at Site 7 than Site 1.

This tendency of higher mean phosphorus concentrations may be due to a number of reasons, namely 1) higher loads of phosphorus through the Pienaars River and the Moreleta/Hartbees Spruit tributaries, 2) higher contributions of phosphorus through recycling of phosphorus from the sediments due to the shallowness of the site, or 3) from recycling of phosphorus from the natural die-off of the phytoplankton population.

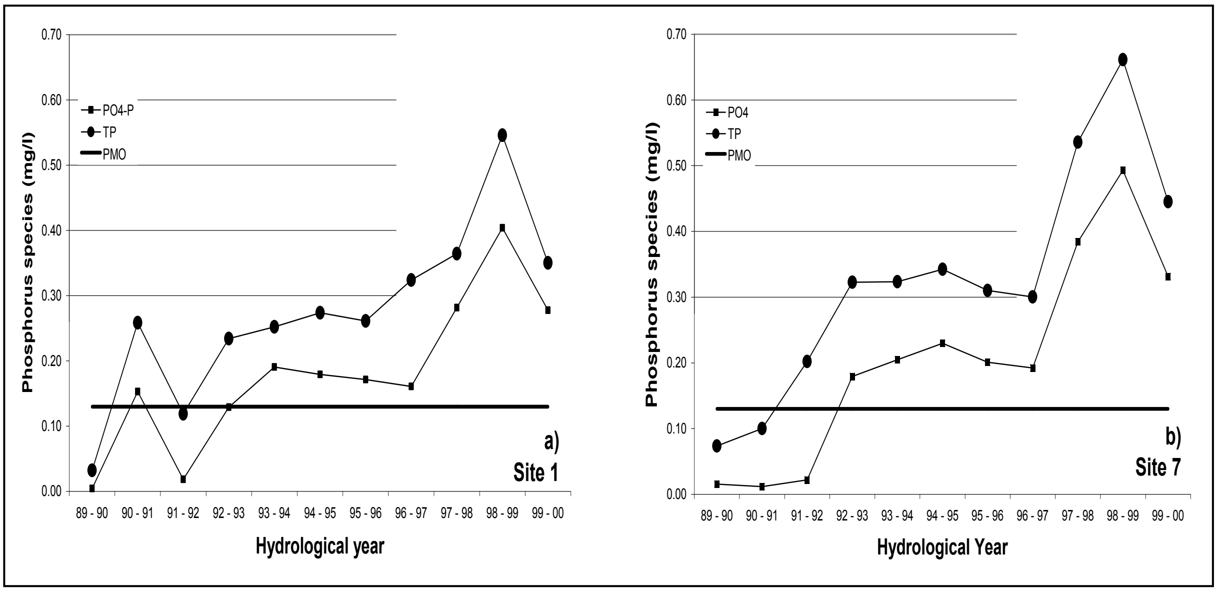

Figure 2. Changes in mean annual TP and PO4-P concentrations in the Roodeplaat Dam (1989–1999). a) Site 1 b) Site 7. PMO = Phosphorus Management Objective for TP concentrations.

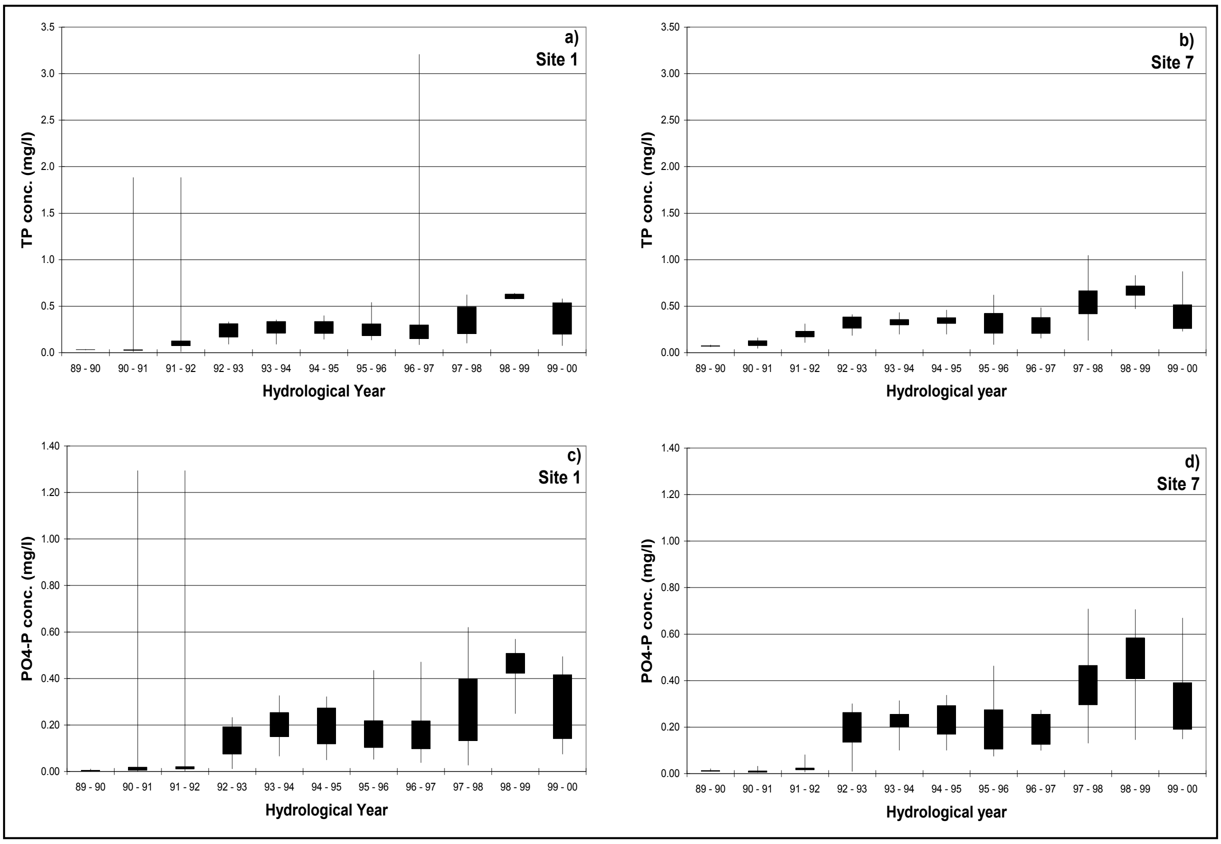

Figure 3. Boxplots showing the historical trends of the TP and PO4-P concentrations in the Roodeplaat Dam at Site 1 (a and c) and Site 7 (b and d). The boxplots show the minimum, maximum, 25th percentile and the 75th percentile for each hydrological year.

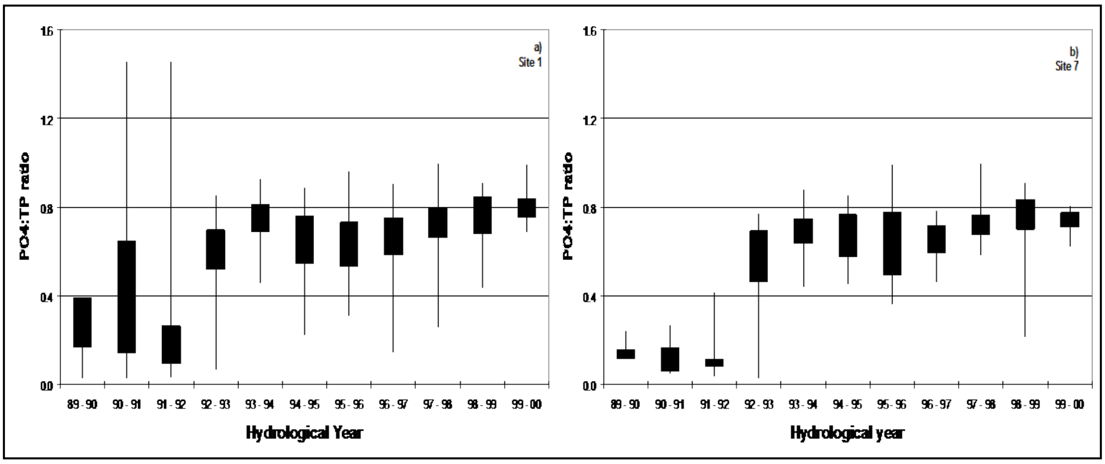

Figure 4. The historical trend in the PO4:TP ratios in the Roodeplaat Dam during the period 1989 to 2000 at a) Site 1 and b)Site 7.

The phosphorus concentrations in the Roodeplaat Dam are, therefore, a major concern in the incidence of decreasing water quality. The concentrations also indicate higher mean TP and PO_4-P values at Site 7 than Site 1, showing that the Pienaars River and Moreleta/Hartbees Spruit region of the impoundment is more highly impacted than the dam wall site.

b) Nitrogen

The mean annual TN concentrations (calculated as the sum of the KN and NO_3+NO_2) at Site 1 and 7 (Figure 5), compared to those of TP and PO_4-P, in the impoundment did not show similar orders of magnitude increases in concentration during the study period. There were, however, noticeable increases in the total nitrogen (TN) and dissolved inorganic nitrogen (DIN) concentrations at both Sites 1 and 7. Despite this phenomenon, the nitrogen concentrations are still within the Target Water Quality Range (TWQR) as set by DWAF for the aquatic environment (DWAF, 1966) for dissolved inorganic nitrogen and the concentrations even decreased slightly after 1994.

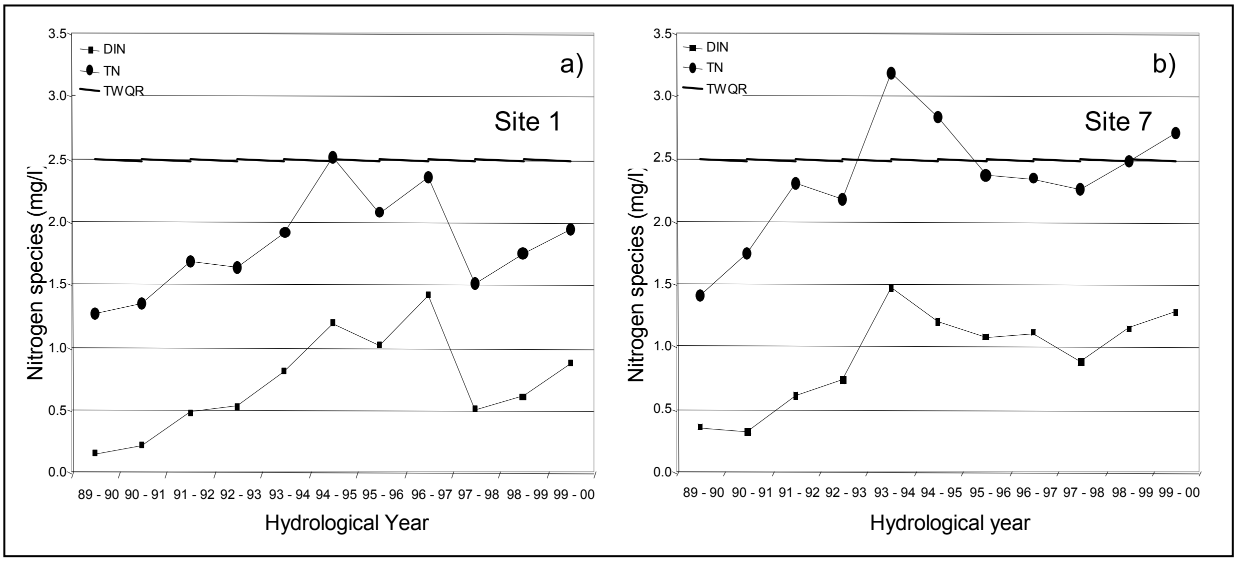

Figure 5. Mean annual concentration for TN (KN & NO3-N+NO2-N) and DIN (NO3-N+NO2-N & NH4-N) in the Roodeplaat Dam (1989 – 1999) compared to the TWQR for dissolved inorganic nitrogen (DWAF 1996c) at a) Site 1 and b) Site 7.

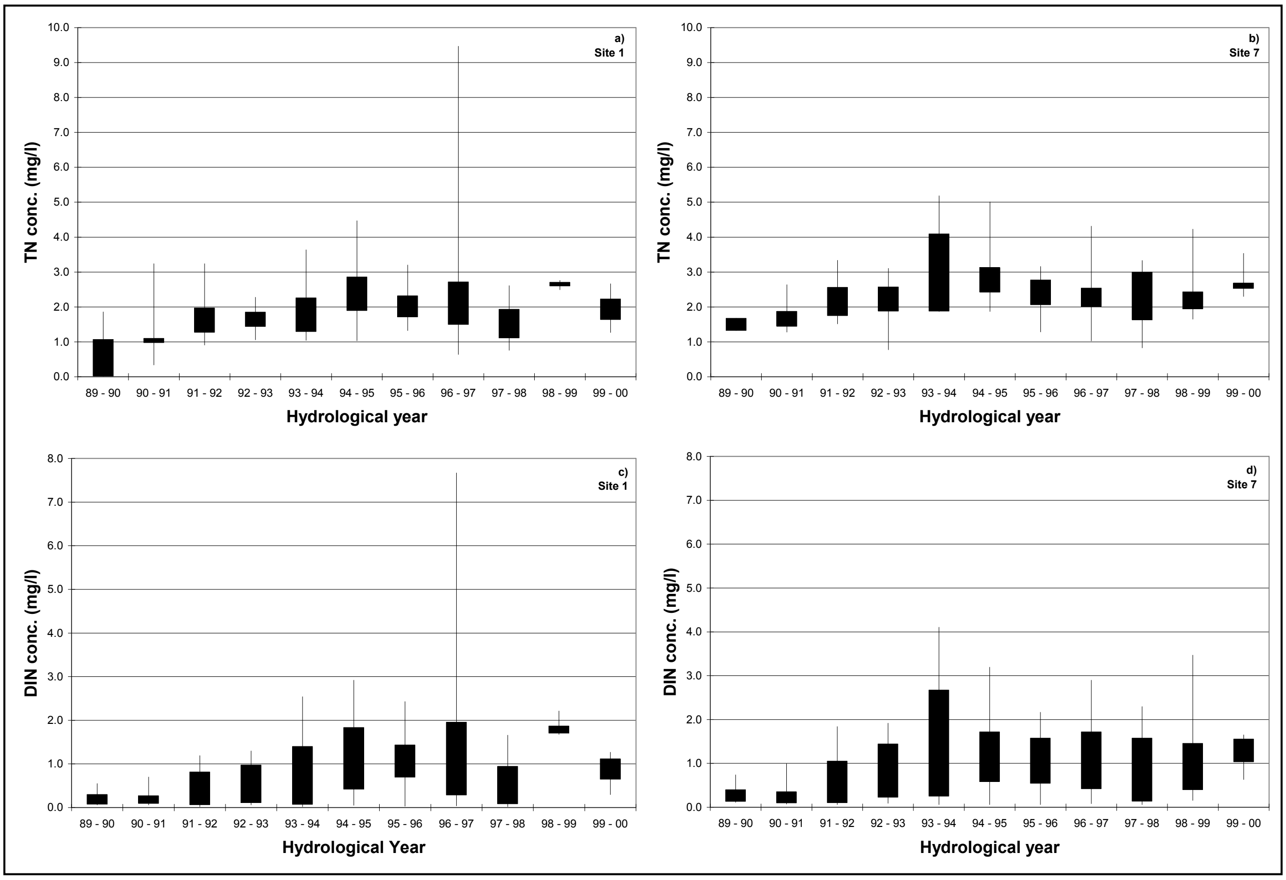

Figure 6. Boxplots showing the historical trends of the TN and DIN concentrations in the Roodeplaat Dam at Site 1 (a and c) and Site 7 (b and d). The boxplots show the minimum, maximum, 25th percentile and the 75th percentile for each hydrological year.

The TN and DIN nitrogen concentrations showed the highest maximum of 9.47 mg/ℓ at Site 1. However, the TN concentrations at Site 7 were generally higher than at Site 1 (Figure 6). The same phenomenon of increased nitrogen concentrations since 1991 is shown in Figure 6, at both the sampling sites.

The minimum, maximum and mean TN concentrations at Site 1 are <0.08, 9.47, and 1.83 mg/ℓ respectively, for the period 1989 to 2000. The minimum, maximum and mean TN concentrations at Site 7 are 0.78, 5.18, and 2.37 mg/ℓ respectively, for the same period. Showing the same higher mean TN tendency at Site 7, compared to Site 1.

Overall, the nitrogen concentrations were within the TWQR for DIN. There were, however, outliers found during 1996 to 1997. Nitrogen does, therefore, contribute to the increased eutrophication in the Roodeplaat Dam as can be seen from the increased incidence of eutrophication symptoms such as extreme algal blooms and nuisance aquatic weed development.

c) TN:TP ratio

The TN:TP ratios are used to determine the limiting nutrient within a system. A TN:TP ratio of greater than 15:1 signifies phosphorus limitation. From an eutrophication management perspective this is the desirable situation as P input into the system is easier to manage. Low phosphorus concentrations also favour green algae, which may be less problematic to manage than cyanobacteria that are commonly linked to the production of toxins. In contrast, a TN:TP ratio less than 10:1 signifies nitrogen limitation. From an eutrophication viewpoint this is a less desirable situation since some of the cyanobacteria are able to fix atmospheric nitrogen and are, therefore, not so dependant on dissolved nitrogen being present. Atmospheric nitrogen is not available to green algae and because of this the low TN:TP ratio indicating nitrogen limitation favours cyanobacteria development and encourages their dominance in a system.

The mean annual TN:TP ratios (Figure 7) followed a decreasing trend where nitrogen has been the limiting nutrient since 1990. This might be the effect of the extremely high input of phosphorus into the system (Figure 2 and 3), while the nitrogen trends in the Roodeplaat Dam increased only slightly. The direct input of effluent into the Roodeplaat Dam from the Zeekoegat Water Care Works (which is situated on the western side of the Roodeplaat Dam) might have contributed significantly towards the changes in nutrient ratios.

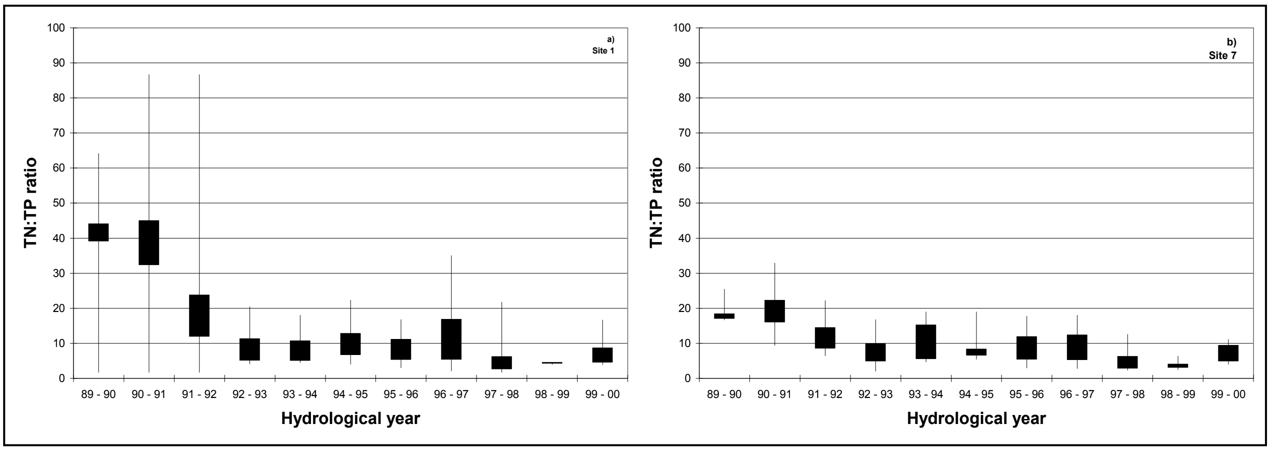

Figure 7. TN:TP ratios in the Roodeplaat Dam at a) Site 1 and b) Site 7 for the period 1989 to 2000.

Salinity

The salinity in the Roodeplaat Dam is only expressed as electrical conductivity (EC). The Roodeplaat Dam does not seem to have problems regarding the salt content in the impoundment. The EC readings varied between 30 mS/m and 60mS/m for the whole study period (Figure 8). The water in the Roodeplaat Dam is, therefore, within the South African Water Quality Guideline for aquatic ecosystems of 450 mg/ℓ total dissolved salts (TDS) (an EC of ±70 mS/m) (DWAF 1996).

The composition of the inorganic salts governs the effects of the TDS. The proportional concentrations of the major ions affect the buffering capacity of the water and hence the metabolism of organisms in the water bodies. Most commonly, the relative concentrations of the major ions tend to be the same as was found in the Roodeplaat Dam (Na^+ (38.4 mg/ℓ) > Ca^{2+} (24.7 mg/ℓ) > Mg^{2+} (15.2 mg/ℓ) > K^+ (7.19 mg/ℓ). The anions show the tendency where Cl^- (40.5 mg/ℓ) > HCO_3^- > SO_4^{2-} (36.7 mg/ℓ) > CO_3^{2-}). The water in the Roodeplaat Dam can, therefore, be described as hardwater where Cl^- predominates. This phenomenon is typically when large volumes of sewage effluent contribute to the water resource. This anion is usually not dominant in open lake systems, but pollution sources of chlorides can modify the natural concentrations (WETZEL, 1983) which is most probably the case in the Roodeplaat Dam. High mean Na^+ (40 mg/ℓ) concentrations were found to be optimal for several cyanobacteria (WETZEL, 1983). The high Na^+ concentrations in the Roodeplaat Dam are, therefore, contributing to the development of the cyanobacterial blooms in the Roodeplaat Dam.

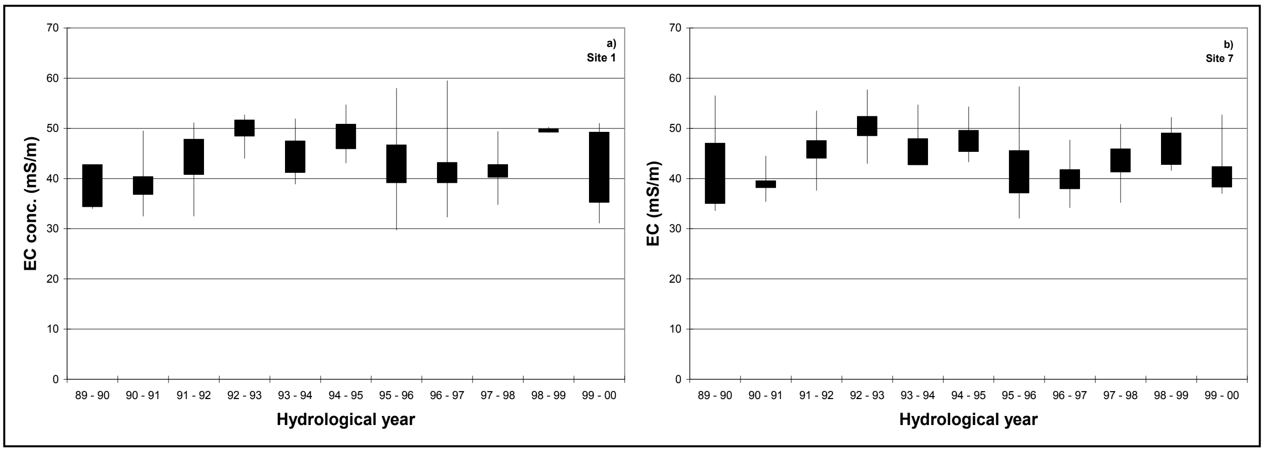

Figure 8. The EC readings in the Roodeplaat Dam at a) Site 1 and Site 7 for the period 1989 to 2000.

Trace metals

According to Hohls *et al.* (1999) the trace metals in the Roodeplaat Dam do not pose any problems, although manganese concentrations in the water abstracted from 20 m depth at the dam wall have previously been found to potentially have aesthetic effects on the end users. These constituents will not be discussed any further.

4.1.2 Biological characteristics

The Roodeplaat Dam has shown increased incidences of toxic cyanobacterial blooms. *Eichhornia crassipes* (the water hyacinth is a macrophyte) was also found in the Roodeplaat Dam for the first time during 1999.

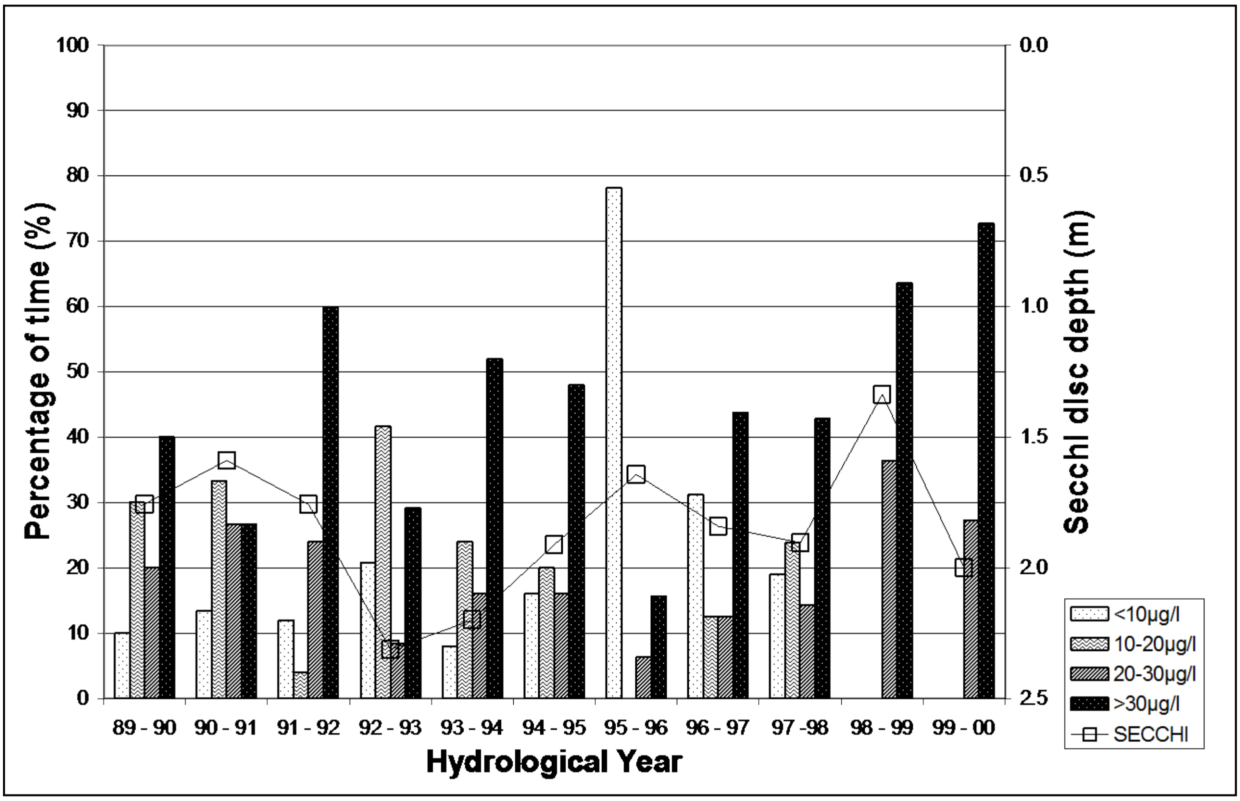

Figure 9. Per cent of the time that chlorophyll-a falls within a specified range of concentrations in the Roodeplaat Dam, at Site 1

a) Chlorophyll-*a* and the phytoplankton population

The data from the Roodeplaat Dam are quite extensive since the IWQS conducts weekly sampling at the impoundment. The ranges of chlorophyll-*a* concentrations at Site 1 in the Roodeplaat Dam are shown in Figure 9. These results indicate that the Roodeplaat Dam experienced algal blooms for more than 20 per cent of the time during all of the hydrological years during the assessment period, except during the 1995 to 1996 year. This is as expected, since the nutrient concentrations are very high and the Roodeplaat is a clear system with low light limitation to algal growth. The mean annual dominance of the cyanobacteria (Figure 10) indicate that the Roodeplaat Dam is subject to potential toxic algal blooms, as was confirmed during the summers of 1998 to 1999 and 1999 to 2000.

Another alarming phenomenon is the fact that the chlorophyll-*a* concentrations at Site 1 during the last two hydrological years were never below the level of 20 µg/ℓ (See Table 1), indicating that the system does not recuperate at any time during these years. The minimum, maximum and mean chlorophyll-*a* concentrations at Site 1 were respectively, 1.7 µg/ℓ, 243 µg/ℓ and 35.3 µg/ℓ for the period 1989 to 2000. At Site 7 the minimum, maximum and mean chlorophyll-*a* concentrations were respectively, 6.1 µg/ℓ, 136.0 µg/ℓ and 47.3 µg/ℓ, for the period 1997 to 2000.

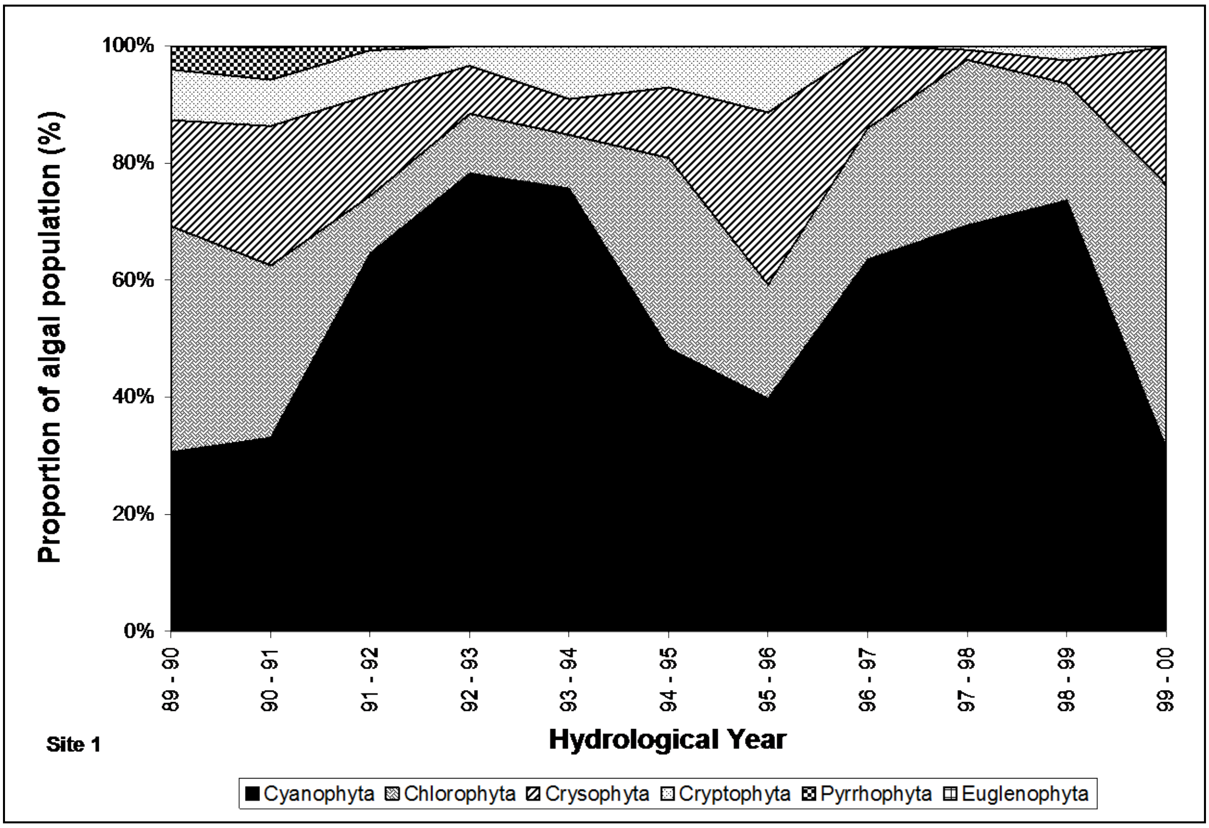

Figure 10. Mean annual composition of algal groups in the Roodeplaat Dam at Site 1.

The cyanobacteria (especially *Microcystis* and *Anabaena* genera) formed the dominant algal group for most of the study period (Figure 10). The cyanobacteria form more than 30 per cent of the phytoplankton population annually. This is an indication that the Roodeplaat Dam is in a serious state of eutrophication and management measures should be taken to improve the situation. Chlorophyta (e.g. *Staurastrum* and *Scenedesmus*), Chrysophyta (*Melosira* and *Cyclotella*) and Cryptophyta (*Cryptomonas*) formed significant parts of the phytoplankton population throughout the study period (Van Ginkel *et al.*, 2000). It is interesting to note that the Pyrrhophyta and the Cryptophyta seem to have disappeared and decreased, respectively, from the phytoplankton population during the last eight years. This might be indicative of the extremely enriched state of the impoundment that is reflected in the phytoplankton population.

The Chlorophyta and the Chrysophyta still form a considerable proportion of the phytoplankton population, but might only reflect the seasonal differences in the phytoplankton population.

b) Microbiology

Microbiological pollution is also potentially a great threat to the fresh water resources of South Africa.

According to Hohls *et al*. (1999) the overall risk of contracting gastrointestinal illness (as determined by geometric mean of faecal coliform counts) within the dam is low – in the acceptable class for long-term exposure. Isolated samples do, however, reflect that there can be a risk of gastrointestinal illness for the occasional recreational water user (Hohls *et al., 1999)*. This is due to the fact that the Zeekoegat WCW discharges into the impoundment in this section of the Roodeplaat Dam and the Baviaanspoort WCW discharges into the Pienaars River upstream of the impoundment. Informal settlements and livestock agricultural practices may also contribute to microbiological pollution during periods of higher rainfall when the surface wash-off could be a major contributor to microbiological and nutrient loads into the impoundment.

4.1.3 Physical characteristics

The Secchi disc readings (Figure 9) taken at Site 1 show a slight negative correlation with the chlorophyll-*a* concentrations (r^2 = -0.45). The suspended solids and the chlorophyll-*a* concentrations do have a significant correlation (r^2 = 0.58) indicating that the phytoplankton population forms a major component of the suspended matter in the impoundment. This indicates also towards the extent of the phytoplankton development in the Roodeplaat Dam. Considering the Secchi disc readings (Figure 9) of the Roodeplaat Dam, the impoundment is a deep, clear system.

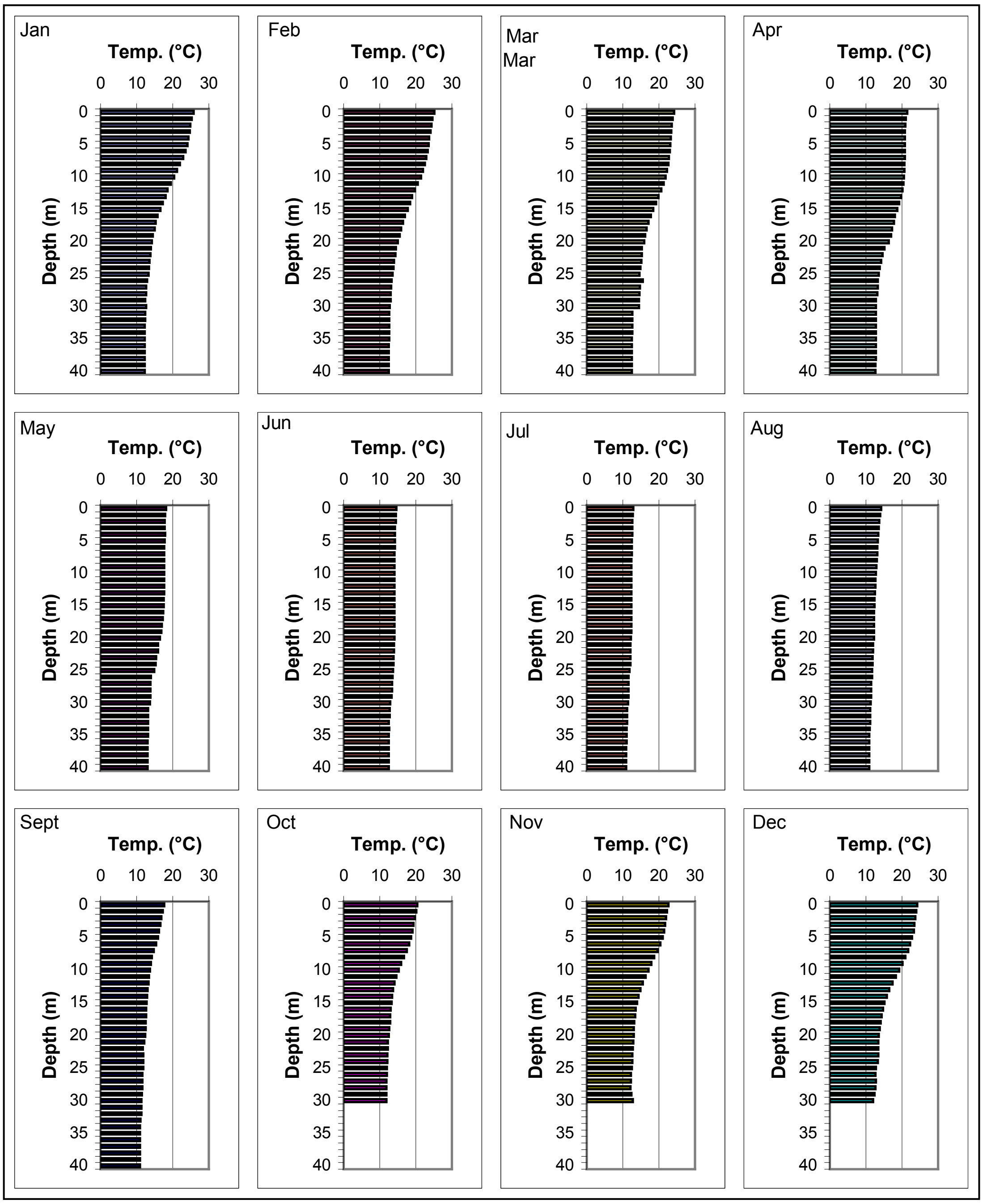

Figure 11. Mean monthly temperature profiles in the Roodeplaat Dam at Site 1 (1980 to 1997)

The mean monthly temperature profiles (Figure 11) indicate a distinct thermocline, which forms between 7 m and 20 m from October to April within Roodeplaat Dam. The mean surface temperatures at Site 1 vary from 12.9 °C to 25.8 °C. Complete mixing, with constant temperatures right through the water column, is present during June and July. This phenomenon coupled to the oxygen contents in the water profile indicates the potential for nutrient releases from the bottom sediments.

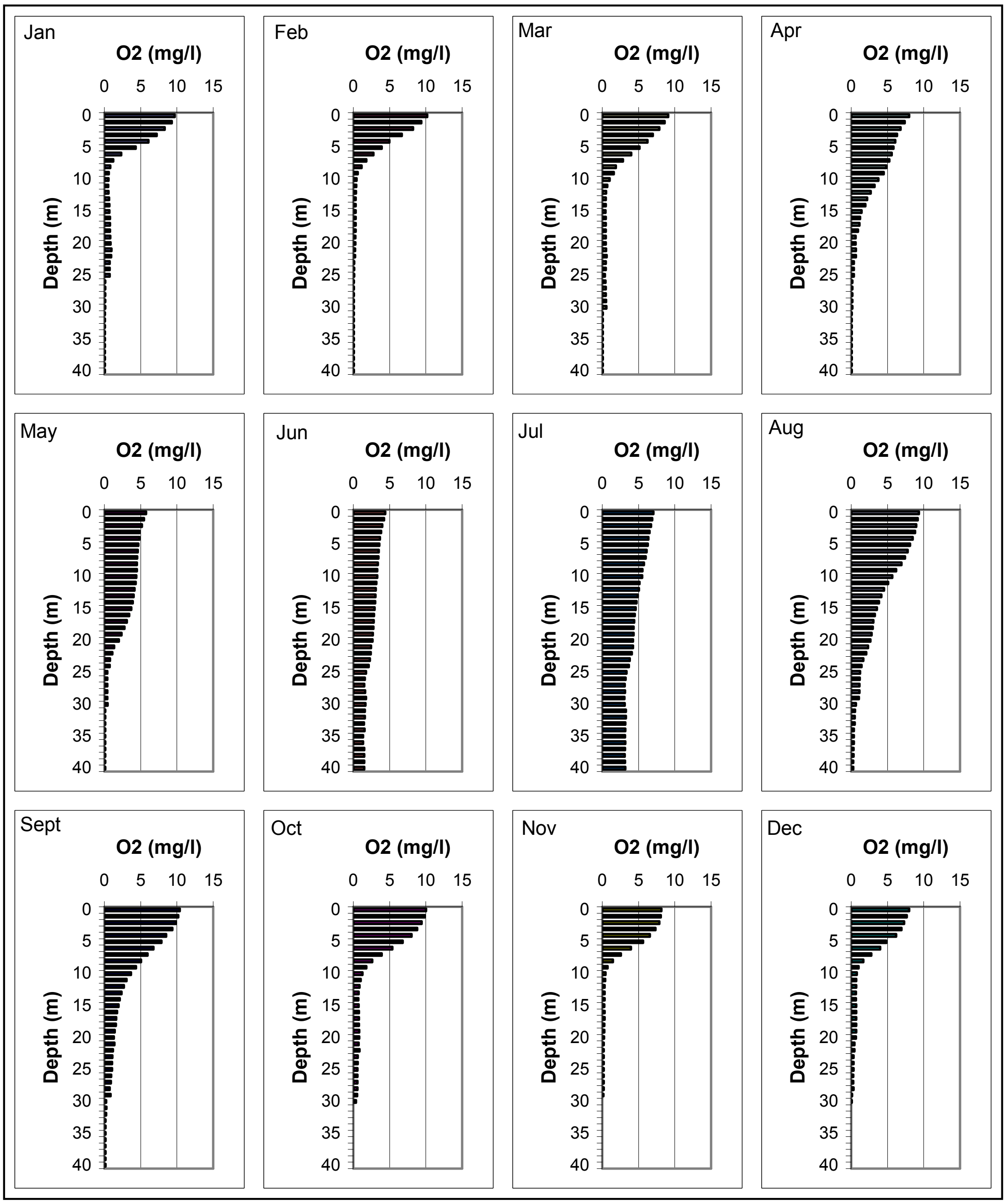

Figure 12. Mean monthly oxygen profiles in the Roodeplaat Dam at Site 1 (1980 to 1997).

The mean monthly oxygen profiles (Figure 12) indicate the extent of anoxic waters in the Roodeplaat Dam at Site 1. The anaerobic hypolimnion establishes itself from August and prevails until April when the anoxic areas decrease until total mixing is present during June and July. The limited oxygenated areas within the profiles are an indication of the extent of eutrophication in the Roodeplaat Dam.

Site 7, shallower than Site 1, would have limnological characteristics similar to the site where the 'pollution incident' manifested itself. The mean monthly temperatures at Site 7 are shown in Figure 13. The warm temperatures during December to March of > 22 °C to a depth of 8 m, show the excellent conditions for primary production in this section of the impoundment. Because the site is shallow and light penetration would, therefore, be high, the conditions favour the development of the cyanobacterial community, especially *Microcystis sp*. that are scum-forming ecostrategists (Chorus and Bartram, 1999). Although the cells have gas vacuoles, the large quantities of carbohydrate, formed when the cells are near the surface during photosynthesis, acts as ballast and induces sinking of the colonies (Utilken et al., 1985). In the deeper, darker water the cells use the carbohydrates to synthesise new gas vacuoles. The ability to regulate their buoyancy enables the colonies to position themselves in optimal light and growth conditions.

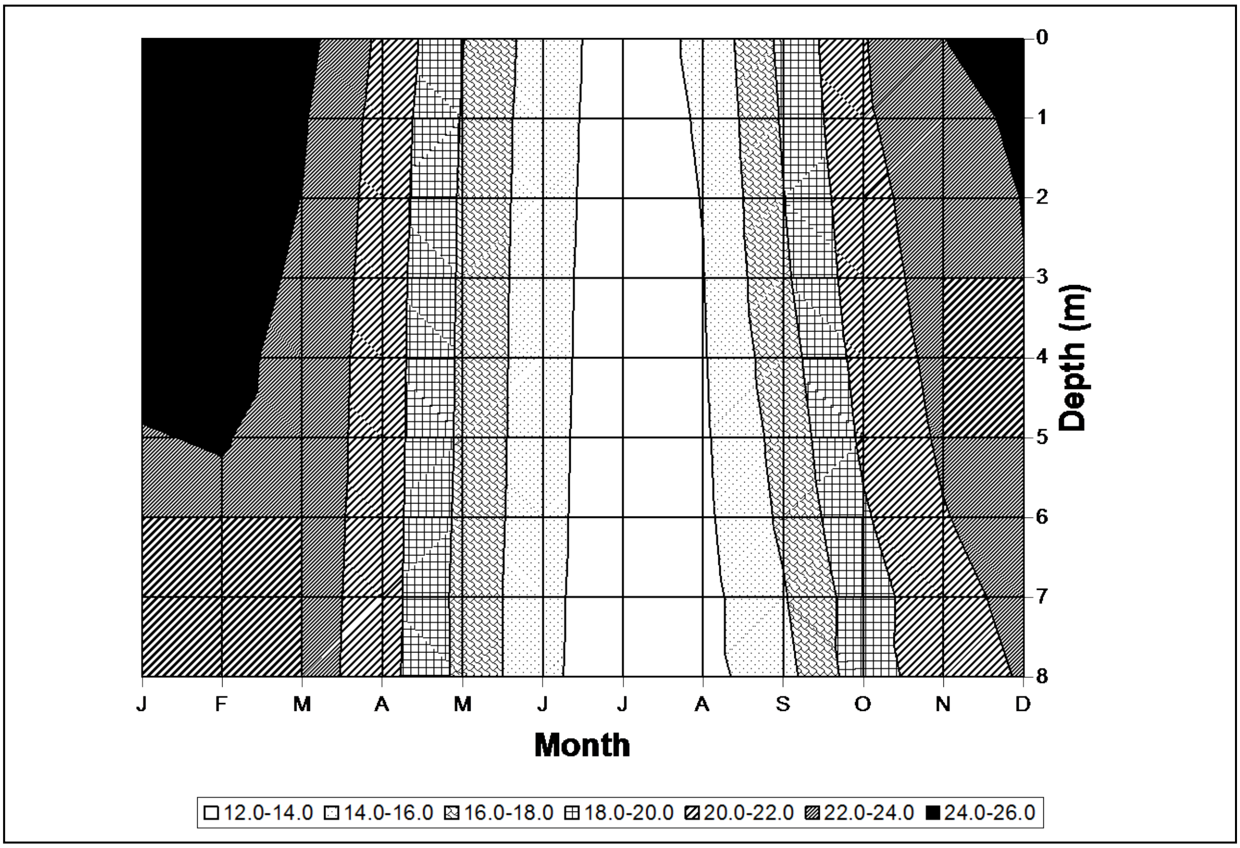

Figure 13. Mean monthly temperature profiles in the Roodeplaat Dam at Site 7 (1990 to 1998). The temperature is expressed in degrees Centigrade.

Figure 14 indicates that the oxygen concentrations at the confluence of the Pienaars River and the Moreleta/Hartbees Spruit (Site 7) in the Roodeplaat Dam are high. During the winter period the oxygen profile shows complete mixing to the bottom waters. However, areas of almost anaerobic conditions prevail near the sediment during the summer periods (November to April). This phenomenon will enhance nutrient releases from the bottom sediments and contributes toward the higher nutrient concentrations and higher chlorophyll-*a* concentrations at this site, as compared to Site 1, as was found by Hohls *et al.* (1999).

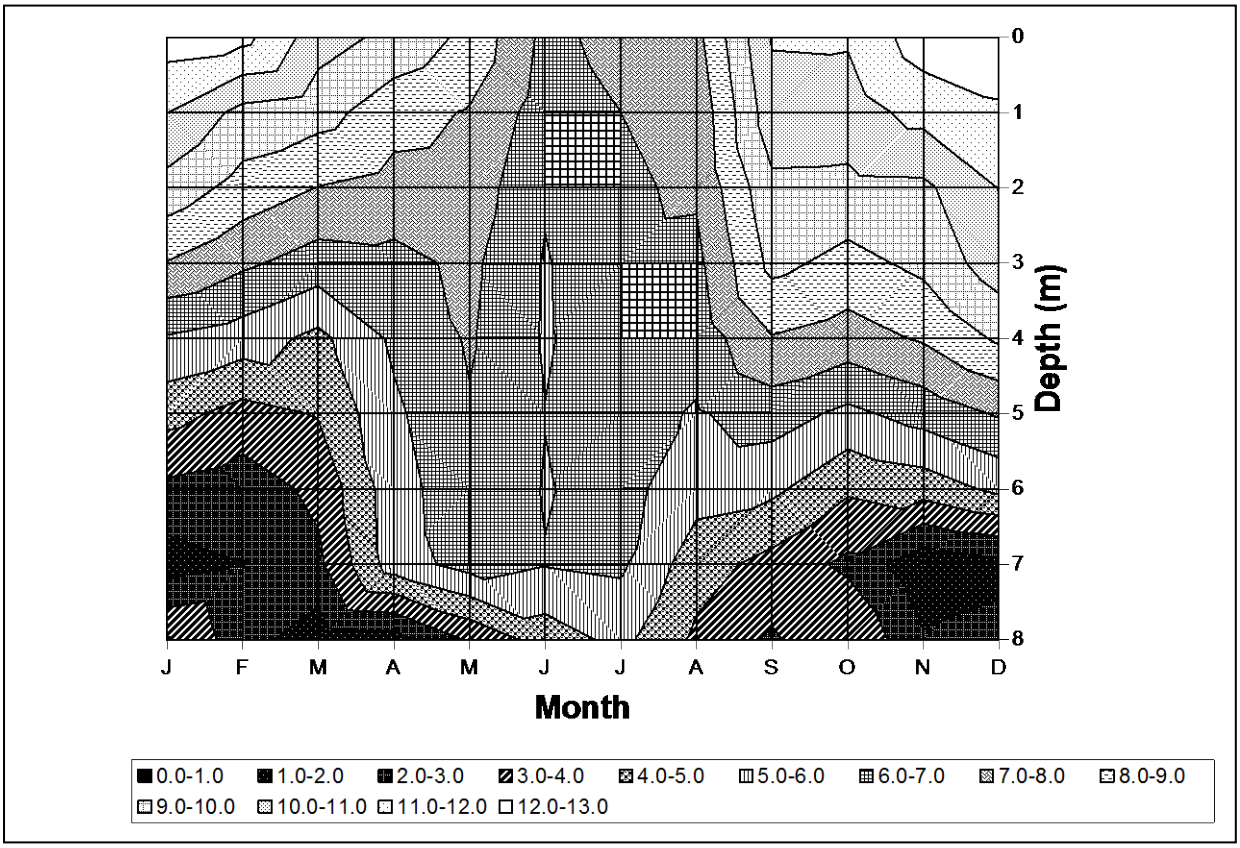

Figure 14. Mean monthly oxygen profiles in the Roodeplaat Dam at Site 7 (1990 to 1998). The oxygen concentration is expressed as mg/ℓ of dissolved oxygen.

4.1.4 Trophic Status of the Roodeplaat Dam

Although decreasing water quality can be attributed to the increasing levels of a number of chemical species, the process of eutrophication describes nutrient enrichment of the water body (Henderson-Sellers and Markland, 1987). The location of a water body along an eutrophication scale from oligotrophic (nutrient poor conditions) to hyper-eutrophic (extreme nutrient enrichment) is called its trophic status.

The trophic status classification method in this report is based on the following variables and is based on the cut-off values as stated in Table 1.

- The **mean annual chlorophyll *a* concentration,** since it is a symptom of eutrophication. Chlorophyll *a* is a direct indicator of the primary production within a system, and represents one of the variables that are used to determine the trophic state of an impoundment or water source.
- The **proportion of the time that the actual chlorophyll-*a* concentrations are greater than 30µg/ℓ (expressed as per cent)**, as formulated for South African conditions by Walmsley and Butty (1980) and Walmsley (1984) as the cut-off value for eutrophic systems. This statistic is used as it indicates the potential duration of algal blooms in an impoundment.
- The **mean annual total phosphorus (TP) concentration**. Walmsley and Butty (1980) proposed cut-off points for mean annual TP concentrations at which different trophic levels are indicated. The TP concentrations are a direct indicator of the extent of eutrophication that exists within an impoundment.
- The **presence of cyanobacteria** (mean annual percentage cyanobacteria in the phytoplankton population).
- The **mean annual transparency** (as determined as Secchi disc depth). Du Plessis *et al.* (1990) proposed transparency categories for the determination of enriched turbid systems. The transparency plays a major role in the development of phytoplankton in the system, and can explain low chlorophyll-*a* concentrations in co-existence with high nutrient concentrations when turbidity is high. This variable is, therefore, included to help in the understanding of the system, but not as a direct indicator of eutrophication.

Table 1. Trophic status indicators and the appropriate ranges used to classify the impoundment.

Variable	**Oligotrophic**	**Mesotrophic**	***Eutrophic***	***Hyper-eutrophic***
Mean Chl *a* (µg/ℓ)	0 –10	10 – 20	20 – 30	> 30
Proportion of time Chl *a* > 30 µg/ℓ (%)	0	< 8	8 – 50	>50
Total Phosphorus (mg/ℓ)	< 0.015	0.015 – 0.047	0.047 – 0.130	> 0.130
Mean annual % cyanobacteria in phytoplankton population	0 - 1	1 – 10	10 - 50	> 50

Mean annual transparency	**Highly turbid**	**Turbid**	**Clear**
Secchi disc depth (m)	< 0.2	0.2 – 0.8	> 0.8

- Even where the first four variables may be indicative of a certain trophic status, the fifth variable (transparency) may play a significant role in the develoment of eutrophication symptoms.

The trophic status of the Roodeplaat Dam was eutrophic in 1989, after which the dam became hyper-eutrophic (Table 2). The mean annual TP concentrations were constantly above the PMO value of 130 µg/ℓ, except for 1989 when TP concentrations were below the PMO threshold value. Of particular concern is the steady increase above the PMO threshold value of the TP concentrations that has occurred since 1991. The mean annual chlorophyll-*a* concentrations were above the 30 µg/ℓ threshold for hyper-eutrophic systems for most of the period and of all the chlorophyll-*a* samples, between 29 and 64 per cent were higher than 30 µg/ℓ. The Roodeplaat Dam is thus in serious need of a management strategy to improve the situation, particularly in terms of inorganic, and thus available, nutrients.

Table 2. Trophic status indicators in the Roodeplaat Dam for the period 1989 –1999 (as extracted from Van Ginkel *et al*. 2000).

Year	Chlorophyll *a*		TP	Cyanobacteria dominance	Mean Secchi disc reading	Trophic Status
	Mean (µg/ℓ)	>30µg/ℓ (%)	Mean (mg/ℓ)	Mean (%)	Mean (m)	
1989-1990	22.4	40	0.032	31	1.76	E & clear
1990–1991	22.9	27	0.258	33	1.59	HE & clear
1991-1992	40.0	60	0.119	57	1.76	HE & clear
1992-1993	24.1	29	0.234	49	2.31	HE & clear
1993-1994	32.0	52	0.252	61	2.20	HE & clear
1994-1995	42.3	48	0.274	39	1.91	HE & clear
1995-1996	54.4	16	0.261	28	1.64	HE & clear
1996-1997	35.8	44	0.324	38	1.84	HE & clear
1997-1998	31.5	43	0.364	54	1.90	HE & clear
1998-1999	37.5	64	0.504	82	1.34	HE & clear

- The shading in the Table is proportional to the level of eutrophication in the impoundment.

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

4.2 *Ad hoc* pollution incident in the Roodeplaat Dam

During May 2000 a pollution incident was reported and the IWQS conducted two *ad hoc* sampling trips to investigate the incident. Thick cyanobacterial mats were found both in the Pienaars River (Site A in Figure 1) and the Moreleta/Hartbees Spruit (Site B in Figure 1) upstream of the confluence of the streams in the Roodeplaat Dam. Results for the chemical, biological and physical variables are shown in Table 2. Both sites had extensive decomposing cyanobacterial mats consisting mostly of *Microcystis aeruginosa.* At Site A traces of *Azolla* sp. were present in between the cyanobacteria. The extremely high chlorophyll-*a* concentration in the Pienaars River was 7 947µg/ℓ. The decomposing component indicated by the high phaeophytin-*a*, was also very high.

The extent of decomposition of the cyanobacterial scum in the Pienaars River explains the presence of cyanobacterial toxins at this site on the 25th May 2000. On lysis (breakdown) of the cyanobacterial cells any toxins present are released. The cyanobacterial toxin present was microcystin-YR. This incidence of the toxic cyanobacterial bloom is the result of extremely high nutrient concentrations (both the nitrogen and the phosphorus) and the extent of decomposition in the phytoplankton community. The conclusion was that the pollution incident was, therefore, eutrophication related. The incident seems to be more related to the long-term increases in nutrients within the system. Yet, the high nitrogen and phosphorus concentrations can be a result of a major influx of nutrients from a point source. It can, however, also be explained by the decomposing state of the phytoplankton population. The breakdown of the algal cells can cause the release or re-circulation of nutrients into the system.

The faecal coliform data and the *E. coli* data (Table 3), show that there is contamination from warm-blooded animals in both the inflowing streams. To determine whether the bacteria are from human or animal origin, the ratio of faecal coliforms to faecal streptococci must be determined (Table 4). On the second sampling date microbiological samples were also tested for faecal streptococci. The ratio of the faecal coliforms : faecal streptococci in the Pienaars River (Site A) indicates human origin, but the ratio in the Moreleta/Hartbees Spruit indicates the microbiological contamination is of animal origin.

These microbiological results and the variation from the mean concentrations of PO_4-P and TDS (Tabel 3) in the Pienaars River tend to indicate a pollution incident from a WCW. In the Moreleta/Hartbees Spruit the pollution is most probably of animal origin. The exact cause and/or whether any large-scale pollution incident did take place can not be confirmed.

Table 3 Results of the *ad hoc* chemical, biological and physical sampling in the Pienaars River and the Moreleta/Hartbees Spruit upstream of the confluence. NA = Not available. With the un-impacted conditions the mean concentration at Site 1 (See page 5 & 6) was used.

Variable	Aquatic Ecosystem Guideline	Pienaars River		Moreleta/Hartbees Spruit	
Date		2000/5/26	2000/6/26	2000/5/26	2000/6/26
Surface Temperature (°C)	NA	16	14.8	16	14.6
Surface O_2 (mg/ℓ)	80 % - 120% saturation	3.62 (36.5%)	5.3 (52.3%)	3.62 (36.5%)	4.6 (45.8%)
Microcystin-YR (µg/ℓ)	NA	>3	NA	NA	NA
Faecal coliforms	NA	300	930	6900	68
Faecal streptococci	NA	NA	152	NA	83
E. coli	NA	300	930	6900	68
Coliform:Streptococci ratio	NA	NA	6.11	NA	0.82
Chlorophyll-*a* (µg/ℓ)	NA	7947	8.30	NA	3.40
Phaeophytin-*a* (µg/ℓ)	NA	1390.2	2.48	NA	2.37
Suspended solids (mg/ℓ)	NA	726	5.2	NA	6.0
Secchi depth (m)	NA	0	0.7	0	1.2
pH	NA	7.7	7.9	7.8	7.9
Kjeldahl nitrogen (mg/ℓ)	NA	64.75	1.67	4.2	1.48
Ammonium (mg/ℓ)	See ammonia	31.2	0.99	3.02	1.09
Ammonia (mg/ℓ)	0.007	± 0.55	± 0.03	± 0.04	± 0.03
Nitrate & nitrite (mg/ℓ) as N	2.5	< 0.04	2.66	0.14	1.41
Fluoride (mg/ℓ)	≤ 0.75	0.3	0.2	0.2	0.2
Alkalinity as $CaCO_3$ (mg/ℓ)	NA	308	172	143	143
Sodium (mg/ℓ)	NA	32	28	23	24
Magnesium (mg/ℓ)	NA	19	18	23	17
Silica (mg/ℓ)	NA	5	5.4	3.4	3.4
Total phosphorus (mg/ℓ) as P	NA	6.109	0.322	1.280	0.227
Ortho-phosphorus (mg/ℓ) as P	< 15 % change from un-impacted conditions	4.269 (2312% increase – compared to Site 1)	0.204 (15.3% increase – compared to Site 1)	0.166 (6% decrease – compared to Site 1)	0.159 (10.2% decrease – compared to Site 1)
TN:TP ratio	NA	10.6	13.5	3.39	12.7
PO_4:TP ratio	NA	0.69	0.63	0.13	0.70
Sulphate (mg/ℓ)	NA	17	28	39	29
Chloride (mg/ℓ)	NA	34	31	33	26
Potassium (mg/ℓ)	NA	14.2	5.1	4.2	4.4
Calcium (mg/ℓ)	NA	31	31	33	30
Electrical Conductivity (mS/m)	NA	76.1	48.3	51	45.2
Total dissolved salts (mg/ℓ)	< 15 % change from un-impacted conditions	577 (84% increase – compared to Site 1)	330 (5% increase – compared to Site 1)	369 (18% increase – compared to Site 1)	314 (0.3% increase – compared to Site 1)

Table 4 Typical faecal coliform:faecal streptococci ratios for humans and various animals from www.ag.ohio-state.edu/ ~ohioline/b795/b795_1.html (June 2000).

Warm-blooded animal	Coliform:Streptococci ratio
Human	4.4
Duck	0.6
Chicken	0.4
Pig	0.4

5. CONCLUSIONS

5.1 The hyper-eutrophic state of the Roodeplaat Dam, with the associated symptoms of hyper-eutrophication, led to the development of yet another pollution incident that was reported.

5.2 There are traces of microbiological pollution in both the Pienaars River and the Moreleta/Hartbees Spruit. Although the origin of this pollution in the Pienaars River seems to be from human wastes, in the Moreleta/Hartbees Spruit the origin seems to be from animal wastes.

5.3 These incidents of toxic cyanobacterial blooms are a potential recreational health hazard as the conditions existing in the impoundment will lead to a more significant establishment of cyanobacterial blooms with their associated potential for toxicity problems.

5.4 The increased nutrient concentrations that led to the incident can be explained by a variety of causes that are all associated with the hyper-eutrophic state of the impoundment. The origin of the extremely high and increasing nutrient loads into the system can be attributed to a) high nutrient containing discharges from WCW, b) diffuse land-uses (including intensive, agricultural feedlot wastes) and c) re-circulation of nutrients from the bottom sediments and decaying plant material. The contribution from these potential sources should be identified for management purposes.

5.5 The incidence of cyanobacterial toxin production needs to be established in the Roodeplaat Dam in order to determine the potential health hazard that exists for recreational users.

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