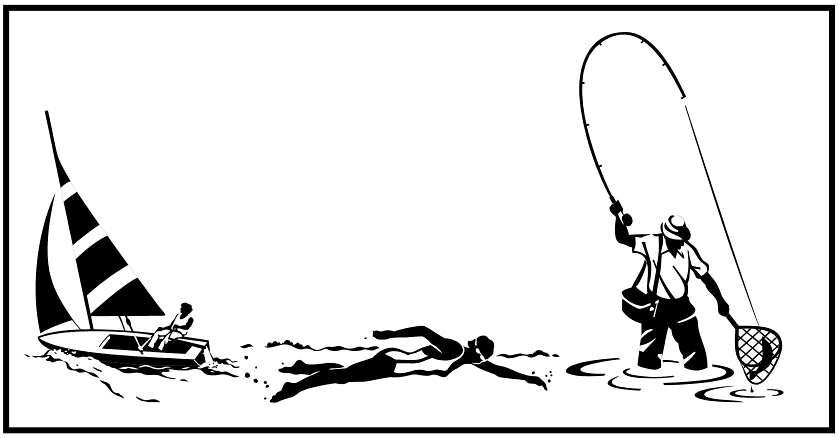
Assessment of the Water Quality of the Wilderness Lakes, the Groenvlei Lake and the Swartvlei Lakes, 1998 - 1999



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EXECUTIVE SUMMARY

Objective of study

The objective of this study is to assess the water quality in the Wilderness Lakes, the Groenvlei Lake and the Swartvlei Lakes to determine potential pollution threats.

Background

This report is the result of a request made by the National Parks Board (NPB) in 1997 to the Institute for Water Quality Studies (IWQS) to assist in the analyses of samples and the assessment of the water quality in the Wilderness Lakes. The NPB did the sampling, and the analyses were conducted by the IWQS. A planned new sewage treatment plant for Sedgefield had been erected south-west of Groenvlei and concerns about the potential adverse impact on the water quality in the Groenvlei Lake initiated this one year monitoring programme. As Groenvlei forms an ecological unit with the Wilderness Lakes, it was decided to include all the lakes in the system in the study. The NPB also requested that recommendations be made towards future monitoring programmes for the various systems for management purposes.

The results of a year’s monitoring (January 1998 to January 1999) were assessed, highlighting the chemical characteristics, biological characteristics, physical properties and the trophic status of the three lake systems.

Summary of Results

Table A. Summary of the results and assessment of the Wilderness Lake System, the Swartvlei Lake System and the Groenvlei Lake.

	Phosphorus	Nitrogen	TN:TP	Nutrients	Trace Metals	Biological	Clarity	Trophic Status
Wilderness Lakes **1. Rondevlei**	Possibility of eutrophication in the eastern section	Dissolved N constitutes small part of total N	P-limiting	Not of concern	No problem	Potential to develop eutrophication symptoms, but low Chl-a	Slightly turbid	Eutrophic
2. Bo-Langvlei	Highest TP in eastern section of lake	KN below 2 mg/L. Low NH_4. No eutrophication risk	P-limiting	Not of concern	No problem	Potential toxin producing species do occur	Clear system	Eutrophic
3. Onder-Langvlei	Within PMO, but TP above eutrophic threshold value	KN below 2 mg/L	P-limiting	Potential for eutrophication problems to occur	No threat to ecology	Potential bloom forming	Clear system	Mesotrophic
4. Wilderness Lagoon	TP never above threshold level – no eutrophication risk	Dissolved inorganic N very low portion of TN. No serious Eutrophication risk	P-limiting but occasional N-limiting	No of concern	No problem	Did not reach nuisance conditions	Clear system	Mesotrophic
Groenvlei Lake & Goukamma River	TP below eutrophic threshold but PO_4-P large proportion of TP	KN below 2 mg/L but higher than Target water quality guideline of 250 µg/L N for Groenvlei	P-limiting	Manageable levels	May be slight problems: Zn & Cd	Low Chl-a	Clear system	Mesotrophic

		Lake						
Swartvlei Lake System **1. Swartvlei**	Low TP. Increasing PO_4-P in Karatara River	KN below 1 mg/L	P-limiting, except at Hoogekraal Plantation	Manageable levels	Mn, Fe, Ni, Cu & Zn higher than target in June	Low Chl-a	Clear system	Oligotrophic
2. Sedgefield Lagoon	TP constantly below PMO and eutrophic threshold levels PO_4-P low	KN very low and NO_3+NO_2 low	Varies between P-limitation and N-limitation. Median is P-limiting	Manageable levels	Zn was higher than target once	Low Chl-a. Some problem causing species but not at nuisance levels	Clear system	Oligotrophic

Conclusions

The study concluded that the water quality in the Wilderness Lakes, the Swartvlei Lakes and the Groenvlei Lake Systems is of good quality. The assessment was based on the South African Guidelines for recreational use, aquatic ecosystems and the natural coastal marine environment. However, the Rondevlei and the Bo-Langvlei lakes did experience occasional eutrophic (nutrient-enriched) conditions.

More specific conclusions are as follows:

- The nutrient concentrations in the lakes did not produce nuisance conditions, with the exception of occasional eutrophic conditions in the Rondevlei and Onder-Langvlei lakes.

- Trace metal concentrations which occasionally exceeded the target aquatic ecosystem guidelines and need further investigation in the Groenvlei Lake and the Swartvlei Lakes System.

- In general, the three lake systems seldom encountered high chlorophyll-*a* concentrations and the lakes all tend towards phosphorus limitation.

- Occasionally, algal species that are potentially problematic did occur, but according to the recreational guidelines, seldom resulted in nuisance conditions being experienced.

- The Wilderness Lakes Systems has the most enriched trophic status of the three systems considered.

Recommendations

- The high recreational value of the Wilderness, Swartvlei and Groenvlei catchments led to the development of a water quality and eutrophication management strategy (FIJEN and KAPP 1995). These recommendations are summarised in Appendix C and it is proposed that the recommendations be followed to ensure that the water quality of the Lakes is sustained for future recreational use.

- The Rondevlei and the Bo-Langvlei lakes deserve the highest priority when resources are allocated for eutrophication management.

- The high recreational value of the Wilderness Lakes necessitates that monitoring of the lakes be continued and that the variables assessed in this study be included. This will enable water management authorities to act pro-actively and take precautionary steps if deterioration of the water quality is detected in future. Monthly monitoring frequency of the lake systems is preferable for the major inorganic substances, but if funding is a problem monitoring can be scaled down and be done on a quarterly basis.

- The source of the occasional unacceptable trace metal concentrations should be investigated further. Especially in the Groenvlei Lake (zinc & cadmium), the Swartvlei Lake (manganese, iron, nickle, copper & zinc) and the Sedgefield Lagoon (zinc).

- Although the Groenvlei Lake water is of acceptable quality (except for the trace metals as mentioned above) for the aquatic freshwater and marine environment, the continued monitoring of the system is essential because it is such an enclosed system and nutrients will accumulate to unacceptable levels if an influx of nutrients should occur. This might cause eutrophication-related problems.

ACKNOWLEDGEMENTS

1. A. Gerber for the training of water quality samplers in the study area.
2. The dedicated samplers of the National Parks Board without whose effort this study would not have been possible.
3. IWQS laboratories for committed analysis of water quality samples.
4. Constructive comments by Dr. P. Kempster, Dr A. Kühn and Mr. S. Mosai.

TABLE OF CONTENTS

1. PURPOSE OF THIS REPORT

This report is the result of a request made by the National Parks Board (See Appendix A and B) that an assessment be done of the water quality in the Wilderness, Groenvlei and Swartvlei Lake Systems. It was also requested that recommendations be made towards future monitoring strategies in terms of water quality for the various systems

2. STUDY AREA

The combined Wilderness, Groenvlei and Swartvlei lakes catchment area is about 595 km^2 in extent. It consists of three separate catchments, namely the Wilderness Lakes system, the Swartvlei Lake system and the Groenvlei Lake system. The areas are bounded in the north by the Outeniqua Mountains, in the south by the Indian Ocean and in the east and west by the catchments of the Kaaimans and Goukamma Rivers, respectively.

The Wilderness Lakes consist of a series of three inter-connected lakes, Rondevlei, Bo-Langvlei and Onder-Langvlei (Eilandvlei) that is connected to the sea via the Wilderness Lagoon. Both the Wilderness and Swartvlei Lakes are connected to the sea by means of an estuary (Figure 1). Tidal exchange takes place when the estuary mouth is open, which occurs 25% and 55% of the time for the Wilderness Lagoon and Swartvlei Lake, respectively (FIJEN and KAPP 1995a). The Wilderness system is fed by the Touws and Duiwe Rivers, and by the Langvlei Spruit. The Swartvlei Lake has four influent Rivers: the Diep, Klein-Wolwe, Hoëkraal and Karatara Rivers. Groenvlei Lake was cut off from the sea some 4000 years ago and is now a slightly brackish inland lake, lacking any influent rivers and is fed from groundwater recharge, direct rainfall and surface runoff.

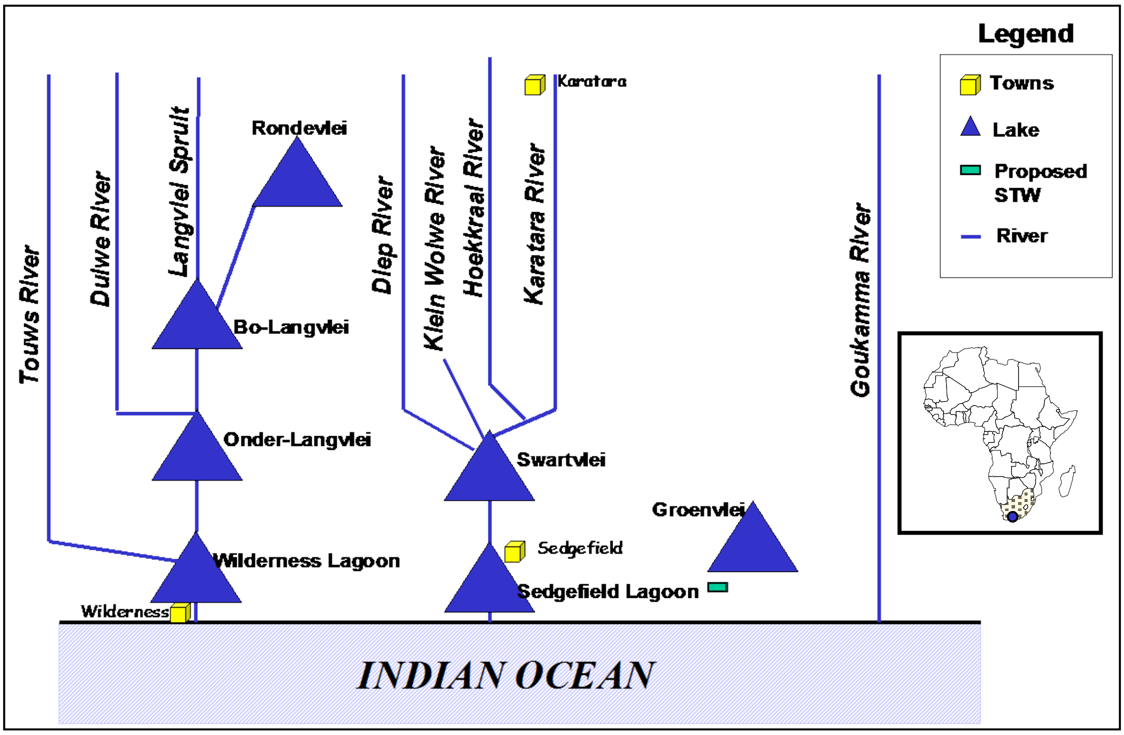

Figure 1. A systems diagram of the study area of the Wilderness, Swartvlei and Groenvlei Lake systems.

3. BACKGROUND

3.1 Background to the Water Quality monitoring in the Wilderness Lakes Area

Groenvlei formed part of a study by DWAF on the water quality and quantity of the Wilderness, Swartvlei and Groenvlei Lakes catchment areas (DWAF, 1995). In general the water quality in the three lake systems was found to be of extremely good quality in terms of the recognised water uses in the area. There was, however, some concern that due to ongoing forestry, agriculture and domestic developments in the catchment, the situation could deteriorate in future. This report stated that the basic water quality principle is to maintain the present good quality of water and to protect all water user groups against the deterioration in this water quality. According to FIJEN (1995) Groenvlei is especially susceptible to deterioration of the water quality as it is a landlocked lake and no flushing out of accumulated material to the sea is possible. A planned new sewage treatment plant for Sedgefield has been erected south-west of Groenvlei and concerns about the potential impact on the water quality in the Groenvlei Lake initiated this one year monitoring programme. As Groenvlei forms an ecological unit with the Wilderness Lakes, it was decided to make a combined monitoring effort.

The monitoring programme (see Table 2) was discussed and approved by the Institute for Water Quality Studies (IWQS), The National Parks Board (NPB) and Cape Nature Conservation (CNC) as a first step towards implementing the catchment management strategy for the Wilderness, Swartvlei and Groenvlei Lakes. CNC agreed to do the sampling and IWQS to provide the sampling bottles, other equipment and training of the samplers. It was agreed that the monitoring programme would be undertaken over a one-year period.

3.2 Background to the variables monitored

The water quality monitoring conducted February 1998 and January 1999 was analysed according to the categoris described below.

3.2.1 Chemical Properties

The chemical properties of the water quality of the lake systems are discussed under three headings, namely nutrients (phosphorus, nitrogen and the TN:TP ratio), salinity and trace metals.

3.2.1.1 Nutrients

Eutrophication is often defined as the enrichment of water bodies with plant nutrients, particularly phosphorus and nitrogen compounds and is a natural phenomenon that occurs normally during the life (this can be thousands of years) of an impoundment or a lake. This phenomenon is also known as the ageing of a lake. The natural trophic succession of lakes is from oligotrophic (low in productivity and species abundance) to eutrophic (high productivity and species abundance). Cultural eutrophication on the other hand, is an unnatural process caused by increased nutrient loading from the surrounding catchment areas as a result of man's activities. Agricultural and urban run-off, municipal and industrial wastewater effluents, and septic tank leach fields all contribute plant nutrients, as well as other pollutants, to catchment areas. This greatly accelerates the eutrophication of lakes and thus reduces the time scale for the ageing of lakes (SKICKO, 1983).

Highly nutrient enriched (eutrophic to hyper-eutrophic) systems result in significant water quality problems (STEYN *et al*. 1976; TOERIEN 1977; BRUWER 1979; WALMSLEY & BUTTY 1980; SKICKO 1983; GROBLER & SILBERBAUER 1984 & 1985 KUCKLENTZ & HAMM 1988). Nutrient enrichment continues to be one of the leading causes of water quality impairment throughout the world.

The TN:TP ratio is used to indicate whether the limiting nutrient is nitrogen or phosphorus in an impoundment. A TN:TP ratio of greater than 15:1 signifies phosphorus limitation. From an eutrophication management perspective this is desirable, as P is easier to manage and P-limitation favours green algae, which may be less problematic to manage than cyanobacteria.

In contrast, a TN:TP ratio less than 10:1 signifies nitrogen limitation. From a eutrophication viewpoint this is a less desirable situation since some of the cyanobacteria are able to fix atmospheric nitrogen, while this form of nitrogen is not available to the green algae. This shifts the nutrient condition to favour cyanobacterial development and encourage their dominance in a system. Cyanobacteria are implicated and associated with the production and release of toxins that are harmful to humans and livestock.

3.2.1.2 Salinity

The Wilderness and Swartvlei Lakes are saline systems due to occasional intrusion by seawater. They are fed by freshwater runoff that enters the lakes via river and direct runoff into the lakes and are connected to the marine environment by estuaries that are occasionally open to the Indian Ocean. It is also likely that the geology is of marine origin, further enhancing the saline nature of the systems. Groenvlei Lake became cut off from the ocean some 4000 years ago and is now a slightly brackish inland lake (FIJEN and KAPP 1995a) lacking any influent rivers and is fed only from groundwater recharge, direct rainfall and surface runoff. In these coastal lakes and estuaries, there is a gradual transition in physical, chemical and biological characteristics caused by the change from fresh to seawater. The salinity in the lakes is discussed as electrical conductivity (EC), and the contributions of the main dissolved salts are mentioned.

3.2.1.3 Trace metals

Trace metal (see page 8 for dissolved trace metals) sampling was included in the monitoring program, usually at one site in each lake. These data were included in the report to determine any potential pollution or ecosystem threats from trace metals. The sampling was done on a quarterly basis and the data are presented in tabular format and compared to target values for primary and secondary consumers in the natural marine environment (DWAF 1995).

3.3 Biological Properties

The variables that were measured to determine the biological properties of the lakes are chlorophyll-*a* and algal species composition. These variables were measured at one site in each of the lakes/lagoons. The biological properties are discussed in relation to potential problems that might be caused by these parameters.

3.4 Physical Properties

The variables measured relating to physical properties include: pH; Secchi disc depth in meter as a measure of turbidity (Secchi disc (m) = 5.07/Turbidity (NTU)); actual turbidity (NTU); and temperature (°C).

3.5 Assessment of Trophic Status

Eutrophication is increasingly endangering the sustainable use of South African water resources by: reducing their recreational value; by posing potential health problems; and by increasing purification costs. Eutrophication also results in impoundments being less suitable for aquatic life forms, thus threatening their biodiversity. A shift from diatom-dominant production, which is easily grazed on by fish/zooplankton and ultimately beneficial to desirable fish stocks, to cyanobacteria-dominant (usually mono-specific algal blooms) that are less heavily grazed on, ultimately results. There is a need to classify water sources in order to determine which systems are in greatest need of management to alleviate problems associated with eutrophication.

The assessment of trophic status of impoundments is a combination of WALMSLEY and BUTTY (1980), DU PLESSIS *et al.* (1990) and VAN GINKEL *et al.* (2000). The trophic status indicators with the appropriate ranges to classify impoundments are shown in Table 1.

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

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** (light/growth limitation)	**Turbid**	**Clear** (no light/growth limitation)
Secchi disc depth (m)	< 0.2	0.2 – 0.8	> 0.8

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

The assessment of trophic status of impoundments is a combination of indicators as specified by WALMSLEY and BUTTY (1980), DU PLESSIS *et al.* (1990) and VAN GINKEL *et al.* (2000). The trophic status indicators with the appropriate ranges to classify impoundments are shown in Table 1and discussed in more detail below.

- **Mean annual chlorophyll-a concentration** since it is a symptom of eutrophication. Chlorophyll-*a* was used as 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.
- **Proportion of time that the actual chlorophyll-*a* concentrations are greater than 30 µg/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.
- **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.
- **Presence of cyanobacteria** (mean annual percentage cyanobacteria in the phytoplankton population).
- **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 where turbidity is high. This variable is, therefore, included to help in the understanding of the system, but not as a direct indicator of eutrophication.

As mentioned in the introductory section on nutrients but dealt with here in more detail, as far as trophic status is concerned, a lake can be classified as oligotrophic (low plant nutrient concentrations and low plant production), mesotrophic (characteristics intermediate between oligotrophic and eutrophic), eutrophic (high plant nutrient concentration and excessive plant production) and hyper-eutrophic (extremely high nutrient concentration and excessive cyanobacterial blooms). WALMSLEY and BUTTY (1980) suggested the first three variables in Table 1. An additional range for mean chlorophyll-a for a hyper-eutrophic system is suggested for management purposes and to help in prioritising the systems that are in most need of management, as seen from a water quality perspective (VAN GINKEL *et al.* 2000). For the percentage of the time that chlorophyll-a is at concentrations greater than 30 µg/L, two additional ranges are added, namely for eutrophic systems (eight to fifty per cent), and for hyper-eutrophic systems (greater than fifty per cent of the time). In the case of the mean TP concentration, the cut-off value for a eutrophic system of 0.130 mg/L P (the value was suggested by DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b, as a phosphorus management objective (PMO)) was included in the classification system. If the mean TP concentration exceeds this value, the system is classified as hyper-eutrophic. The Secchi disc depth is included to explain the occurrence of low chlorophyll-a concentrations where high nutrient concentrations are present. This indicates a system that is light limited rather than nutrient limited.

In the classification of the lakes, the mean annual TP concentration was used as the most important indicator. The development of the chlorophyll-a concentration might, however, be limited by other factors, such as light penetration into the water column.

4. SAMPLING AND ANALYSIS METHODS

Sampling sites were chosen by the CNC and the IWQS did the analysis of the monitoring programme samples (See Appendix A).

4.1 Sampling sites

The number of sampling sites within each lake/system is shown in Table 2. Major inorganic chemical and biological samples were taken on a monthly basis. Sampling for the presence of trace metals was done on a quarterly basis.

Table 2. The number of sampling sites in each lake indicating the variables and the frequency of sampling for each monitoring type.

Lake System	Lake	No. of Sites	Variables	Frequency
Wilderness Lagoons	Rondevlei Lake	3	Macro	Monthly
		3	Turbidity	Monthly
		1	Trace	3 monthly
		1	Biological	Monthly
	Bo-Langvlei	3	Macro	Monthly
		3	Turbidity	Monthly
		1	Trace	3 monthly
		1	Biological	Monthly
	Onder-Langvlei	3	Macro	Monthly
		3	Turbidity	Monthly
		1	Trace	3 monthly
		2	Biological	Monthly
	Wilderness Lagoon	4	Macro	Monthly
		4	Turbidity	Monthly
		1	Trace	3 monthly
		1	Biological	Monthly
Groenvlei Lake	Groenvlei	5	Macro	Monthly
		5	Turbidity	Monthly
		1	Trace	3 monthly
		2	Biological	Monthly
Swartvlei Lakes	Swartvlei	4	Macro	Monthly
		4	Turbidity	Monthly
		1	Trace	3 monthly
		1	Biological	Monthly
	Sedgefield Lagoon	4	Macro	Monthly
		4	Turbidity	Monthly
		1	Trace	3 monthly
		2	Biological	Monthly

Macro = Major inorganic chemical variables *Trace = Trace metal constituents*
Biological = Chlorophyll a & algal identifications

4.2 Equipment

Sampling equipment was provided by the IWQS to all officials that conducted sampling at the impoundments. This equipment included:

The once-off supply of:
- 5 m weighted hose pipe (in order to take 5 m integrated water samples)
- Secchi disc and measured rope
- Beaker
- Filter apparatus
- Hand pump

And a regular supply of:

- Sampling bottles (Macro* bottles, turbidity bottles, bottles/test-tubes with ethanol for chlorophyll-a sample, bottles with Lugol's preservative for algal identification, filter papers for suspended solids and chlorophyll-a determinations.)
- Preservative ($HgCl_2$) for the macro samples
- Labels for macro and turbidity bottles
- String
- Boxes for posting of samples to IWQS
- Free Post labels
- Information sheets to note any important situations during sampling.

* A macro sample refers to a major inorganic constituent sample.

4.3 Sampling procedures

Sampling was conducted by boat. The sampling procedure was as follows:

- A Secchi disc reading was taken *in situ* by lowering the disc (standard 20 cm diameter disc with black and white quadrants) into a shaded area of the water, until the disc just disappeared from sight (no sunglasses should be used). The depth markings on the rope were then read off to determine the depth at which the disc was just no longer visible.
- Water was collected with the hose pipe sampler (0 to 5 m) and transferred to the beaker for an integrated sample.
  Or
  A beaker was filled with water from just under the surface of the water (0 m).
- Water was poured into a small glass bottle with Lugol's preservative (4 drops of Lugol's preservative could also be added later). Relevant information was written on the labels of the sampling bottles.
- The unmarked filter paper (glass micro-fibre filter) was inserted into the filtration unit, 250 ml water poured into the top half and the vacuum pump was used to pump the water through the filter paper. Water from the bottom half of unit was discarded and the procedure repeated. Depending on the clarity of the water, less water could be filtered as long as the volume filtered was recorded on the label. The filter unit was then unscrewed and the filter paper lightly rolled to fit into the glass tube. Tweezers or a suitable object was then used to press the paper down until it was covered with ethanol (90 %).
- The same procedure was also followed with the marked filter paper. This filter paper was placed into the petri-dish and the required information was written on the label on the lid.
- The plastic macro bottle was filled up to the base of the neck with the remaining water in the beaker and preserved with mercuric chloride. The label was completed for the bottle.
- The information sheet was also completed.
- Samples were mailed to IWQS.

4.4 Analysis procedures

The samples were received by Sample Reception at the IWQS and then distributed to the relevant laboratories. A list of the analysis done follows:

- The macro analyses included Kjeldahl nitrogen (KN), total phosphorus (TP), 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.

- 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.

- 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.

5. RESULTS AND DISCUSSION

The results are discussed under the three separate catchment areas. Firstly the water quality of the Wilderness Lakes (Rondevlei, Bo-Langvlei, Onder-Langvlei Lakes and the Wilderness Lagoon) is discussed. Secondly the Swartvlei Lake and Sedgefield Lagoon are discussed, and thirdly the Groenvlei Lake water quality is discussed in comparison with the Goukamma River data.

5.1 The Wilderness Lakes

The Wilderness Lakes comprise a series of three lakes including the Rondevlei, Bo-Langvlei and Onder-Langvlei Lakes that enter the Indian Ocean via the Wilderness Lagoon. Each lake and the lagoon is discussed separately.

5.1.1 Rondevlei Lake

The Rondevlei Lake is the first in the series of Wilderness Lakes (Figure 1 and 2). Three sites were sampled on a monthly basis for one year. There is no major river that feeds into this lake.

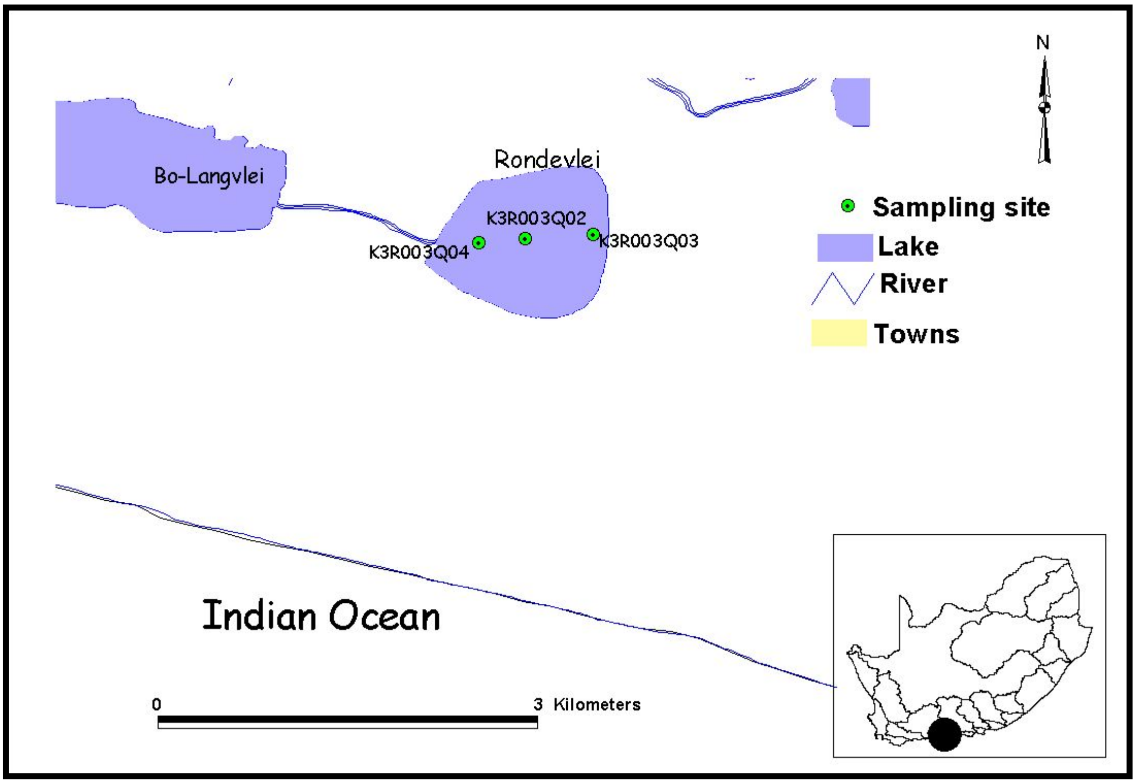

Figure 2. The sampling sites in the Rondevlei Lake.

5.1.1.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Rondevlei Lake extends from January 1998 to January 1999. Figure 3 indicates that in the Rondevlei Lake the TP concentrations for the study period were consistently within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b). TP concentrations were, however, occasionally above the threshold level for eutrophic systems of 0.047 mg/L P as is suggested in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990).

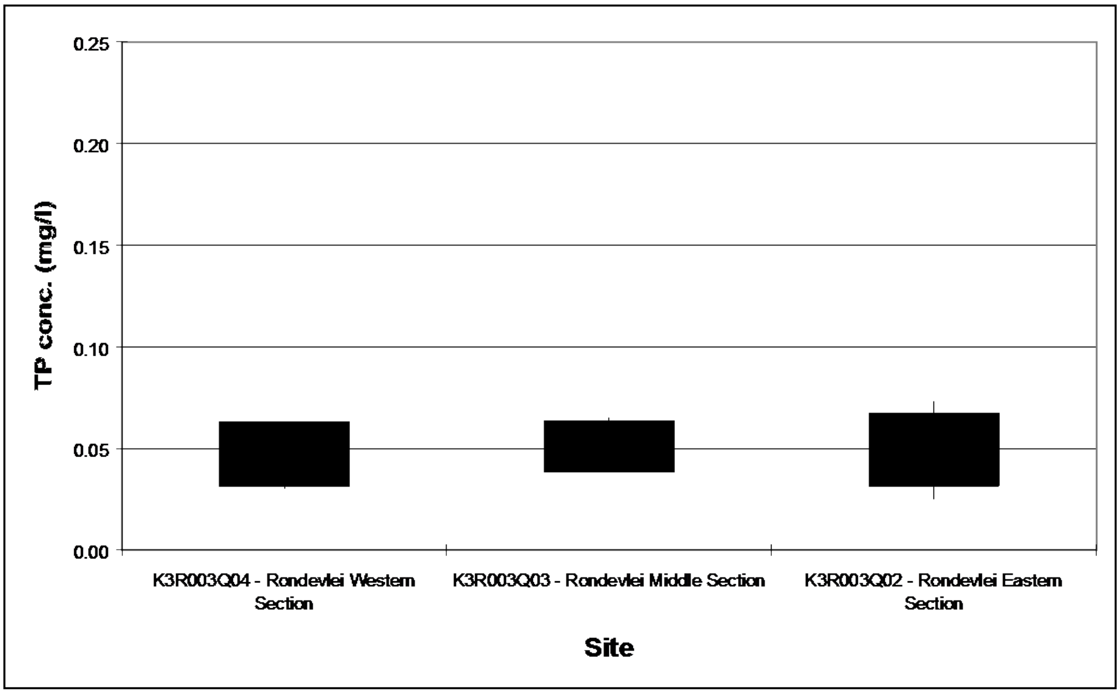

Figure 3. Variability in TP (as P) concentrations at the three sampling sites in the Rondevlei Lake (1998-1999).

The PO_4-P concentrations in the Rondevlei Lake were, especially at the eastern Section of Rondevlei, higher than 0.025 mg/L P (the upper limit for mesotrophic conditions for the aquatic ecosystem guideline according to DWAF 1996b). There was a decrease in PO_4-P concentrations from the eastern section of the Rondevlei to the western section of the Lake. The concentrations in the whole of the Rondevlei Lake are all lower than the mean PO_4-P concentration of 0.094 mg/L P found by FIJEN and VAN ZYL (1995) for the period 1977 to 1993. Eutrophication problems might, therefore, occur in the eastern section of the Lake, even though the concentrations did seem to have decreased since previous studies. The PO_4-P forms the major component of the TP concentration in the Rondevlei Lake, and most of the TP is, therefore, available for primary production.

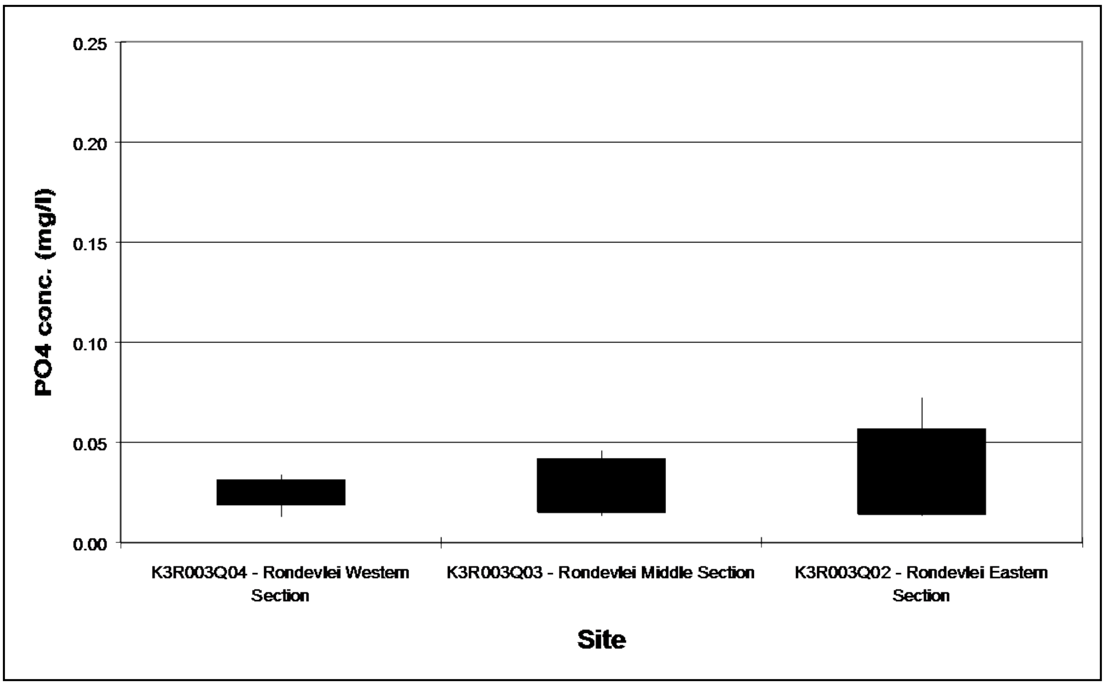

Figure 4. Variability in PO_4-P (as P) concentrations at the three sampling sites in the Rondevlei Lake (1998-1999).

Nitrogen

The variability in TN (as N) concentrations (an indication of the non-available and available nitrogen for primary production in the system) in the Rondevlei Lake is reflected in Figure 5. It shows clearly that the western section of the Lake had higher mean TN (as N) concentrations than those found in the Eastern Section. However, the middle section and the Eastern Section showed greater variability in the TN concentrations. Dissolved nitrogen also constitutes a very small proportion of the nitrogen component.

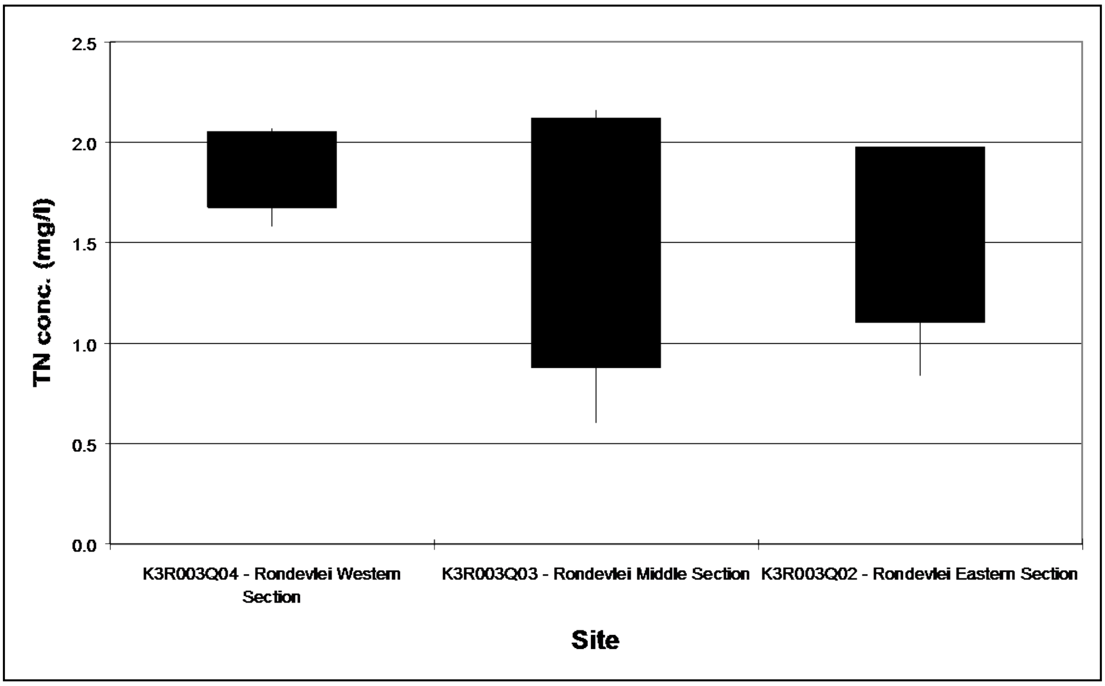

Figure 5. Variability in TN (as N) concentrations at the three sampling sites in the Rondevlei Lake (1998-1999).

The dissolved inorganic nitrogen (DIN) concentrations (NO_3+NO_2 and NH_4) are very low. The DIN concentrations consistently below 1 mg/L N (Figure 6) in the Western Section and the Eastern Section. However, the middle section have concentrations exceeding 2 mg/L as N. The mean concentrations for both NO_3+NO_2 (0.03 mg/L as N) and NH_4 (0.03mg/L as N) are much lower than the mean NO_3+NO_2 (0.28 mg/L as N) and NH_4 (0.35 mg/L as N) concentrations found by (FIJEN and VAN ZYL, 1995). There was, therefore, a decrease in nitrogen concentrations since 1989-1993. Nutrient concentrations are at this stage not of any concern as it is consistently below the 2.5 mg/L as N upper limit for NO_3+NO_2, indicating mesotrophic conditions (DWAF 1996b).

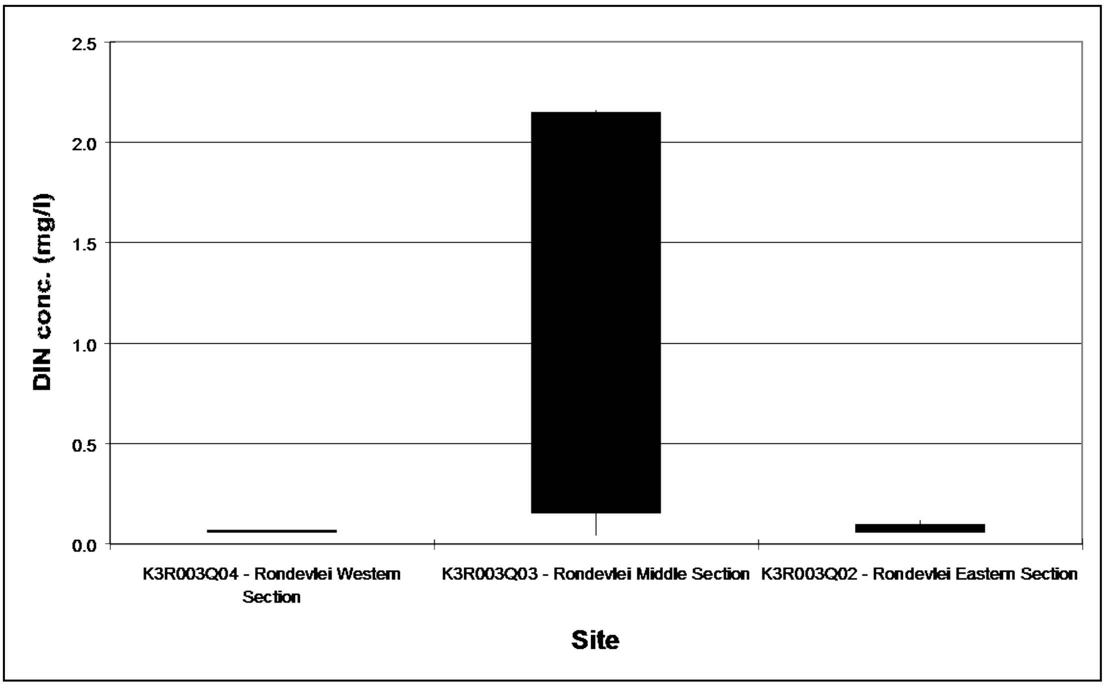

Figure 6. Variability in DIN (NO_3-N+NO_2-N and NH_4-N) concentrations at the three sampling sites in the Rondevlei Lake (1998-1999).

TN:TP ratio

The minimum, median and maximum TN:TP ratios for the Rondevlei Lake are shown in Table 3. TN:TP ratios that are constantly above 20 (except for the minimum in the middle section of the Lake) indicate that the water quality in the Rondevlei Lake is phosphorus limited. The nutrient concentrations of the impoundment thus indicate that the system does not favour the development of cyanobacteria and is still within manageable levels.

Table 3. The minimum, median and maximum TN:TP ratios at the three sites in the Rondevlei Lake during 1998 to 1999.

Site	Minimum TN:TP ratio	Median TN:TP ratio	Maximum TN:TP ratio
K3R003Q02 - Rondevlei Eastern Section (**n=11)**	22.2	31.6	56.8
K3R003Q03 - Rondevlei middle section **(n=11)**	13.5	32.1	52.0
K3R003Q04 - Rondevlei Western Section **(n=11)**	28.5	32.8	59.8

Salinity

The Rondevlei Lake is very saline, especially in the Eastern Section of the Lake. EC readings of greater than 1500 mS/m are found at this site, while the other two sites never have EC readings higher than 1500 mS/m (Figure 7).

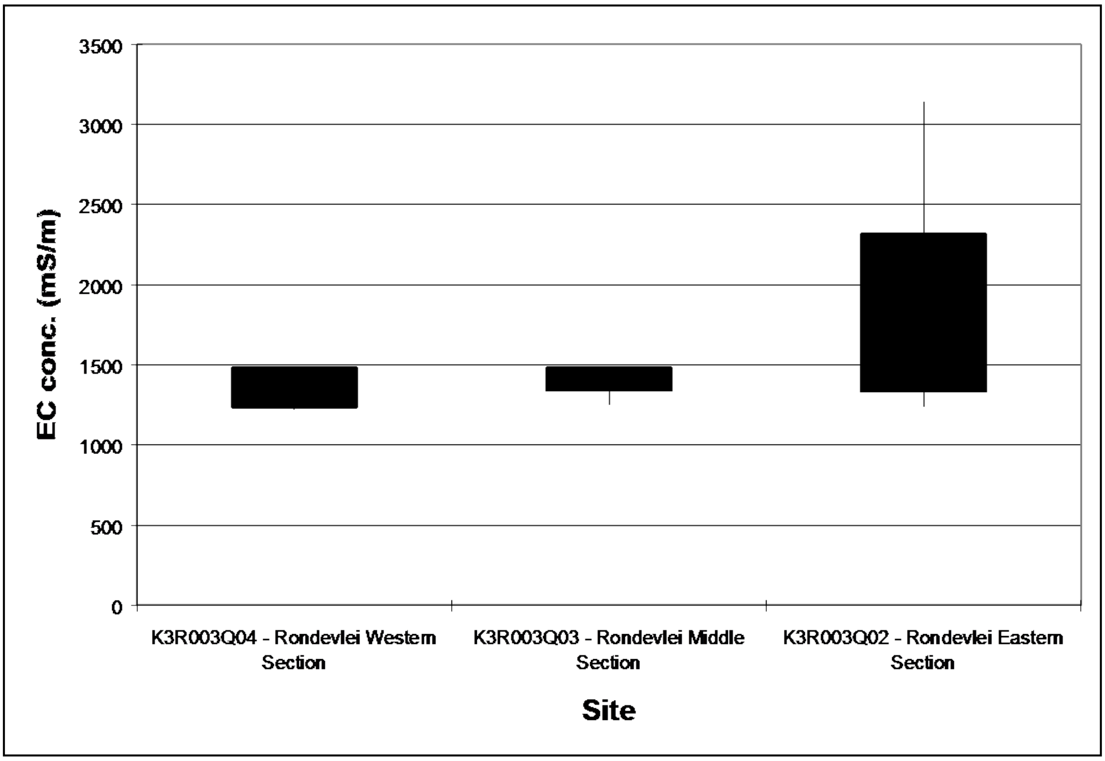

Figure 7. EC readings in the Rondevlei Lake from 1998 to 1999.

The dissolved salts concentrations in the Rondevlei Lake (Figure 8) show that the Eastern Section of the Lake shows the same tendency of higher major ion concentrations as indicated by the EC readings. There seems to be an elevated concentration of salts in the eastern section, especially of high chloride and sodium concentrations. The reason for this phenomenon is not known to the authors. The relative concentrations of the major ions show the tendency of Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+. The relative proportions of the major solutes vary greatly from one saline lake to the next. Sodium (Na^+) dominates most saline waters, with very few lakes having Ca^{2+} or Mg^{2+} as major dominant cations (WETZEL, 1983). The dominating anion is commonly Cl^-, as is the case in the Rondevlei Lake.

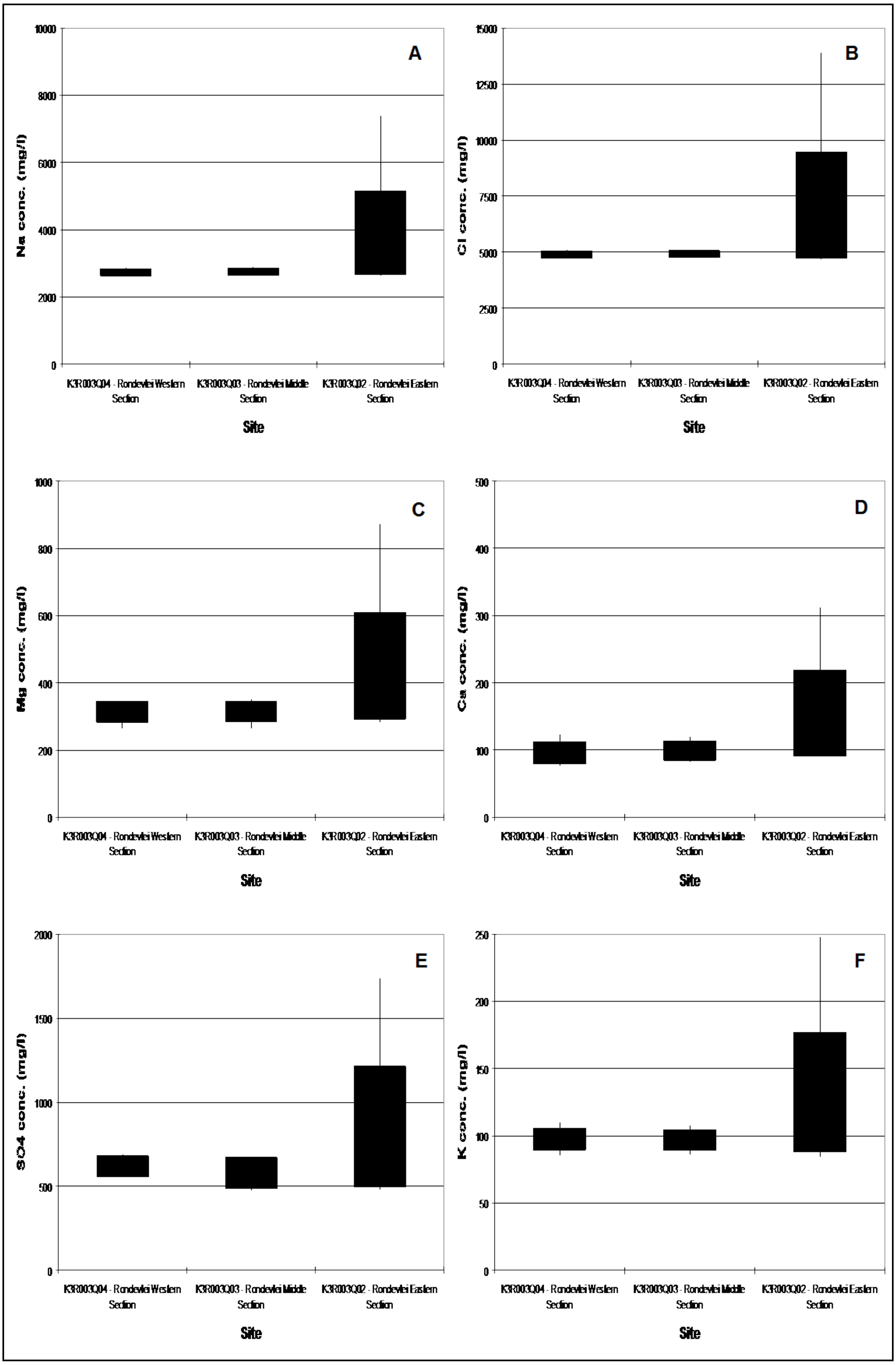

Figure 8. Variability of the specific dissolved salts concentrations at the sites in the Rondevlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations and F Potassium concentrations.

Trace metals

Dissolved trace metal samples were only taken at the Eastern Section site in the Rondevlei Lake (Table 4). The minimum, median and maximum values of the different dissolved trace metals that were analysed for are compared to the available target values for primary and secondary consumers for coastal marine environments. The trace metal concentrations measured on a quarterly basis showed high concentrations of boron and strontium, however, no guidelines exist for these two metals. According to WETZEL (1983) boron is stimulatory to photosynthesis to levels of 100 mg/L and often found in elevated concentrations in saline lakes. Strontium is a readily accepted substitution of calcium, an essential inorganic element of algae, in some algal species, but in other algae, calcium utilisation is strongly inhibited by strontium (WETZEL, 1983).

On one occasion (1998/5/19) the cadmium concentration was higher than the target values for both primary and secondary consumers and might have had negative effects on the ecological equilibrium.

Table 4. The dissolved trace metal concentrations at the Eastern Section in the Rondevlei Lake during 1998 on three sampling occasions and compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/05/19**	**1998/08/20**	**1998/11/23**
Boron (B) (mg/L)	NA	NA	1.005	1.177	1.083
Aluminium (Al) (mg/L)	NA	NA	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	0.016	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	<0.003	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	<0.003	<0.003	<0.003
Nickel (Ni) (mg/L)	0.025	0.025	0.01	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	<0.002	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	0.06	<0.004	<0.004
Strontium (Sr) (mg/L)	NA	NA	1.536	1.772	1.653
Molybdenum (Mo) (mg/L)	NA	NA	0.027	<0.005	<0.005
Cadmium (Cd) (mg/L)	0.004	0.004	0.013	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	0.055	0.009	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015

Trace metals, therefore, seem not to be a problem in the Rondevlei Lake.

5.1.1.2 Biological characteristics

The chlorophyll-*a* concentration in the Rondevlei Lake (Fig. 9) was mostly between 10 µg/L and 20 µg/L, and was never above 30 µg/L during the study period. The higher chlorophyll-a concentrations may be due to the phosphorus concentrations that are periodically high enough to result in eutrophic symptoms.

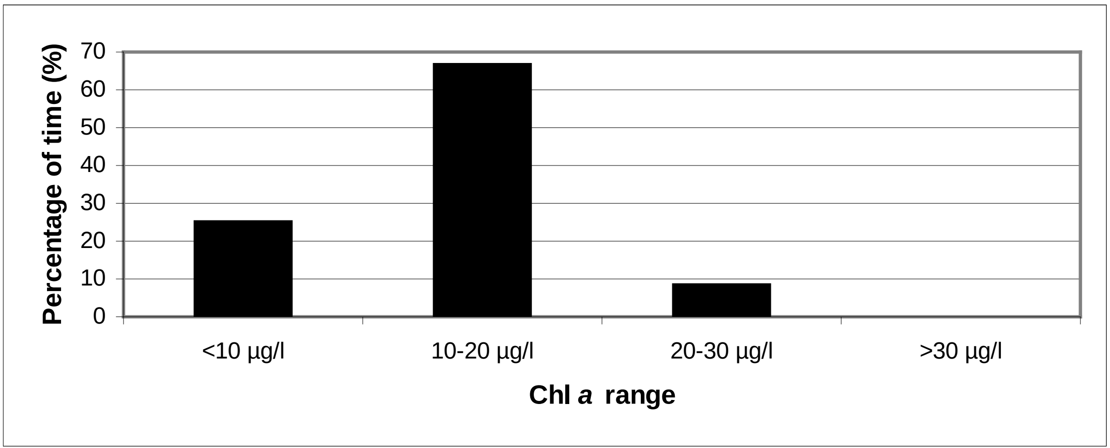

Figure 9. Per cent of the time that chlorophyll-a concentrations are within a specified range in the Rondevlei Lake in the Eastern Section of the lake.

Pyrrhophyta (*Peridinium*) was the dominant algal group during the study period (Figure 10). *Peridinium* is a large genus of small to medium sized dinoflagellates, some but not all of which are photosynthetic. Species of Pyrrhophyta occur in freshwater and marine planktonic habitats. At least a few photosynthetic species may form significant toxic blooms (called "red tides" in the marine environment). Some of these blooms are associated with nuisance odours and fish kills, although the most devastating "red tide" dinoflagellates belong to other genera (WWW 1 2000).

Chlorophyta (e.g. *Chlamydomonas and Volvox*), Chrysophyta (*Chlorocromonas* and *Tribonema*) and Euglenophyta (*Euglena* and *Trachelomonas*) occasionally contributed noticeably to the phytoplankton population during the study period. Cyanobacteria were not present in the Rondevlei Lake during the study period.

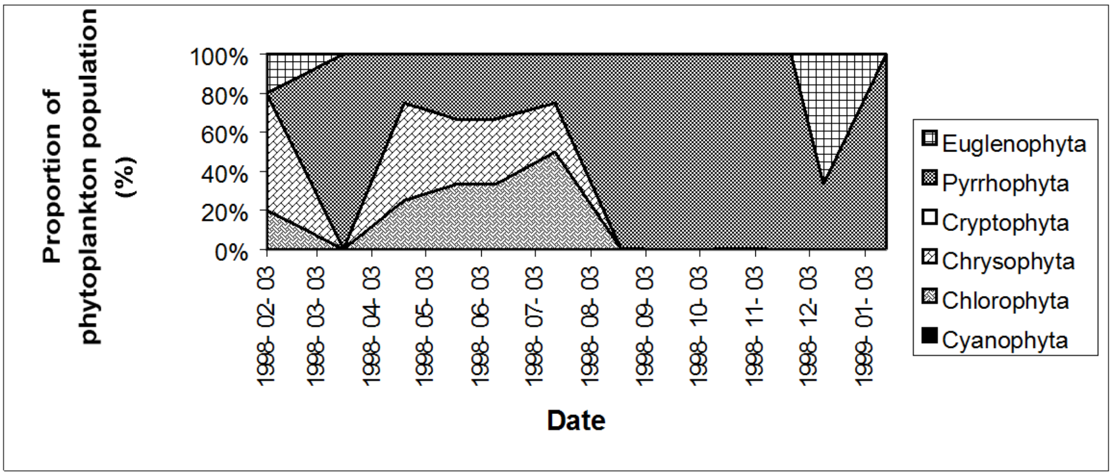

Figure 10. Monthly dominance of algal groups in the Rondevlei Lake.

These results indicate that the lake does have the potential to develop eutrophic conditions. The fairly low chlorophyll-*a* concentrations may, however, be the result of the saline nature of the system that prevents nuisance phytoplankton blooms from developing.

5.1.1.3 Physical characteristics

The mean Secchi disc reading was 1.95 m. The Secchi disc readings varied between 0.78 m and 3.2 m. The lake is, therefore, a clear system with little light limitation in terms of primary production. Due to a limited number of Secchi disc readings, no correlation determination between the chlorophyll-*a* and the Secchi disc readings was attempted. This correlation is used to determine the effect of the phytoplankton to the clarity of the system.

Figure 11 indicates that the Rondevlei Lake is alkaline with varying pH readings between 8 and 8.5. These values are much higher than the mean pH value (7.73) found by FIJEN and VAN ZYL (1995) in an earlier study on the water quality of the Rondevlei Lake.

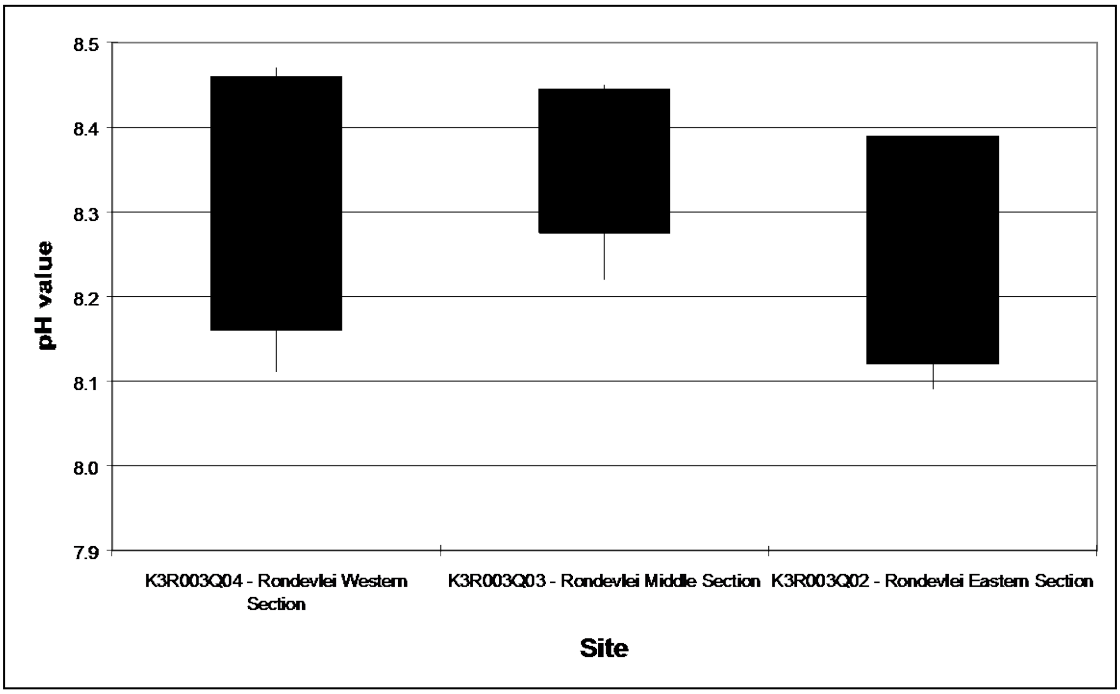

Figure 11. Variability of the pH values at the three sites in the Rondevlei Lake.

The turbidity in the Rondevlei Lake is below 5 NTU's (1.01 m as Secchi disc depth – see page 3) and the lake is, therefore, slightly more turbid than the Groenvlei Lake that has turbidity readings of lower than 2 NTU's (2.54 m as Secchi disc depth – see page 3). The increased levels of turbidity might be due to the increased incidence of phytoplankton when compared to the Groenvlei Lake, however, this is still clear water and of no concern.

5.1.1.4 Trophic status of the Rondevlei Lake

Table 5 indicates that the Rondevlei Lake is mesotrophic with a tendency towards being eutrophic when considering phosphorus. This is not really reflected in the other trophic status indicators, since the chlorophyll-*a* concentrations never exceeded the 30 µg/ℓ hyper-eutrophic conditions and cyanobacteria did not feature as a dominant phytoplankton group. The saline nature of the system might have a limiting effect on the phytoplankton growth. There is a concern as to the specific algal genera present since they fall within a group of algal species that are known to cause ‘red tides’, a phenomenon that has health implications because the algal species produce toxins that are harmful to humans and aquatic organisms.

Table 5. Trophic status indicators in the Rondevlei Lake for the period 1998 –1999.

Year	**Chlorophyll *a***		**TP**	**Cyanobacteria dominance**	**Mean Secchi disc reading**	**Trophic Status**
	Mean (µg/ℓ)	>30µg/ℓ (%)	Mean (mg/ℓ)	Mean (%)	Mean (m)	
1998-1999	12.1	0	**0.051**	0	1.95	**E & clear**

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

  O = oligotrophic M = mesotrophic
  E = eutrophic HE = hyper-eutrophic

- The Rondevlei Lake has a tendency towards eutrophic conditions.
- Management and monitoring of the impoundment should be continued because of the high recreational value of the system.

5.1.2 Bo-Langvlei Lake

The Bo-Langvlei Lake is the second of the Wilderness Lakes being assessed in this study and is situated on the Langvlei Spruit, north-west and feeding into the Onder-Langvlei Lake (Figure 12). Three sampling sites were studied for a year.

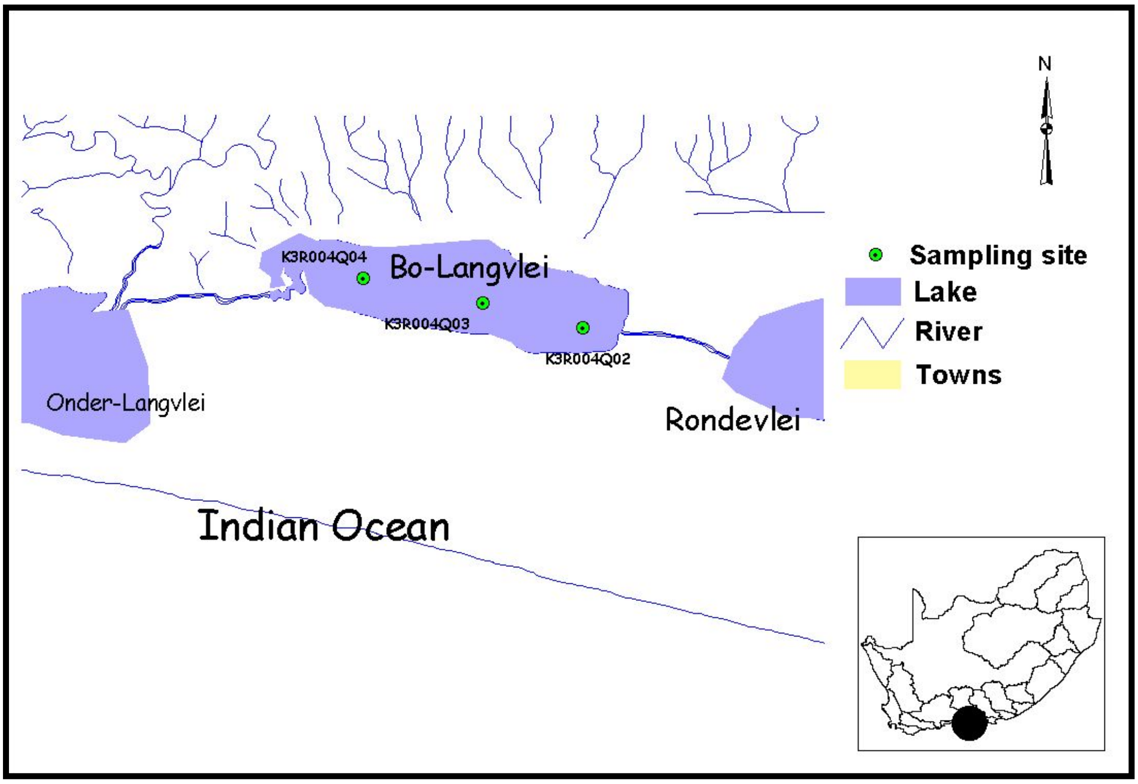

Figure 12. The sampling sites in the Bo-Langvlei Lake.

5.1.2.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Bo-Langvlei Lake extends from February 1998 to January 1999. Figure 13 indicates that in the Bo-Langvlei Lake, the mean annual TP concentrations for the period were consistently within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b). The lake, therefore, seems not to be very productive although the TP concentrations were constantly above the threshold level for freshwater eutrophic systems of 0.047mg/L P as is suggested in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990).

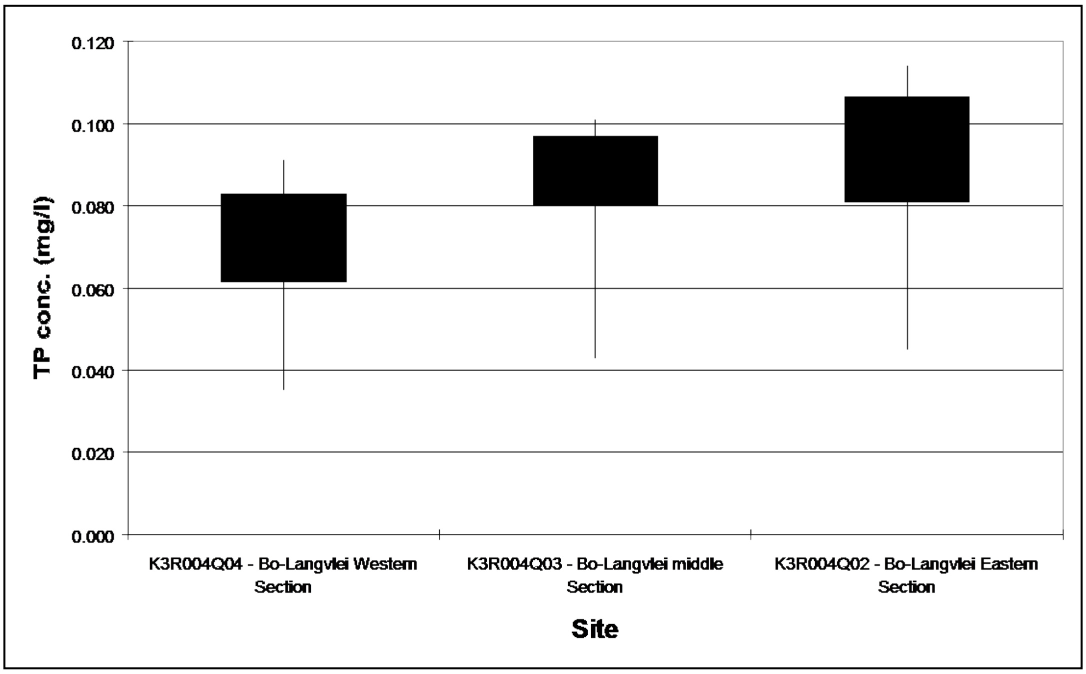

Figure 13. Variability in TP concentrations at the three sampling sites in the Bo-Langvlei Lake (1998-1999).

Figure 14 indicates that the largest proportion of reactive phosphorus contributing to the TP concentration was found at the middle section of the Bo-Langvlei Lake. The Eastern Section of the Bo-Langvlei had the highest concentrations of TP (Figure 13), although the PO_4-P concentrations were much lower than in the middle section of the Lake (Figure 14). The mean PO_4-P concentrations were higher at the middle section (0.055 mg/L) and the eastern section (0,050 mg/L) than the mean PO_4-P concentration (0.044 mg/L) found by FIJEN and VAN ZYL (1995). However, the mean PO_4-P concentration at the western Section of the lake (0.035 mg/L) was lower than the concentration found by FIJEN and VAN ZYL (1995).

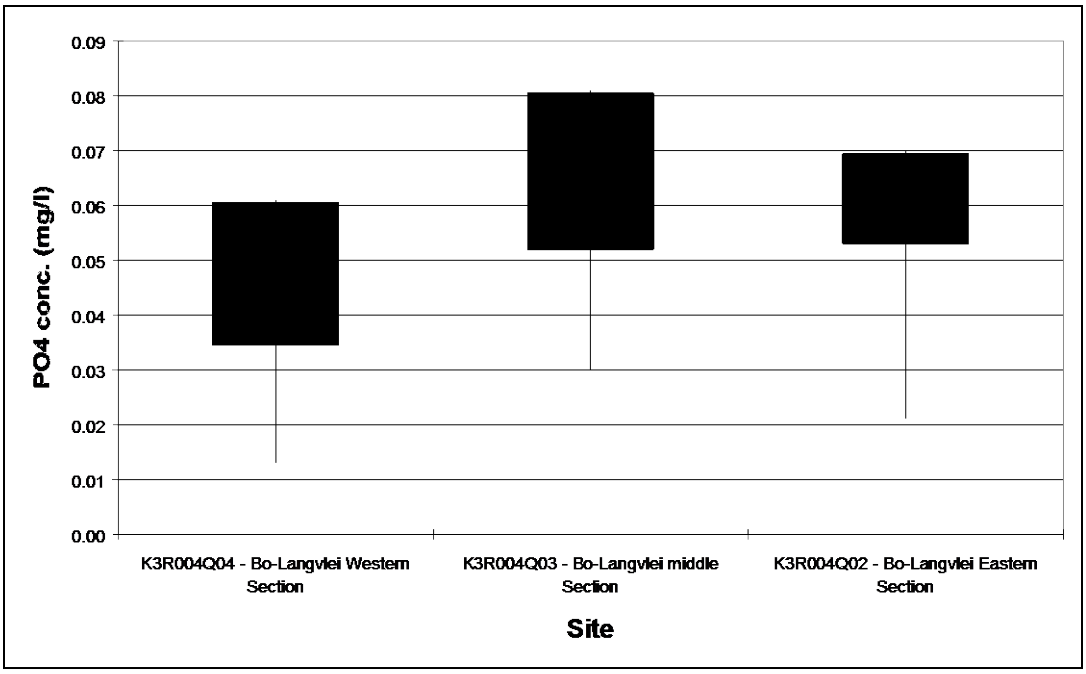

Figure 14. Variability in PO_4-P concentrations at the three sampling sites in the Bo-Langvlei Lake (1998-1999).

Nitrogen

The variability in TN concentrations in the Bo-Langvlei Lake is reflected in Figure 15 and indicates that the nitrogen concentrations within the impoundment were constantly below 2 mg/L. The three sites in the Bo-Langvlei showed similar KN concentrations. Although the DIN concentrations (Figure 16) were consistently below the Target Water Quality Range of 2.5 mg/L for inorganic nitrogen (DWAF 1996b), the middle section of the Bo-Langvlei again showed the highest concentrations of NO_3+NO_2.

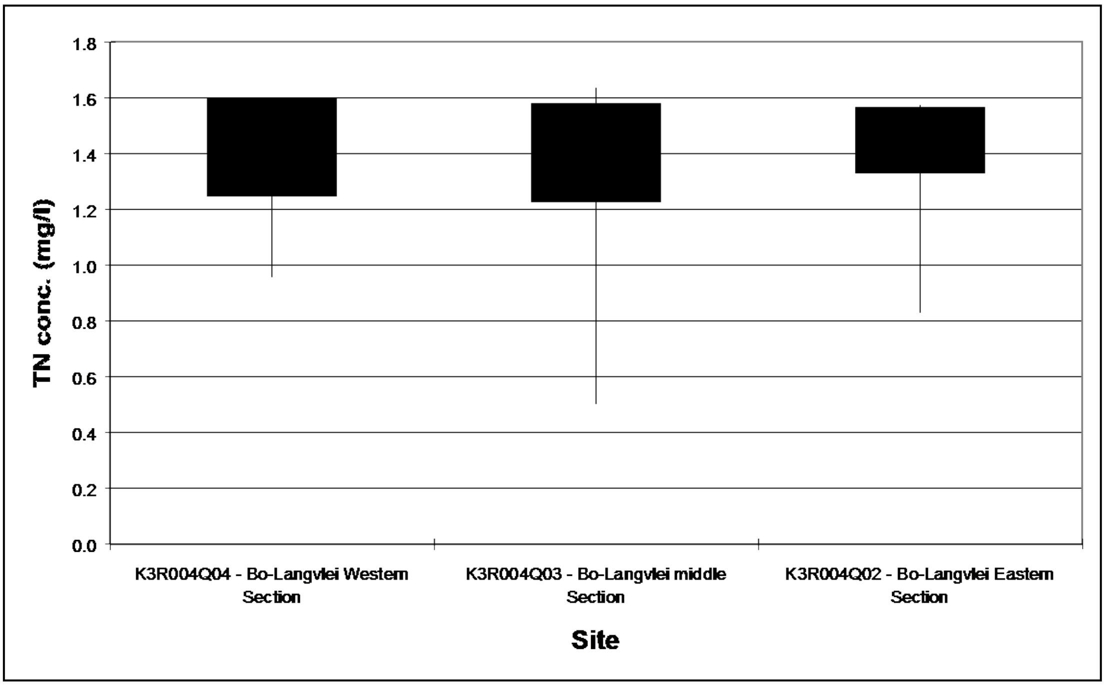

Figure 15. Variability in TN concentrations at the three sites in the Bo-Langvlei Lake (1998 – 1999).

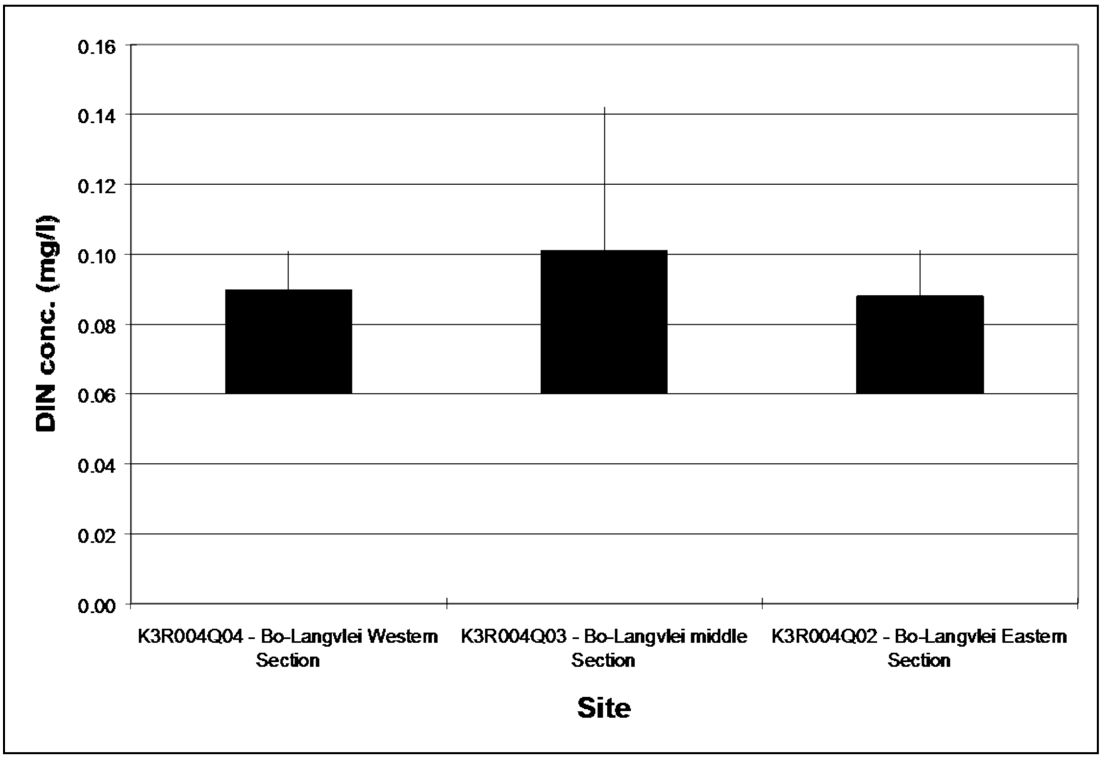

Figure 16. Variability in DIN (NO_3+NO_2 and NH_4 as N) concentrations at the three sites in the Bo-Langvlei Lake (1998 – 1999).

The mean NO_3+NO_2 as N concentration of between 0.03 mg/L and 0.04 mg/L at the three sites in the Bo-Langvlei Lake were lower than the 0.30 mg/L found by FIJEN and VAN ZYL (1995).

The mean NH_4 (as N) concentrations were below 0.04 mg/L and would not be likely to pose any ecological threat to the natural populations within the lake. There was, therefore, a decrease in NH_4 (as N) when compared to the mean NH_4 (as N) concentration of 0.195 mg/L found by FIJEN and VAN ZYL (1995). The nitrogen concentrations in the Bo-Langvlei would not cause any major eutrophication problems, due to the low concentrations present in the lake during the sampling period.

TN:TP ratio

The TN:TP ratios range from 13.5 to 20.6 in the eastern section, from 5.5 to 23.7 in the middle section and from 12.7 to 34.8 in the western section of the Bo-Langvlei Lake (Table 6). These TN:TP ratios indicate that the water quality in the Bo-Langvlei is inclined towards phosphorus limitation, although there were occasions when nitrogen limitation did prevail, specifically in the middle section of the Lake. The nutrient concentrations of the lake indicate that the system is still within manageable levels and should not be prone to develop serious algal and cyanobacterial blooms if the current nutrient concentrations are maintained.

Table 6. The minimum, median and maximum TN:TP ratios at the three sites in the Bo-Langvlei Lake during 1998 to 1999 and the number of samples (n) at each site.

Site	**Minimum TN:TP ratio**	**Median TN:TP ratio**	**Maximum TN:TP ratio**
K3R004Q02 - Bo-Langvlei Eastern Section (**n=11)**	13.5	16.7	20.6
K3R004Q03 - Bo-Langvlei middle section **(n=11)**	5.5	16.4	23.7
K3R004Q04 - Bo-Langvlei Western Section **(n=10)**	12.7	23.0	34.8

Salinity

Coastal lakes such as the Wilderness and the Swartvlei Lakes share many of the attributes of estuaries and of the associated wetlands to form complex and interactive ecosystems. The Bo-Langvlei that forms one of a series of natural lakes and is, therefore, highly saline with EC values around 1000 mS/m (as shown in Figure 17) at all three of the sampling sites in the Bo-Langvlei.

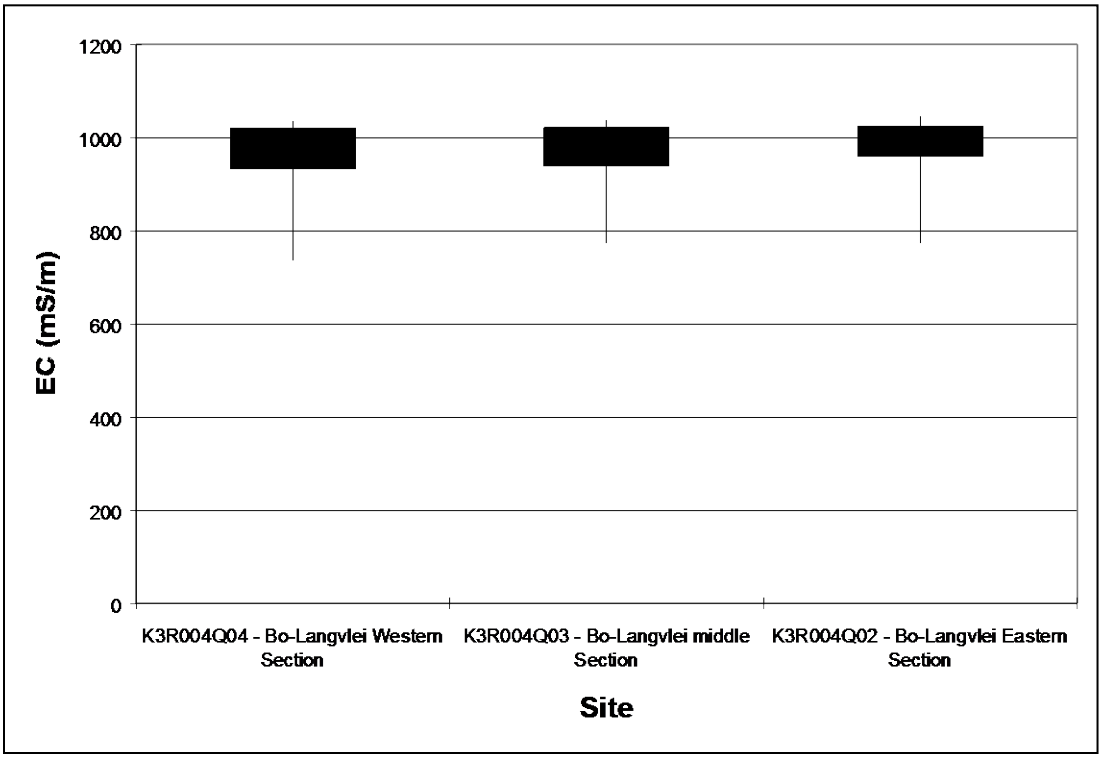

Figure 17. EC readings in the Bo-Langvlei Lake during 1998 and 1999.

The dissolved salts concentrations in the Bo-Langvlei (Figure 18) show that the three sites in the Bo-Langvlei exhibit the same tendencies as those of the ions, except for the calcium concentrations. The Ca concentrations decrease significantly from the Eastern Section towards the Western Section site in the Bo-Langvlei. There is also a slight decrease in Na^+ and SO_4^{2-} from the eastern section towards the western section of the lake, with all the other ions showing no spatial trends.

The spatial changes and variability in Ca^{2+} and SO_4^{2-} are explained by the dynamic nature of these ions that are strongly influenced by microbial metabolism (WETZEL, 1983). The relative concentrations of the major ions show the tendency of $Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+$. Again the lake is a saline system with Cl^- being the major anion contributing to the saline nature.

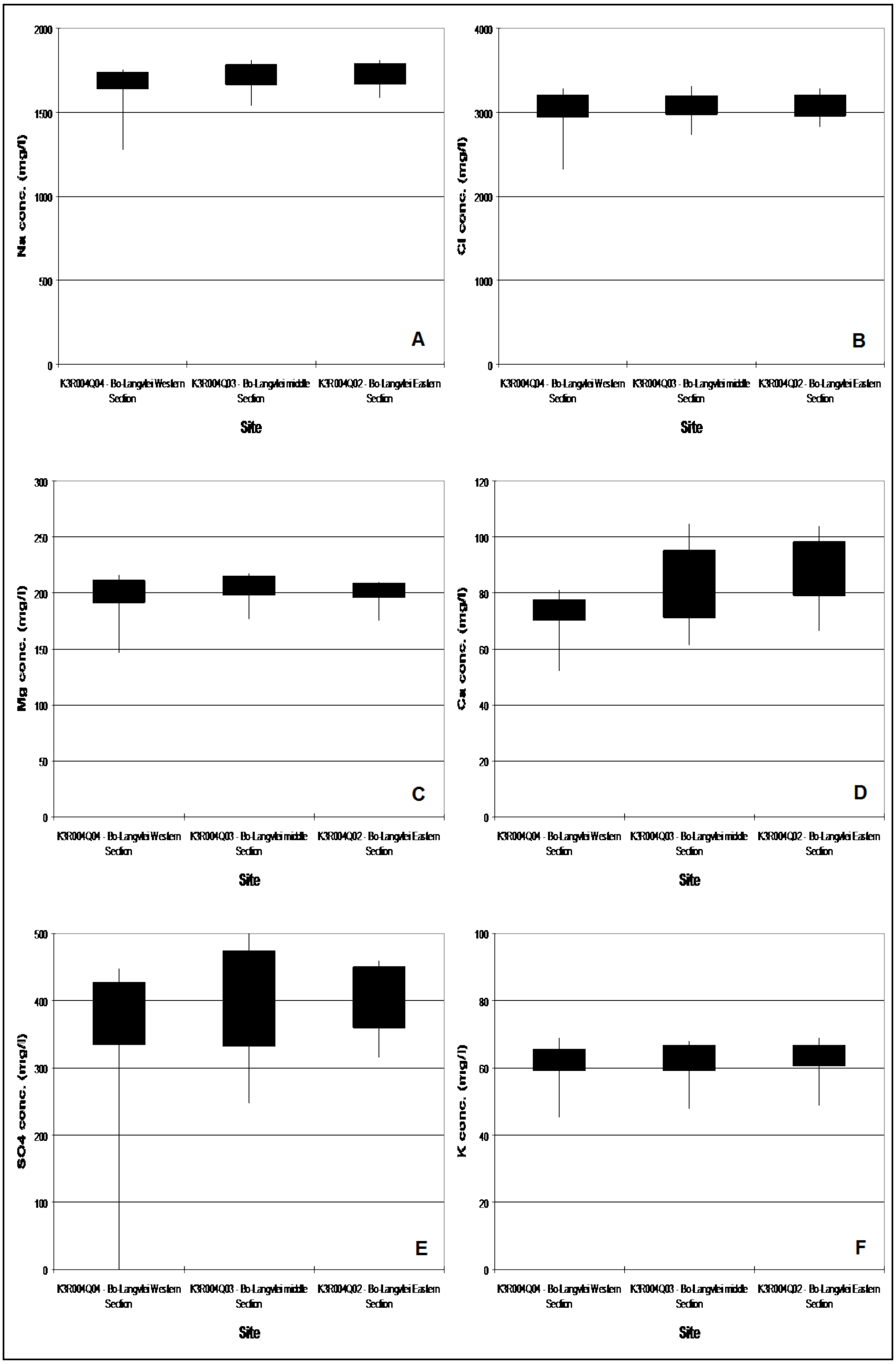

Figure 18. The dissolved salts concentration variability at the three sites in the Bo-Langvlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations, and F Potassium concentrations.

Trace metals

Dissolved trace metal samples were only taken at the eastern section of the Bo-Langvlei on three occasions (Table 7). These results are compared to the available target values for primary and secondary consumers for coastal marine environments. Fairly high boron (B) concentrations and strontium (Sr) concentrations were found at the eastern section site in the Bo-Langvlei on all three sampling occasions, as is normal for saline systems (WETZEL, 1983). However, no target values are available for these two variables (DWAF 1995). Target values are available for chromium, nickel, copper, zinc, cadmium and lead. Cadmium and zinc concentrations were higher than the target values on 20 May 1998, but were below the target values on the other two sampling occasions.

Table 7. The dissolved trace metal concentrations at the eastern section in the Bo-Langvlei Lake during 1998 on three sampling occasions and compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/05/20**	**1998/08/20**	**1998/11/24**
Boron (B) (mg/L)	NA	NA	0.618	0.734	0.745
Aluminium (Al) (mg/L)	NA	NA	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	0.024	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	0.005	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	0.009	<0.003	<0.003
Nickel (Ni) (mg/L)	0.025	0.025	0.017	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	0.002	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	0.031	<0.004	<0.004
Strontium (Sr) (mg/L)	NA	NA	1.02	1.144	1.235
Molybdenum (Mo) (mg/L)	NA	NA	0.016	<0.005	<0.005
Cadmium (Cd) (mg/L)	0.004	0.004	0.017	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	<0.001	<0.001	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015

Trace metal concentrations seem, therefore, not to pose a major threat to the lake at this stage.

5.1.2.2 Biological characteristics

For 65 per cent of the time the chlorophyll-*a* concentrations (Figure 19) were below 10 µg/L in the lake, but often rose above 10 µg/L. The chlorophyll-*a* concentration during 1998 posed no problem, and was in accordance with the nutrient concentrations of the system.

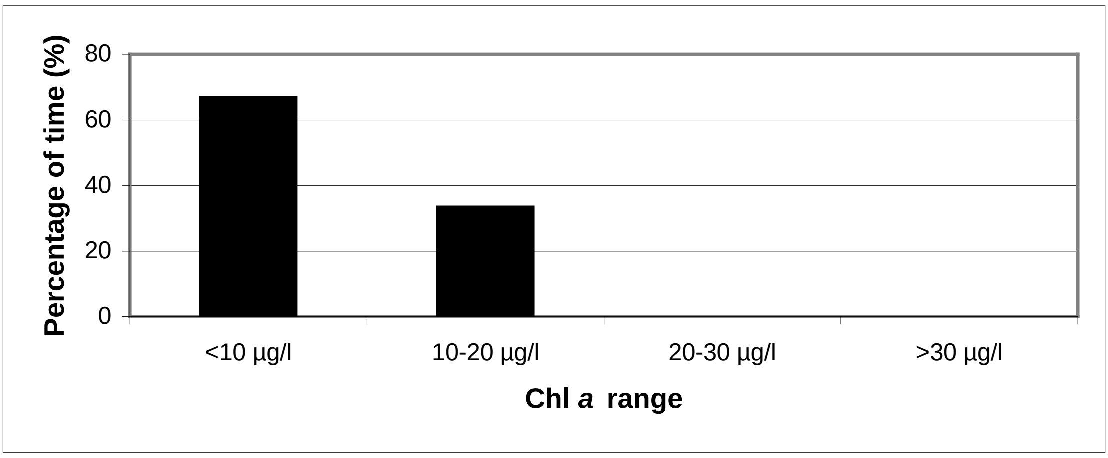

Figure 19. Per cent of the time that chlorophyll-*a* concentrations are within a specified range in the Eastern Section of the Bo-Langvlei Lake,.

Chrysophyta (*Chlorocromonas, Cyclotella* and *Tribonema*), Chlorophyta (*Ankistrodesmus*) and Pyrrhophyta (*Peridinium*) were the dominant groups during the study period (Figure 20).

"The Chrysophyta of the kingdom Protista, known as the golden algae, are simple organisms (not complex). The chrysophytes are characterised by their yellowish xanthophyll pigments which mask the green of the chlorophyll pigments that are also present" (WWW 2, 2000).

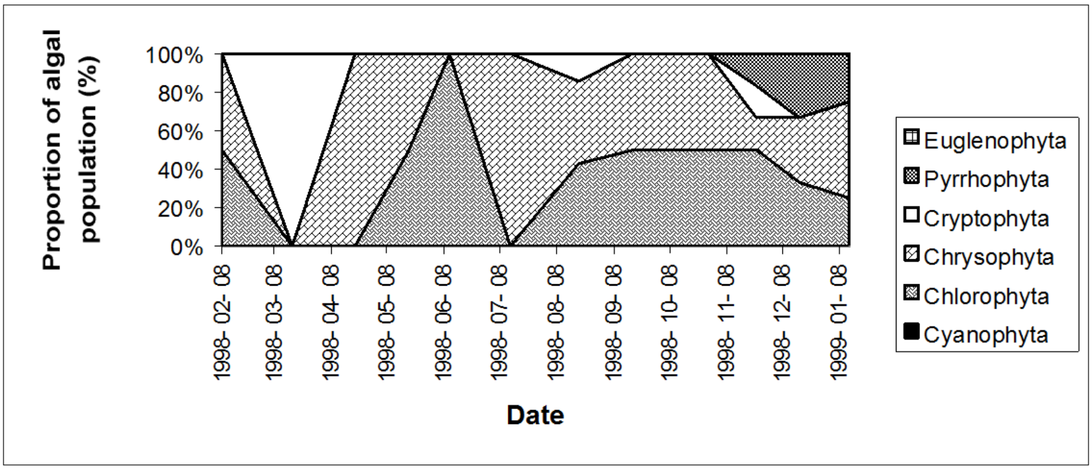

Figure 20. Mean annual dominance of algal groups in the Bo-Langvlei Lake.

Chlorophyta are characterised by the green colour from chlorophyll-*a* and -*b* in the same proportions as the 'higher' plants, ß-carotene and various xanthophylls (WWW 3, 2000).

Peridinium is the only species that might pose a problem in the system. Peridinium is an extensive genus of small to medium sized dinoflagellates, some but not all of which are photosynthetic. Species occur in freshwater and marine planktonic habitats worldwide. At least a few photosynthetic Pyrrhophyta species may form significant blooms ("red tides"). Some of these blooms are associated with nuisance odours and fish kills, although the most devastating "red tide" dinoflagellates belong to other genera (WWW 4, 2000).

Most species of *Cyclotella* are found in freshwater environments, of which ten live in brackish, estuarine and coastal waters (WWW 5, 2000)

Cyanobacteria did not form a significant proportion of the phytoplankton population within the Bo-Langvlei Lake.

5.1.2.3 *Physical characteristics*

The mean Secchi disc reading was 3.21 m. The lake is, therefore, a clear system. Due to the limited number of Secchi disc readings taken, no correlation determination between the chlorophyll-a and the Secchi disc readings was done. Suspended solids concentrations were not determined for the Bo-Langvlei Lake.

No temperature and oxygen profiles were taken during the study period.

Figure 21 indicates the alkaline nature of the Bo-Langvlei Lake. The pH values show greater variability in the western section of the lake compared to the eastern section. These pH values are again much higher than the mean value of 7.83 found by FIJEN and VAN ZYL (1995) for the data period from 1970 to 1993. According to DWAF (1996a) water of this pH is acceptable for swimming, although some eye, skin, ear and mucous irritation may occur.

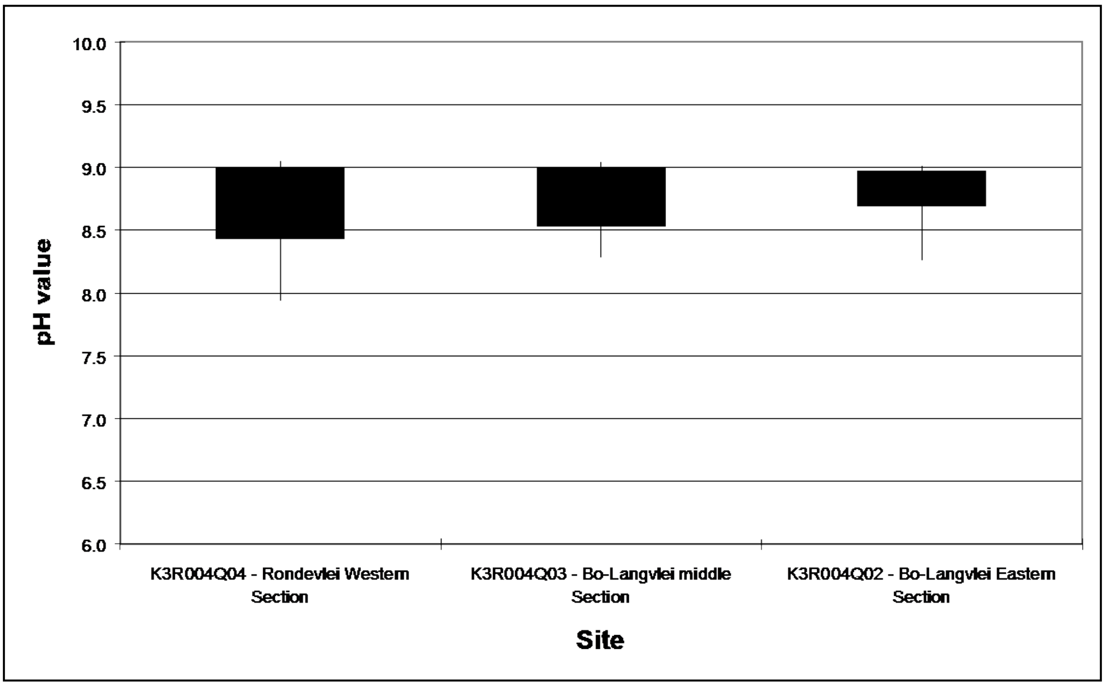

Figure 21. Variability of the pH values at the three sites in the Bo-Langvlei Lake.

5.1.2.4 *Trophic status of the Bo-Langvlei Lake*

Table 8 indicates that the Bo-Langvlei Lake is eutrophic when total phosphorus is considered. However, no eutrophication symptoms are encountered and the chlorophyll-*a* concentrations are much lower than those found in the Rondevlei Lake. This phenomenon is most probably due to the location and the saline nature of the system.

Table 8. Trophic status indicators in the Bo-Langvlei Lake for the period 1989 –1999 (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)	
1998-1999	1.2	0	**0.074**	0	3.21	**E & clear**

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

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

- The Bo-Langvlei Lake has the potential for eutrophic conditions to develop, but no symptoms of eutrophication were encountered.
- The monitoring of the system is essential for future management regarding eutrophication.

5.1.3 Onder-Langvlei Lake (Eilandvlei)

The Onder-Langvlei Lake, the third lake in the Wilderness Lake System, is situated upstream of the Wilderness Lagoon and downstream of the Bo-Langvlei on the Serpentine River (Figure 1) and had three sampling sites (Figure 22). The Onder-Langvlei discharges into the Serpentine River.

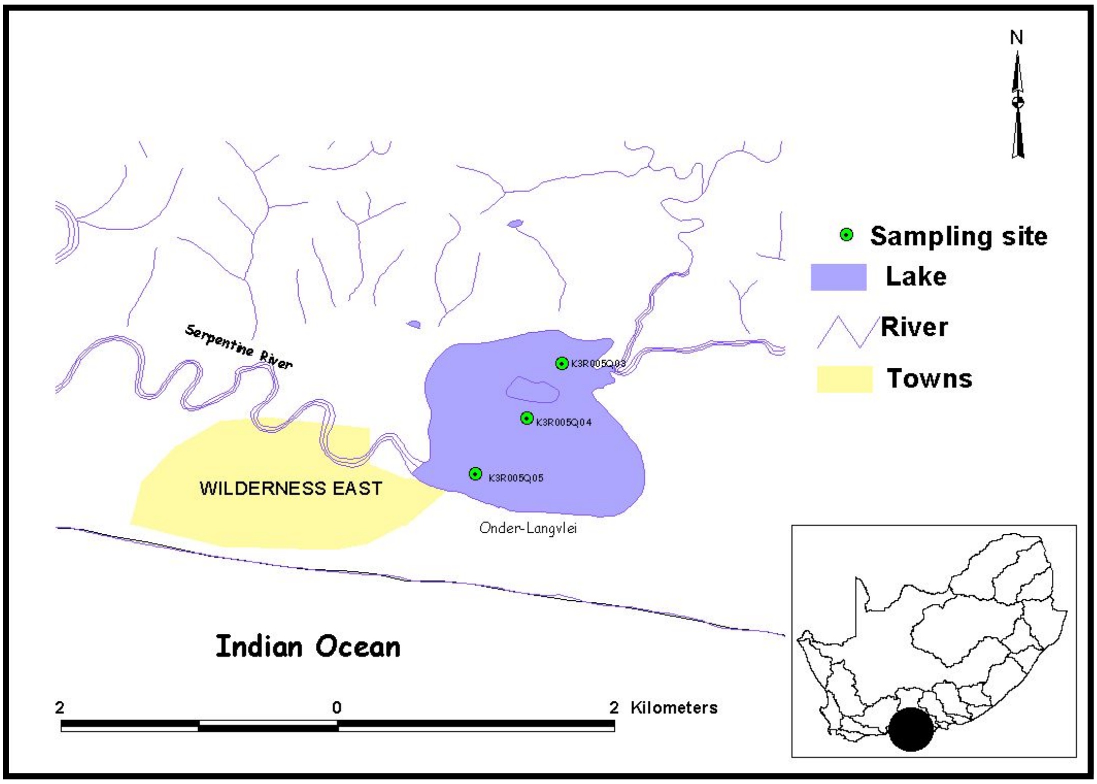

Figure 22. The sampling sites in the Onder-Langvlei Lake.

5.1.3.1 *Chemical characteristics*

Phosphorus

Figure 23 indicates that in the Onder-Langvlei Lake the TP concentrations, for the period extending from 1998 to January 1999, were consistently within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b). The TP concentrations were, however, often above the threshold level for eutrophic systems of 0.047 mg/L P as is indicated in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990) at the inflow of the Duiwe River and decreasing towards the middle of the lake. The PO_4-P concentrations (Figure 24) followed the same pattern with concentrations often higher than the Water Quality Guideline of 0.025 mg/L P for Aquatic Ecosystems (DWAF 1996b). These phosphorus concentrations indicate slight enrichment of the system, however, if the salinity of the system is considered, the nutrient enrichment should not pose any problem at this stage. If, however, the nutrient enrichment increases over time, eutrophication problems might occur.

Since the FIJEN and VAN ZYL (1995) study the mean PO_4-P concentration of 0.053 mg/L showed a decrease to between 0.018 mg/L to 0.022 mg/L at the three sites in the Onder-Langvlei Lake.

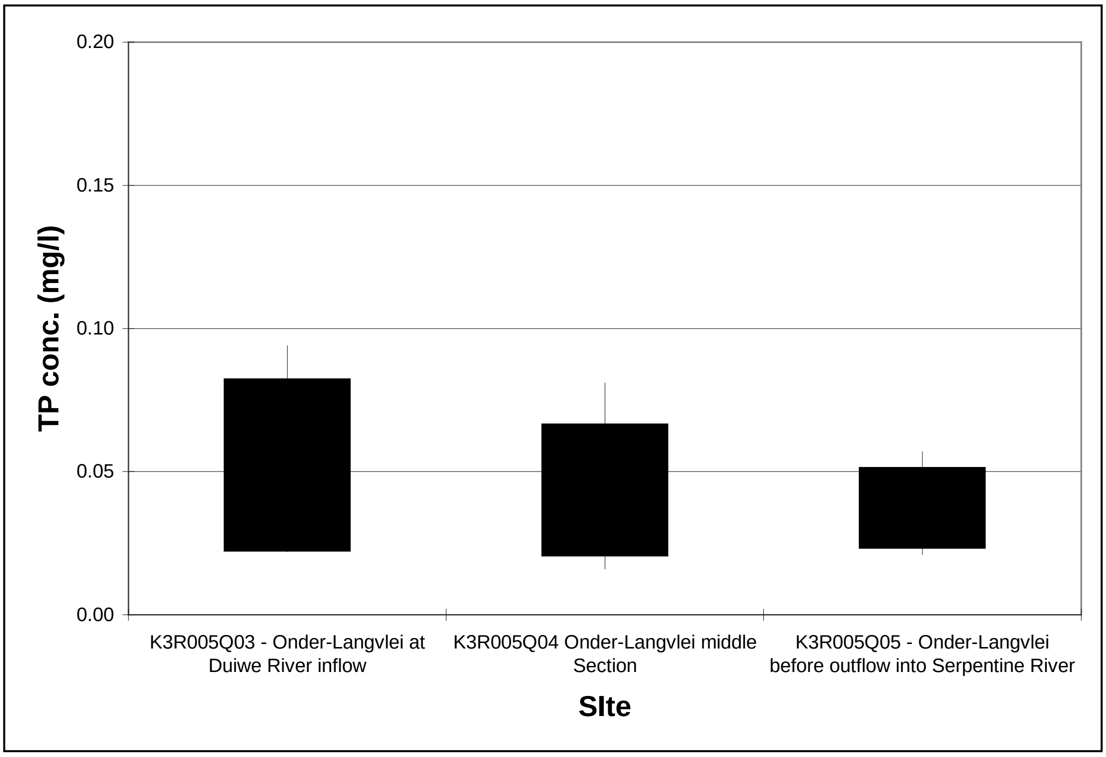

Figure 23. Variability in TP (as P) concentrations at the three sites in the Onder-Langvlei Lake catchment (1998 – 1999).

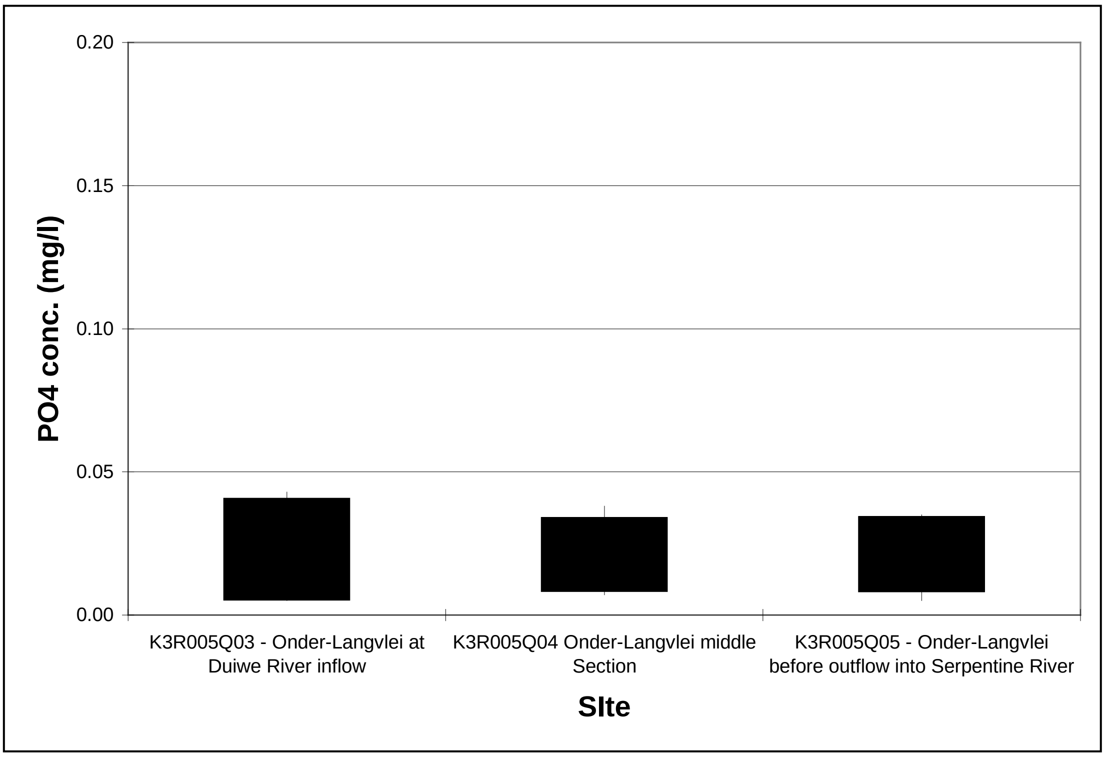

Figure 24. Variability in PO_4-P (as P) concentrations at the three sites in the Onder-Langvlei Lake catchment (1998 – 1999).

The TN concentrations in the Onder-Langvlei Lake are reflected in Figure 25 and indicate that the nitrogen concentrations were consistently below 2 mg/L as N and decreased in variability towards the outflow into the Serpentine River.

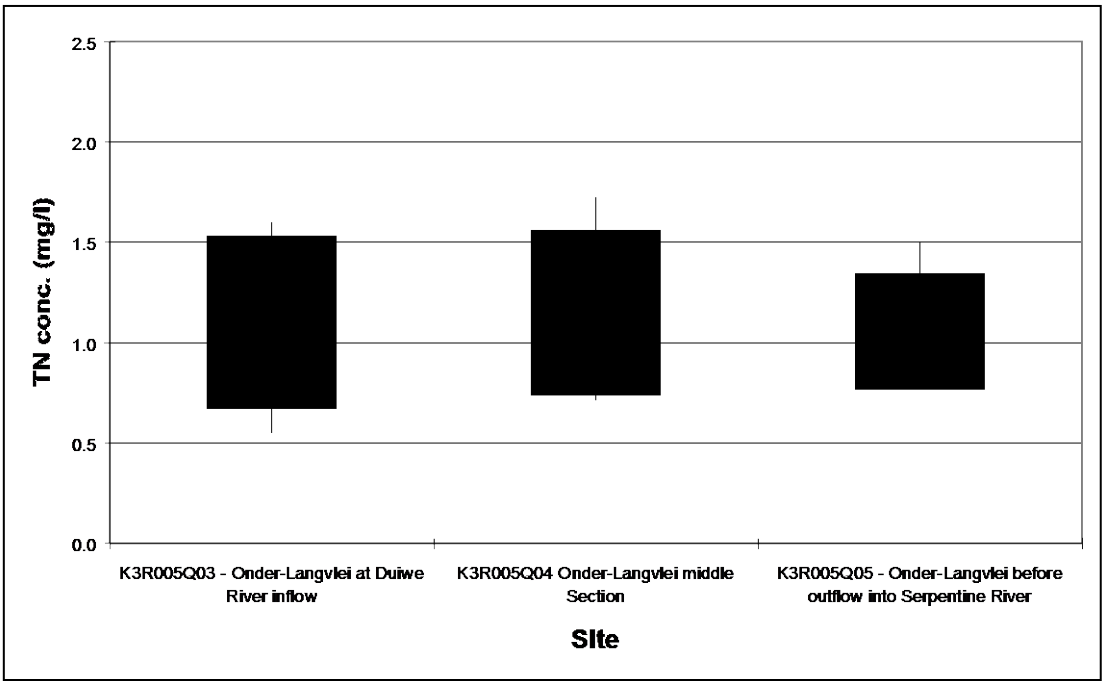

Figure 25. Variability in TN concentrations at the three sites in the Onder-Langvlei Lake catchment (1998 – 1999).

The dissolved inorganic nitrogen (DIN) concentrations are very low (Figure 26), indicating that most of the nitrogen in the lake is not available for primary growth.

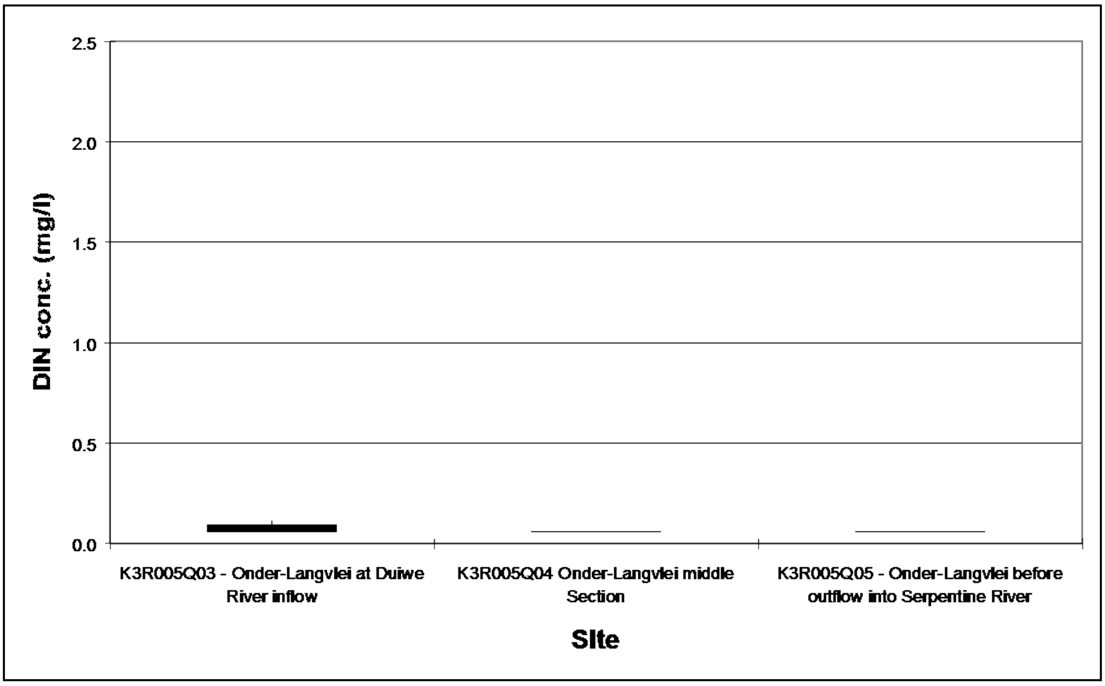

Figure 26. Variability in DIN (as N) concentrations at the three sites in the Onder-Langvlei Lake catchment (1998 – 1999).

The mean NO_3+NO_2 (as N) concentration of between 0.03 mg/L and 0.04 mg/L at the three sites in the Onder-Langvlei Lake were lower than the 0.303 mg/L found by FIJEN and VAN

ZYL (1995). The NH_4 (as N) at the three sites in the lake (0.03 mg/L) when compared to the mean NH_4 (as N) concentration of 0.162 mg/L found by FIJEN and VAN ZYL (1995) also indicated a decrease.

TN:TP ratio

The minimum, median and maximum TN:TP ratios in the Onder-Langvlei Lake are shown in Table 9. The TN:TP ratios indicate that the water quality in the Onder-Langvlei Lake was phosphorus limited for the entire period. The development of cyanobacteria are, therefore, not likely. The nutrient concentrations of the impoundment indicate that the system is only slightly enriched and still within manageable levels.

Table 9. The minimum, median and maximum TN:TP ratios at the three sites in the Onder-Langvlei Lake during 1998 to 1999.

Site	**Minimum TN:TP ratio (n=12)**	**Median TN:TP ratio (n=12)**	**Maximum TN:TP ratio (n=11)**
K3R005Q03 - Onder-Langvlei at Duiwe River inflow	14.0	26.9	38.7
K3R005Q04 Onder-Langvlei middle section	13.3	31.3	52.3
K3R005Q05 - Onder-Langvlei before outflow into Serpentine River	17.0	30.4	47.0

Salinity

Coastal lakes such as the Wilderness and the Swartvlei Lakes share many of the attributes of estuaries and of the associated wetlands to form complex and interactive ecosystems. The Onder-Langvlei that forms one of a series of natural lakes is, therefore, highly saline with EC values lower than those found in the Bo-Langvlei Lake, of approximately 800 mS/m (Figure 27), at all three the sampling sites in the Onder-Langvlei.

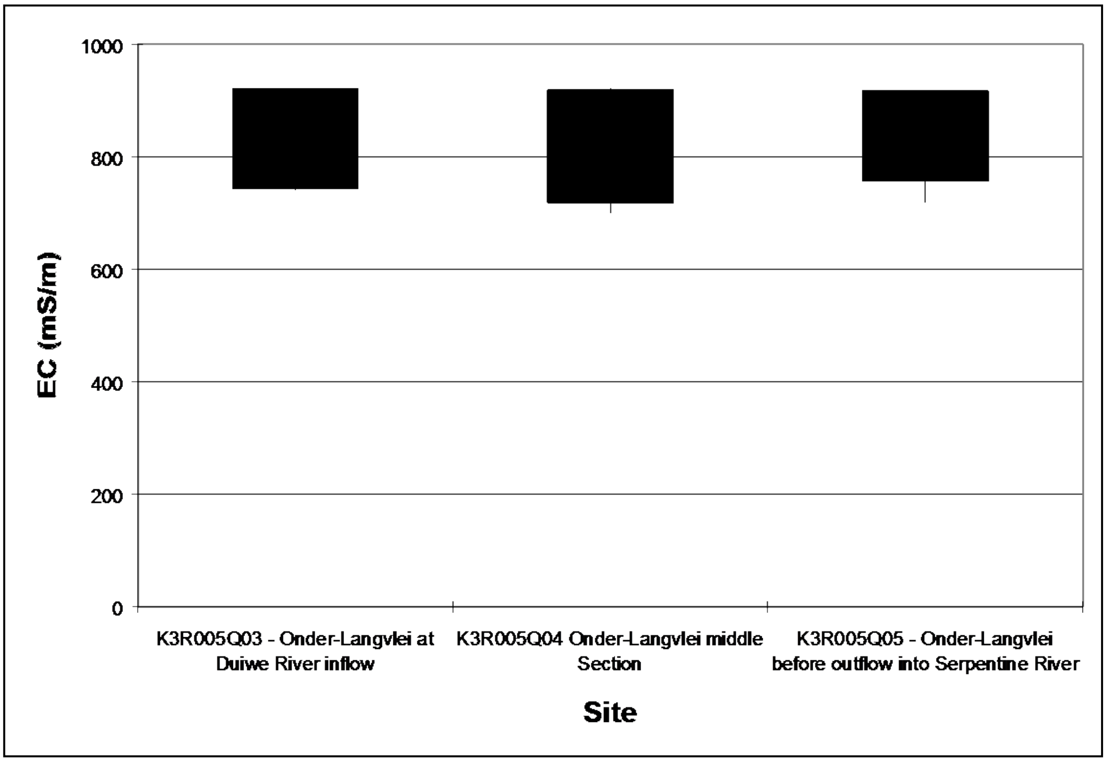

Figure 27. EC readings in the Onder-Langvlei Lake during 1998 and 1999.

The dissolved salts concentrations in the Onder-Langvlei (Figure 28) show that the three sites in the Onder-Langvlei exhibit the same tendencies of the ions, except for the calcium and sulphate concentrations. The Ca^{2+}, SO_4^{2-} and K^+ concentrations decrease significantly towards the outflow into the Serpentine River in the Onder-Langvlei. The other ions show no spatial trends. The spatial changes and variability in Ca^{2+} and SO_4^{2-} are explained by the dynamic nature of these ions that are strongly influenced by microbial metabolism (WETZEL, 1983). The relative concentrations of the major ions show the tendency of $Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+$. The lake is a saline system with Cl^- being the major anion contributing to the saline nature.

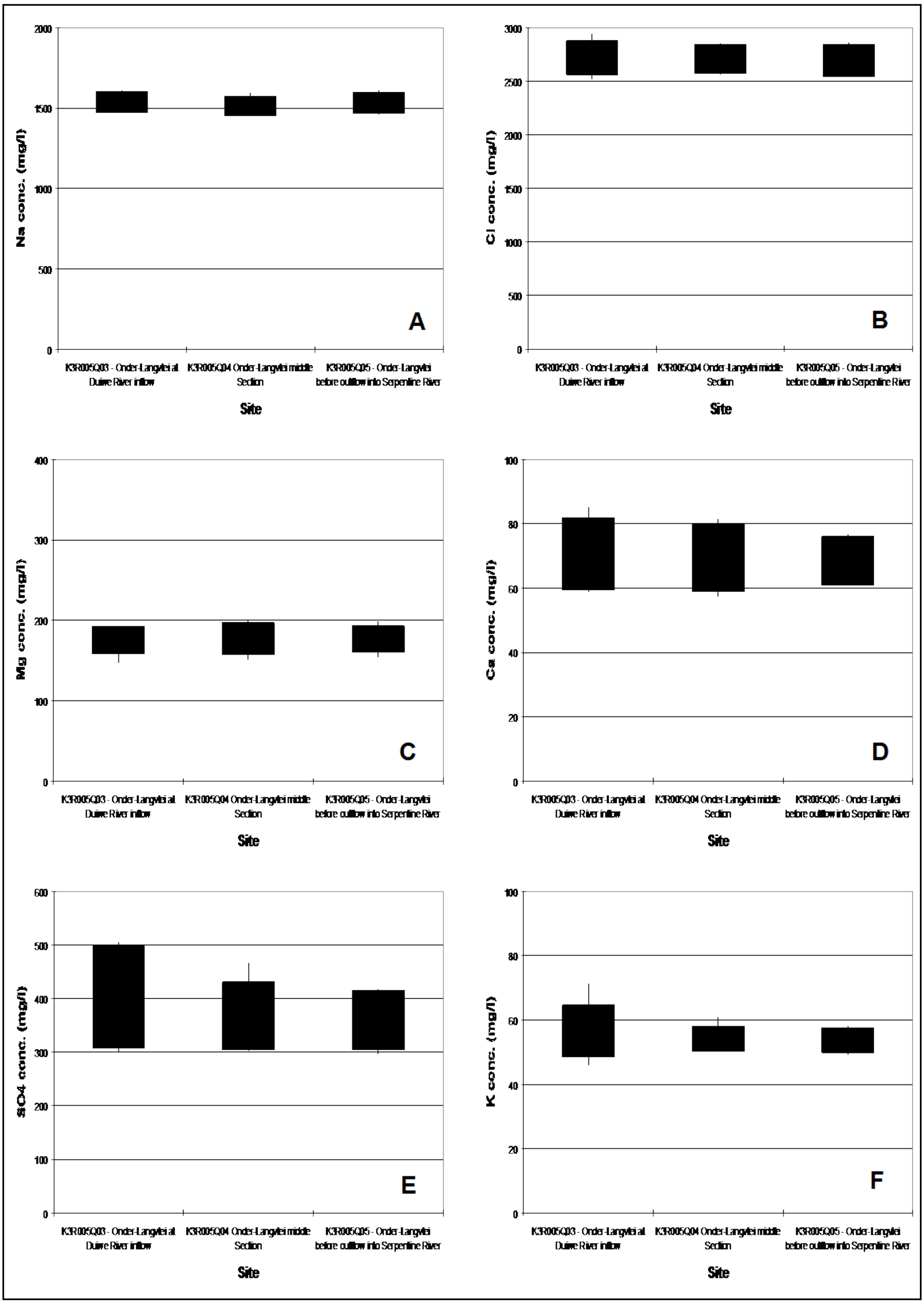

Figure 28. The dissolved salts concentration variability at the three sites in the Onder-Langvlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations; and F Potassium concentrations.

Trace metals

Dissolved trace metal samples were only taken in the middle section of the Onder-Langvlei on four occasions (Table 10). These results are compared to the available target values for primary and secondary consumers for coastal marine environments. Fairly high boron (B) concentrations and strontium (Sr) concentrations were found at the middle section site in the Bo-Langvlei on all four sampling occasions, as is normal for saline systems (WETZEL, 1983). However, no target values are available for these two variables (DWAF 1995). Target values are available for chromium, nickel, copper, zinc, cadmium and lead. The zinc concentration was higher than the detection limit on 22/05/1998, but was still below the target value.

Table 10. The dissolved trace metal concentrations at the middle section in the Onder-Langvlei Lake during 1998 on four sampling occasions and compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/04/19**	**1998/05/22**	**1998/08/21**	**1998/11/24**
Boron (B) (mg/L)	NA	NA	0.656	0.512	0.654	0.625
Aluminium (Al) (mg/L)	NA	NA	<0.02	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	0.002	0.009	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	<0.003	<0.003	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	<0.003	<0.003	<0.003	<0.003
Nickel (Ni) (mg/L)	0.025	0.025	<0.006	<0.006	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	<0.002	<0.002	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	<0.004	0.019	<0.004	<0.004
Strontium (Sr) (mg/L)	NA	NA	1.063	0.917	1.098	1.099
Molybdenum (Mo) (mg/L)	NA	NA	<0.005	<0.005	<0.005	<0.005
Cadmium (Cd) (mg/L)	0.004	0.004	<0.002	<0.002	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015	<0.015

The trace metals measured seem, therefore, to pose no threat to the ecology of the system.

5.1.3.2 Biological characteristics

The chlorophyll-a concentrations (Figure 29) were below 10 µg/L in the lake for over 60 % of the time. There was a period of elevated chlorophyll-a concentrations where concentrations were above 10 µg/L. The concentrations above the threshold level for eutrophic systems of 30 µg/L indicate that the system might experience eutrophic symptoms and algal blooms periodically. Cyanobacteria (*Oscillatoria)* were dominant on one occasion in the system (Figure 30). Chrysophyta (*Chlorocromonas* and *Tribonema*) were the dominant algal groups. Chlorophyta (Stigeoclonium and *Volvox*) and Chrysophyta (*Gymnodinium* and *Peridinium*) periodically form a part of the phytoplankton population.

The phytoplankton genera *Oscillatoria*, *Gymnodinium* and *Peridinium* might all produce toxins. The fact that they are present in the system, and that the lake exhibited periods of increased chlorophyll-*a* concentrations that indicates potential bloom conditions, should be a concern to managers of these recreational centres.

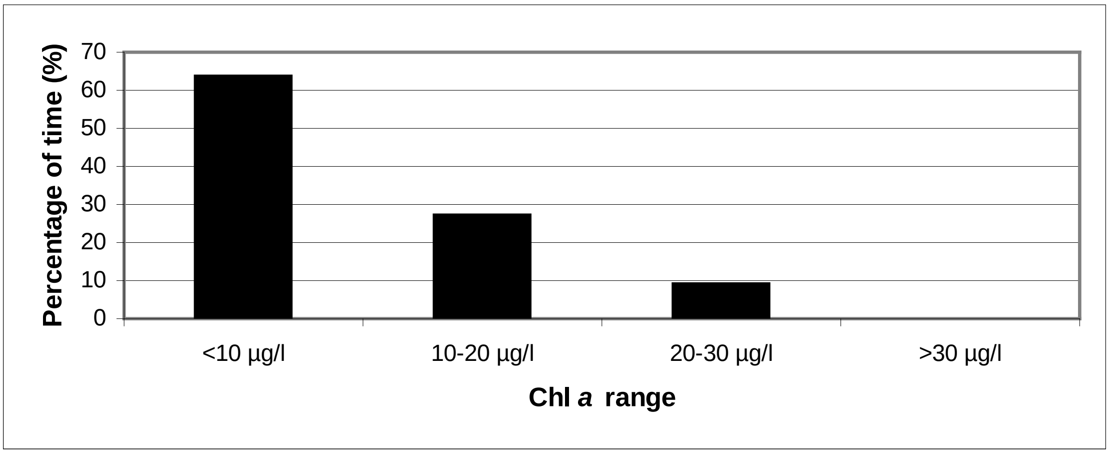

Figure 29. Per cent of the time that chlorophyll-*a* concentrations are within a specified range in the Onder-Langvlei Lake upstream of the outflow into the Serpentine River.

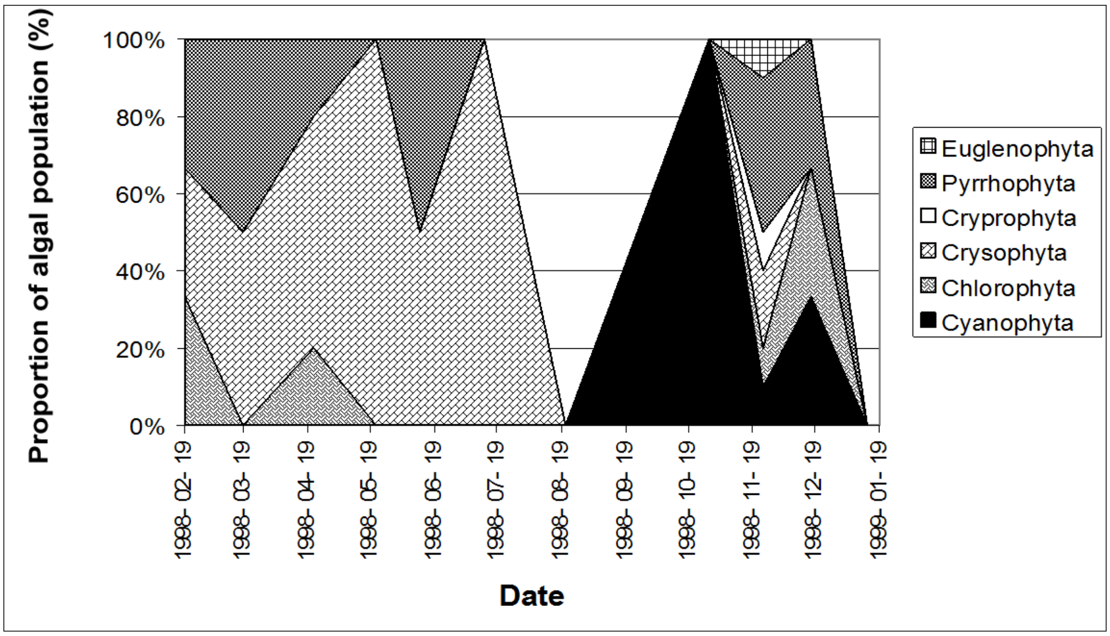

Figure 30. Dominance of algal groups in the Onder-Langvlei Lake.

5.1.3.3 Physical characteristics

The mean Secchi disc reading was 3 m. The lake is, therefore, a clear system. Due to the limited number of Secchi disc readings, no correlation determination between the chlorophyll-a concentrations and the Secchi disc readings was done.

Figure 31 indicates the pH range recorded at the 3 locations of the Onder-Langvlei Lake. The lake is alkaline with the pH concentration showing an increasing tendency from the inflow at the Duiwe River towards the outflow of the lake into the Serpentine River. The water is acceptable for recreational use according to DWAF (1996a).

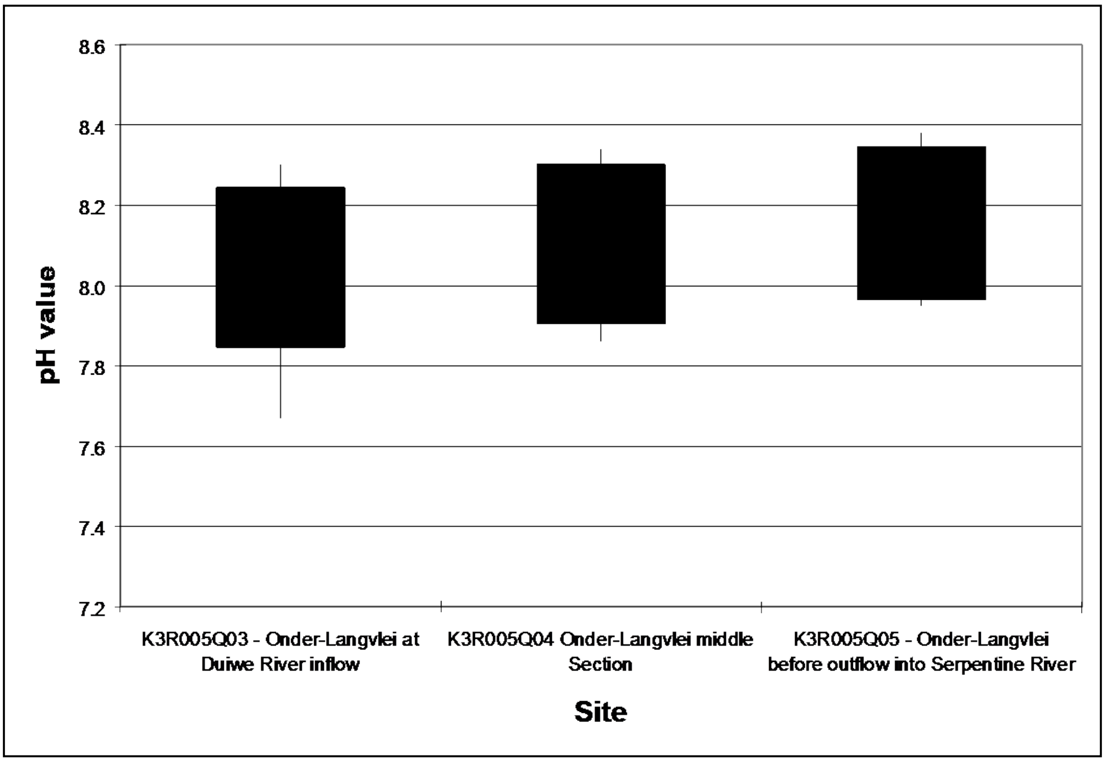

Figure 31. Variability of the pH values at the three sites in the Onder-Langvlei Lake.

5.1.3.4 Trophic status of the Onder-Langvlei Lake

Table 11 indicates that the Onder-Langvlei Lake is mesotrophic. Limited occurrences of high chlorophyll-a concentrations were found, but the overall perspective is that the Onder-Langvlei Lake water was of high quality and within acceptable nutrient limits. Cyanobacteria were occasionally dominant in the system.

Table 11. Trophic status indicators in the Onder-Langvlei Lake for the period 1998 – 1999 (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)	
1998-1999	11.2	0	**0.033**	0	1.44	**M & clear**

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

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

- The Onder-Langvlei Lake was mesotrophic.
- Monitoring of the impoundment should be continued, as the impoundment's water quality is close to pristine and will serve as a reference for mesotrophic, saline systems.
- The occurrence of cyanobacteria should closely be monitored, as potentially toxic species are present within the system.

5.1.4 Wilderness Lagoon

The Wilderness Lagoon connects the three previously discussed lakes to the Indian Ocean (Figures 1 and 32). Four sites were sampled on a monthly basis for a period of one year. The Touws River and the Serpentine River feed into the lagoon. The mouth of the estuary is open for 25 % of the year (FIJEN and KAPP 1995a).

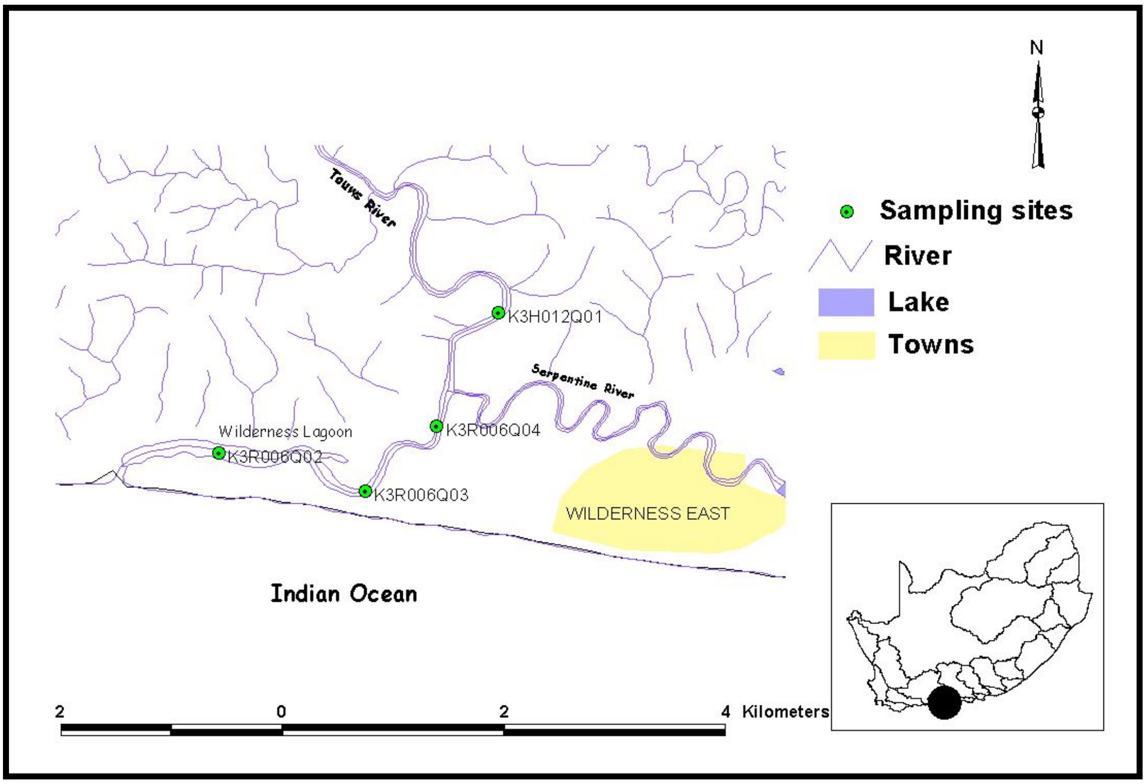

Figure 32 Sampling sites in the Wilderness Lagoon.

5.1.4.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Wilderness Lagoon comprises the whole of 1998 and January 1999. Figure 32 indicates that in the Wilderness Lagoon the TP concentrations for the study period were consistently within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b). TP concentrations were also never above the threshold level for eutrophic systems of 0.047 mg/L P, as is suggested in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990). There was a slight increase in TP concentrations towards the estuary mouth.

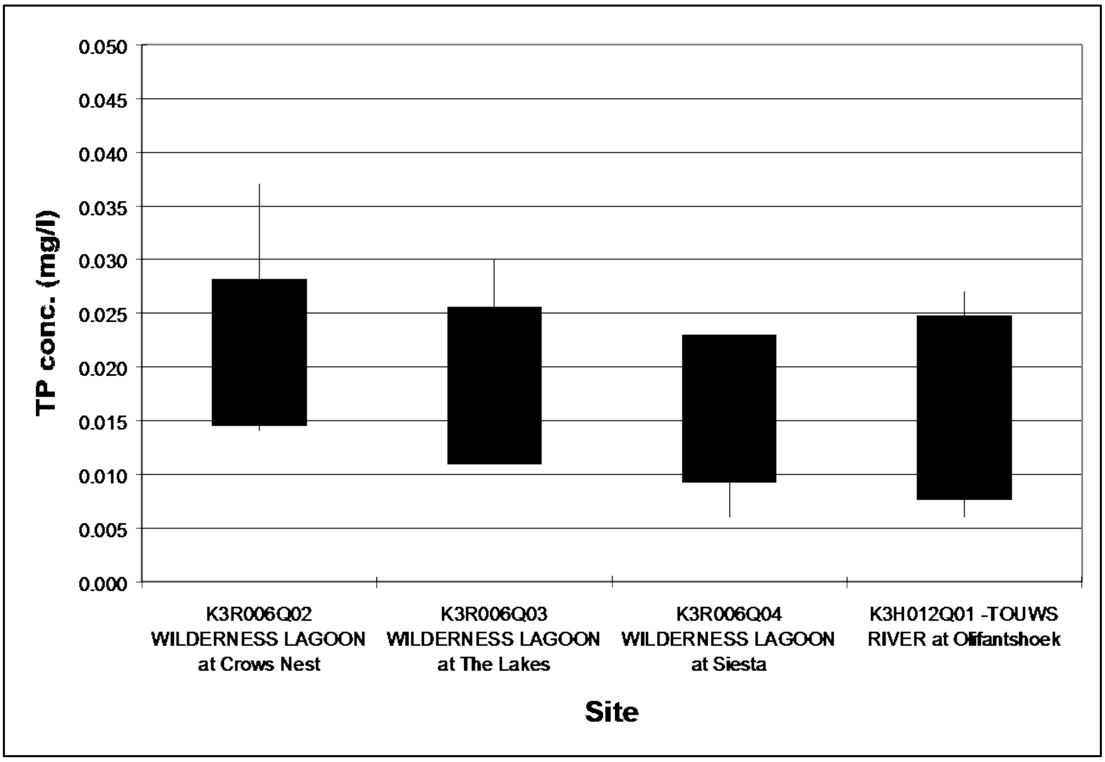

Figure 32. Variability in TP (as P) concentrations at the three sampling sites in the Wilderness Lagoon (1998-1999).

The PO_4-P concentrations in the Wilderness Lagoon never exceeded 0.025 mg/L P (Figure 36). There was no distinct spatial change in PO_4-P concentrations from the inflowing streams towards the eastern section of the Wilderness Lagoon. FIJEN and VAN ZYL (1995) found that the mean PO_4-P concentration for the period 1977 to 1993 was 0.023 mg/L P. This mean PO_4-P concentration is higher than the mean PO_4-P concentration found during this assessment in the Wilderness Lagoon (between 0.011 mg/L and 0.014 mg/L).

The phosphorus component of the nutrients does not, therefore, pose a problem regarding the development of eutrophication problems.

Nitrogen

The variability in KN concentrations in the Wilderness Lagoon is reflected in Figure 37. Slightly higher KN concentrations were found at the lakes in the Wilderness Lagoon and in the Touws River, yet the concentrations were low and should not cause serious eutrophication problems or have a major impact on the environment. Dissolved nitrogen also constitutes a very small proportion of the nitrogen component.

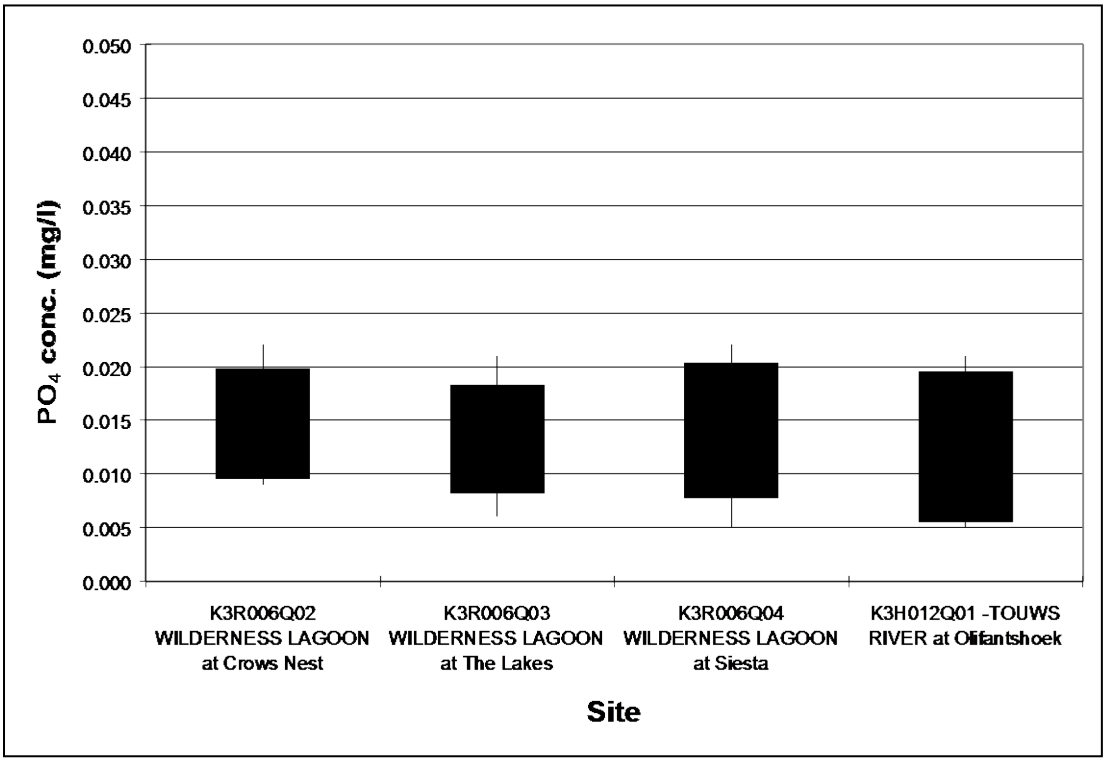

Figure 33. Variability in PO_4-P (as P) concentrations at the three sampling sites in the Wilderness Lagoon (1998-1999).

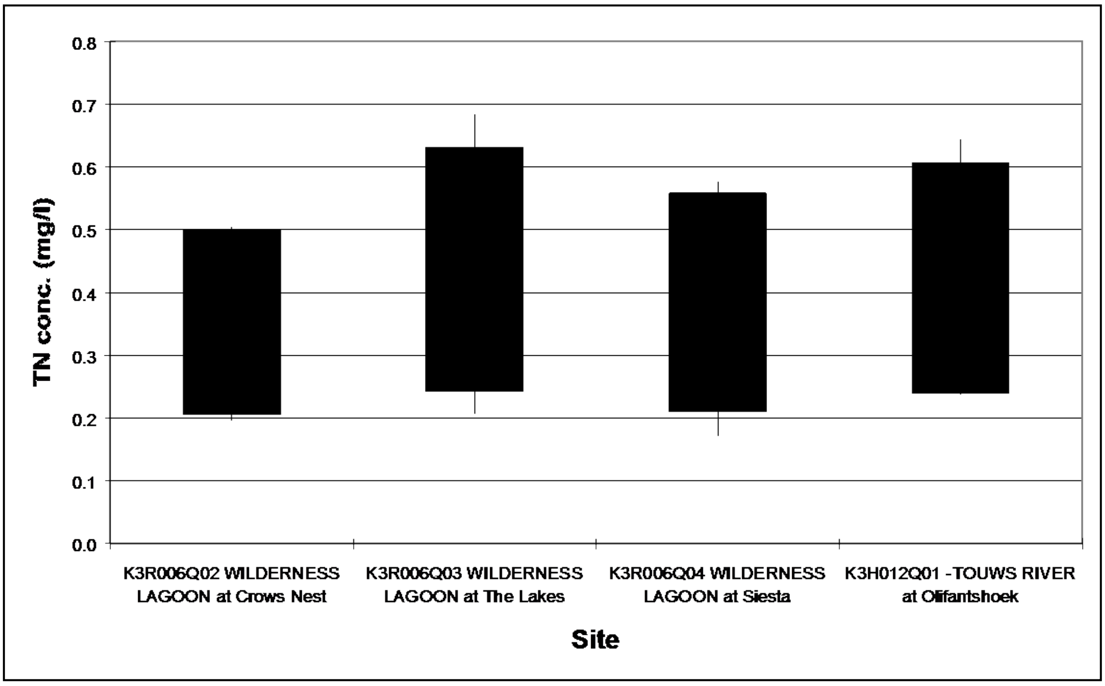

Figure 34. Variability in TN (as N) concentrations at the three sampling sites in the Wilderness Lagoon (1998 - 1999).

The dissolved inorganic nitrogen concentrations (DIN) are very low, consistently below 0.2 mg/L N. The Touws River site showed greater variability than the other sites (Figures 35) but were also low. The mean NO_3+NO_2 concentrations (0.039 mg/L to 0.048 mg/L as N) are, however, slightly higher than the mean NO_3+NO_2 (0.033 mg/L N) concentrations found by

(FIJEN and VAN ZYL, 1995). The mean NH_4 concentrations (0.030 mg/L to 0.037 mg/L as N) were slightly lower than the mean NH_4 (0.078 mg/L N) concentration found by (FIJEN and VAN ZYL, 1995). Nutrient concentrations are at this stage not of any concern.

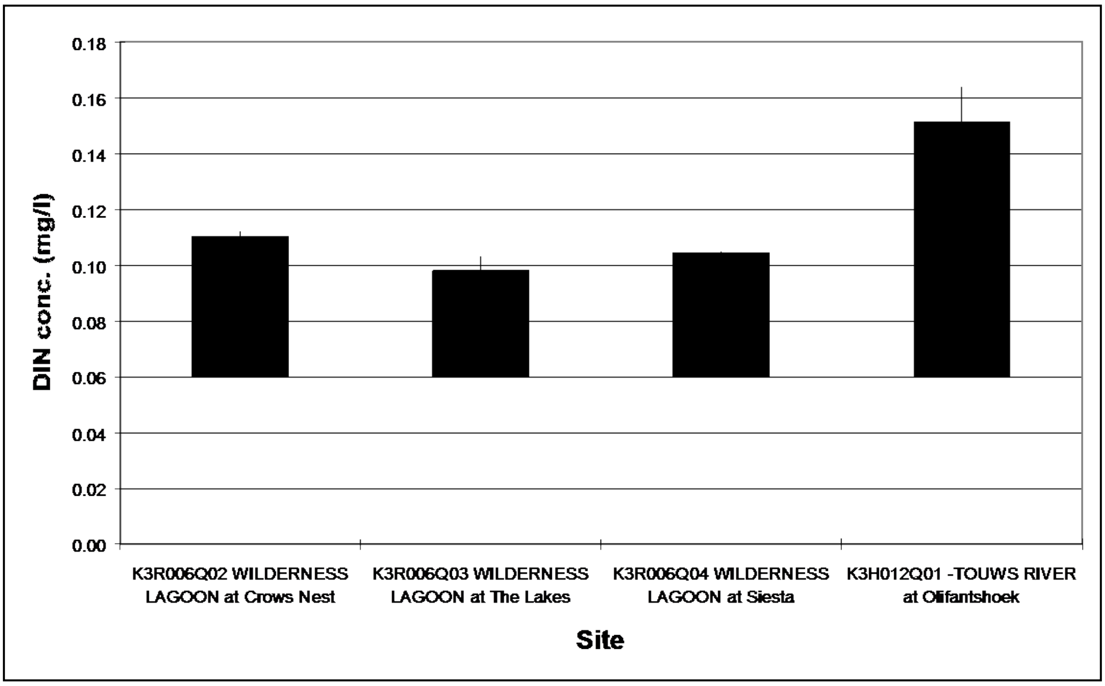

Figure 35. Variability in NO_3+NO_2 concentrations at the three sampling sites in the Wilderness Lagoon (1998-1999).

TN:TP ratio

The minimum, median and maximum TN:TP ratios for the Wilderness Lagoon are shown in Table 12. Median TN:TP ratios that are constantly above 16 and indicate that the water quality in the Wilderness Lagoon is phosphorus limited. The minimum TN:TP ratios indicate occasional nitrogen limitation that might lead to cyanobacterial bloom development.

Table 12. The minimum, median and maximum TN:TP ratios at the three sites in the Wilderness Lagoon during 1998 to 1999.

Site	**Minimum TN:TP ratio**	**Median TN:TP ratio**	**Maximum TN:TP ratio**
K3R006Q02 WILDERNESS LAGOON at Crows Nest (n=12)	10.4	16.7	33.7
K3R006Q03 WILDERNESS LAGOON at The Lakes (n=12)	10.9	23.7	39.3
K3R006Q04 WILDERNESS LAGOON at Siesta (n=11)	8.2	21.8	63.2
K3H012Q01 -TOUWS RIVER at Olifantshoek (n=10)	11.4	30.1	49.3

Salinity

The Wilderness Lagoon is an estuary with opening of the mouth for up to 25 % of the year. The EC reading never exceeded 2000 mS/m (Figure 36). The fresher nature of the Touws River compared to the other Wilderness Lagoon sites can be seen in Figure 40. The influence of this influx of freshwater is evident in the spatial change of fresher water from the site at Siesta towards the more saline water at the Crows Nest site, which is the closest to the lagoon and, therefore, the saline marine environment.

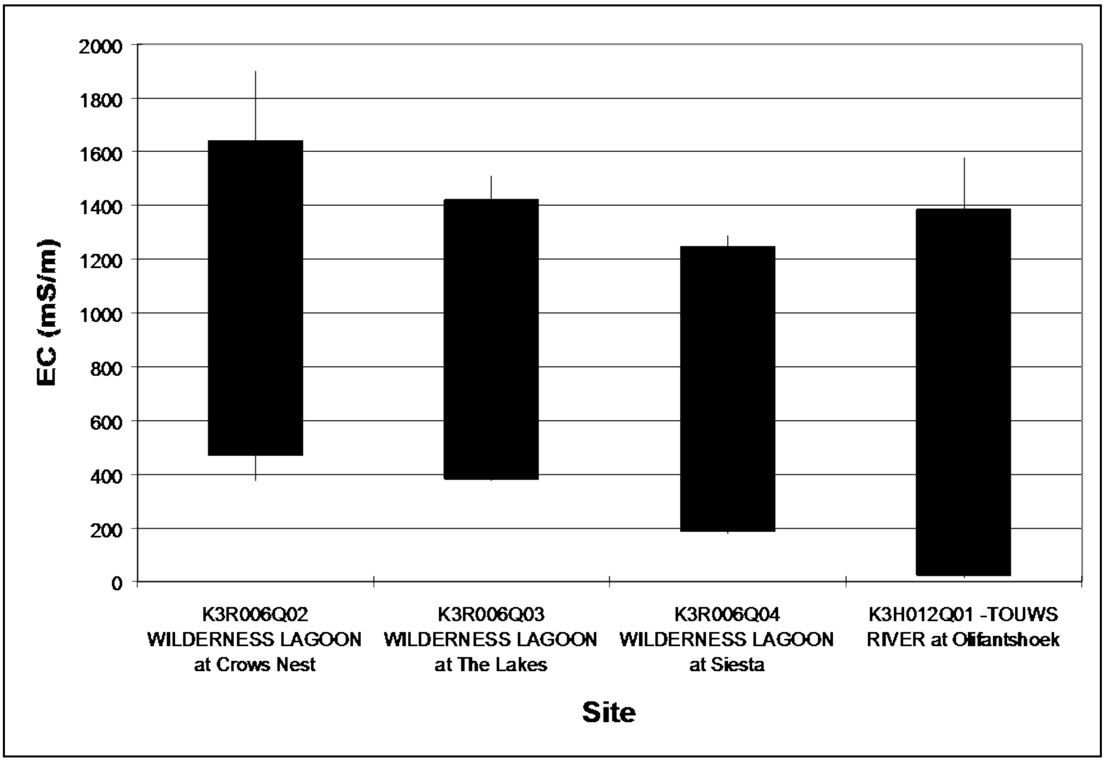

Figure 36. EC readings in the Wilderness Lagoon during 1998 and 1999.

The dissolved salts concentrations in the Wilderness Lagoon (Figure 37) show the same spatial tendency of higher major ions towards the estuary of the Wilderness Lagoon was indicated by the EC readings. The relative concentrations of the major ions show the tendency of Cl^{-} > Na^{+} > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^{+}. The relative proportions of the major solutes vary greatly from one saline lake to the next. Na^{+} dominates most saline waters, with very few lakes having Ca^{2+} or Mg^{2+} as major dominant cations (WETZEL, 1983). The dominating anion is commonly Cl^{-}, as is the case in the Wilderness Lagoon.

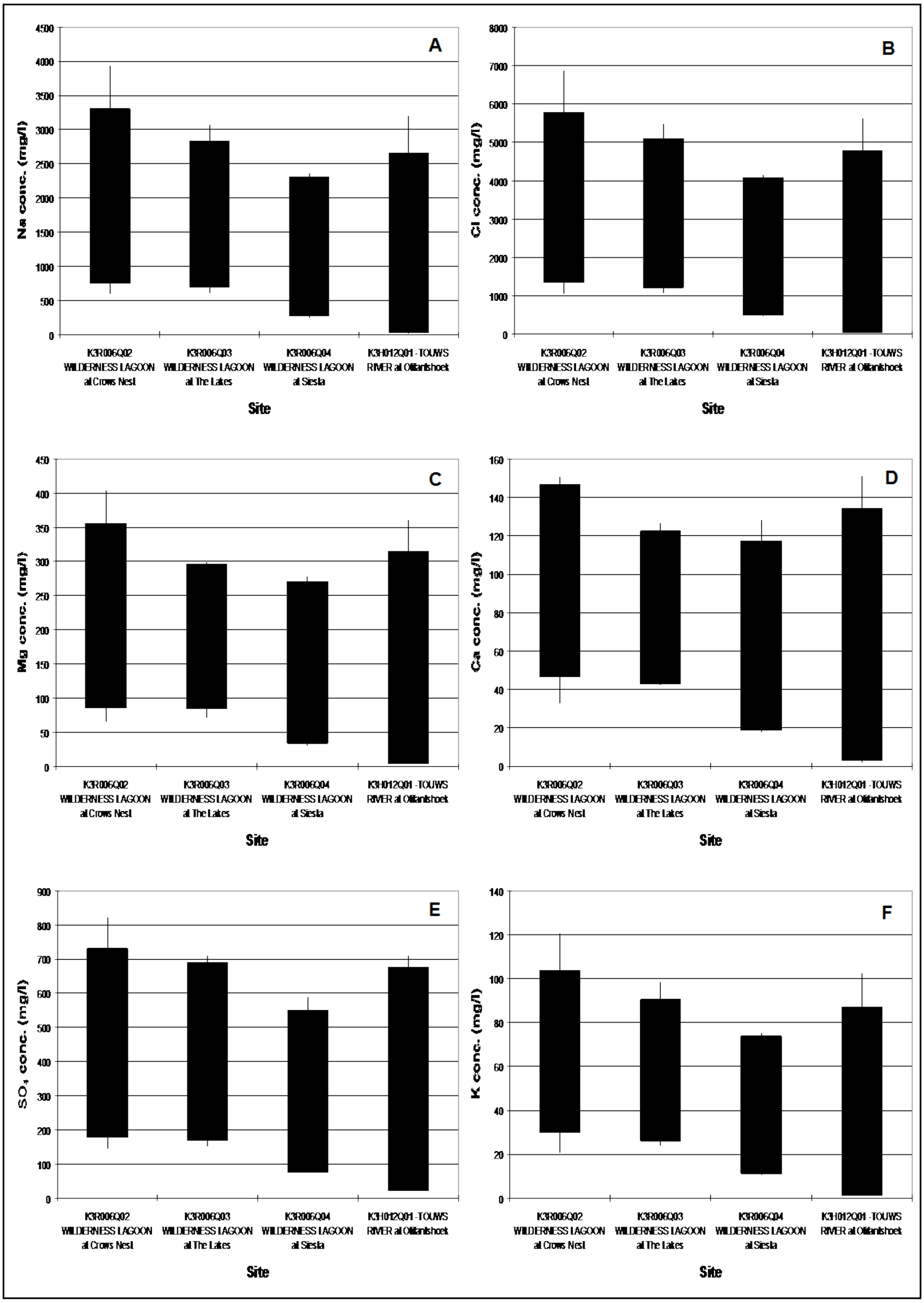

Figure 37. Variability of the dissolved salts concentration at the three sites in the Rondevlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations, and F Potassium concentrations.

Trace metals

Dissolved trace metal samples were only taken at the Lakes site in the Wilderness Lagoon (Table 13). The minimum, median and maximum values of the different dissolved trace metals that were analysed are compared to the available target values for primary and secondary consumers for coastal marine environments. The trace metal concentrations measured on a quarterly basis showed high concentrations of boron and strontium, however, no guidelines exist for these two metals. According to WETZEL (1983) boron is stimulatory to photosynthesis to levels of 100 mg/L boron and are often found in elevated concentrations in saline lakes. Strontium is a readily accepted substitute for calcium, an essential inorganic element of algae, in some algal species, but in other algae, calcium utilisation is strongly inhibited by strontium (WETZEL, 1983).

On one occasion (1998/5/2) the aluminium concentration was higher than the detection limit, but no target values for both primary and secondary consumers have been established.

Table 13. The dissolved trace metal concentrations at the Lakes site in the Wilderness Lagoon during 1998 on four sampling occasions and compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/05/02**	**1998/05/22**	**1998/08/21**	**1998/11/24**
Boron (B) (mg/L)	NA	NA	0.953	0.832	0.715	0.584
Aluminium (Al) (mg/L)	NA	NA	0.076	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	<0.002	0.003	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	<0.003	<0.003	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	<0.003	<0.003	<0.003	<0.003
Nickel (Ni) (mg/L)	0.025	0.025	0.011	<0.006	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	<0.002	<0.002	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	<0.004	0.039	<0.004	<0.004
Strontium (Sr) (mg/L)	NA	NA	1.507	1.498	1.178	0.968
Molybdenum (Mo) (mg/L)	NA	NA	<0.005	0.013	<0.005	<0.005
Cadmium (Cd) (mg/L)	0.004	0.004	<0.002	<0.002	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015	<0.015

Trace metals seem, therefore, not to be a problem in the Wilderness Lagoon.

5.1.4.2 Biological characteristics

The chlorophyll-*a* concentration in the Wilderness Lagoon (Fig. 38) is mostly below 10 µg/L and for only 20 % of the time exceeded 10 µg/L but did not exceed 20 µg/L. The chlorophyll-*a* concentrations never reached nuisance concentrations of higher than 20 µg/L during the study period.

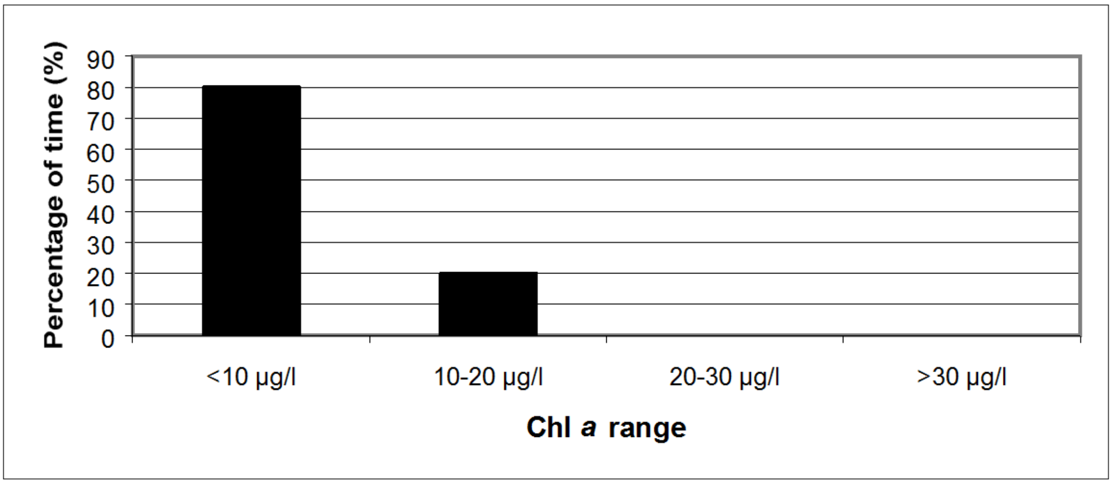

Figure 38. Per cent of the time that chlorophyll-*a* concentrations were within a specified range in the eastern section of the Wilderness Lagoon.

Pyrrhophyta (*Peridinium*) was the dominant algal group during the spring and summer periods (Figure 39). *Peridinium* is a large genus of small to medium sized dinoflagellates, some but not all of which are photosynthetic. Pyrrhophyta species occur in freshwater and marine planktonic habitats. At least a few photosynthetic species may form significant blooms ("red tides"). Some of these blooms are associated with nuisance odours and fish kills, although the most devastating "red tide" dinoflagellates belong to other genera (WWW 1, 2000).

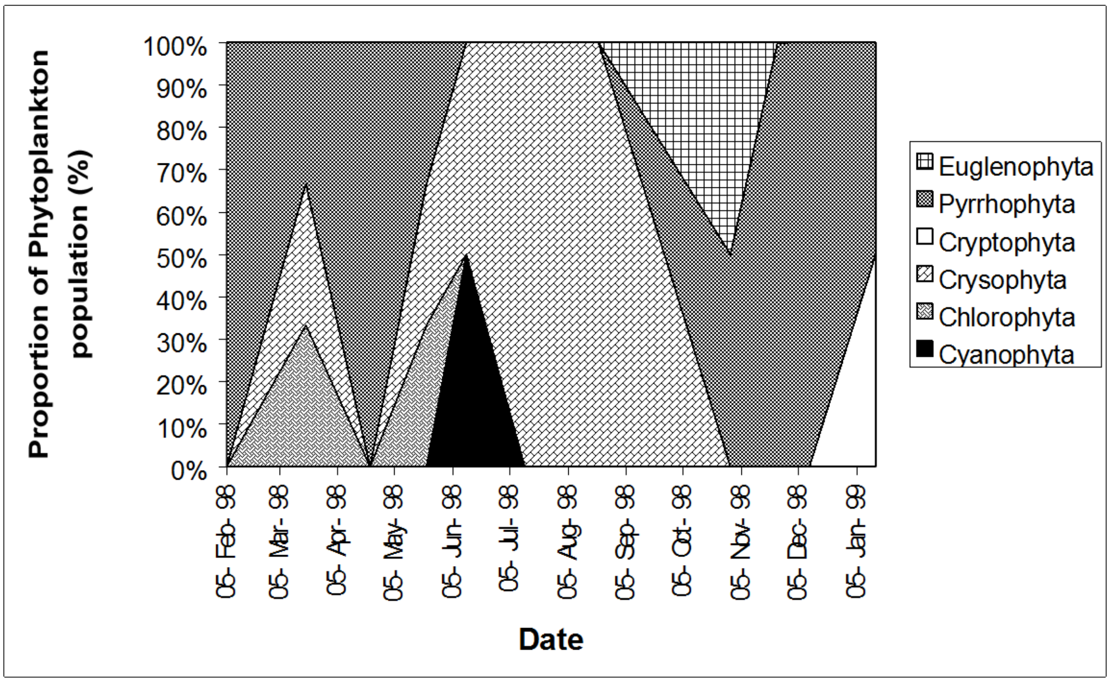

Figure 39. Monthly dominance of algal groups in the Wilderness Lagoon.

Chrysophyta (*Tribonema*) was dominant during the winter period. During the study period Chlorophyta (*Ankistrodesmus*), Cryptophyta (*Cryptomonas*) and Euglenophyta (*Euglena*) occasionally contributed a noticeable proportion of the phytoplankton population. Cyanobacteria (*Anabaena*) were present once in the Wilderness Lagoon during the study period but in such low numbers that they were negligible.

These results indicate that the lagoon does have the potential to develop occasional eutrophic nuisance conditions. The fairly low chlorophyll-*a* concentrations may, however, be the result of a combination of the salinity and the low nutrient conditions in the system.

5.1.4.3 Physical characteristics

The Secchi disc readings taken at the Lakes site varied between 1.26 m and 1.44 m. The lagoon is, therefore, a relatively clear system. Due to limited Secchi disc readings, no correlation determination between the chlorophyll-*a* and the Secchi disc readings was done.

Figure 40 indicates that the Wilderness Lagoon is alkaline with pH readings varying between 7.5 and 9. These values are much higher than the mean pH value of 7.71 found by FIJEN and VAN ZYL (1995) in an earlier study on the water quality of the Wilderness Lagoon, with the exception of the Touws River site. The higher variability and much lower minimum pH found in the Touws River is an established phenomenon in the Western Cape Rivers. The pH indicates that the water is acceptable for recreational use (DWAF 1996a).

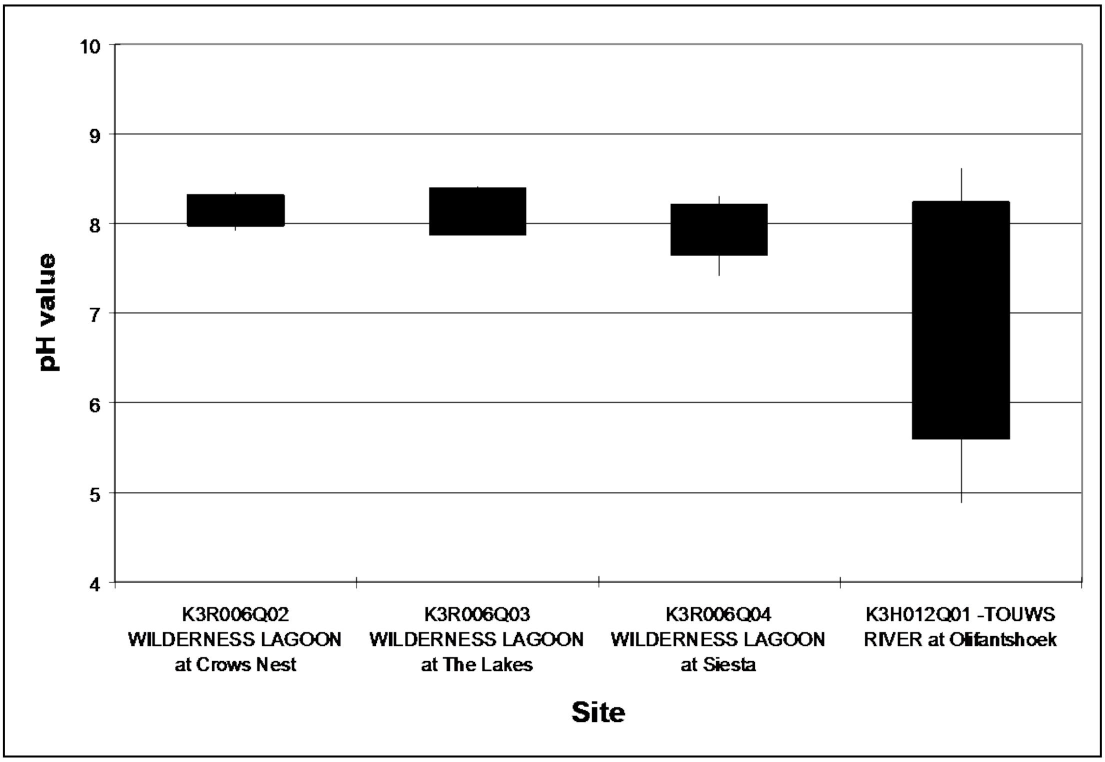

Figure 40. Variability of the pH values at the three sites in the Wilderness Lagoon.

The turbidity in the Wilderness Lagoon is between 0.5 NTU (Secchi disc depth of ± 10 m) and 2 NTU (Secchi disc depth of ± 2.5 m). These values show that the Wilderness Lagoon is a clear system with little light limitation to primary production. In the Touws River, values were higher due to turbulence and the normal flow of the river but it could still be considered to be clear.

5.1.4.4 Trophic status of the Wilderness Lagoon

Table 14 indicates that the Wilderness Lagoon has a tendency to be oligotrophic with occasional mesotrophic conditions prevailing within the system, especially when phosphorus is considered. This is not really reflected in the other trophic status indicators as they show an oligotrophic tendency. The saline nature of the system might have a limiting effect on the phytoplankton growth causing the phenomenon of low chlorophyll-*a* concentrations when compared to the nutrient enrichment.

Table 14. Trophic status indicators in the Wilderness Lagoon for the period 1998 – 1999 (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)	
1998-1999	5.3	0	**0.017**	0	1.40	**M & clear**

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

  O = oligotrophic M = mesotrophic

  E = eutrophic HE = hyper-eutrophic

- The Wilderness Lagoon has a tendency towards mesotrophic conditions.
- Management and monitoring of the impoundment should be continued because of the high recreational value of the system.

5.2 Groenvlei Lake and the Goukamma River

These two systems are discussed together since the Groenvlei Lake has a very small catchment area and relies mostly on rainwater (FIJEN 1995). The Goukamma River forms the eastern boundary to the lakes discussed in this report.

5.2.1 Groenvlei Lake

The Groenvlei Lake is situated east of Sedgefield (Figure 41). The area is bounded in the north by a dune ridge just north of the N2 National Road, in the west by Sedgefield Municipality, in the east by the Goukamma River catchment and in the south by a coastal dune ridge (FIJEN 1995).

The surface area of the Groenvlei Lake is approximately 2.5 km² while the total catchment area is about 13.8 km² (FIJEN and KAPP, 1995a). The lake has a length of about 3.7 km and a width of 0.9 km. The maximum depth is 5.6 m but it is generally not more than 3.7 m deep. There are no settlements or townships within the Groenvlei Lake catchment, other than a small part of the Sedgefield extension, called Groenvlei, which was under development in 1995 (FIJEN 1995). A treatment works was planned towards the western side of the lake that would not discharge into the lake.

In contrast with the other Wilderness lakes, Groenvlei Lake has no connection with the sea. This coastal lake was separated from the influence of the sea approximately 4000 years ago and is slightly brackish (FIJEN and KAPP, 1995a). In the water management strategy for the Groenvlei Lake (FIJEN 1995) it is mentioned that clarity, pH, and algae are water quality constituents of concern. This report incorporates these variables of concern.

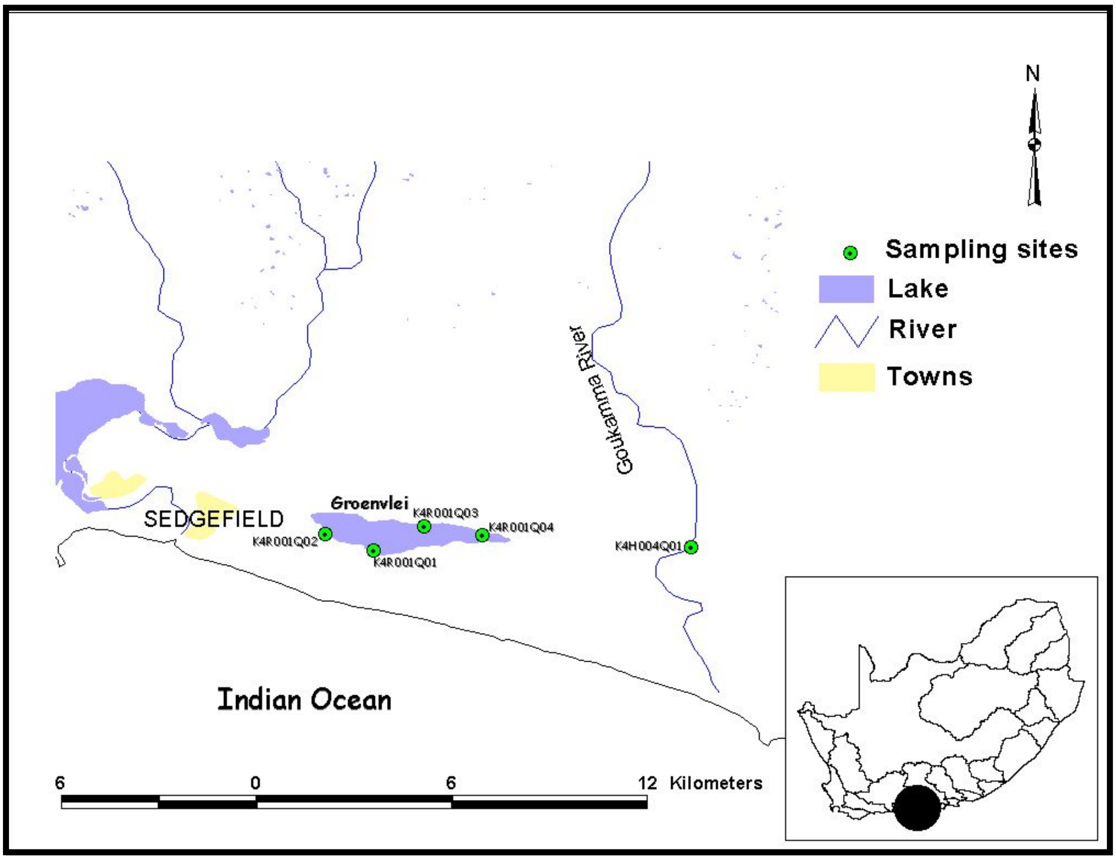

Figure 41. The sampling sites in the Groenvlei Lake and the Goukamma River.

4.2.1.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Groenvlei Lake extends from 1998 to 1999. Figure 42 indicates that the TP concentrations at all the sites in the Groenvlei Lake catchment were within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANONYMOUS 1988a, ANONYMOUS 1988b). The TP concentrations were also below the threshold level for eutrophic systems of 0.047 mg/L P as is suggested in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990) for most of the results. The TP concentrations did, however, occasionally exceed the 0.047 mg/L P level. FIJEN (1995) noted that the target water quality guideline for TP for the natural environment in the Groenvlei Lake is below 0.060 mg/L P. The only time that this concentration was exceeded was for the maximum recorded at the Ranger's House site.

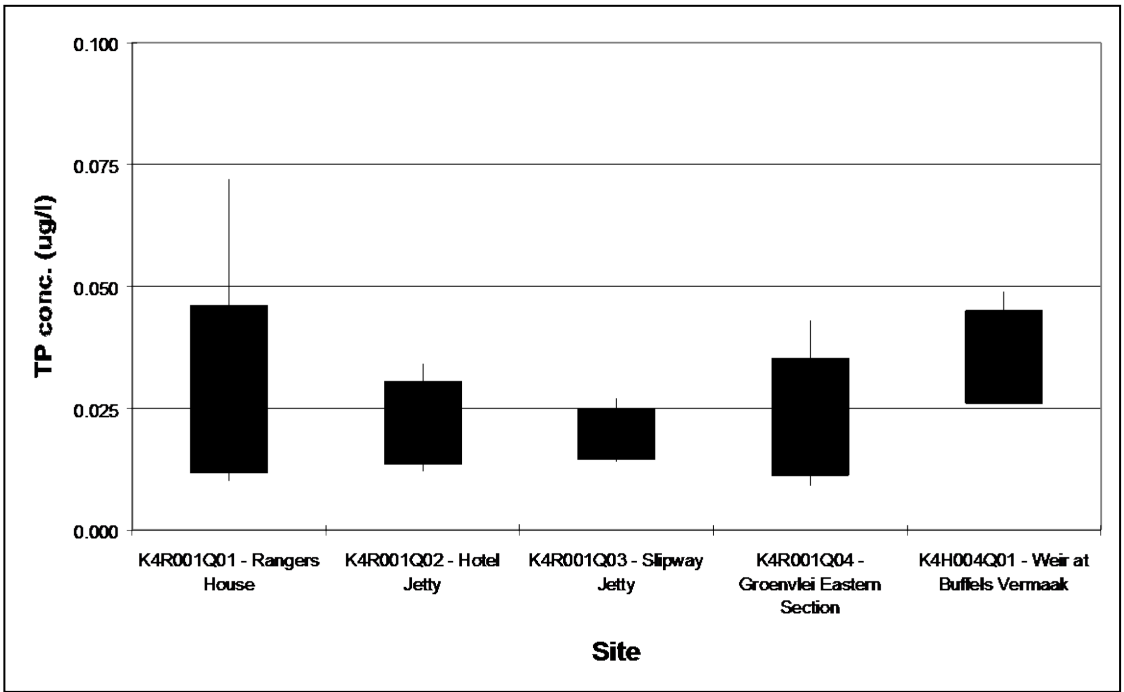

Figure 42. Variability in TP (as P) concentrations at the five sites in the Groenvlei Lake catchment (1998 – 1999).

The PO_4-P concentrations at the five sites in the Groenvlei Lake Catchment (Figure 43) show that the available reactive phosphorus did occasionally exceed the 0.025 µg/ℓ P Target Water Quality Range for Aquatic Ecosystems (DWAF, 1996b). The PO_4-P forms a large proportion of the TP.

The Groenvlei Lake should, therefore, be monitored on a long-term basis, to detect, in time, the potential hazardous impact that the sewage treatment works might have on the water quality of the lake.

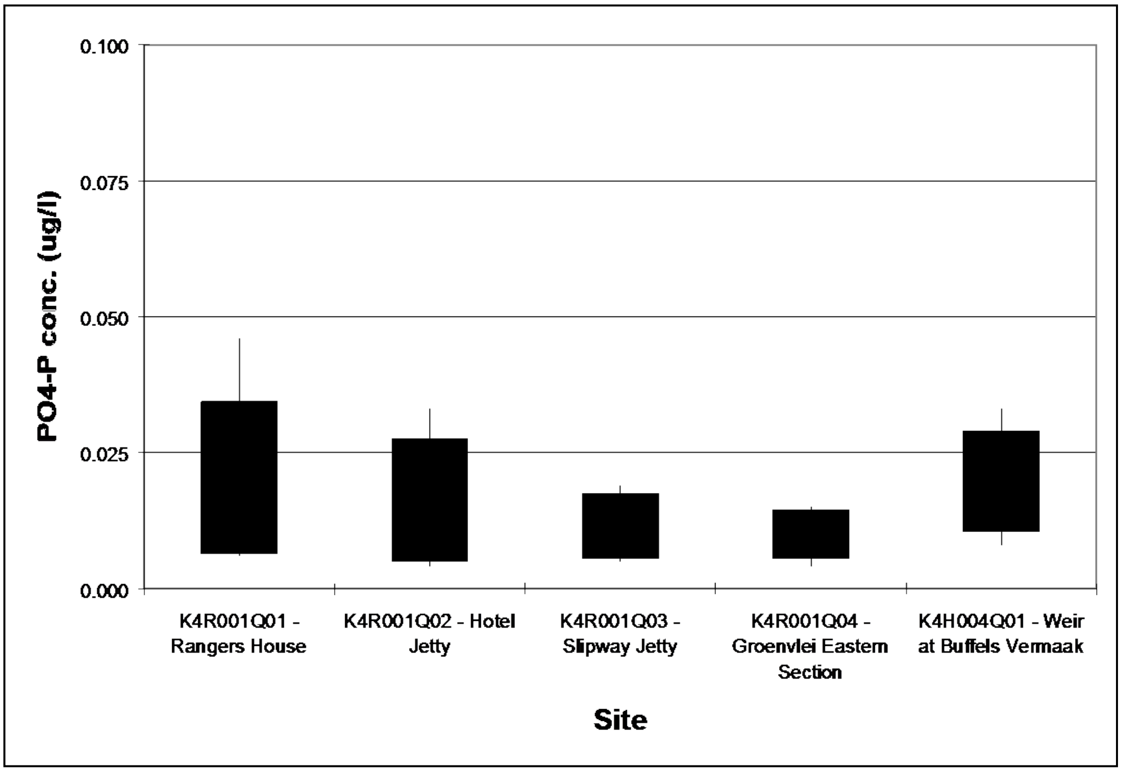

Figure 43. Variability in PO_4-P (as P) concentrations at the five sites in the Groenvlei Lake catchment (1998 – 1999).

The impoundment is, therefore, as yet not very productive from a phosphorus perspective. However, the available reactive phosphorus might lead to eutrophication related problems.

Nitrogen

The TN concentrations in the Groenvlei Lake are reflected in Figure 44 and indicate that the nitrogen concentrations within the impoundment were continuously below 2 mg/L N at all the sites in the Groenvlei Lake Catchment. The sites with the lowest nitrogen concentrations are the eastern section of the Groenvlei Lake and the KN concentrations at the Buffels Vermaak Weir on the Goukamma River. FIJEN (1995) noted that the target water quality guideline for TN for the natural environment in the Groenvlei Lake is below 0.25 mg/L N. The KN concentrations exceeded this value and the nitrogen concentrations were thus higher than the target water quality guideline.

The DIN concentrations at the five sites in the Groenvlei Lake catchment (Figure 45) show that the dissolved inorganic nitrogen concentrations are constantly below the TWQR for the aquatic ecosystem of fresh water. The mean NH_4 nitrogen (as N) concentrations (between 0.03 and 0.04 mg/L as N) were low and should not pose any threat to the ecosystem. The dissolved inorganic nitrogen (as NO_3+NO_2 and as NH_4) is readily available to the primary producers in the system.

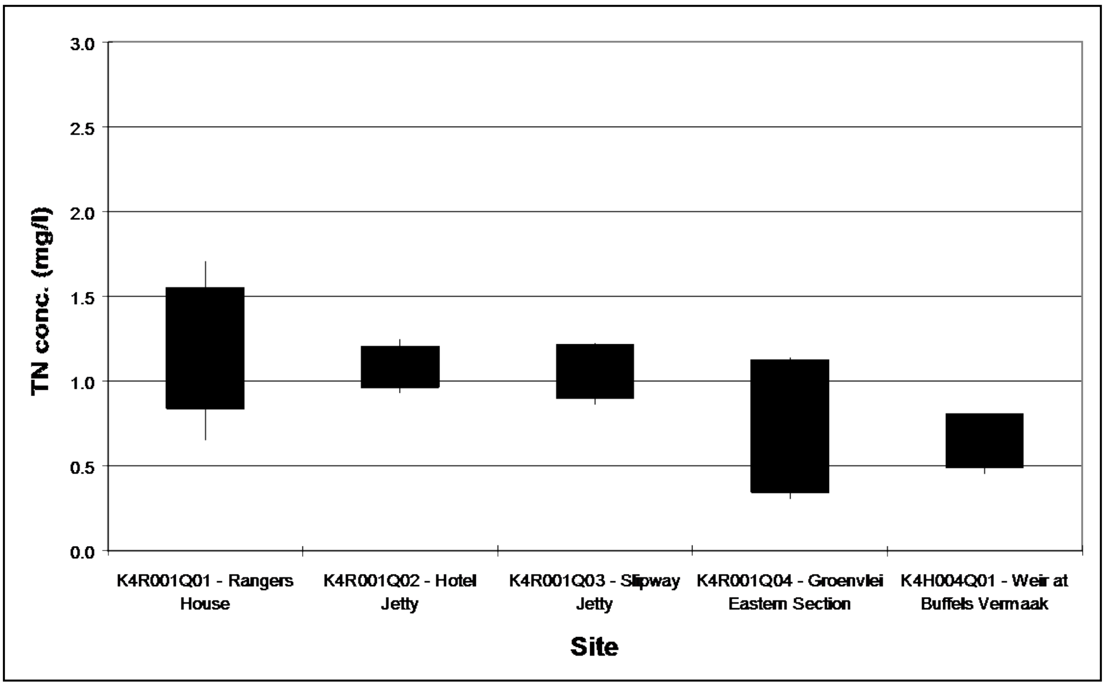

Figure 44. Variability in TN (as N) concentrations at the five sites in the Groenvlei Lake catchment (1998 – 1999).

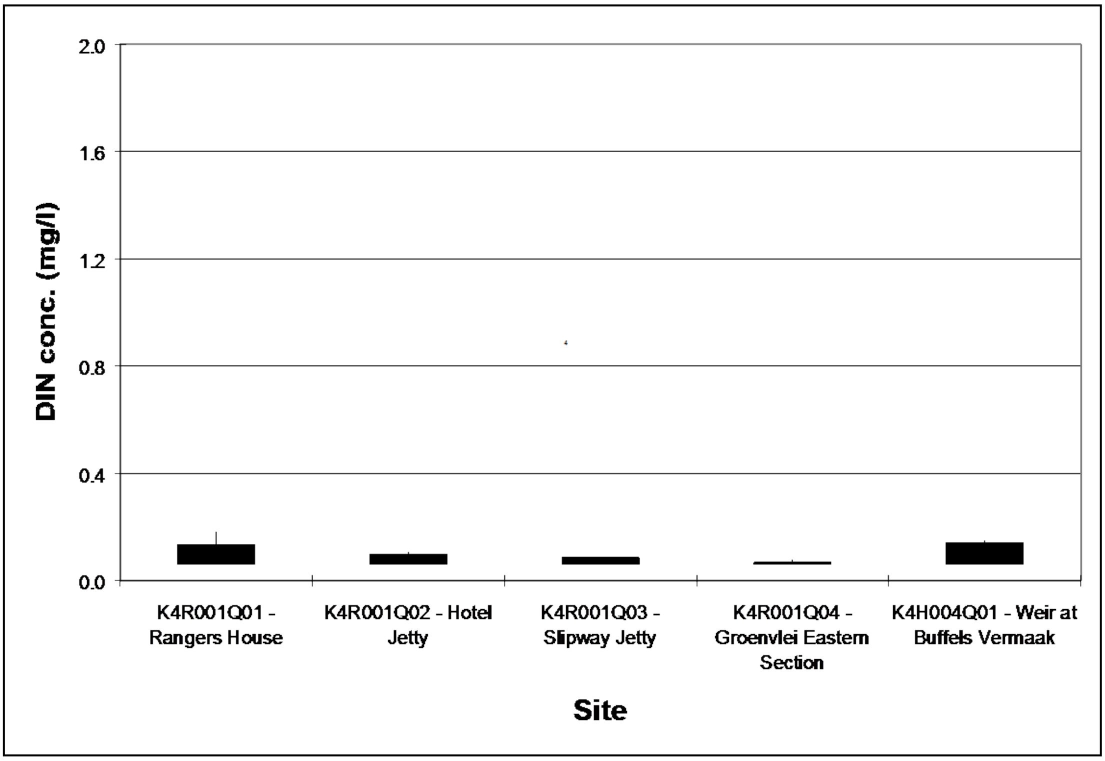

Figure 45. Variability in DIN (as N) concentrations at the five sites in the Groenvlei Lake catchment (1998 – 1999).

TN:TP ratio

The TN:TP ratios for the Groenvlei Lake are shown in Table 15. The TN:TP ratios that are consistently above 11 indicate that the water quality in the Groenvlei Lake is phosphorus limited. This is preferable as, in contrast to this, nitrogen limitation within a system has the result that the phytoplankton population favours the development of cyanobacteria that can result in toxicity and taste and odour problems.

Table 15. The minimum and maximum TN:TP ratios at the five sites in the Groenvlei Lake catchment during 1998 to 1999.

Site	**Minimum TN:TP ratio**	**Median TN:TP ratio**	**Maximum TN:TP ratio**
K4R001Q01 – Ranger's House (n=12)	23.69	55.6	100.1
K4R001Q02 - Hotel Jetty (n=11)	36.65	54.8	97.4
K4R001Q03 - Slipway Jetty (n=11)	42.36	57.2	75.0
K4R001Q04 - Groenvlei Eastern Section (n=12)	19.19	51.8	87.7
K4H004Q01 - Weir at Buffels Vermaak (n=11)	11.33	18.8	28.4

The nutrient concentrations and the TN:TP ratios indicate that the system is still within manageable levels. This means that the system should not, in the foreseeable future, develop any eutrophication-related problems.

Salinity

FIJEN and KAPP (1995a) described the Groenvlei Lake as being slightly brackish. The EC readings from the five sites in the Groenvlei Lake catchment indicate that the lake itself has an EC of ± 400 mS/m (Figure 46). The greatest variability is found at the Buffels Vermaak Weir in the Goukamma River. This site had concentrations varying from as low as 20.4 to as high as 1 086 mS/m. This variability is as a result of all the dissolved salts (Figure 47) in the Gaukamma River, except for calcium that was present in very low concentrations at the Buffels Vermaak Weir. This phenomenon is as expected, since the Buffels Vermaak Weir is in the Goukamma River and is susceptible to low flows and to high flow scenarios, while all the other sites are in the enclosed Groenvlei Lake. The eastern section site indicated the lowest EC readings. These EC readings showed that the Groenvlei Lake is less saline than the Bo-Langvlei Lake that had EC readings consistently at approximately 1000 mS/m.

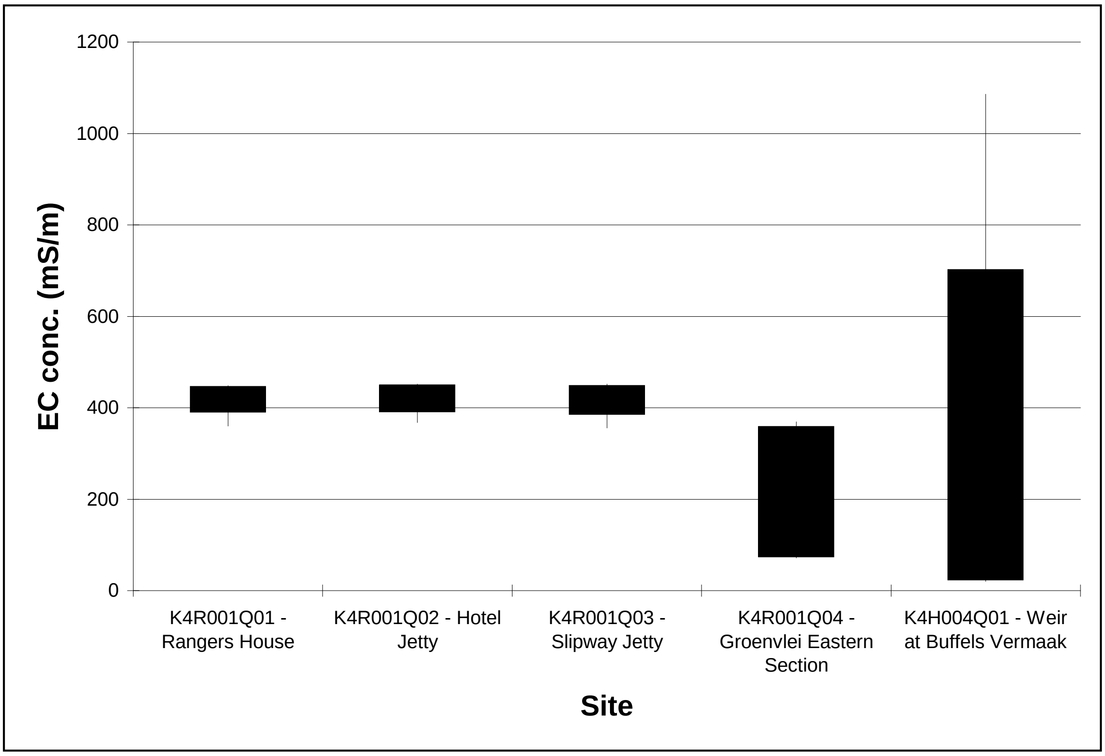

Figure 46. Variability in EC readings at the five sites in the Groenvlei Lake catchment (1998 – 1999).

The calcium concentrations showed completely different variability as compared to the other dissolved salts (Figure 47). High calcium concentrations were found at the Ranger's house site. The relative concentrations of the major ions show the tendency of Cl^- > Na^+ > Mg^{2+} > SO_4^{2-} > Ca^{2+} > K^+ at all the sites except at the Ranger's house site. At this site the major ions show the tendency of Cl^- > Na^+ > Ca^{2+} > SO_4^{2-} > Mg^{2+} > K^+.

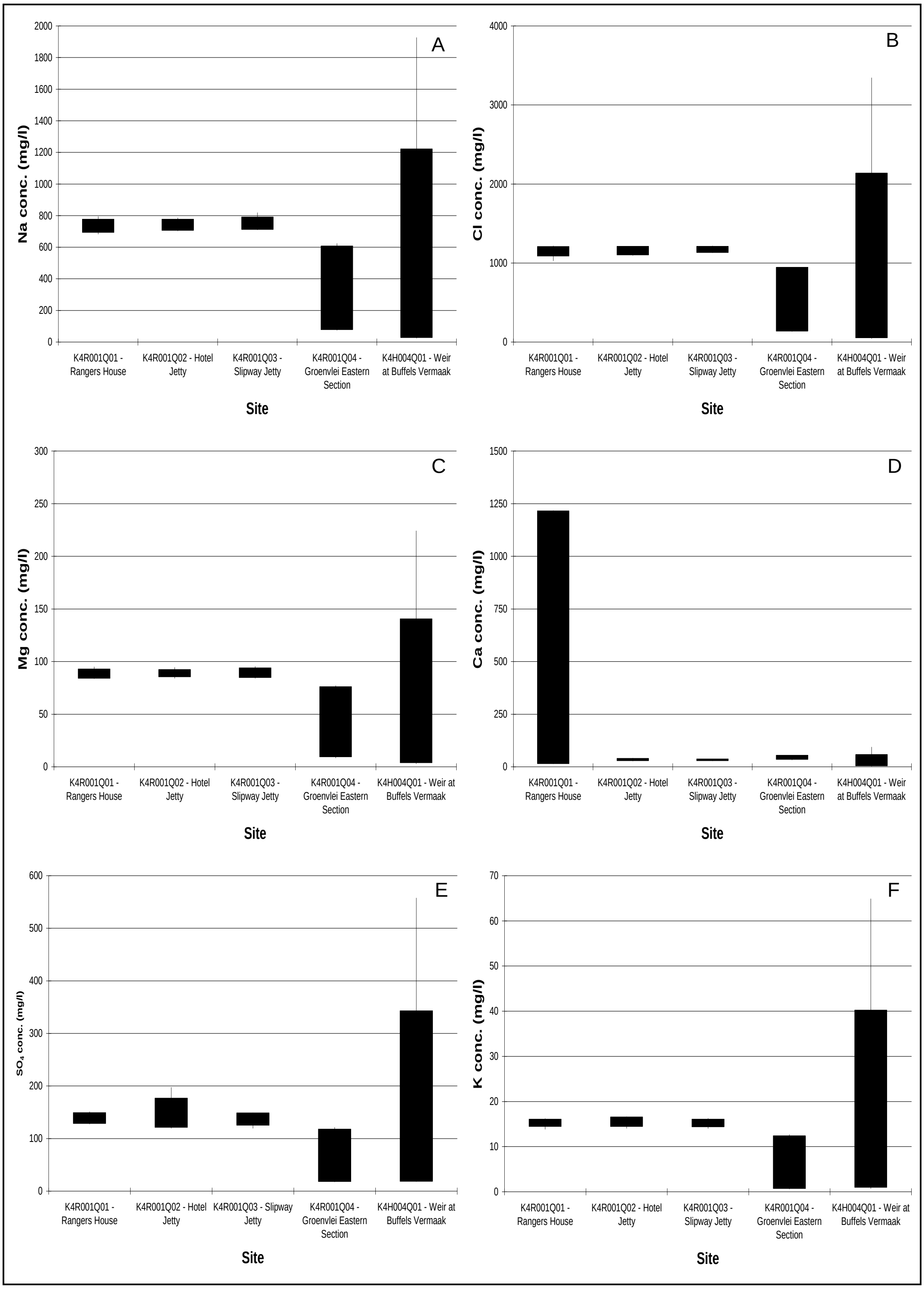

Figure 47. The dissolved salts concentration variability at the three sites in the Groenvlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations and F Potassium concentrations.

Trace Metals

Dissolved trace metal samples were taken at a monthly interval at the Slipway Jetty site in the Groenvlei Lake (Table 16). The minimum, median and maximum values of the respective dissolved trace metals that were analysed for are compared to the available target values for primary and secondary consumers for coastal marine environments. Fairly high boron (B) concentrations and strontium (Sr) concentrations were found at the Slipway Jetty site in the Groenvlei lake on all three sampling occasions, as is normal for saline systems (WETZEL, 1983). Boron and strontium concentrations were relatively high, but no target values or guidelines are available for these two variables. In the Groenvlei Lake at the Slipway Jetty site, the maximum zinc and cadmium concentrations were higher than the target values for both the primary and the secondary consumers. There might, therefore, be occasional problems with these two variables in the system. None of the other trace metals were present in problem forming concentrations during the study period.

Table 16. The dissolved trace metal concentrations at the Slipway Jetty site in the Groenvlei Lake during 1998 and 1999 showing the minimum, median and maximum concentrations of various dissolved trace metals. These values are compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995). The number of samples (n) taken is also reflected in the Table.

Variable	Target value for Primary Consumers	Target value for Secondary Consumers	Minimum (n=11)	Median (n=11)	Maximum (n=11)
Boron (B) (mg/L)	NA	NA	0.484	0.556	0.601
Aluminium (Al) (mg/L)	NA	NA	0.01	0.01	0.031
Vanadium (V) (mg/L)	NA	NA	0.001	0.001	0.012
Chromium (Cr) (mg/L)	0.008	0.005	0.001	0.001	0.001
Manganese (Mn) (mg/L)	NA	NA	0.0005	0.0005	0.013
Iron (Fe) (mg/L)	NA	NA	0.001	0.001	0.254
Nickel (Ni) (mg/L)	0.025	0.025	0.003	0.003	0.043
Copper (Cu) (mg/L)	0.005	0.005	0.001	0.001	0.001
Zinc (Zn) (mg/L)	0.025	0.025	0.002	0.002	0.837
Strontium (Sr) (mg/L)	NA	NA	0.473	0.491	0.56
Molybdenum (Mo) (mg/L)	NA	NA	0.002	0.002	0.046
Cadmium (Cd) (mg/L)	0.004	0.004	0.001	0.001	0.015
Barium (Ba) (mg/L)	NA	NA	0.0005	0.0005	0.0005
Lead (Pb) (mg/L)	0.012	0.012	0.007	0.007	0.007

None of the trace metals pose a hazard at this stage for users of the lake water.

5.2.1.2 Biological characteristics

The chlorophyll-*a* concentration (Fig. 48) is below 10 µg/L in the lake for 100 % of the time. The primary production in the Groenvlei Lake is, therefore, constantly within the target water quality guideline for chlorophyll-*a* for both intermediate contact recreation (<15 µg/L) and non-contact recreation (< 20 µg/L) as set by FIJEN (1995) and is at this stage not of any concern in terms of eutrophication and water quality problems.

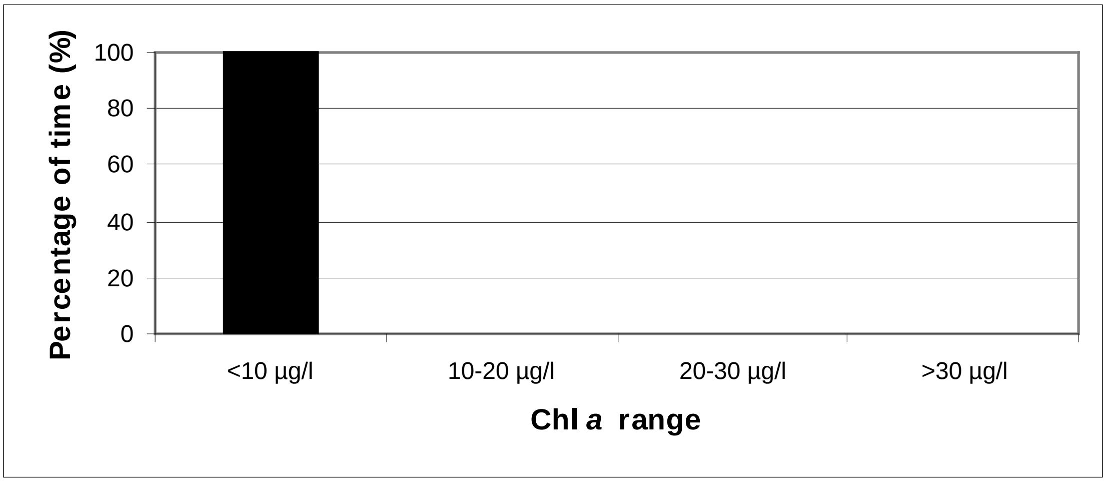

Figure 48. Per cent of the time that chlorophyll *a* concentrations were within a specified range in the Groenvlei Lake near the Slipway Jetty site.

The Pyrrhophyta (*Gymnodinium*) were the dominant group during the study period (Figure 49). The chlorophyll-*a* concentrations were present in such low numbers that the algal cell numbers were not detectable from June 1998 until January 1999. *Gymnodinium* is a genus of marine or freshwater organisms called dinoflagellates. Members of the genus are bilaterally symmetrical with a delicate pellicle (or envelope) and disk-shaped chromatophores, which, when visible, contain yellow, brown, green, or blue pigments. *Gymnodinium,* which may be bioluminescent, undergoes periodic blooms, or population increases, and may colour water bright yellow or red. These species also produce a toxin similar to that of the dinoflagellate *Gonyaulax.* Both toxins are fatal to fish and irritate the nose and throat of human beings (WWW 6, 2000).

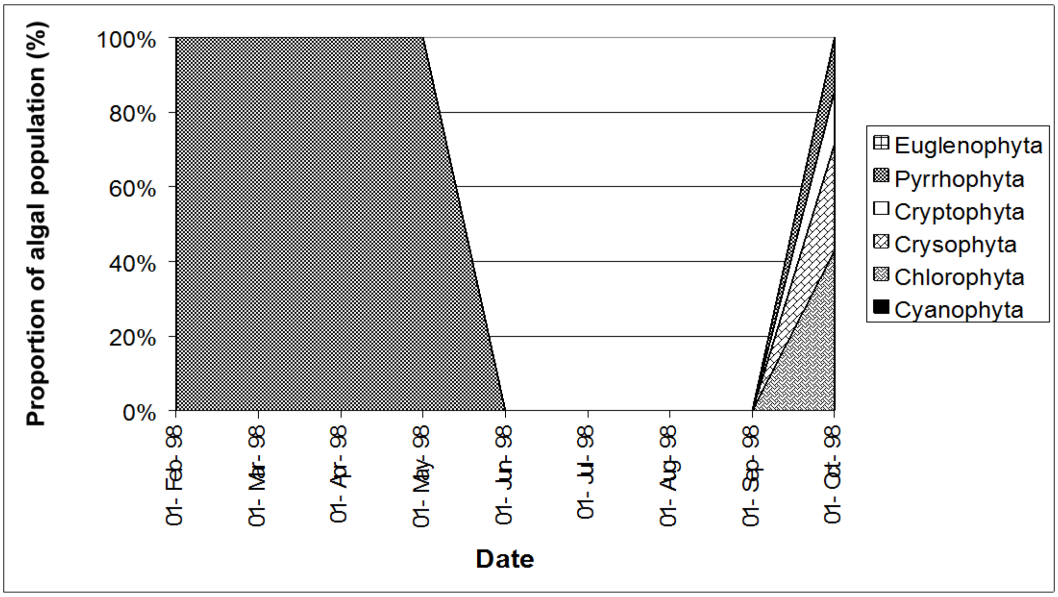

Figure 49. Dominance of algal groups in the Groenvlei Lake near the Slipway Jetty site.

Primary production does not pose a problem in the Groenvlei Lake at this stage. If the sewage treatment works does have an impact on the system, the primary production of the Lake will be one of the first signs of the effect of increased nutrient loads.

5.2.1.3 Physical characteristics

The mean Secchi disc reading was 3.0 m. Therefore, the lake is a clear system. Due to the limited Secchi disc readings, no correlation determination between the chlorophyll *a* and the Secchi disc readings was done. The suspended solids concentrations were not determined for the Groenvlei Lake.

The pH values in the Groenvlei Lake (Figure 50) were more alkaline than the pH values found at the Buffels Vermaak Weir in the Goukamma River. The pH readings at the Buffels Vermaak weir are considerably lower than the other sites assessed, and may warrant closer inspection to determine the cause.

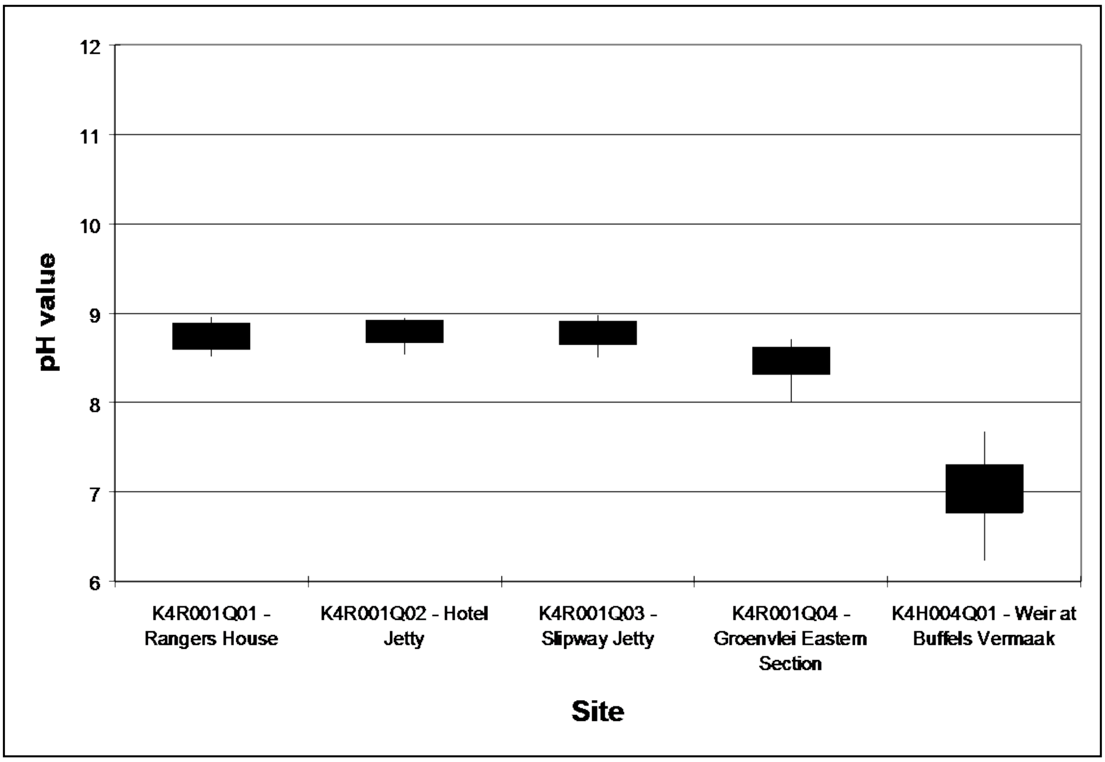

Figure 50. Variability in pH values at the five sites in the Groenvlei Lake Catchment (1998 – 1999).

The turbidity in the Groenvlei Lake is below 2 NTU's (± 2.5 m Secchi disc depth) and the mean Secchi disc reading of 3.0 m indicates, therefore, that the lake is a clear system. The site in the Goukamma River was clearly more turbid than the Groenvlei Lake (Figure 51). This is as expected, since the river would show periods of high flow with associated higher turbidity.

The Groenvlei Lake sites were the only sites where temperature data were collected. The temperatures varied between 13 °C and 28 °C at the five sites. The Goukamma River had slightly higher temperatures compared to the Groenvlei Lake sites (Figure 52). The river and the lake reach, therefore, had fairly high temperatures during summer. This would favour the development of potentially problem algae. However, the fact that no problem algae were found to date, might be as a result of the highly saline nature of the system.

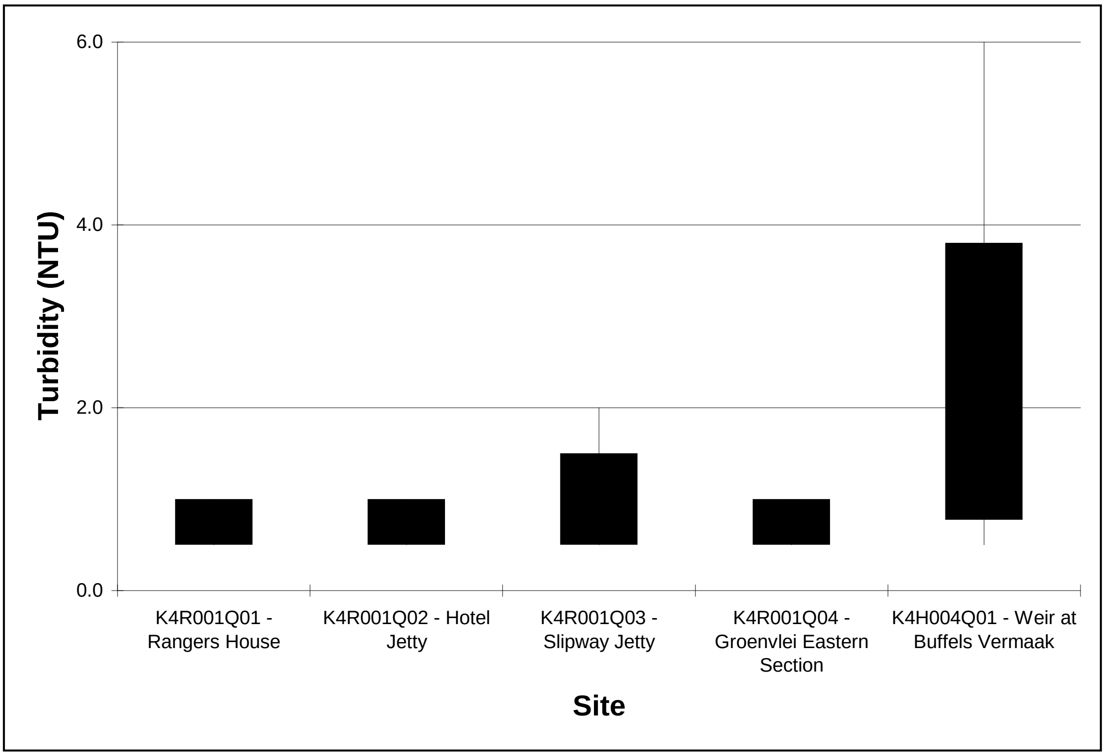

Figure 51. Variability in turbidity (NTU) at the five sites in the Groenvlei Lake and Goukamma River Catchment (1998 – 1999).

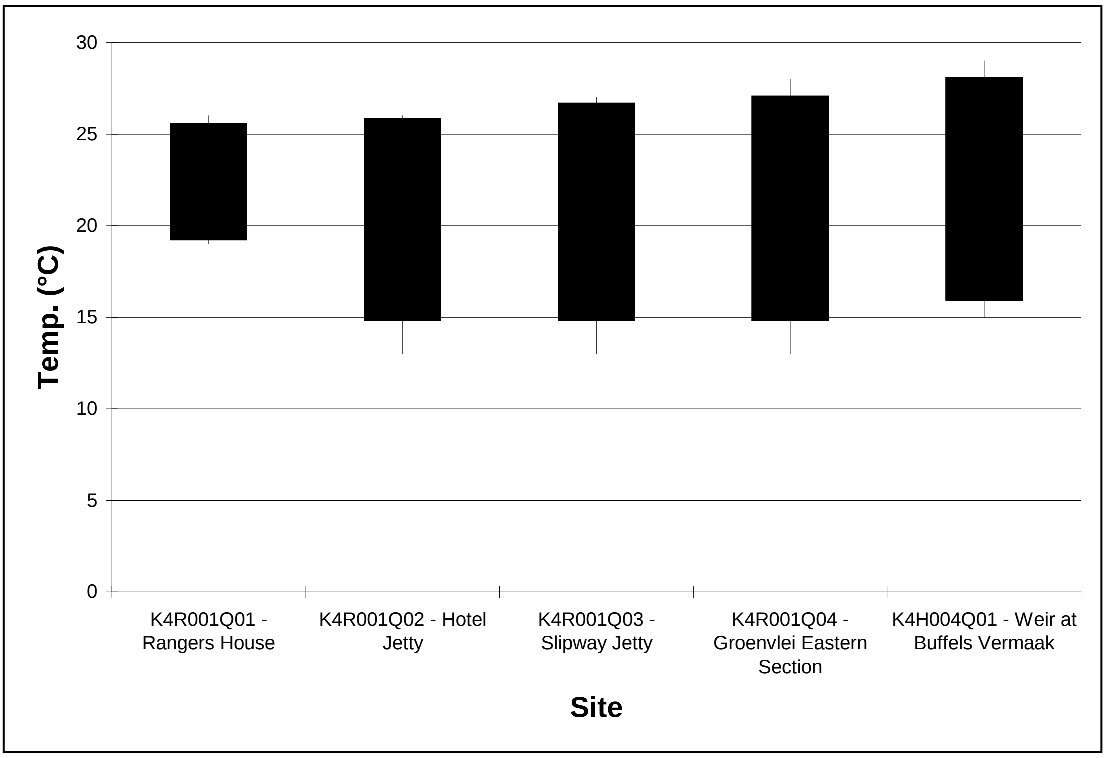

Figure 52. Variability in temperature (°C) at the five sites in the Groenvlei Lake and Goukamma River Catchment (1998 – 1999).

5.2.1.4 Trophic status of the Groenvlei Lake

Table 17 indicates that the Groenvlei Lake was mesotrophic. The mean TP concentration was lower than the mean PO_4-P concentration of 0.031 mg/L found by FIJEN and KAPP in 1995a. The water in the Groenvlei Lake is, therefore, within manageable limits and should not be of any concern at this stage. It is, however, essential to continue monitoring the system to be able to pick up any changes in water quality due to the sewage treatment works that is situated west of the lake. For recreational purposes and to manage the system to such an extent so as to keep the impoundment in a mesotrophic state, management options should be considered if the water quality deteriorates.

Table 17. Trophic status indicators in the Groenvlei Lake for the period 1998 –1999 (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)	
1998-1999	1.9	0	**0.019**	0	3.00	**M & clear**

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

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

- The Groenvlei Lake is mesotrophic.
- Nitrogen concentrations are higher than the target water quality guideline for the Groenvlei Lake.
- Monitoring of the impoundment should be continued for management purposes.

5.3 Swartvlei Lake System

This system includes the Swartvlei Lake and the Sedgefield Lagoon that connects the Swartvlei Lake to the estuary at Sedgefield.

5.3.1 Swartvlei Lake

The Swartvlei Lake, the largest of the series of lakes, is situated at the confluence of the Karatara, Klein Wolwe and Hoëkraal Rivers. The lake is used extensively for recreational purposes. Four sampling sites were monitored in the Lake (Figure 53).

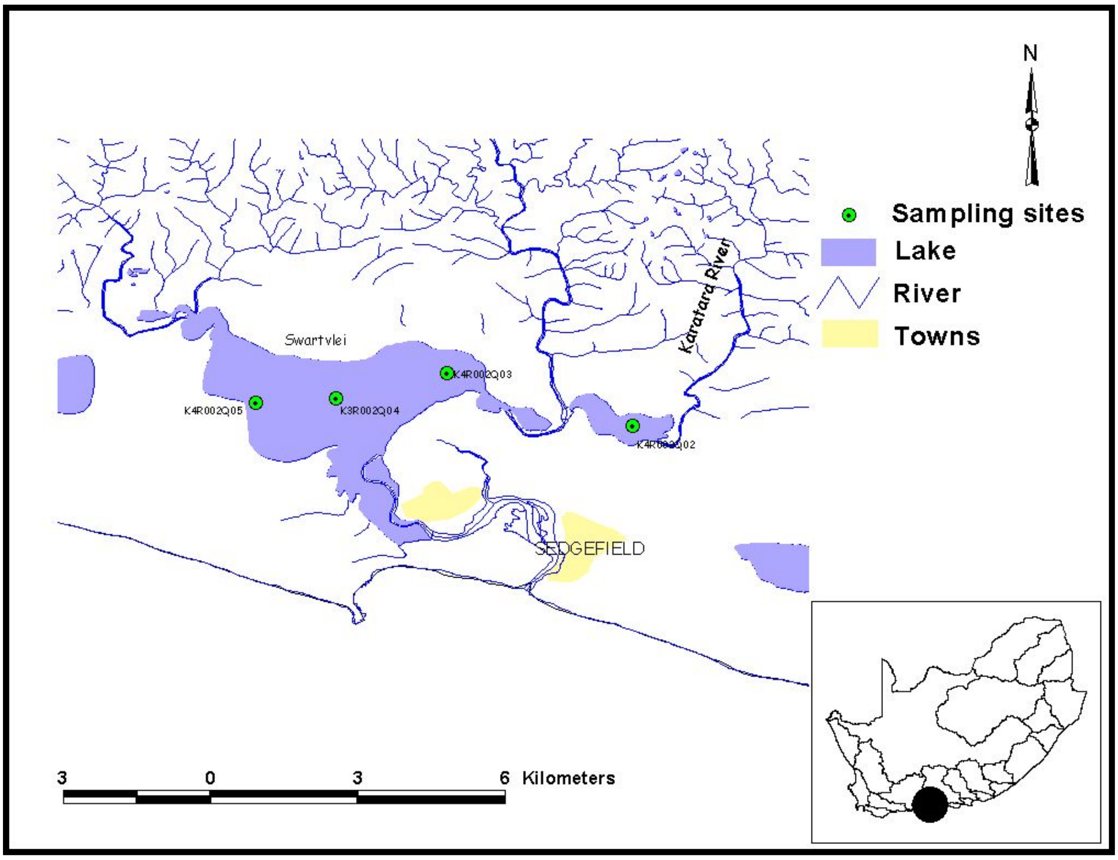

Figure 53. The sampling sites in the Swartvlei Lake.

5.3.1.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Swartvlei Lake extends from 1998 to January 1999. Figure 54 indicates that the TP concentrations at all the sites in the Swartvlei Lake catchment were within the required Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANON 1988a, ANON 1988b). The TP concentrations were also below the threshold level for eutrophic systems of 0.047 mg/L P as is suggested in the literature (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990). In the Swartvlei Lake the phosphorus concentrations showed increased tendencies at two sites, namely a) in the Karatara River below the Hoogekraal Plantation and b) in the middle section of the lake.

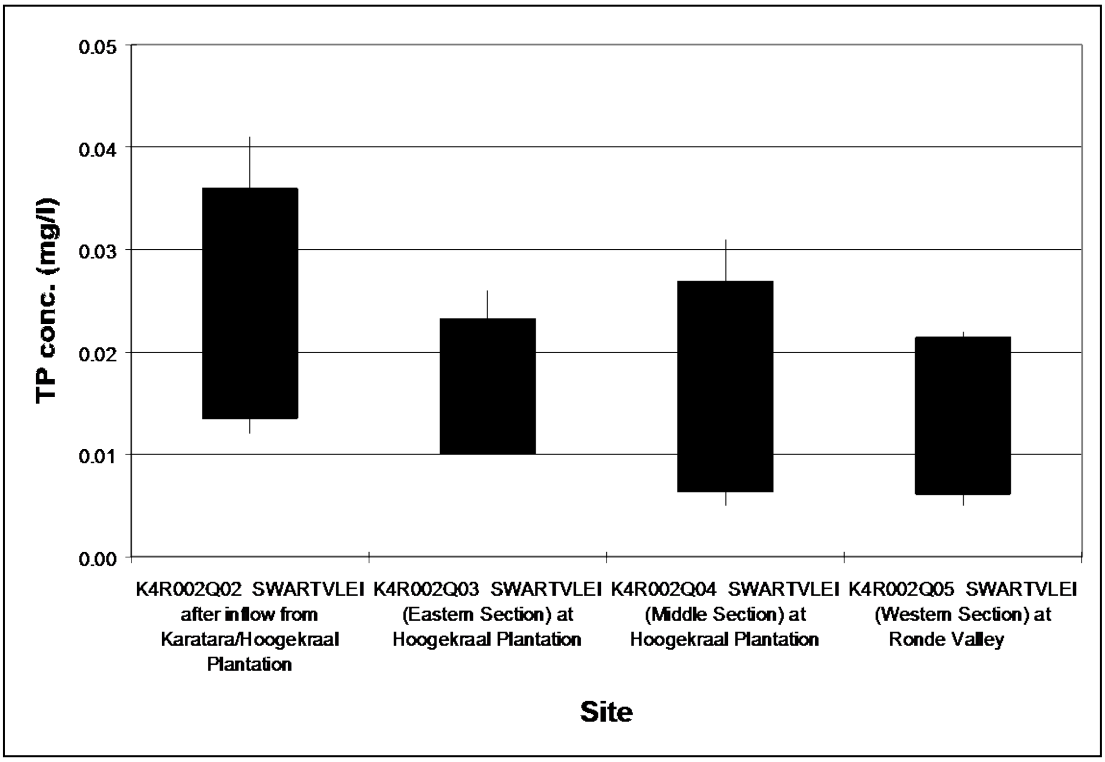

Figure 54. Variability in TP (as P) concentrations at the four sites in the Swartvlei Lake catchment (1998 – 1999).

The PO_4-P concentrations at the four sites in the Swartvlei Lake Catchment (Figure 55) show that the available reactive phosphorus exceeded the 0.025 mg/L P Target Water Quality Range for Aquatic Ecosystems (DWAF 1996b) occasionally at the same two sites as mentioned in the previous paragraph.

Therefore, at this stage the lake is not very productive from a phosphorus perspective. However, if incidents of higher phosphorus concentrations become more regular, it may lead to eutrophication related problems.

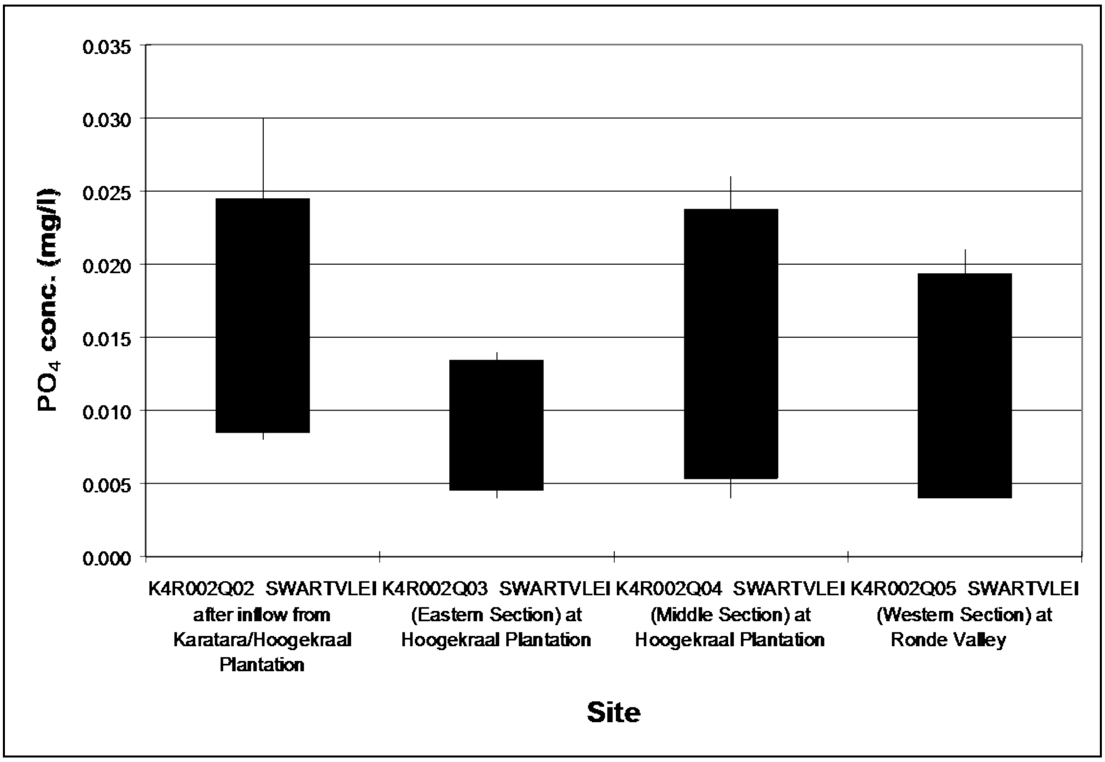

Figure 55. Variability in PO_4-P (as P) concentrations at the four sites in the Swartvlei Lake catchment (1998 – 1999).

Nitrogen

The TN concentrations in the Swartvlei Lake are reflected in Figure 56 and indicate that the nitrogen concentrations within the impoundment were consistently below 1 mg/L N at all the sites. The TN concentrations are, therefore, very low and should not pose any problem to the system when eutrophication is considered. However, the concentrations at the inflow of the Karatara River below the Hoogenkraal Plantation had noticeably higher TN concentrations when compared to the other sites.

The DIN concentrations at the four sites in the Swartvlei Lake catchment (Figure 57) showed that the nitrogen concentrations of this form were constantly below the 2.5 mg/L N as NO_3 + NO_2 TWQR for the aquatic ecosystem. There were, however, higher concentrations found at the Hoogekraal Plantation site. DIN is readily available to the primary producers in the system, but the low DIN concentrations should not pose any threat to the ecosystem.

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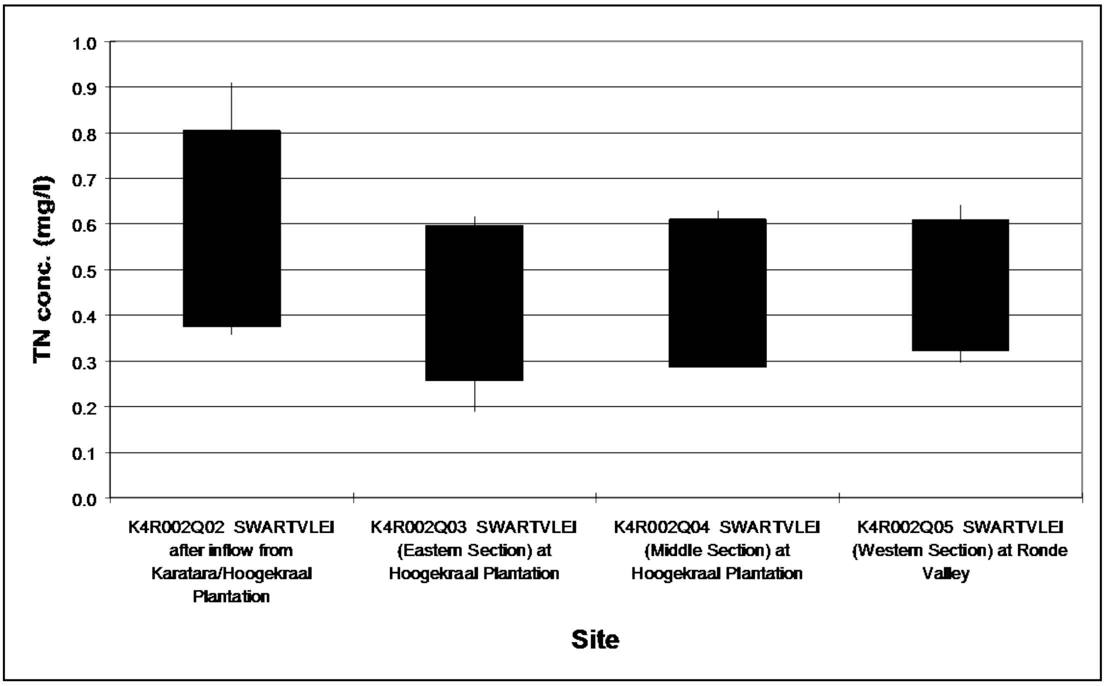


Figure 56. Variability in TN (as N) concentrations at the four sites in the Swartvlei Lake catchment (1998 – 1999).

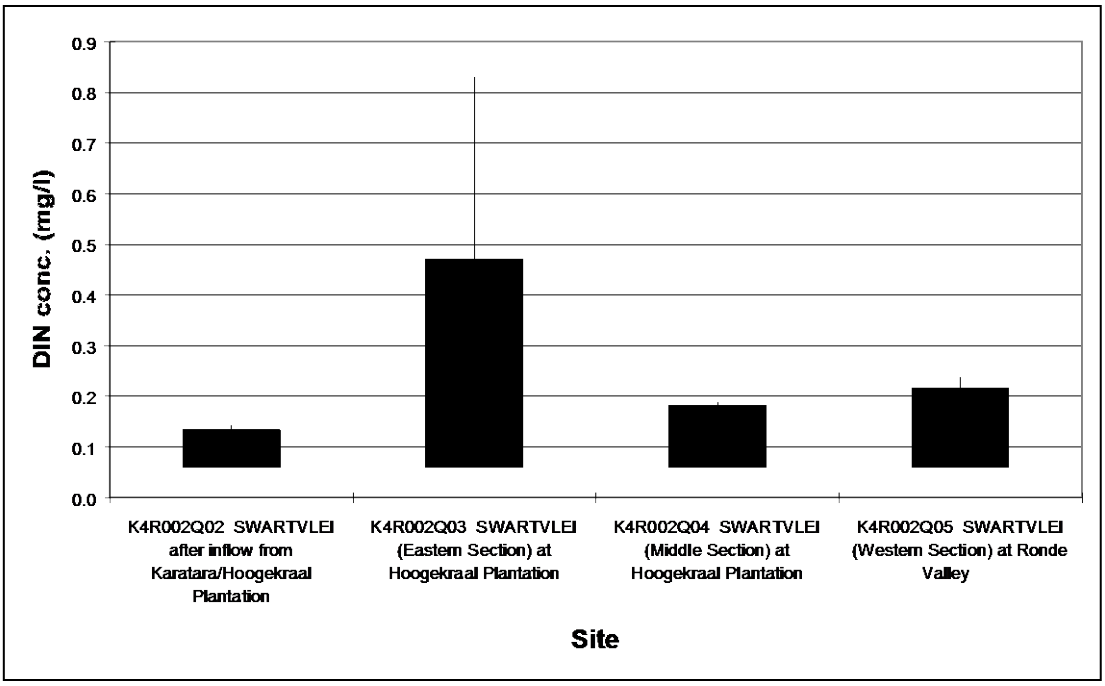


Figure 57. Variability in DIN (as N) concentrations at the four sites in the Swartvlei Lake catchment (1998 – 1999).

TN:TP ratio

The TN:TP ratios for the Swartvlei Lake are shown in Table 18. The TN:TP ratios were above 10 for most of the assessment period and indicate that the water quality in the Swartvlei Lake was largely phosphorus limited. There was a minimum TN:TP ratio at the site at the Hoogekraal Plantation that had a minimum TN:TP ratio of 8.9, indicating a period where nitrogen became the limiting nutrient at that site. The phenomenon of TN:TP ratios lower than

10:1 favour the development of cyanobacteria, however, it is not the norm in the Swartvlei Lake and should, therefore, not be a concern, as to the development of potentially nuisance blooms at this stage.

Table 18. The minimum, median and maximum TN:TP ratios at the five sites in the Swartvlei Lake catchment during 1998 to 1999, as well as the number of samples (n) taken at each site.

Site	**Minimum TN:TP ratio**	**Median TN:TP ratio**	**Maximum TN:TP ratio**
K4R002Q02 SWARTVLEI after inflow from Karatara/Hoogekraal Plantation (n=11)	18.4	22.2	39.8
K4R002Q03 SWARTVLEI (Eastern Section) at Hoogekraal Plantation (n=12)	8.9	35.1	58.1
K4R002Q04 SWARTVLEI (Middle Section) at Hoogekraal Plantation (n=10)	18.7	30.0	107.2
K4R001Q05 - Groenvlei Eastern Section (n=12)	17.6	38.1	96.4

The nutrient concentrations and the TN:TP ratios indicate that the system is still within manageable levels. This means that the system should not develop any eutrophication-related problems in the foreseeable future.

Salinity

The Sedgefield Lagoon (FIJEN and KAPP 1995) connects the Swartvlei Lake to the sea. Tidal exchange, therefore, takes place whenever the estuary mouth is open. The EC readings from the four sites in the Swartvlei Lake indicate the increasing effect of the marine environment on the freshwater inflow from the Karatara River. The site at the inflow showed much higher variability (between 200 and 1300 mS/m) than the other sites that had EC readings of ± 1400 mS/m and higher (Figure 58) and this is indicative of the fresh nature of the inflowing waters.

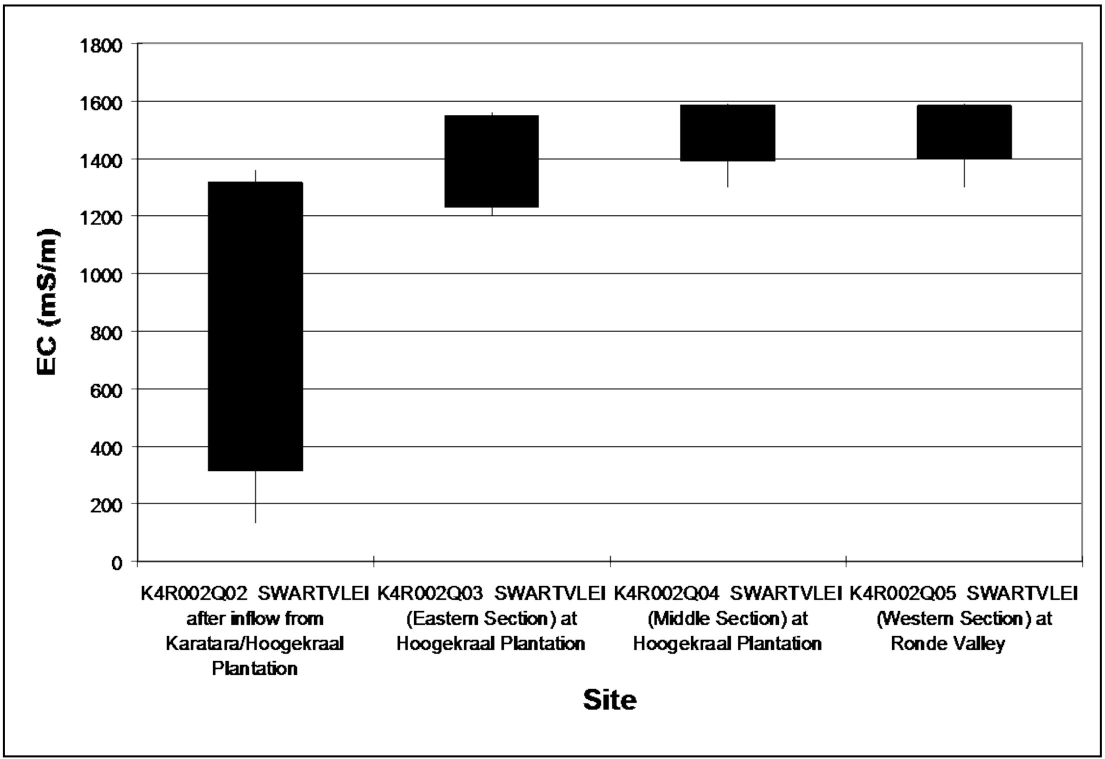


Figure 58. Variability in EC readings at the five sites in the Swartvlei Lake catchment (1998 – 1999).

Chloride and sodium dominated the ions in the Swartvlei Lake and the relative concentrations of the major ions show the tendency of Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+ at all of the sites. Again the lower salinity at the inflow of the Karatara River is shown (Figure 59). The Swartvlei Lake is, therefore, a highly saline system with an increasing salinity tendency from the eastern side of the lake towards the western side of the lake.

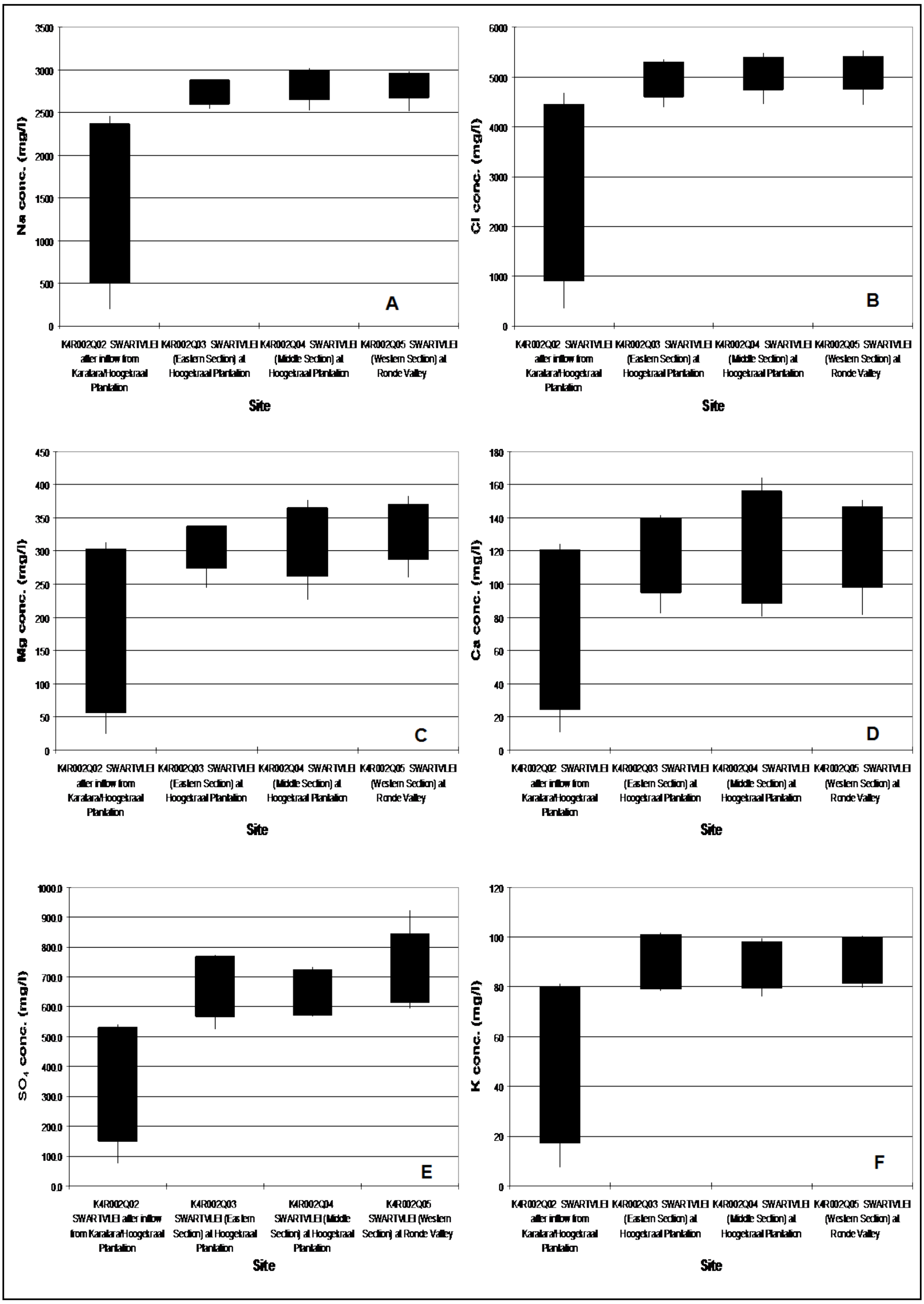


Figure 59. The dissolved salts concentration variability at the three sites in the Swartvlei Lake. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations and F Potassium concentrations.

Trace Metals

Dissolved trace metal samples were only taken at the western section site in the Swartvlei Lake (Table 19). The concentrations of the various dissolved trace metals that were analysed for on four occasions are compared to the available target values for secondary and primary consumers for coastal marine environments. Fairly high boron (B) concentrations and strontium (Sr) concentrations were found at the western section site in the Swartvlei Lake on all four sampling occasions, as is normal for saline systems (WETZEL, 1983). In the Swartvlei Lake at the western section site the manganese, iron, nickel, copper and zinc concentrations were higher than the target values for the primary and the secondary consumers during the June sampling exercise. This phenomenon might be a seasonal occurrence, but does need further investigation. None of the other trace metals posed any problems during the study period.

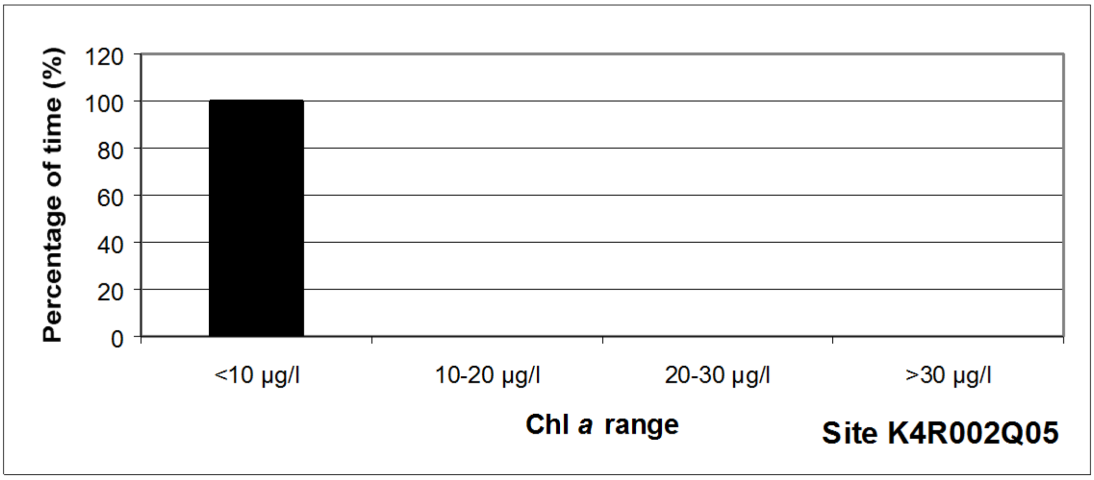
Table 19. The dissolved trace metal concentrations at the western section site in the Swartvlei Lake during 1998 showing the minimum, median and maximum concentrations of various dissolved trace metals. These values are compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/02/17**	**1998/06/11**	**1998/08/19**	**1998/11/23**
Boron (B) (mg/L)	NA	NA	1.095	0.818	1.067	0.922
Aluminium (Al) (mg/L)	NA	NA	<0.02	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	<0.002	0.009	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	<0.003	<0.003	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	0.011	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	<0.003	0.267	<0.003	0.15
Nickel (Ni) (mg/L)	0.025	0.025	<0.006	0.055	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	<0.002	0.014	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	0.013	0.039	<0.004	0.302
Strontium (Sr) (mg/L)	NA	NA	2.01	1.583	1.958	1.792
Molybdenum (Mo) (mg/L)	NA	NA	0.004	0.004	0.004	0.004
Cadmium (Cd) (mg/L)	0.004	0.004	<0.002	<0.002	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015	<0.015

The dissolved trace metal concentrations in the Swartvlei Lake are at this stage of no concern.

5.3.1.2 Biological characteristics

The chlorophyll-*a* concentrations were measured at two sites in the Swartvlei Lake. It is evident in Figure 60 that the chlorophyll-*a* concentrations are consistently below 10 µg/L in the lake at the two sites. Cyanobacteria were only found at the eastern section site (K4R002Q03) during the first sampling trip, otherwise they were absent from the system during the assessment period (Figure 61).



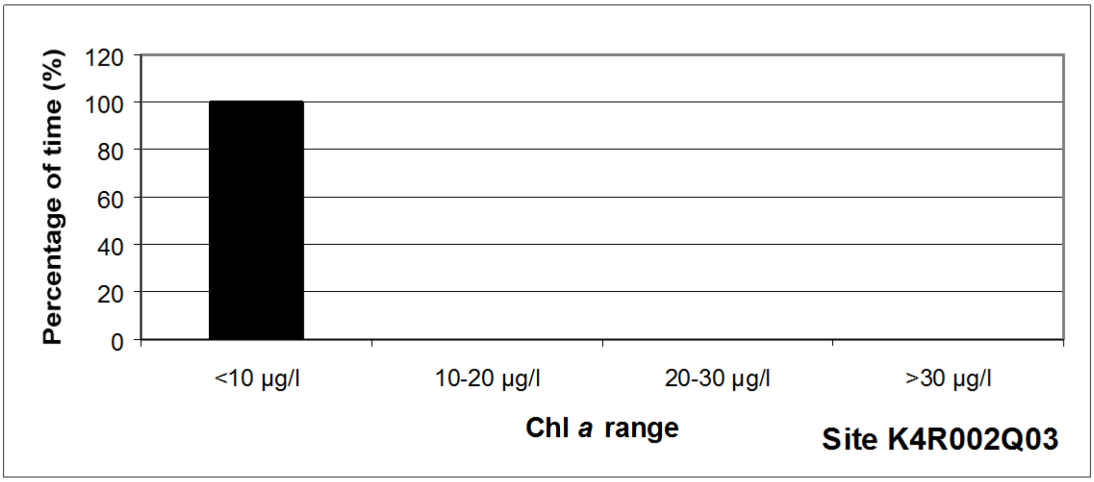


Figure 60. Per cent of the time that chlorophyll-*a* concentrations were within a specified range in the western section site of the Swartvlei Lake, K4R002Q05 (above), and the eastern section site at Hoogekraal Plantation, K4R002Q03 (below).

Pyrrhophyta (*Peridinium*) were the dominant phytoplankton group in the lake at two sites (Figure 61). However, at times Chlorophyta (e.g. Volvox), Chrysophyta (Cyclotella and Tribonema), Cryptophyta (Cryptomonas), and Euglenophyta (Euglena) formed noticeable proportions of the phytoplankton population. The fact that the chlorophyll-*a* concentrations were so low indicates that although potentially troublesome algae (e.g. *Peridinium*) are present, they pose no threat to the system at this stage.

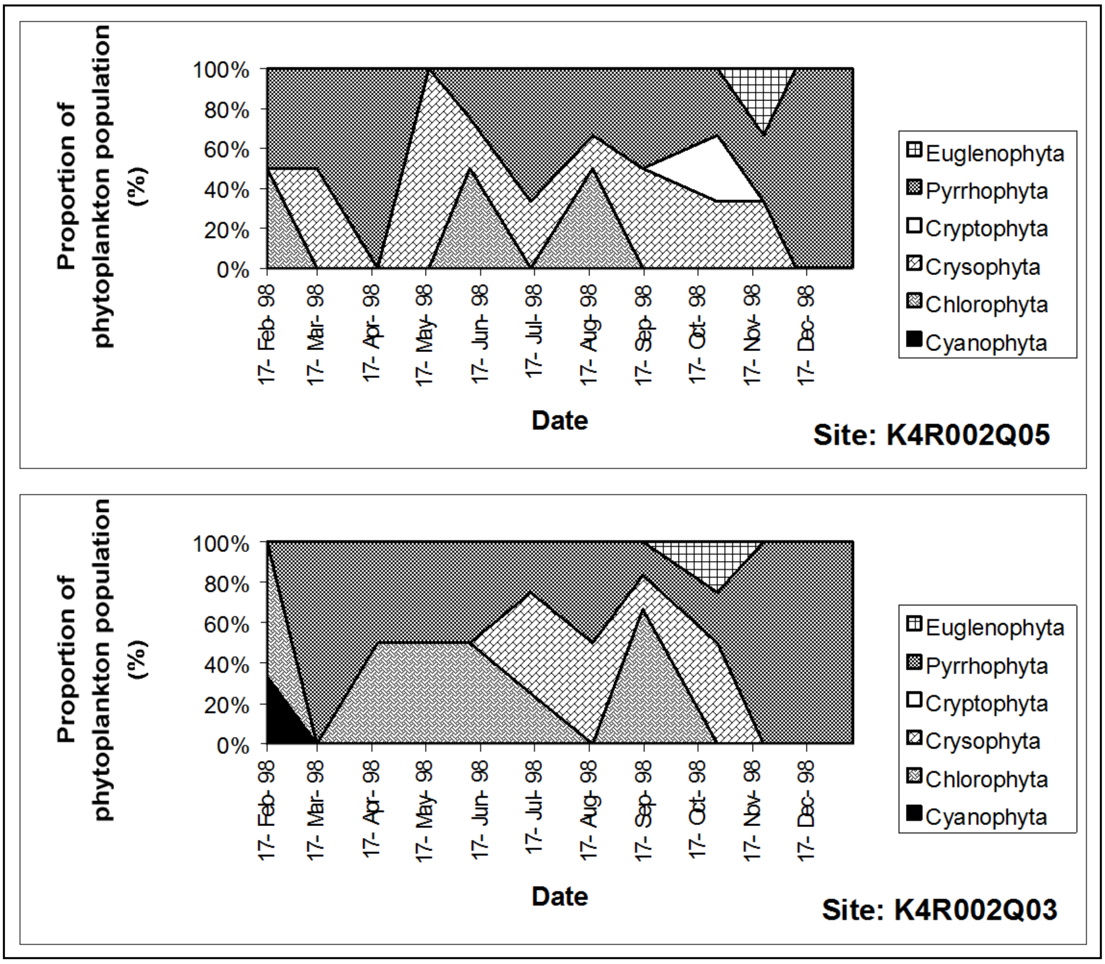


Figure 61. Dominance of algal groups at two sites in the Swartvlei Lake at site K4R002Q05 (above) and site K4R002Q03 (below).

5.3.1.3 Physical characteristics

The mean Secchi disc reading was 3.0 m. Therefore, the lake is a clear system. Due to the limited Secchi disc readings, no correlation determination between the chlorophyll *a* and the Secchi disc readings was done. The suspended solids concentrations were not determined for the Swartvlei Lake.

The pH values in the Swartvlei Lake (Figure 62) showed a distinct difference between the inflowing site in the Karatara River compared to the other three sites in the Swartvlei Lake. The other three sites within the lake were noticeably more alkaline than the site at the Karatara River inflow.

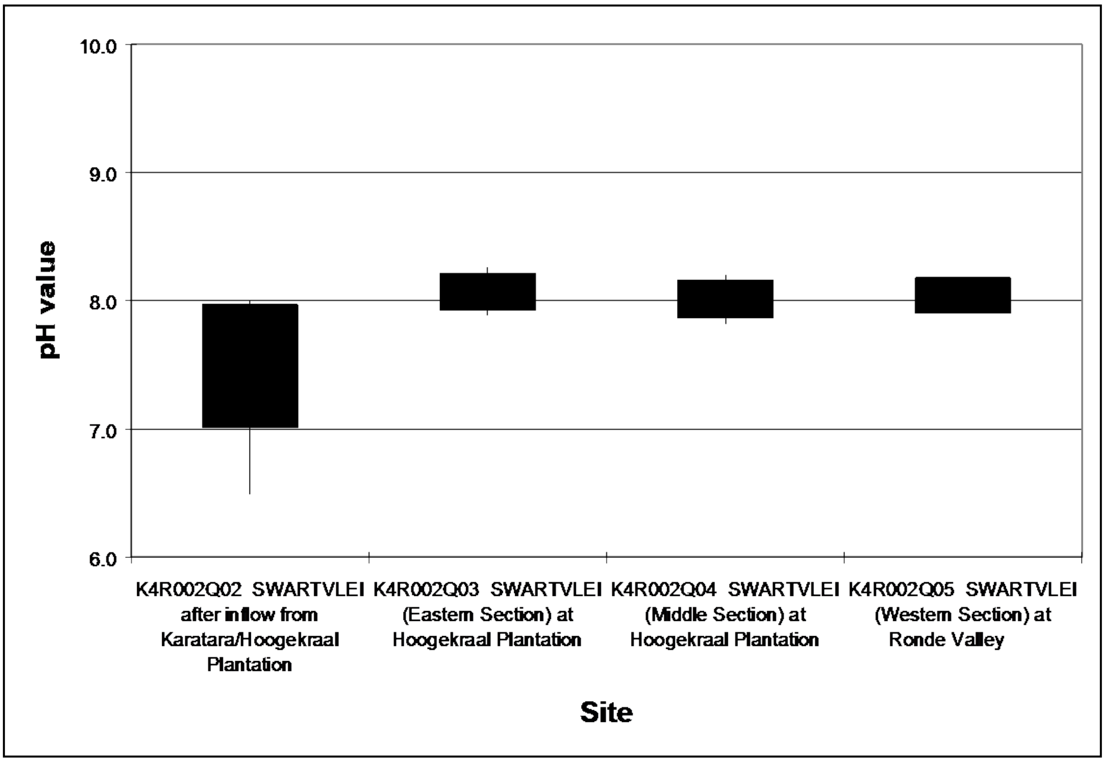


Figure 62. Variability in pH values at the four sites in the Swartvlei Lake Catchment (1998 – 1999).

The turbidity in the Swartvlei Lake is below 3 NTU's (± 1.7 m as Secchi disc reading) (Figure 63) and the lake is, as also shown by the mean Secchi disc reading (3.0 m), a clear system. Again, the site at the inflow of the Karatara River into the lake showed distinct differences to the other three sites of the system. This can be explained by the fact that the site is subject to higher turbulence due to higher flows and turbulence when compared to the lake sites.

The Secchi disc depth readings (Figure 64) that are also an indication of the turbidity within the system showed great variability at the eastern section site in the lake when compared to the western section site. Both these sites showed, however, that the system is clear with Secchi disc readings of up to 4 m measured in the eastern section of the lake.

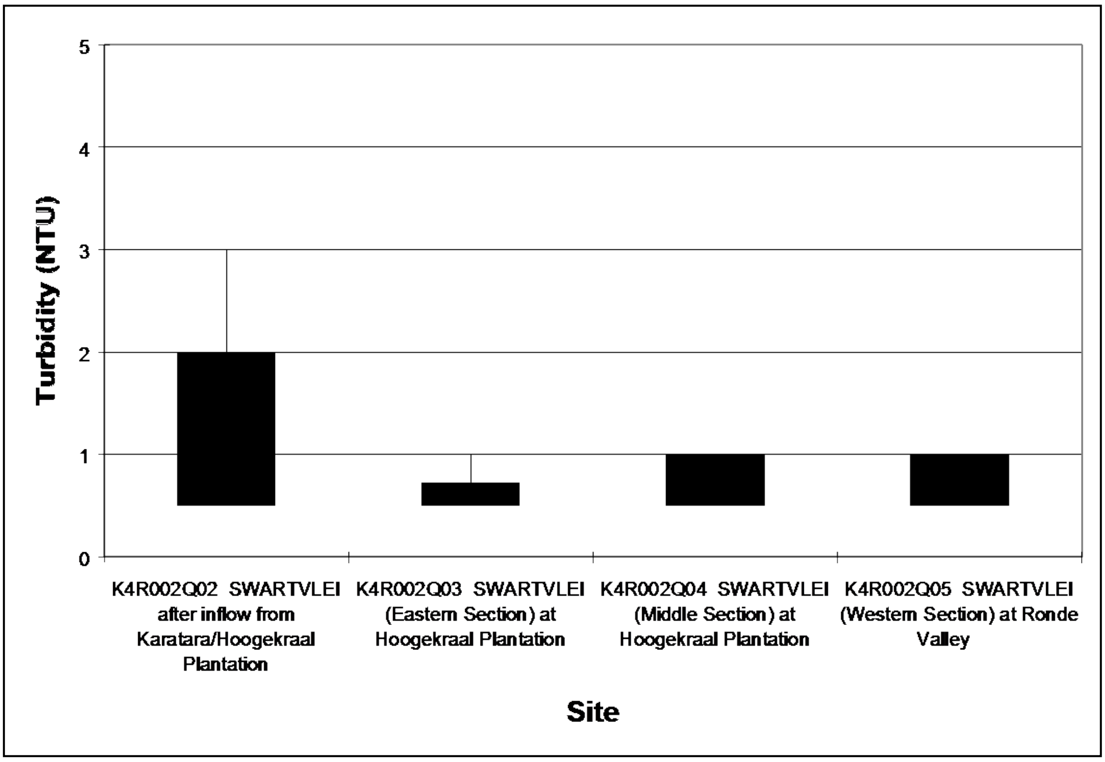


Figure 63. Variability in turbidity (NTU) at the four sites in the Swartvlei Lake (1998 – 1999).

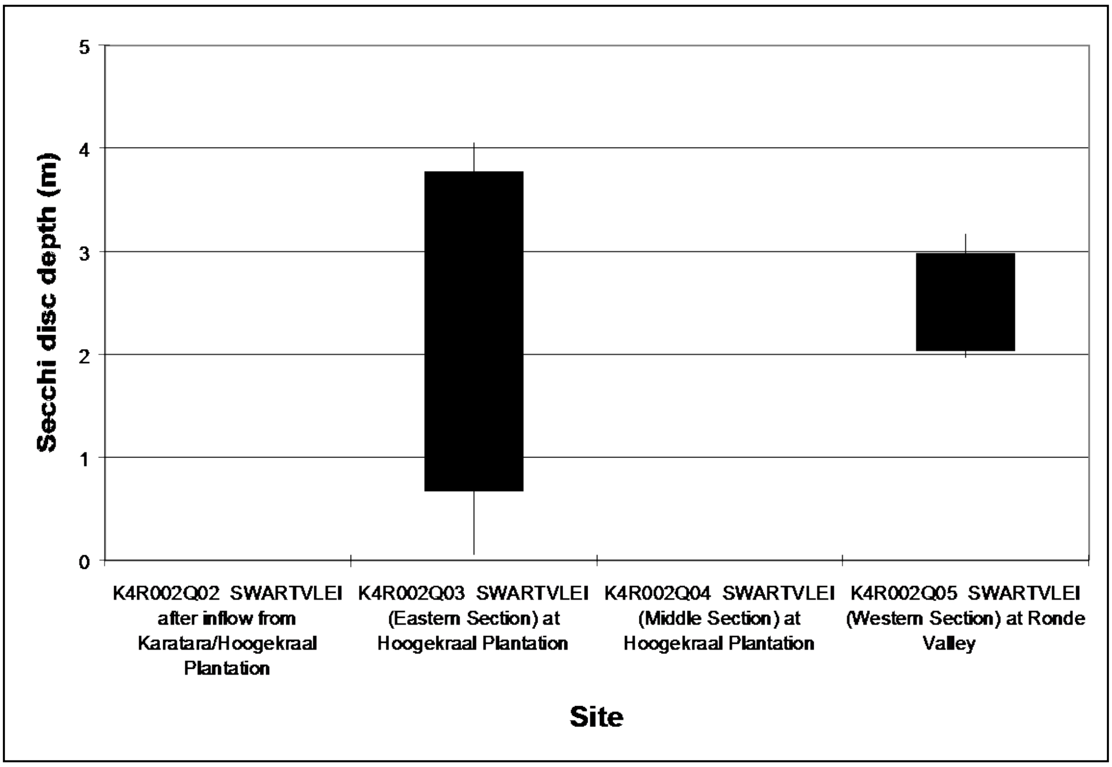


Figure 64. Variability in Secchi disc depth (m) at two sites in the Swartvlei Lake (1998 – 1999).

5.3.1.4 Trophic status of the Swartvlei Lake

Table 20 indicates that the Swartvlei Lake is oligotrophic when all the variables are considered. The chlorophyll-*a* concentrations are low. More information is needed in order to determine the occasional increases in the trace metal concentrations in the Swartvlei Lake system.

Table 20. Trophic status indicators in the Swartvlei Lake for the period 1998 –1999.

Year	**Chlorophyll *a***		**TP**	**Cyanobacteria dominance**	**Mean Secchi disc reading**	**Trophic Status**
	Mean (µg/ℓ)	>30µg/ℓ (%)	Mean (mg/ℓ)	Mean (%)	Mean (m)	
1998-1999	1.2	0	**0.013**	0	2.43	**O & clear**

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

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

- The Swartvlei Lake was oligotrophic.
- Occasional increases in trace metal concentrations should be investigated.
- Monitoring of the impoundment should be continued to monitor the water quality of the lake for any changes in trophic status.

5.3.2 Sedgefield Lagoon

The Sedgefield Lagoon is situated south-east of the Swartvlei Lake just upstream of the estuary at Sedgefield. Four sites were sampled in the Sedgefield Lagoon. The Sedgefield Lagoon forms an integral part of the Swartvlei Lake and connects it to the Indian Ocean. The Sedgefield Lagoon is, therefore, a semi-marine environment with high levels of salinity and estuarine characteristics.

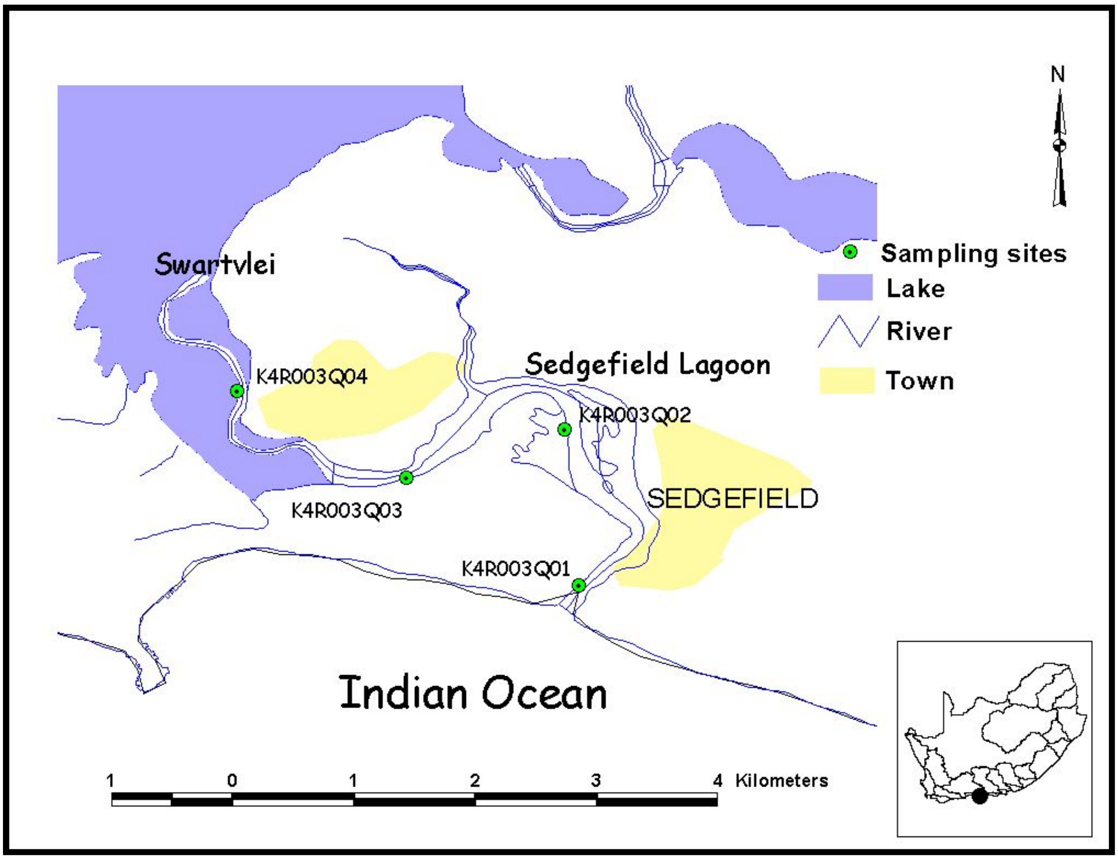


Figure 65. The sampling sites in the Sedgefield Lagoon.

5.3.2.1 Chemical characteristics

Phosphorus

The period that nutrient data are available for the Sedgefield Lagoon extends from January 1998 to January 1999. Figure 66 indicates that in the Sedgefield Lagoon the TP concentrations are low and constantly within the Phosphorus Management Objective (PMO) of 0.130 mg/L P (DWA 1988, ANON 1988a, ANON 1988b) and the threshold level for eutrophic systems of 0.047 mg/L P (WALMSLEY & BUTTY, 1980; DU PLESSIS *et al*., 1990). The system is, therefore, not enriched.

The PO_4-P concentrations (Figure 67) were also consistently low. The impoundment is, therefore, not very productive and the water is of high quality from a phosphorus perspective.

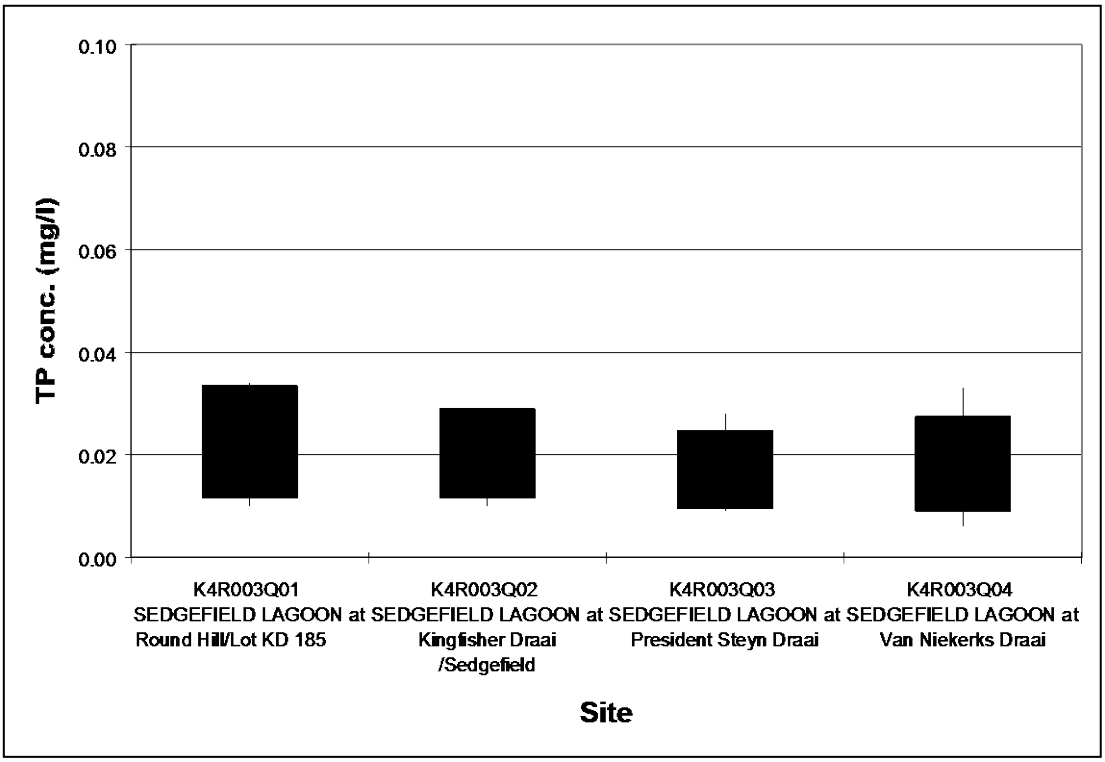


Figure 66. Variability in TP (as P) concentrations at the four sites in the Sedgefield Lagoon catchment (1998 – 1999).

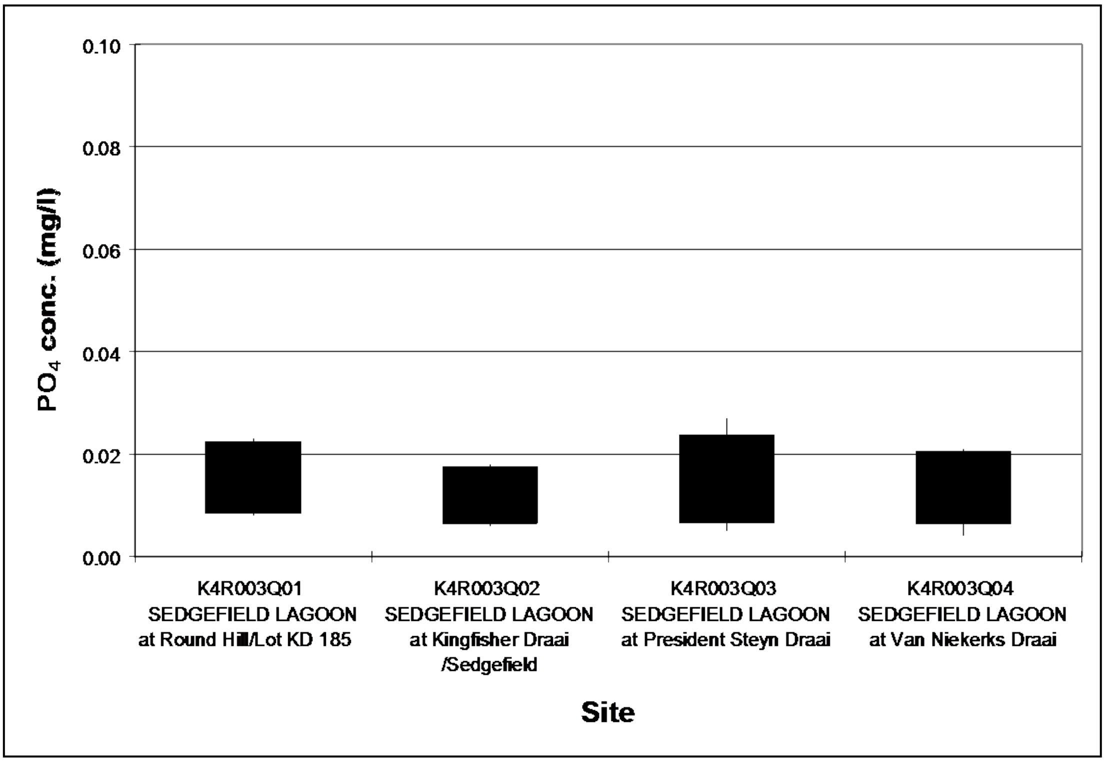


Figure 67. Variability in PO_4-P (as P) concentrations at the four sites in the Sedgefield Lagoon catchment (1998 – 1999).

Nitrogen

The TN concentrations in the Sedgefield Lagoon are reflected in Figure 68. The nitrogen concentrations within the lake showed variation, albeit at very low concentrations and the concentrations were consistently within the 2.5 mg/L Target Water Quality Range for NO_3 (as N) (DWAF 1996b).

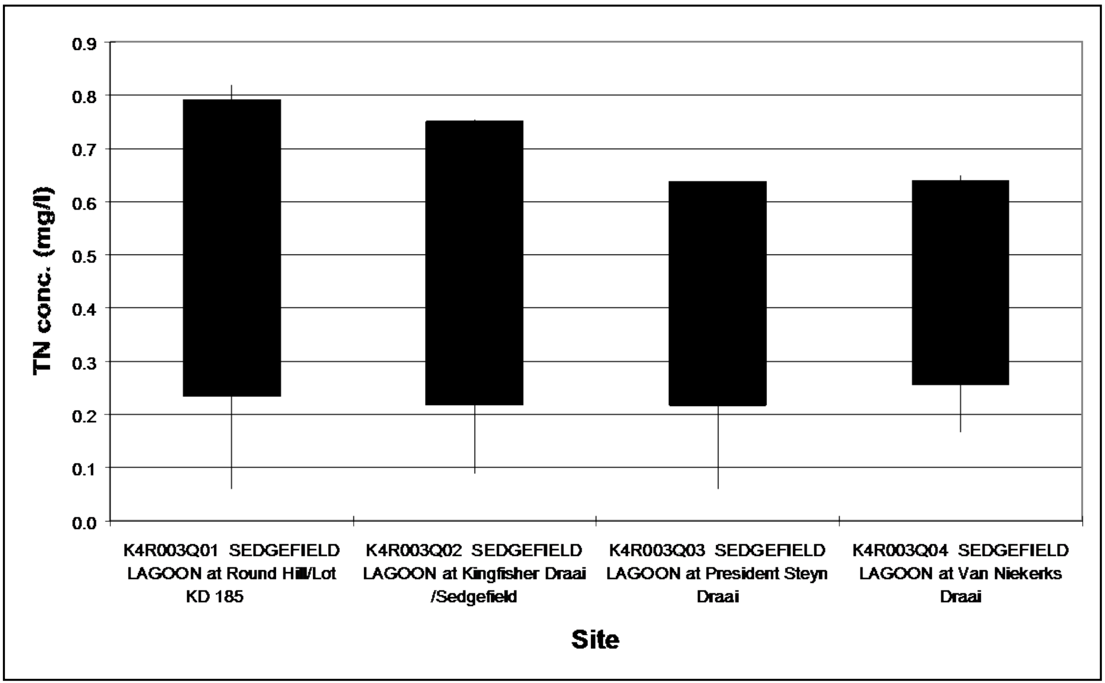


Figure 68. Variability in TN (as N) concentrations at the four sites in the Sedgefield Lagoon catchment (1998 – 1999).

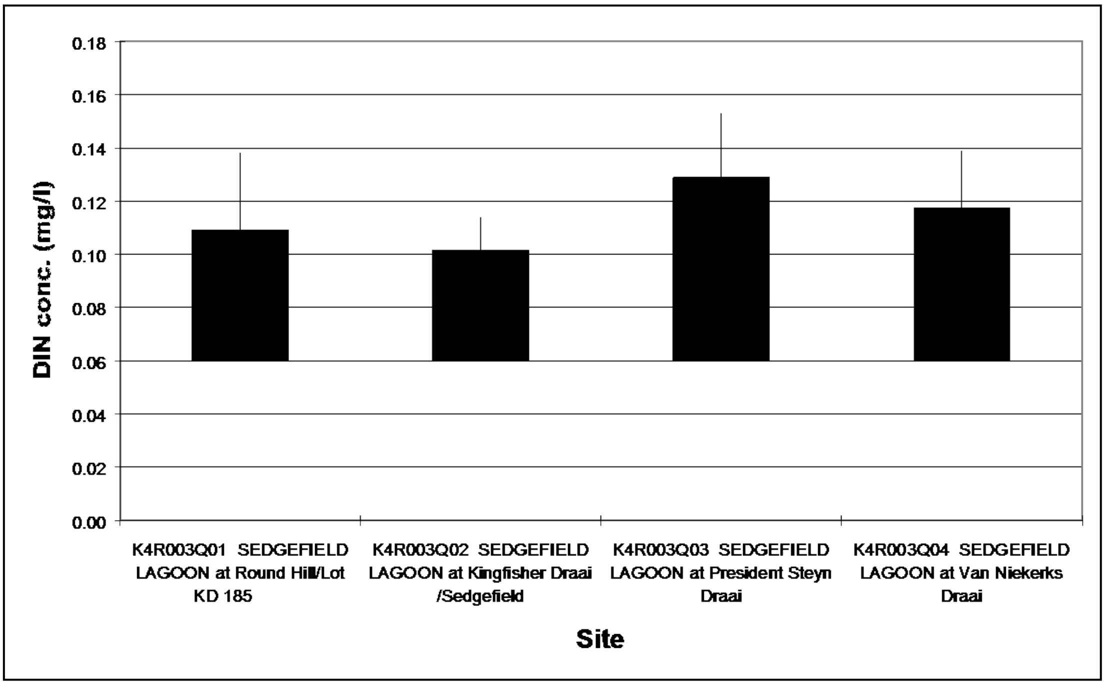


Figure 69. Variability in DIN (as N) concentrations at the four sites in the Sedgefield Lagoon catchment (1998 – 1999).

The DIN (as N) concentrations (Figure 69) were very low. Nitrogen is, therefore present in very low concentrations and does not contribute to the development of eutrophication problems.

TN:TP ratios

The TN:TP ratios for the Sedgefield Lagoon are shown in Table 21. The TN:TP ratios indicate that the water quality in the Sedgefield Lagoon varies between being phosphorus limited and being nitrogen limited. At all four of the sites in the Sedgefield Lagoon the minimum TN:TP ratios were below 10. The nutrient concentrations of the impoundment indicate that the system is still within manageable levels but might favour the development of cyanobacteria during periods of nitrogen limitation.

Table 21. The minimum, median and maximum TN:TP ratios at the five sites in the Sedgefield Lagoon catchment during 1998 to 1999.

Site	**Minimum TN:TP ratio**	**Median TN:TP ratio**	**Maximum TN:TP ratio**
K4R003Q01 SEDGEFIELD LAGOON at Round Hill/Lot KD 185 (n=11)	1.8	24.9	59.8
K4R003Q02 SEDGEFIELD LAGOON at Kingfisher Draai /Sedgefield (n=11)	4.9	29.7	58.9
K4R003Q03 SEDGEFIELD LAGOON at President Steyn Draai (n=12)	5.5	25.4	68.9
K4R003Q04 SEDGEFIELD LAGOON at Van Niekerks Draai (n=11)	5.0	28.7	79.5

Salinity

The Sedgefield Lagoon is connected to the ocean by an estuary (FIJEN and KAPP 1995). Tidal exchange, therefore, takes place whenever the estuary mouth is open. The decreasing salinity at the four sites in the lagoon (Figure 70) indicates the effect of the fresh water influence from the Swartvlei Lake, as expected.

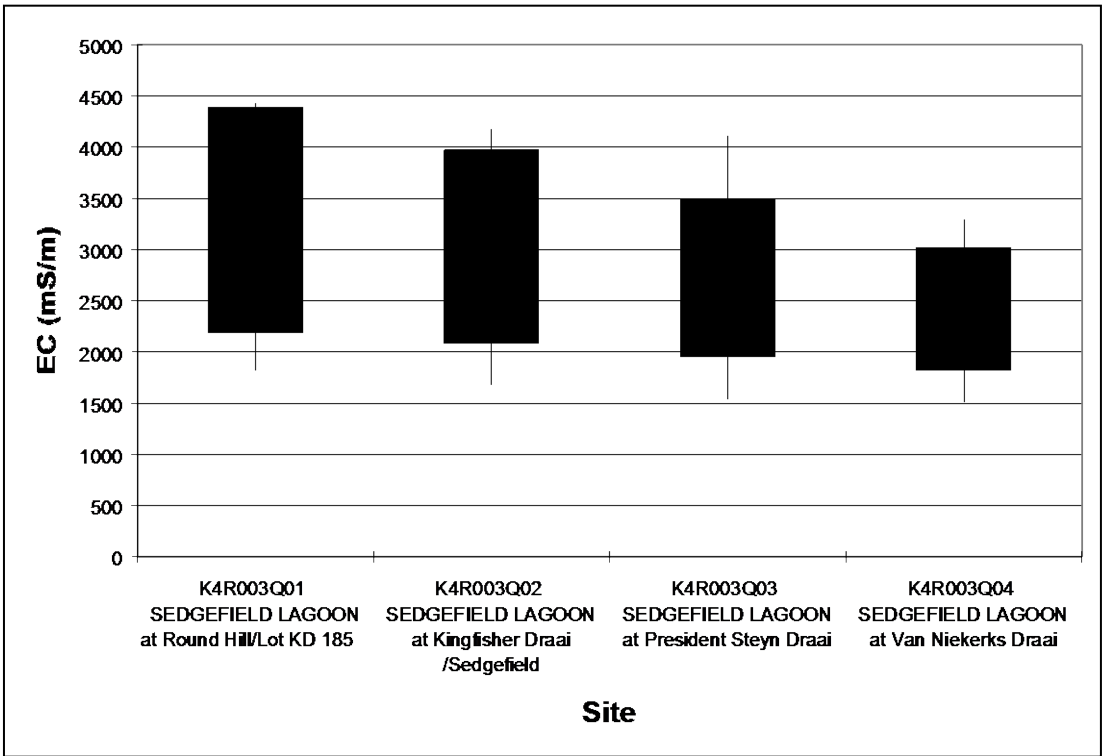


Figure 70. Variability in EC readings at the four sites in the Sedgefield Lagoon catchment (1998 – 1999).

Chloride and sodium dominated the ions in the Sedgefield Lagoon as expected and the relative concentrations of the major ions show the tendency of Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+ at all four of the sites. The lowest salt concentrations were found at Van Niekerk's Draai close to the Swartvlei Lake (Figure 71). The Sedgefield Lagoon showed the highest salinity of all the lakes that were assessed in this study. The Cl^- concentrations reached values of ± 19 000 mg/L and the Sedgefield Lagoon is, therefore, a highly saline system comparable to a marine environment.

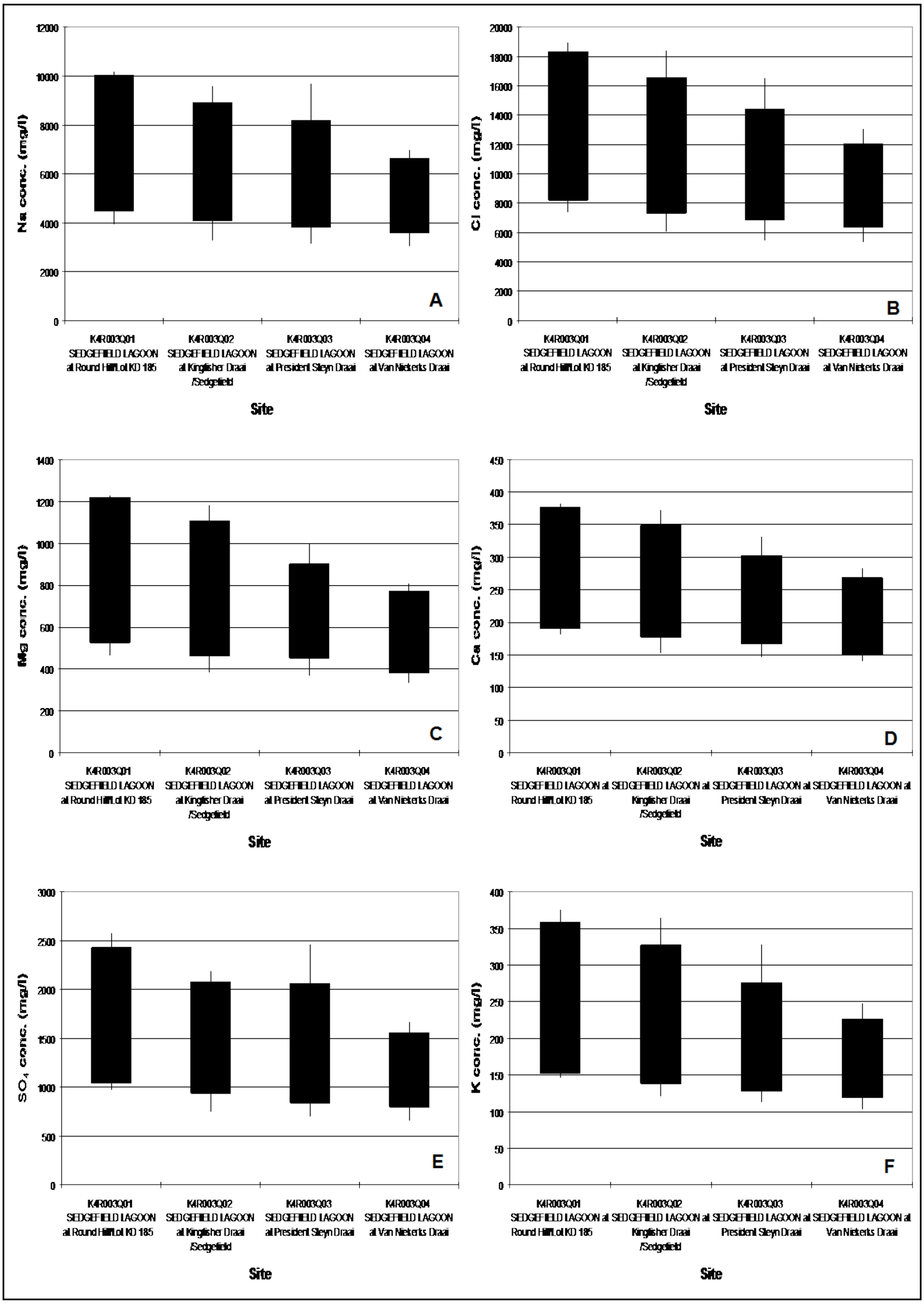


Figure 71. The dissolved salts concentration variability at the four sites in the Sedgefield Lagoon. A Sodium concentrations; B Chloride concentrations; C Magnesium concentrations; D Calcium concentrations; E Sulphate concentrations and F Potassium concentrations.

Trace Metals

Dissolved trace metal samples were only taken at the President Steyn Draai site in the Sedgefield Lagoon (Table 22). The concentrations of the different dissolved trace metals that were analysed for on four occasions are compared to the available target values for secondary and primary consumers for coastal marine environments. Fairly high boron (B) concentrations and strontium (Sr) concentrations were found at this site in the lagoon on all four sampling occasions, as is normal for saline systems (WETZEL, 1983). In the Sedgefield Lagoon the zinc concentrations were higher than the detection limit on three occasions and once exceeded the target values for the primary and the secondary consumers during the June sampling exercise. None of the other variables posed any problems during the study period.

Table 22. The dissolved trace metal concentrations at the President Steyn Draai site in the Sedgefield Lagoon during 1998 and 1999 showing the minimum, median and maximum concentrations of various dissolved trace metals. These values are compared to the target values for primary and secondary producers of the marine coastal natural environment (DWAF 1995).

Variable	**Target value for Primary Consumers**	**Target value for Secondary Consumers**	**1998/02/17**	**1998/05/19**	**1998/08/19**	**1998/11/23**
Boron (B) (mg/L)	NA	NA	1.139	2.194	1.662	1.396
Aluminium (Al) (mg/L)	NA	NA	<0.02	<0.02	<0.02	<0.02
Vanadium (V) (mg/L)	NA	NA	<0.002	<0.002	<0.002	<0.002
Chromium (Cr) (mg/L)	0.008	0.005	<0.003	<0.003	<0.003	<0.003
Manganese (Mn) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Iron (Fe) (mg/L)	NA	NA	<0.003	0.104	<0.003	<0.003
Nickel (Ni) (mg/L)	0.025	0.025	<0.006	<0.006	<0.006	<0.006
Copper (Cu) (mg/L)	0.005	0.005	<0.002	<0.002	<0.002	<0.002
Zinc (Zn) (mg/L)	0.025	0.025	0.013	0.063	<0.004	0.016
Strontium (Sr) (mg/L)	NA	NA	2.078	4.017	3.048	2.575
Molybdenum (Mo) (mg/L)	NA	NA	<0.005	<0.005	<0.005	<0.005
Cadmium (Cd) (mg/L)	0.004	0.004	<0.002	<0.002	<0.002	<0.002
Barium (Ba) (mg/L)	NA	NA	<0.001	<0.001	<0.001	<0.001
Lead (Pb) (mg/L)	0.012	0.012	<0.015	<0.015	<0.015	<0.015

In the Sedgefield Lagoon the zinc concentrations may occasionally be a concern. None of the other trace metals posed any problems during the assessment period.

5.3.2.2 Biological characteristics

The chlorophyll-*a* concentrations (Fig. 72) were below 10 µg/L in the lagoon for the whole period. The lagoon is, therefore, not prone to algal blooms. The nutrient concentrations in the lagoon were also very low and at that concentration will not support algal blooms. Cyanophyta (*Oscillatoria*) were present during two sampling events (Figure 73), but did not form a significant proportion of the phytoplankton population. The Chrysophyta (*Chlorocromonas* and *Tribonema*), Chlorophyta (e.g. *Ankistrodesmus* and *Chlorella*) and Pyrrhophyta (*Peridinium*) periodically formed the most dominant algal groups in the Sedgefield Lagoon. The Euglenophyta (*Euglena* and *Trachelomonas*) were present during October 1998. The chlorophyll-*a* concentrations indicate that although potentially problem algae like *Oscillatoria* and *Peridinium* do occur in the lagoon, nuisance conditions will not occur.

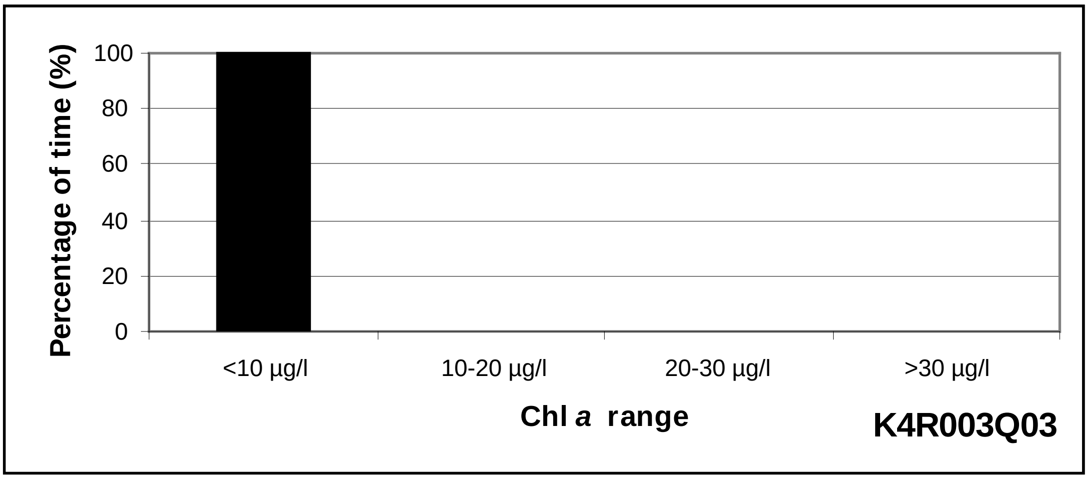


Figure 72. Per cent of the time that chlorophyll *a* concentrations were within a specified range in the Sedgefield Lagoon at the President Steyn Draai.

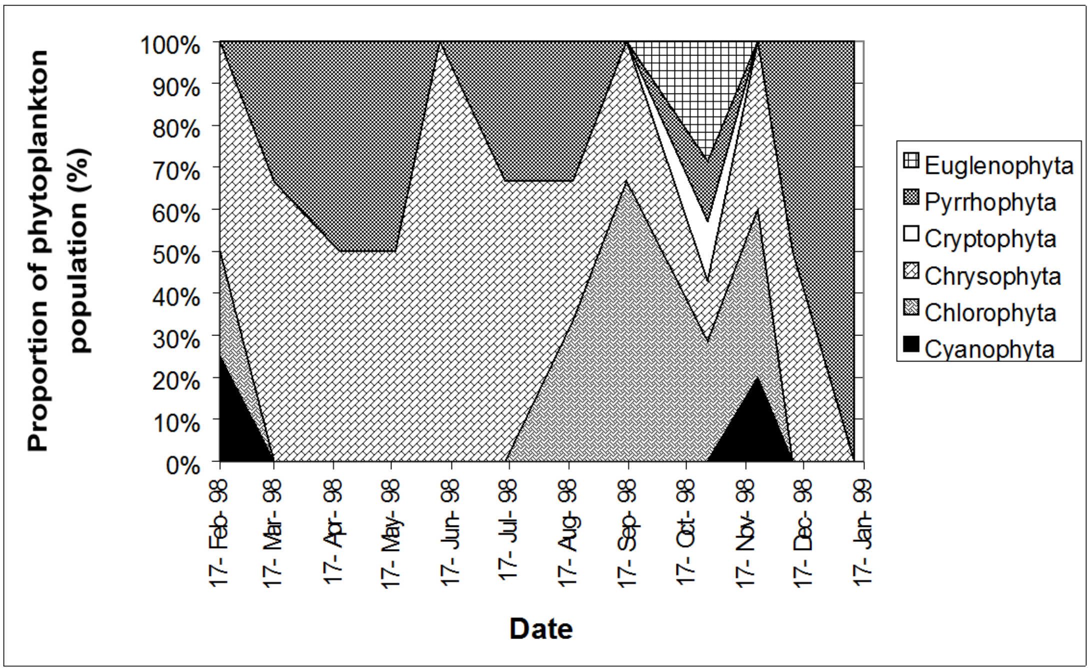


Figure 73. Dominance of algal groups in the Sedgefield Lagoon.

5.3.2.3 Physical characteristics

No Secchi disc readings were taken. The suspended solids were not determined for the Sedgefield Lagoon.

No temperature and oxygen profiles were taken during the study period.

The pH values in the Sedgefield Lagoon (Figure 74) were continuously above 8 and indicate that the system is distinctly alkaline. Slightly higher readings were recorded at the Kingfisher Draai in the Sedgefield Lagoon than at the other sites.

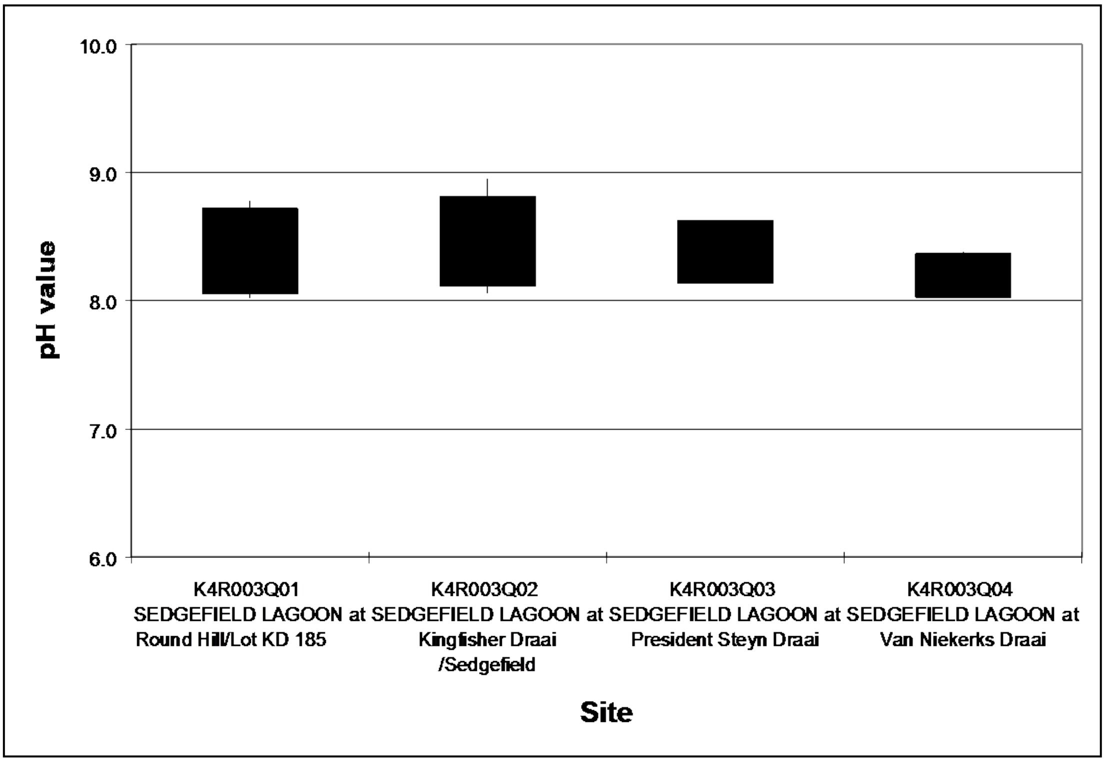


Figure 74. Variability in pH values at the four sites in the Sedgefield Lagoon Catchment (1998 – 1999).

The turbidity in the Sedgefield Lagoon (Figure 75) is continuously below 1 NTU (5.07 m as Secchi disc reading) and the lagoon is, therefore, a clear system.

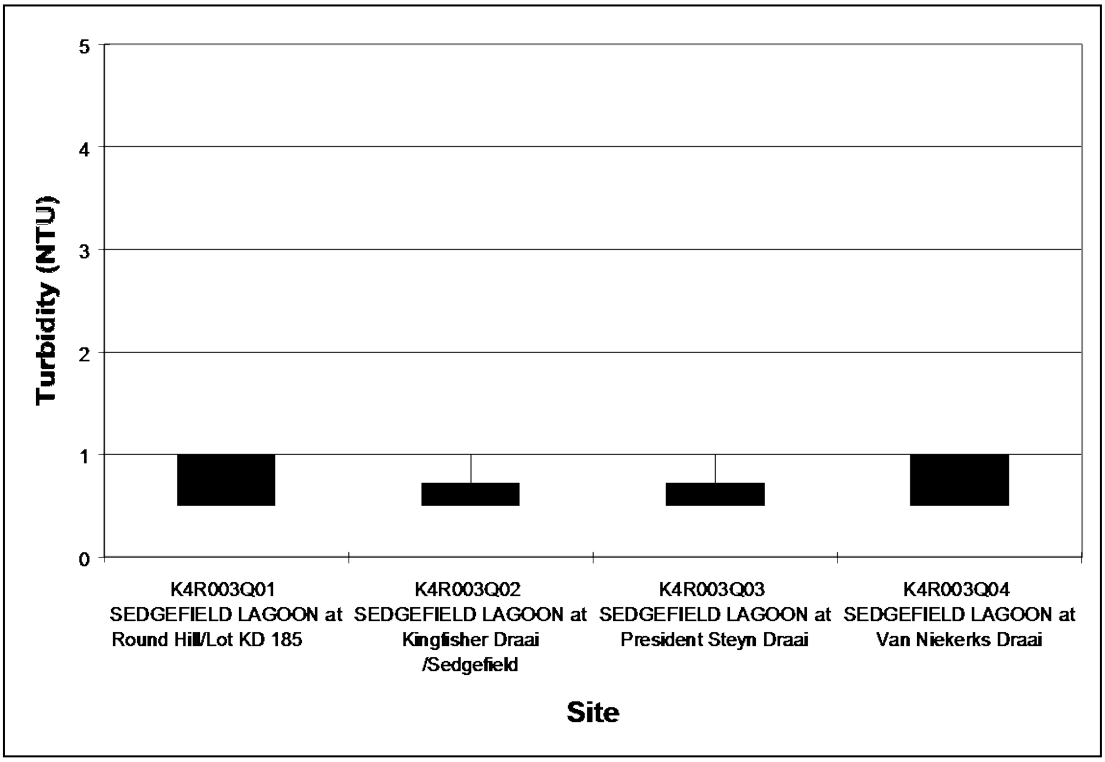


Figure 75. Variability in turbidity (NTU) at the four sites in the Sedgefield Lagoon (1998 – 1999).

5.3.2.4 Trophic status of the Sedgefield Lagoon

Table 23 indicates that the Sedgefield Lagoon was oligotrophic at the time of sampling. The nutrient enrichment in the Sedgefield Lagoon seems to be within manageable limits and the system is not prone to algal bloom development. Problem algae, e.g. *Oscillatoria* and *Peridinium*, do occur but at such low concentrations that they should not cause any nuisance conditions. Monitoring of the impoundment is essential in managing the system for optimum recreational use.

Table 23. Trophic status indicators in the Sedgefield Lagoon for the period 1998 –1999 (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)	
1998-1999	1.1	0	**0.016**	0	-	**O**

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

O = oligotrophic M = mesotrophic

E = eutrophic HE = hyper-eutrophic

- The Sedgefield Lagoon is oligotrophic.
- Algal blooms did not occur.
- Zinc concentrations should be monitored.

6.
7. CONCLUSIONS AND RECOMMENDATIONS

The Wilderness Lake system, the Swartvlei Lake System and the Groenvlei Lake were assessed in terms of chemical characteristics, biological characteristics and physical properties. Following on from this assessment a determination of their trophic status was conducted.

6.1 Conclusions

In general the water quality of the Wilderness Lakes, Swartvlei Lakes and Groenvlei Lake Systems is of good quality when measured against the recreational, aquatic ecosystems and the natural environment of the coastal marine water guidelines. Although the lakes seem to deteriorate trophic-wise towards the Wilderness Lakes System (Table 23), there was a decrease in the nutrient concentrations (PO_4-P, NO_3+NO_2 as N and NH4 as N) since the FIJEN and KAPP (1995) study, specifically in the Wilderness lake system. However, the Wilderness Lake system deserves the highest priority when eutrophication related problems are considered. The nutrient concentrations in the Wilderness Lakes have the highest trophic status. The one management option that should definitely be implemented, as recommended by FIJEN and KAPP (1995b), is that no treated sewage effluent should be discharge into the Wilderness lakes.

- The nutrient concentrations in the lakes did not produce nuisance conditions, with the exception of occasional eutrophic conditions in the Rondevlei and Onder-Langvlei lakes.
- In general, the three lake systems seldom encountered high chlorophyll-*a* concentrations and the lakes all tend towards phosphorus limitation.
- Occasionally, algal species that are potentially problematic did occur, but according to the recreational guidelines, seldom resulted in nuisance conditions being experienced.
- The Wilderness Lakes Systems has the most enriched trophic status of the three systems considered.

The water quality objectives and goals of the FIJEN and KAPP (1995b) study are summarised in Appendix C. If all these water quality objectives and goals are met, the water quality of the three lake systems should be preserved for sustainable use.

The occasional high trace metal concentrations (zinc, cadmium, nickel, manganese and iron) should be monitored (Table 23). The origin of these trace metals must be determined and managed.

- Trace metal concentrations which occasionally exceeded the target aquatic ecosystem guidelines and need further investigation in the Groenvlei Lake and the Swartvlei Lakes System.

Table 23. The summarised conclusions of the assessment of the Wilderness Lake System, the Swartvlei Lake System and the Groenvlei Lake.

	Phosphorus	Nitrogen	TN:TP	Nutrients	Trace Metals	Biological	Clarity	Trophic Status
Wilderness Lakes **1. Rondevlei**	Possibility of eutrophication in the eastern section	Dissolved N constitutes small part of total N	P-limiting	Not of concern	No problem	Potential to develop eutrophication symptoms, but low Chl-a	Slightly turbid	Eutrophic
2. Bo-Langvlei	Highest TP in eastern section of lake	KN below 2 mg/L. Low NH_4. No eutrophication risk	P-limiting	Not of concern	No problem	Potential toxin producing species do occur	Clear system	Eutrophic
3. Onder-Langvlei	Within PMO, but TP above eutrophic threshold value	KN below 2 mg/L	P-limiting	Potential for eutrophication problems to occur	No threat to ecology	Potential bloom forming	Clear system	Mesotrophic
4. Wilderness Lagoon	TP never above threshold level – no eutrophication risk	Dissolved inorganic N very low portion of TN. No serious Eutrophication risk	P-limiting but occasional N-limiting	No of concern	No problem	Did not reach nuisance conditions	Clear system	Mesotrophic
Groenvlei Lake & Goukamma River	TP below eutrophic threshold but PO_4-P large proportion of TP	KN below 2 mg/L but higher than Target water quality guideline of 250 µg/ℓ N for Groenvlei Lake	P-limiting	Manageable levels	May be slight problems: Zn & Cd	Low Chl-a	Clear system	Mesotrophic
Swartvlei Lake System **1. Swartvlei**	Low TP. Increasing PO_4-P in Karatara River	KN below 1 mg/L	P-limiting, except at Hoogekraal Plantation	Manageable levels	Mn, Fe, Ni, Cu & Zn higher than target in June	Low Chl-a	Clear system	Oligotrophic
2. Sedgefield Lagoon	TP constantly below PMO and eutrophic threshold levels PO_4-P low	KN very low and NO_3+NO_2 low	Varies between P-limitation and N-limitation. Median is P-limiting	Manageable levels	Zn was higher than target once	Low Chl-a. Some problem causing species but not at nuisance levels	Clear system	Oligotrophic

6.2 Recommendations

The assessment of the Wilderness Lake System, the Swartvlei Lake system and the Groenvlei Lake led to the following recommendations:

- The high recreational value of the Wilderness, Swartvlei and Groenvlei catchments led to the development of a water quality and eutrophication management strategy (FIJEN and KAPP 1995). These recommendations are summarised in Appendix C and it is proposed that the recommendations be followed to ensure that the water quality of the Lakes is sustained for future recreational use.

- The Rondevlei and the Bo-Langvlei lakes deserve the highest priority when resources are allocated for eutrophication management.

- The high recreational value of the Wilderness Lakes necessitates that monitoring of the lakes be continued and that the variables assessed in this study be included. This will enable water management authorities to act pro-actively and take precautionary steps if deterioration of the water quality is detected in future. Monthly monitoring frequency of the lake systems is preferable for the major inorganic substances, but if funding is a problem monitoring can be scaled down and be done on a quarterly basis.

- The source of the occasional unacceptable trace metal concentrations should be investigated further. Especially in the Groenvlei Lake (zinc & cadmium), the Swartvlei Lake (manganese, iron, nickel, copper & zinc) and the Sedgefield Lagoon (zinc).

- Although the Groenvlei Lake water is of acceptable quality (except for the trace metals as mentioned above) for the aquatic freshwater and marine environment, the continued monitoring of the system is essential because it is such an enclosed system, and nutrients will accumulate to unacceptable levels if an influx of nutrients should occur. This might cause eutrophication-related problems.

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APPENDIX A

Text not available.

APPENDIX B

Text not available.

APPENDIX C

The recommendations of FIJEN and KAPP (1995) towards the management of the water quality of the Wilderness Lakes are summarised below.

- The ideal water quality target ranges as determined for the Wilderness, Swartvlei and Groenvlei catchments should be accepted.
- No discharge of toxic materials to the river systems should be allowed.
- Cutting/cleaning of aquatic plants should remain the responsibility of the National Parks Board. The report suggested that the cutting of reeds in the Touw River estuary be terminated.
- General littering should be discouraged and a litter control strategy should have been developed.
- Industrial discharges into any of these systems are forbidden.
- Storm water discharges should be cleared.
- Contingency plans for accidental spillage events on the N2 highway, need to be put in place.
- The proposed Sewage Treatment Works discharges should not be discharged into the Wilderness or Swartvlei Lakes. A special/stringent standard should be implemented for nutrients and micro-organisms, if this is the only option for the treated effluent.
- No discharge or final effluent should be allowed to enter Groenvlei Lake.
- Water quality monitoring should include occasional testing for pesticides.
- Increased monitoring for faecal contamination during Christmas and Easter periods whne use of the Lakes is at its peak.
- Potential relocation of Thesen’s timber-processing factory should be carefully considered.
- No further development of septic tanks in the Groenvlei area should be allowed.
- The ban of petrol-driven boats on Groenvlei is endorsed.
- The occasional release of conservancy tank effluent into estuarine areas should be monitored.
- Promotion of best forestry and agricultural practices regarding contour ploughing, etc should be encouraged.
- Reduction of nutrient and pesticide runoff to water courses
- Relocation of the waste site location at Sedgefield.