A NATIONAL SURVEY OF THE INCIDENCE OF CYANOBACTERIAL BLOOMS AND TOXIN PRODUCTION IN MAJOR IMPOUNDMENTS

By

C.E. van Ginkel

April 2004

Directorate: Resource Quality Services

Department of Water Affairs and Forestry

Private Bag X313

Pretoria 0001

Republic of South Africa

TITLE:	A National Survey of the incidence of cyanobacterial blooms and toxin production in major impoundments
REPORT NUMBER:	N/0000/00/DEQ/0503
PROJECT:	National Eutrophication Monitoring Programme (NEMP)
STATUS OF REPORT:	Final
DATE:	April 2004

This report should be cited as:

Van Ginkel, C.E. (2003). A National Survey of the incidence of cyanobacterial blooms and toxin production in major impoundments. Internal Report No. N/0000/00/DEQ/0503. Resource Quality Services, Department of Water Affairs and Forestry. Pretoria.

EXECUTIVE SUMMARY

Eutrophication is the process of nutrient enrichment and the associated increase in primary production. Eutrophication is a natural ageing process of lakes but is accelerated by human impacts. The development of cyanobacterial blooms is one of the main problems resulting from eutrophication and is the main focus of this report. The results of a screening survey to determine the occurrence of toxic cyanobacteria in selected impoundments for the period February to March 2002 are presented.

Cyanobacterial blooms and their effects are widespread, frequent and typically seasonal. The increasing number of events of cyanobacterial blooms in South African impoundments and rivers is a cause of concern to the Department of Water Affairs and Forestry. The Department has the mandate to develop monitoring programmes and the responsibility to warn raw water users in the event of any hazard to human health. Thus a better understanding of the incidence of toxic cyanobacterial blooms is essential.

There is no structured monitoring programme for the incidence of cyanobacterial toxins in South African water resources. During 1990 to 2001 toxic cyanobacterial events were monitored on an *ad hoc* basis by means of national and local investigations only when algal blooms were reported. Only the Department and large Water Boards had the capability to test for cyanobacterial toxins (cyanotoxins).

There was a lot of drive since 1990 both internationally and nationally to increase our knowledge regarding the driving forces of cyanobacterial blooms and cyanotoxin production. Studies funded by the WRC over the last four years reviewed the extent of research and monitoring for cyanobacteria and their associated toxins in South Africa. The studies indicated that there is a lack of knowledge on the extent of cyanobacterial bloom development in South Africa. This study was aimed at filling that gap. The study highlighted the fact that there is a lack of understanding on, and the ability to predict the development of toxic cyanobacterial blooms. The studies also highlighted the lack of analytical laboratories to analyse and quantify cyanotoxins in raw water and in the drinking water supplies.

Toxic cyanobacterial blooms is a threat to the supply of safe drinking water in large areas of South Africa. The lack of knowledge and analytical capacity for cyanobacterial toxins is a compounding factor.

There is thus more research needed to determine the driving forces for cyanobacteria toxin production.

Conclusions

- Sampling procedures need to be designed and standardized for South Africa to be able to compare the results.
- *Microcystis'* dominance during blooms can be used as an indicator of toxicity for hyper-trophic impoundments in South Africa, although it is not conclusive.
- Toxin production seems to be highly seasonal in especially Hartbeespoort and Roodeplaat dams and is associated with the presence of *Microcystis*.

- The Bon Accord and Klipvoor dams experienced extremely high primary production during the study period without expressing serious cyanobacterial scum forming blooms. This phenomenon needs further investigation to clarify the driving forces behind the cyanobacterial blooms and cyanotoxin production for prediction purposes.
- Succesion of cyanobacterial species/presence of different microcystins need further investigation with special focus on th e monitoring of fresh water resources

Recommendations

The studies that were done during the past four years lead to the following recommendations.

- South Africa need to develop standardized sampling and analyses methods
- Analytical laboratories, both for algal identification and cyanobacterial toxin analyses, need to be established on a regional, provincial or CMA level for more efficient data acquisition and dissemination of information.
- A National Cyanobacterial Monitoring Programme possibly as part of the National Eutrophication Monitoring Programme should include all water resources.
- The integration of biological and meteorological research is needed to understand and estimate the consequences of climate variations on the ecosystem.
- Sampling surveys on small farm dams and irrigation systems should be initiated on a regional level to determine the potential hazard to rural domestic water users and agricultural users.
- Eutrophication management strategies need to be developed on a National and Regional level and implemented to reduce toxic cyanobacterial bloom development in South Africa's freshwater resources and to ascertain safe domestic, agricultural and recreational water supplies.

ACKNOWLEDGEMENTS

- The Organic, Hydrobiological and Chemical Laboratories of Resource Quality Services were essential to this project and are acknowledged for their contribution to the final product.
- The Technical Division of Resource Quality Monitoring and the monitors that were involved in the historical Trophic Status Project are acknowledged. for their dedication, in consistently collecting samples at selected Dams,
- The CD:Resource Quality Information is acknowledged for providing the time and resources to complete this report.
- The contribution of the WRC funded projects, done by Dr Bill Harding and Mr. Tim Downing, are acknowledged as their products largely contributed towards the final product of this study.
- Mr Axel Diefenbach for producing the maps indicating the distribution of the cyanobacteria in South Africa.

TABLE OF CONTENTS

EXECUTIVE SUMMARY ii

ACKNOWLEDGEMENTS iii

Chapter 1. INTRODUCTION 1

1.1 Project Aim

1.2 Objectives

1.3 Background

Chapter 2. LITERATURE SURVEY 3

2.1 Historical Overview of Cyanobacteria in South Africa

2.2 Evaluation of available data

2.3 Known extent of cyanobacterial problems in South Africa

2.4 Factors leading to cyanobacterial dominance

2.4.1 Physical factors

2.4.2 Chemical factors

2.4.3 Biological factors

2.4.4 Conclusions

2.5 Toxicity of cyanobacterial blooms

Chapter 3. SELECTION OF IMPOUNDMENTS 9

3.1 Selection methods

3.2 Selected impoundments

Chapter 4. TRAINING OF SAMPLING PERSONNEL 12

4.1 Training methods

4.2 Training material

Chapter 5. DATA ACQUISITION 15

5.1 Trophic Status Project

5.2 National Eutrophication Monitoring Programme

5.3 Water Management Institutions

5.4 Literature Review

5.5 Screening Survey for Toxic Cyanobacteria

Chapter 6. DATA ASSESSMENT..17

6.1 Assessment of the Trophic Status Project and the NEMP data

6.2 Screening Survey for Toxic Cyanobacteria

6.3 Discussion

Chapter 7. CYANOBACTERIAL TOXIN PRODUCTION IN SELECTED IMPOUNDMENTS..23

7.1 Methods

7.2 Results and discussion

7.2.1 Temporal toxin production

7.2.2 Seasonality of toxin production

7.2.3 Cyanobacterial species responsible for known toxin production

7.3 Conclusions

Chapter 8. KNOWN DISTRIBUTION OF CYANOBACTERIA IN SOUTH AFRICA..35

Chapter 9. CONCLUSIONS AND RECOMMENDATIONS....................41

Chapter 10. REFERENCES..43

APPENDICES

Chapter 1.
INTRODUCTION

1.1 Project Aim

The main aim of this project was to determine the incidence of cyanobacterial blooms and cyanobacterial toxin production in selected major DWAF managed impoundments. This information and experience will be used in the development and future implementation of a national cyanobacterial surveillance programme as part of the National Eutrophication Monitoring Programme (NEMP).

1.2 Objectives

The more detailed objectives of the project to achieve the aim are as follows:

1.2.1 To conduct a national survey of the incidence of cyanobacterial blooms and cyanobacterial toxin production in South African impoundments.

1.2.2 To build capacity of DWAF Water Control Officers at the selected impoundments to monitor for cyanobacterial blooms.

1.2.3 To determine the nature and extent of cyanobacterial toxin production in 5 selected impoundments.

1.3 Background

One of the major symptoms of eutrophication, the development of nuisance cyanobacterial blooms that may also turn out to be toxic, is addressed within this project. Toxic cyanobacterial blooms are of concern to the Department of Water Affairs and Forestry as the Department has the mandate to develop monitoring programmes as well as the responsibility to warn raw water users in the event of any hazard to human health.

Cyanobacteria have a notorious reputation as noxious blooms develop rapidly from obscurity and can just as abruptly recede. Some waters exhibit frequent and even sustained aggregations of these bacteria, while others experience evanescent, but often extremely noxious growth events. A significant proportion of cyanobacteria genera produce one or more of a range of cyanotoxins (Namikoshi and Rinehart, 1996; WHO, 1999). The toxicity and structures of these cyanotoxins (hepatotoxins, neurotoxins and saxitoxins) have been studied extensively. If water containing high cyanobacterial toxin concentrations is ingested (in drinking or recreational water), they present a risk to animal and human health.

According to the proceedings of a 'Workshop to discuss research and capacity building in the eutrophication research field' (Walmsley 2001), eutrophication is not regarded as a national crisis. However, it is indeed a crisis in many localised water resource systems (e.g. Hartbeespoort Dam, Roodeplaat Dam etc.) (Van Ginkel *et al.* 2000, Van Ginkel *et al.* 2001a), and it was recognised as an emerging problem at the WRC workshop (Walmsley 2001).

Chapter 2.
LITERATURE SURVEY

Two recent studies reviewed a) the history of cyanobacterial research in South Africa (Harding & Paxton, 2001) and b) the known extent of cyanobacterial problems in South Africa (Downing & Van Ginkel, 2003). These studies provided a summary of the local literature on cyanobacteria and the cyanobacterial status in South African water systems . This report, therefore, only broadly summarises the findings of the above mentioned two studies. Additional reading material can be found in these reports.

2.1 Historical Overview of Cyanobacteria in South Africa

The study by Harding and Paxton (2001) highlighted the initial pioneering research that was done on cyanobacteria in South Africa by numerous researchers during the period 1927 to 1989. Dr. Steyn, from the Onderstepoort Veterinary Institute, reported the first cases of cyanobacterial poisoning in South Africa in 1927. Since 1927 most cases of cyanobacterial toxicosis were associated with animal or stock deaths.

During 1990 to 2001 cyanotoxic events were monitored by *ad hoc* national and local investigations only when algal blooms were reported. Only the DWAF and large Water Boards had the capability to test for cyanotoxins. There is no structured monitoring programme for the incidence of cyanobacterial toxins in South African water resources at present.

The study by Harding and Paxton (2001) highlighted the lack of a national monitoring system regarding cyanobacteria in South African water resources. The national survey by Downing and van Ginkel (2003) on the incidence of cyanobacterial blooms and toxin production in major impoundments was initiated to fill this gap and contribute towards the development of a national cyanobacterial monitoring programme in South African water resources. It must be noted that this study was only aimed at cyanobacteria in fresh water resources however the Department has not lost vision of the potential hazard in South Africa's marine environments.

2.2 Evaluation of available data

The largest database, on the presence of cyanobacteria in South Africa, exists within DWAF at Resource Quality Services (RQS). This data was collected under the Trophic Status Project monitoring programme that was initiated during the eighties after the 1 mg/ℓ Phosphate Standard was implemented in seven major catchment areas (Van Ginkel *et al.*, 2001a). Downing and Van Ginkel (2003) used this existing database to calculate seasonality of the cyanobacterial biomass as related to the chlorophyll *a* content within the impoundments that had data available for the period 1990 to 2000. Although not all the impoundments had continuous information available, the data show that some impoundments, like Hartbeespoort and Roodeplaat dams have annual cyanobacterial blooms of varying degrees, while many impoundments have only occasional blooms (e.g. Rietvlei, Grootdraai, Bloemhof and Erfenis Dams).

Van Ginkel, Silberbauer and Vermaak (2000) found that *Microcystis* spp. are the most common and dominant cyanobacteria in the eutrophic catchments of South Africa. *Microcystis* spp usually occur during the summer to autumn periods. The second most important species in South Africa is *Anabaena* spp that occur mostly during the spring to early summer period.

The study by Downing and Van Ginkel (2003) highlighted the lack of information regarding cyanobacterial toxin incidence in South African water resources. The lack of analytical facilities to analyse for cyanobacterial toxins and knowledge by small water treatment works on how to handle cyanobacterial blooms is a cause of concern. The potential health hazard may be enhanced by this lack of knowledge as well as early warning systems to alert treatment works in time. The cyanobacterial event in the Orange River during 2000 highlighted the problems experienced by the smaller treatment works (Van Ginkel and Conradie 2001), where limited treatment is practiced due to the historical turbid nature and quality of the Orange River water. A similar event started during March 2003 (Conradie, Pers. Com. 2003) and persisted for up to five months.

2.3 Known extent of cyanobacterial problems in South Africa

According to the World Health Organisation (1999) information regarding cyanobacteria is essential for the following reasons:

- Understanding the human health impacts of individual cyanotoxins;
- Synthesis and dissemination of available information;
- The efficiency of cyanotoxin removal in drinking water treatment systems is limited, and
- Epidemiological studies regarding cyanobacterial exposure.

The study by Downing and van Ginkel (2003) aimed at addressing some of these shortcomings mentioned in the South African literature. The study found that little information is available on cyanobacterial toxin production in South Africa. Information that is available is the seasonal and temporal extent of cyanobacterial genera present in major South African dams. *Microcystis* is the dominant problem cyanobacterial genus locally (Van Ginkel, Silberbauer and Vermaak, 2000) as well as internationally (Namikoshi and Rinehart, 1996). Vasconcelos *et al.* (1996) has found that *Microcystis aeruginosa* is the dominant cyanobacterial species in toxic cyanobacterial blooms that occurred in Portugal. *Anabaena* occurs commonly (Downing and Van Ginkel, 2003). *Oscillatoria (Planktothorix)* and *Cylindrospermopsis* (Harding, 1997a; Van Ginkel and Conradie, 2001, Janse van Vuuren, 2001) have occurred in nuisance conditions in South Africa.

The two major problems associated in South Africa with cyanobacterial bloom events or increased cyanobacterial biomass to date, are animal and stock deaths (Harding and Paxton, 2001) and taste and odour problems in the purification for drinking water purposes (Van Ginkel & Conradie 2001; Downing and Van Ginkel 2003; Wnorowski 1992). No national trends in frequency of bloom events, toxin production or taste and odour problems could be established with the existing information (Downing and Van Ginkel, 2003). Wnorowski (1992) determined that only in four of the fifty-four dams studied taste and odours were associated with toxins and this was found in association with the dominance of *Microcystis*. All incidents in taste and odour production in the Wnorowski (1992) study were associated with cyanobacterial presence.

The study by Downing and Van Ginkel (2003) highlighted the need for

- National coverage on eutrophication and associated algal and cyanobacterial status;
- Increased monitoring for cyanobacterial toxin and geosmin/MIB
- Information on appropriate alert levels as only the major Water Boards analyse for the presence of phytoplankton populations and cyanobacterial toxins.
- Standardised sampling and analyses procedures.

The available information for the incidence of cyanobacteria in South African water resources showed that little information is available on informal water resources, farm dams or irrigation systems.

2.4 Factors leading to cyanobacterial dominance

The information in Harding and Paxton (2001) was based on data collected in the arid climate of South Africa and may differ from the understanding of similar factors in the north-temperate regions. It should be kept in mind that a suite of changing factors determines the outcome of the successional blooms within a phytoplankton population. It is only when a single parameter becomes limiting that it begins to exert control (Harding and Paxton, 2001).

2.4.1 Physical factors

A suite of physical factors, including temperature, water column stability and stratification, evaporation, turbidity, colour and lake morphology influence the development of cyanobacterial dominance within a water resource

Cyanobacterial dominance occurs at temperatures in excess of 20 °C (Harding and Paxton, 2001), however the different genera have a wide range of temperature tolerance.

Water column stability is affected by turbulence (wind-induced and/or large-scale recreational activities) flow, temperature or a combination thereof. Cyanobacteria are present in large numbers in stable water column conditions. Thermal stratification causes reversed nutrient stratification with nutrient layers in the deeper layers being unavailable to the phytoplankton. Turbulence is considered to reduce cyanobacterial development, however, Harding (1997b) found that regular mixing of the system results in higher productivity.

The process of evaporation alters nutrient and total dissolved salt concentrations, and thus the availability of the nutrients and the saline environmental characteristics of the system.

This may favour halo-tolerant cyanobacterial genera (e.g. *Nodularia*) to dominate the phytoplankton population. None of the major impoundments had dominance by *Nodularia* (Van Ginkel *et al.* 2001a).

Increased turbidity, as a consequence of run-off or phytoplankton growth, reduces the light availability below the surface. At low to moderate levels, ambient turbidity often favours cyanobacterial development

In the low pH and nutrient poor waters of the western and southern Cape the level of ambient watercolour reduces the ability of photo-synthetically active radiation. Yet these waters are known for their propensity to support sustained and problematic blooms of cyanobacteria.

According to Harding and Paxton (2001) the development of aggregations of cyanobacterial cells tends to be favoured by shallow, warm and sheltered conditions.

2.4.2 Chemical factors

Nutrients, pH, CO_2, salinity and dissolved oxygen are the main chemical factors that contribute to the development of dominant cyanobacterial blooms.

The relationship between the excessive enrichment of aquatic ecosystems with plant nutrients and the consequent positive algal growth is well known (WHO 1999, Lawrence *et al.* 2002). While certain genera of filamentous, nitrogen-fixing cyanobacteria can overcome low levels of nitrogen availability, phosphorus is accepted as being the essential growth-limiting nutrient. It must however be stressed that the simple non-limiting availability of phosphorus does not, in itself, provide this group of bacteria with the ability to become dominant. The suitable combinations of both nutrients, abiotic and biotic factors described above, have to prevail in order for the cyanobacteria to gain the selective advantage.

Much has been made of the N:P ratio in the development of cyanobacteria as dominant phytoplankton groups. This is, however not a controlling factor, but should be linked to nutrient availability and prediction of which element is likely to become limiting during the algal growth phase (Reynolds, 1992). It is most probably more a result of the dominance of the cyanobacteria, rather than a driving force for cyanobacterial dominance.

Internal recycling of nutrients plays a profound role in the availability, and therefore, management of the nutrient load in both deep and shallow systems. Conditions of high pH or a low CO_2 availability commonly favours cyanobacterial growth (Shapiro, 1990). On a daily basis the dense aggregations of cyanobacteria results in early morning minima in pH and dissolved oxygen with late afternoon maxima in both variables.

Cyanobacteria genera exhibit a wide range of tolerance to salinity. Manipulating the salinity of a water resource to levels unfavourable to the growth of problem cyanobacteria has been attempted (Harding and Paxton, 2001), however, this is not a feasible option in freshwater resources as it would lead to water quality problems of a different kind.

Shallow, well-mixed, warm, eutrophic water bodies commonly have sufficient dissolved oxygen available for primary production. When a cyanobacterial or algal bloom collapses all available oxygen is consumed and often lead to fish kills in a system. Assessments of fish kill investigations done by Resource Quality Services (Van Ginkel 1999) found that during the collapse of the cyanobacterial bloom pH increases and high temperatures usually prevails. Under these conditions most of the nitrogen present is in the ammonia form that is highly toxic to fish.

2.4 3 Biological factors

Biological factors include the trophic web interactions, ecosystem degradation and macrophytes.

Imbalances in the trophic web interactions and ecosystem degradation may lead to the dominance of cyanobacteria. Overgrazing of zooplankton by the fish population may lead to the development of dominant unwanted phytoplankton groups.

Eradication of riparian macrophytes will influence

- the stabilization of sediments by plant roots;
- uptake of nutrients through macrophytes;
- provision of refugia for zooplankton;
- Provision of habitat for juvenile fish, etc (Harding and Paxton, 2001).

All these factors will contribute to the dominance of cyanobacteria in a water resource.

2.4.4 Conclusions

Although all the prevailing factors during cyanobacterial blooms are known, little research has been done on the climatological impacts that may initiate blooms (Downing and Van Ginkel, 2003). Knowledge of cyanobacterial blooms and the prediction thereof are important factors for precautionary management of the problems associated with cyanobacteria (and must be established in time). A holistic approach is required in ecological studies to understand how ecosystems accommodate different levels of external and internal variability and their interactions. The integration of biological and meteorological research is needed to understand and estimate the consequences of climate variations on the ecosystem. There is, therefore, a need to determine e.g. the impact of rainfall events, and their duration and intensity, on the predictability of cyanobacterial blooms and toxin production in South Africa.

2.5 Toxicity of Cyanobacterial Blooms

The driving forces for toxin production is not yet fully understood. Both toxic and non-toxic strains of the various cyanobacterial species are known to exist (Quibell *et al.* 1995, Rae *et al.* 1999, WHO 1999). It is important to know whether all cyanobacterial blooms are associated with toxin production. This section therefore looked into available information into the potential for a cyanobacterial bloom to be toxic. According to WHO (1999) cyanobacterial blooms are not necessarily associated with human activities causing "cultural eutrophication". Massive blooms have been reported in Australian reservoirs and in Switzerland with its pristine to near-pristine catchments.

WHO (1995) produced a table showing percentage of bloom samples that showed toxicity to mice. Some of the studies used were done over many years while others were done in one season. The results showed frequencies of mass occurrences of toxic cyanobacteria in freshwaters between 22% and 95%. Vasconcelos *et al.* (1996) found that all the blooms studied in Portugal were hepatotoxic to mice. In all samples tested two to seven different toxins were found. The toxin found most commonly was microcystin-LR. There was however variability in toxin concentrations. Namikikoshi and Rinehart (1996) found that about 50% of *Microcystis* blooms to show hepatotoxicity to mammals and other animals.

There is large variability within strains of the same species. The combinations of extremely toxic strains and non-toxic strains cannot only be identified by microscope (WHO 1999). It is therefore essential to initiate Laboratory facilities that can conduct the necessary analysis to determine toxicity of cyanobacterial blooms in South Africa.

Chapter 3
SELECTION OF IMPOUNDMENTS

To determine the potential for the development of cyanobacterial blooms and production of toxins, on a national scale, a number of selection methods were chosen to select impoundments that will be included in the final report of the project.

3.1 Selection methods

3.1.1 Selection method one

The five impoundments monitored by Resource Quality Services (RQS), namely Hartbeespoort Dam, Roodeplaat Dam, Rietvlei Dam, Bon Accord Dam and Klipvoor Dam will be included for the determination of the incidence of cyanobacteria and cyanotoxin production. These impoundments have been selected because of the availability of historical data (Trophic Status Project (1985 – 2002) and the National Eutrophication Monitoring Programme (2002 – 2003)). And there would thus be no extra sampling costs involved .

3.1.2 Selection method two

An additional number of impoundments that had not prviously been monitored and for which no previous cyanobacterial information is available also needed to be included in the monitoring survey. It was decided to include impoundments in areas where local capacity as well as commitment exits, and where local personnel have been trained to collect samples for cyanobacterial blooms.

The land uses in the catchment within which the impoundment is situated will play a significant role in the development of toxic cyanobacterial blooms. The basis for the development of nuisance eutrophication conditions in impoundments is due to excess nutrients, and specifically phosphorus and nitrogen. Land uses that contribute to irreversible eutrophication, namely large urban developments (formal or informal areas) with their associated point and non-point sources and the agricultural sector are important activities that need to be considered in a selection process.

The following factors were decided on as part of Selection method two:

- The median ortho-phosphorus (PO_4-P) concentration for the period 1995 to 2000 in the impoundments under consideration was used to prioritise the impoundments from worst to best. The median was used as it gives a better perspective than the 95th percentile of the phosphorus concentration in an impoundment. It is internationally known that toxic cyanobacteria do not only occur in eutrophic systems, therefore for a national survey it is necessary to not only include the worst scenario cases. It is essential to include impoundments from the whole range of trophic status to determine the potential of cyanobacterial bloom and toxin production. The upper 30 impoundments with highest median PO_4-P concentrations, the middle 30 impoundments and the lower 30 impoundments were thus chosen to be included in the survey.

- The landuses included in the selection procedure are the five primary landuse activities, namely urban, industrial, intensive agricultural (irrigation and sugarcane), extensive agricultural (dry land and subsistence farming) and natural vegetation. The landuse data was abstracted from the database for quaternary catchments. The catchment of each impoundment was determined from any upstream impoundment/s up to the dam wall of the relevant impoundment.

Quibell *et al.* (1995) have prioritised the impoundments in South Africa according to the 95th percentile of the ortho-phosphorus (PO_4-P) concentration and the water use (with the highest priority factor the use of a water resource for domestic use, and secondly for recreational use). Quibell *et al.* (1995) also used the dominance and presence of potentially toxic cyanobacterial genera, as well as chlorophyll a concentrations. It is evident from Quibell *et al.* (1995)'s findings that little information is available on the latter variables. These can therefore, not be used in the selection of impoundments.

3.1.3 Selection method three

The third selection method will be based on impoundments where historical and present information, on the presence of cyanobacteria and the severity (chlorophyll *a*) of cyanobacterial presence, is available.

The study by Downing and Van Ginkel (2003), funded by the WRC, summarised the information for these impoundments. The report included mostly the data provided by the historical Trophic Status Project of the Department of Water Affairs and Forestry and to a lesser extent by some water boards. The Trophic Status Project impoundments were selected according to the sensitivity of catchments that were prone to eutrophication and mostly included drinking water resources.

This selection method will therefore include most of the raw water resources used for drinking water purposes.

3.1.4 Selection method four

The list of impoundments based on the above selection methods were then compiled and presented to the WQM directorate of the Department of Water Affairs and Forestry to confirm that all impoundments that may be of specific concern to them were included in the list. They were satisfied with the final list

3.2 Selected impoundments

The selected impoundments are shown in Figure 1. The impoundments are distributed throughout South Africa (Figure 1) and covers impoundments with a history of cyanobacterial problems as well as numerous impoundments that have no previous history of cyanobacterial blooms. The median PO_4-P concentrations and land-use activities are shown in Appendix A (Table 1).

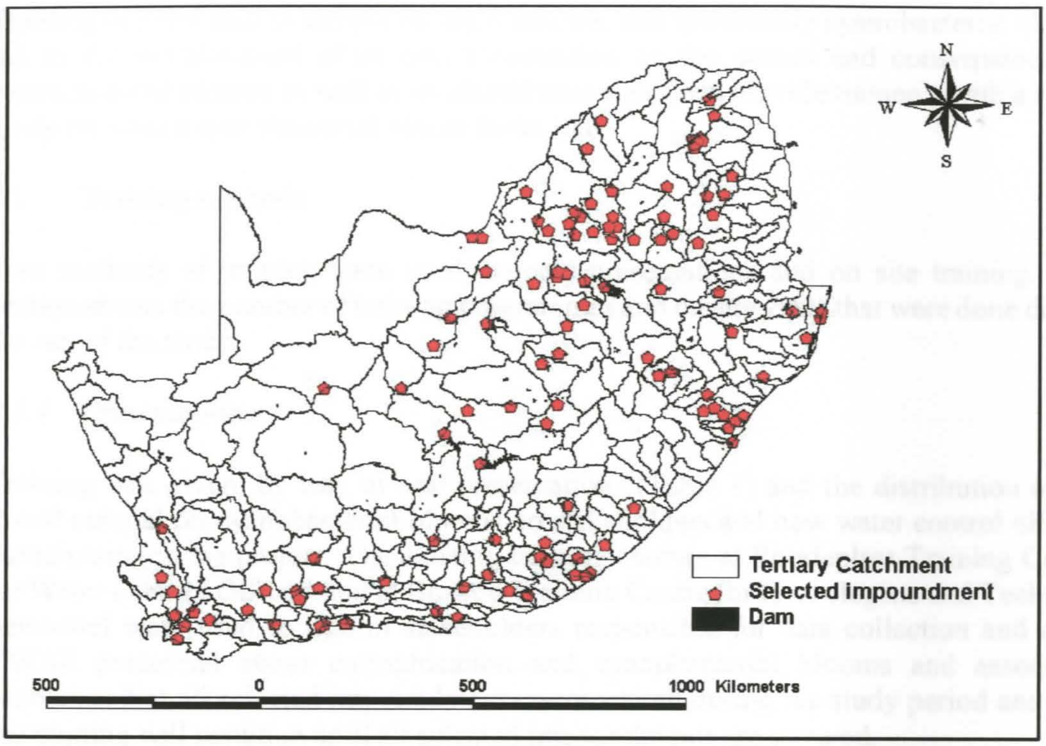

Figure 1. The impoundments selected for the National Cyanobacterial Survey.

Chapter 4
TRAINING OF SAMPLING PERSONNEL

Training of personnel to sample for algal blooms, and specifically cyanobacterial blooms led to the development of an oral presentation on the causes and consequences of cyanobacterial blooms as well as an identification guide to provide trainee's with a visual guide on what a cyanobacterial bloom looks like.

4.1 Training methods

Two methods of training were used, namely presentations and on site training. This section shows the number of training programmes and on site visits that were done during the run of the study.

4.1.1 Presentations

Training was given, by way of oral presentations (Table 1) and the distribution of the visual manual on cyanobacterial blooms, to stakeholders and new water control officers participating in the project. The existing training courses at Roodeplaat Training Centre for Water Control Officers and at Boskop Training Centre for Hydrologists and Technical personnel were used to inform stakeholders responsible for data collection and other DWAF personnel about eutrophication and cyanobacterial blooms and associated problems. Not all selected impoundments were visited during the study period and thus the training will continue until all selected impoundments are covered.

4.1.2 On-site personnel training

On site training usually start with an information session to give the sampler and staff involved in data collection the background on the problem of eutrophication and the symptomatic problems associated with it. Training was done at numerous (34) impoundments as part of the implementation of the National Eutrophication Monitoring Programme. The training included the identification and sampling of cyanobacterial blooms. Table 1 show the list of people that have been trained during the last three years.

Table 1 The people that were trained at impoundments for the NEMP and cyanobacterial monitoring

Site	Person trained	Date	Trainer
Koppies Dam	Jacob Erasmus	Aug 2001	C van Ginkel
Umtata Dam		Oct 2002	C van Ginkel & PP van Deventer
Nahoon Dam	Amatola Water	Oct 2002	C van Ginkel & PP van Deventer
Laing Dam	Amatola Water	Oct 2002	C van Ginkel & PP van Deventer
Wriglleswade Dam	Amatola Water	Oct 2002	C van Ginkel & PP van Deventer
Gubu Dam	Amatola Water	Oct 2002	C van Ginkel & PP van Deventer

Knellpoort Dam	Nico Olivier	Feb 2003	C van Ginkel
Welbedacht Dam	Nico Olivier	Feb 2003	C van Ginkel
Vondo Dam	NP Ngobeli	Oct 2002	L Musekene
Albasini Dam	NF Mulaudzi	Oct 2002	L Musekene
Doorndraai Dam	HD Mabada & KW Mosefowa	Oct 2002	L Musekene
Middle Letaba Dam	EH Shirinda	Oct 2002	L Musekene
Nsami Dam	E Nkuna	Oct 2002	L Musekene
Mutshedzi Dam	D Mavhunga	Oct 2002	L Musekene
Nwanedi/Lupepe	NE Tshikovhi	Oct 2002	L Musekene
Thsakhuma Dam	J Netshivhodza	Oct 2002	L Musekene
Hout Dam	TP Makgoka & LR Toubatla	Oct 2002	L Musekene
Glen Alpine Dam	HD Mabada & KW Mosefowa	Oct 2002	L Musekene
Nzhelele Dam	TP Makgoka & LR Toubatla	Oct 2002	L Musekene
Makolo Dam	VB Shengani & S Makuwa	Oct 2002	L Musekene
Nandoni Dam	R Ngoasheng	Oct 2002	L Musekene
Sereni Dam	M Maake	Oct 2002	L Musekene
Vishgat Dam	M Maake	Oct 2002	L Musekene
Cramer Dam	B Mahlangu & MJ Kadiaka	Oct 2002	L Musekene
Driekoppies Dam	Angel Gweru	Jun 2002 May 2003	C van Ginkel & N Rosouw (Ninham Shand)
Maguga Dam	Eric B Khoza	Jun 2002 May 2003	C van Ginkel & N Rosouw (Ninham Shand)
Boegoeberg Dam		Aug 2000	C van Ginkel
Neusberg Suid/Noord		Aug 2000	C van Ginkel
Vaalhartz Weir		Aug 2000	C van Ginkel
Spitskop Dam		Aug 2000 July 2003	C van Ginkel PP van Deventer
Taung Dam		Aug 2000	C van Ginkel
Vanderkloof Dam		Aug 2000 & Feb 2003	C van Ginkel
Allemaskraal Dam	Q Kemp	Feb 2003 & May 2003	C van Ginkel & PP van Deventer
Erfenis Dam	Neville Swarts	May 2003	PP van Deventer

4.2 Training material

4.2.1 Presentations

An oral presentation for training purposes were compiled and used by the trainers in the workshops and courses. The presentation gives a background on eutrophication and the symptomatic problems associated with eutrophication. Background is also given in visual format on the possible extent and associated problems with cyanobacterial blooms and the potential health risks for users associated with such blooms. A copy of the CD is available on request from DWAF: Resource Quality Services (Carin van Ginkel Tel: (012) 8080374).

4.2.2 Cyanobacterial bloom identification manual

The identification of a bloom when it has never before been encountered could be very difficult. It necessitated the development of a basic and visual manual to show samplers how to identify an algal bloom. As the monitoring of cyanobacterial blooms is an integral part of the NEMP, the WRC project for the development of the implementation plan for the NEMP, sponsored the reproduction of a large amount of these manuals. A copy of the manual is available on request from DWAF: Resource Quality Services (Carin van Ginkel Tel: (012) 8080374).

Chapter 5
DATA ACQUISITION

5.1 Trophic Status Project

The Trophic Status Project was initiated in 1985 after the promulgation of the 1mg/ℓ PO_4-P standard for wastewater effluents during 1980. The monitoring programme aimed at establishing the effect of the P-Standard on eutrophication. The monitoring programme was thus established in the catchments that were affected by this management intervention (Van Ginkel *et al.* 2001a).

5.2 The National Eutrophication Monitoring Programme

The implementation document for the National Eutrophication Monitoring Programme was completed in 2002 (Murray *et al.* 2002) and is available on the DWAF's website (http://www.dwaf.gov.za/IWQS/eutrophication/NEMP/default.htm). The implementation of the monitoring programme was started shortly thereafter. The historical Trophic Status Project data as well as the NEMP data collected to date have been included into this document. The data was extracted from the WMS database of the Department of Water Affairs and Forestry.

5.3 Water Management Institutions

Downing and Van Ginkel (2003) visited numerous water management institutions during the study to determine their knowledge about the extent of cyanobacterial problems in South African water resources and also to identify their information and resource needs. The conclusion of the study by Downing and Van Ginkel (2003) was that cyanobacterial blooms and the effects thereoff are widespread, frequent and typically seasonal.

Downing and Van Ginkel (2003) found that the major problems that were experienced by water mangement institutions due to cyanobacterial blooms were taste and odour complaints by users. However, very few of the institutions actually analyse for algal composition or cyanobacterial toxins due to the high costs of analysis. The need for a central subsidised laboratory was expressed by a number of the institutions.

5.4 Literature Review

The Rae *et al.* (1999), Van Ginkel *et al.* (2001a), Van Ginkel and Conradie (2001) Harding and Paxton (2002) and Downing and Van Ginkel (2003) studies provided data and information on cyanobacterial distribution and toxin production in South Africa. The data was used to define the known distribution of the different cyanobacterial species in South Africa. These studies concluded that *Microcystis* is the dominant cyanobacterial species in South African impoundments.

Cyanobacteria have been found to be also a problem for water treatment works abstracting water from rivers (Van Vuuren 2002, Van Ginkel and Conradie 2001).

5.5 Screening Survey for Toxic Cyanobacteria

During the year 2000 DWAF: Resource Quality Services (the then Institute for Water Quality Studies) did a once-off screening survey. Seventy-one sites were visited and algal identifications were done by inverted microscope. Cyanobacterial toxin determinations were done with the ELISA screening method for cyanobacterial toxins. The aim of this study was to determine a wider perspective on the national distribution of the different species in South Africa. This data are being presented in this report.

Chapter 6
DATA ASSESSMENT

6.1 Assessment of DWAF data

DWAF is in the process of replacing the historical Trophic Status Project with the NEMP. The data available on WMS (nutrients & algae) as well as data on algal identifications done at DWAF was assessed to determine the distribution and extent of cyanobacterial blooms in South African freshwater resources.

Table 2 shows the mean annual total phosphorous concentration, the annual chlorophyll *a* concentration, the percentage of time that Chl *a* exceeded 30 µg/ℓ and the percent of time that Cyanobacteria exceeded 30% dominance in the phytoplankton population. The first three variables were used to determine the trophic status of the impoundments. This information helps to assist in assessing the potential for plant (algal or macrophyte) growth in a water body. The forth variable in Table 2, namely the percent of time that cyanobacteria constitute more than 30 per cent of the phytoplankton population, gives an indication of the potential of toxin production in each dam.

Table 2 below: **LP** = Low potential for plant productivity, **MP** = Moderate potential for plant productivity, **SP** = Significant potential for plant productivity, **SER** = Serious potential for plant productivity, **LCN** = Low current nuisance algal blooms, **MCN** = Moderate current nuisance algal blooms, **SCN** = Significant current nuisance algal blooms and **SECN** = Serious current nuisance algal blooms. The data for the period October 2001 to September 2002 was used. * Indicate that the data was not sufficient to make a proper assessment; ♦ Show data from NEMP and Trophic Status Programme; ♦♦ Show data from Cyanobacterial survey

Dam Name	♦ Mean TP (mg/ℓ)	♦ Mean Annual Chlorophyll *a* (µg/ℓ)	♦ Per cent of time Chl *a* > 30 µg/ℓ	♦♦ Per cent of time Cyanobacteria > 30% dominant	Status of Dam
Albert Falls Dam	0.030 (15)	9.9 (24)	8	16	Oligotrophic,MP, LCN
Allemanskraal Dam	0.349 (2)	-	-	NA	SER*
Bloemhof Dam	0.090 (27)	12.7 (10)	10	65	Mesotrophic, SP, SCN
Boegoeberg Dam	0.064 (17)	5.6 (21)	0	14	Oligotrophic, SP, LCN
Bon Accord	0.229 (40)	174.0 (44)	84	5	Hypertrophic, SER, SECN
Boskop Dam	0.033 (43)	2.4 (9)	0	16	Oligotrophic, MP, LCN
Bospoort	0.789 (1)	-	-	86	SER*
Bridledrift Dam	0.193 (1)	1.25 (1)	-	NA	Oligotrophic, SER*
Bronkhorstspruit Dam	0.081 (34)	31.6 (14)	43	9	Hypertrophic, SP, SECN
Buffelspoort	0.015 (1)	4.4 (1)	-	0	Oligotrophic, LP *
Cook's Lake	0.302 (18)	25.1 (18)	39	20	Eutrophic, SER, SECN

Disaneng Dam	0.047 (48)	4.1 (21)	0	11	Oligotrophic, MP, LCN
Driekloof Dam	0.034 (3)	-	-	NA	MP*
Ebenezer Dam	0.012 (1)	-	-	0	LP *
EJ Smith Dam	0.018 (10)	17.7 (12)	17	54	Mesotrophic, MP, SCN*
Erfenis Dam	0.174 (16)	4.1 (28)	4	16	Oligotrophic, SER, MCN
Gariep Dam	0.057 (13)	1.7 (7)	0	0	Oligotrophic, SP, LCN
Grootdraai Dam	0.087 (60)	13.8 (26)	15	25	Mesotrophic, SP, SCN
Hartbeespoort Dam	0.145 (315)	47.1 (298)	51	48	Hypertrophic, SER, SECN
Henley Dam	0.004 (17)	4.4	0	0	Oligitrophic, LP, LCN
Inanda Dam	0.024 (11)	3.7 (27)	0	23	Oligotrophic, MP, LCN
Klipfontein Dam	0.164 (30)	191.5 (2)	-	43	Hypertrophic, SER*
Klipvoor	0.545 (46)	133.7 (41)	73	43	Hypertrophic, SER, SECN
Koppies Dam	0.091 (10)	6.3 (4)	0	33	Oligotrophic, SP, LCN
Kosterrivier Dam	0.045 (36)	3.0 (26)	0	14	Oligotrophic, MP, LCN
Laing Dam	0.214 (5)	1.9 (12)	0	50	Oligotrophic, SER, LCN
Lindleyspoort Dam	0.060 (47)	3.1 (29)	0	19	Oligotrophic, SP, LCN
Loskop Dam	0.036 (23)	4.2 (22)	0	25	Oligotrophic, MP, LCN
Lotlamoreng Weir	0.112 (32)	27.9 (17)	35	22	Eutrophic, SP, SCN
Magoebaskloof Dam	0.040 (14)	1.8 (11)	0	5	Oligotrophic, MP, LCN
Middelburg Dam	0.043 (28)	2.8 (37)	0	30	Oligotrophic, MP, LCN
Midmar Dam	0.066 (9)	3.0 (26)	0	31	Oligotrophic, SER, LCN
Misverstand Dam	0.221 (18)	11.4 (20)	5	8	Mesotrophic, SER, MCN
Nagle Dam	0.027 (21)	9.5 (24)	0	0	Oligotrophic, MP, LCN
Nahoon Dam	-	119.6 (2)	-	-	Hypertrophic*
Nungwane Dam	0.005 (17)	5.3 (27)	0	-	Oligotrophic, LP, LCN
Rietvlei	0.206 (39)	92.8 (42)	50	71	Hypertrophic, SER, SCN
Roodekopjes	0.204 (4)	9.04 (5)	20	-	Oligotrophic, SER, SCN*
Roodeplaat	0.263 (290)	26.5 (312)	54	59	Eutrophic, SER, SECN
Setumo Dam	0.099 (31)	13.9 (19)	0	20	Mesotrophic, SP, LCN
Shongweni Dam	0.059 (19)	24.7 (21)	36	67	Eutrophic, SP, SCN
Spitskop Dam	0.084 (26)	21.3 (9)	0	60	Eutrophic, SP, LCN
Sterkfontein Dam	0.030 (64)	2.2 (37)	0	5	Oligotrophic, MP, LCN
Tzaneen Dam	0.051 (25)	2.0 (12)	0	15	Oligotrophic, SP, LCN
Vaal Barrage Weir	0.075 (30)	6.9 (15)	0	-	Oligotrophic, SP, LCN
Vaal Dam	0.115 (53)	7.1 (14)	7	40	Oligotrophic, SP, MCN
Vaalkop	0.038 (16)	8.1 (12)	0	36	Oligotrophic, MP, LCN
Voelvlei Dam	0.060 (26)	3.7 (27)	5	43	Oligotrophic, SP, MCN
Witbank Dam	0.046 (26)	4.4 (28)	0	52	Oligotrophic, MP, LCN

The results show that 13.7% of the impoundments monitored are hypertrophic. Another 9.8% of the impoundments are eutrophic. Twenty-seven per cent of the impoundments monitored experienced significant to serious cyanobacterial blooms. Although the Trophic Status monitoring programme was designed for eutrophication-impacted areas in South Africa, it was decided during the implemetation of the Trophic Status and the NEMP to include impoundments of lesser Trophic Status in the monitoring programme. The above results show that eutrophication is a real problem in the country and that it needs to be addressed on a management level.

6.2 Screening Survey for Toxic Cyanobacteria

The survey was conducted during February to March 2000. The high summer season was chosen for the survey as it has shown to be the period that cyanobacteria, specifically *Microcystis*, are dominant in the South African water resources (Van Ginkel, Silberbauer and Vermaak 2000). Chlorophyll *a* concentrations above 20 µg/ℓ indicate that an impoundment may experience significant to serious algal blooms. The data collected from the seventy-one dams showed that 20% had indications of algal blooms (Figure 2).

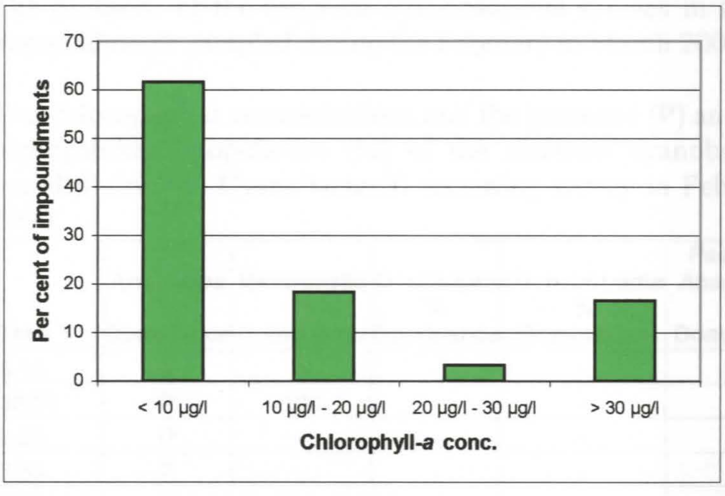

Figure 2. Percent of impoundments sampled during the cyanobacterial screening survey in 2000 that had chlorophyll *a* concentrations within the four different trophic status categories for chlorophyll *a*.

The presence and dominance of cyanobacterial species were investigated. The results show that *Microcystis* and *Anabaena* is present in an equal number of impoundments (Figure 3). *Oscillatoria* is the third most common species, while *Merismopedia* (a non toxin producer) is forth on the list. Other species that where found to be present in a number of impoundments are *Spirulina, Pseudoanabaena* and *Cylindrospermopsis*.

Microcystis was found to be present in 8 cases in extremely high chlorophyll *a* conditions, while the other species present in high chlorophyll *a* conditions was *Oscillatoria* and *Cylindrospermopsis* in only 1 case respectively (Table 3). This confirms the findings to date that *Microcystis* is the dominant bloom forming cyanobacterial species in South Africa (Wnorowski 1992, Harding and Paxton 2002, Downing and Van Ginkel 2003).

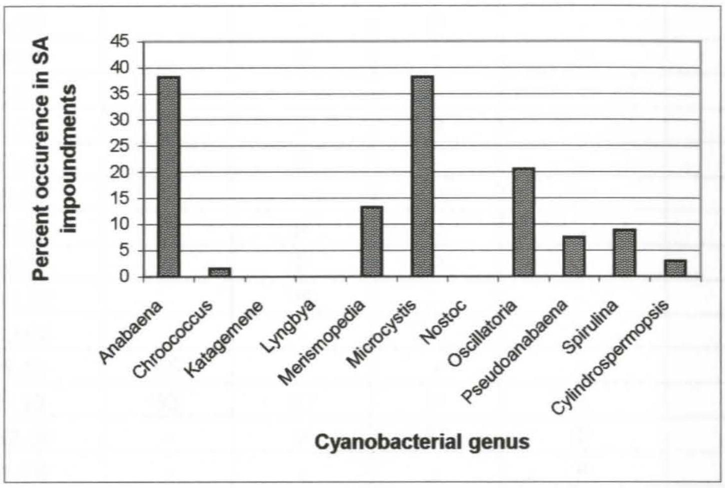

Figure 3. The presence of the different cyanobacterial species in the seventy-one impoundments sampled during the February to March 2000 survey.

Table 3. The chlorophyll *a* concentrations and the presence (P) and dominance in phytoplankton population (%) of the different cyanobacterial species found during the Cyanobacterial screening survey in February to March 2000.

Dam	Chl *a*	*Anabaena* % Dominance	*Microcystis* % Dominance	*Oscillatoria* % Dominance	*Merismopedia* % Dominance	*Pseudo-Anabaena* % Dominance	*Spirulina* % Dominance	*Cylindrospermopsis* % Dominance
Albert Falls	8.45	56	P	-	-	-	-	-
Allemanskraal	430.63	P	100	-	-	-	-	-
Belfast	6.26	P	-	-	-	-	-	-
Bloemhof	5.66	P	-	-	-	-	-	-
Boegoeberg	27.3	P	15	22	-	-	-	58
Bon Accord	52.84	18	P	-	-	-	P	-
Boskop	7.83	-	P	-	P	-	-	-
Buffelskloof	3.63	-	-	P	-	-	-	-
Donaldson	2.57	-	-	P	-	-	-	-
Douglas Weir	18.79	-	-	P	-	-	-	-
Groot Marico	15.4	-	P	-	-	-	-	-
Erfenis	5.2	P	-	-	-	-	-	-
Grootdraai	1.39	70	P	-	-	P	-	-
Hartbeespoort	231.96	P	100	P	-	-	-	-
Klein Maricopoort	23.05	-	52	-	-	-	P	-
Klipdrif	253.73	P	100	-	-	P	-	-
Klipvoor	19.76	P	-	-	P	-	-	-
Koppies	330.33	P	93	-	-	-	-	-

Kosterrivier	10.87	-	P	-	-	-	-	-
Kromellenboog	2.81	P	-	-	-	-	-	-
Laing	1510.8	P	100	-	-	P	-	-
Leeukraal	18.98	P	-	-	-	-	-	-
Loskop	6.08	-	P	P	-	-	-	-
Middelburg	8.97	-	-	P	-	-	-	-
Midmar	5.09	-	P	-	P	-	-	-
Molatedi	5.57	P	-	-	-	-	-	-
Nagle	5.24	P	-	P	-	-	P	-
Piet Gouws	9.49	P	P	-	-	-	-	-
Rhenosterkop	6.55	-	-	P	20	-	-	-
Rietvlei	42.9	-	P	-	-	-	-	-
Roodekopjes	15.06	P	P	P	-	-	-	-
Roodeplaat	98.72	-	78	-	-	P	P	-
Rust de Winter	13.68	-	-	-	P	-	-	-
Shongweni	6.46	55	-	-	-	-	-	-
Spioenkop	5.18	33	67	P	-	-	-	-
Spitskop	52.86	-	P	37	P	-	P	63
Sterkfontein	1.33	-	-	-	P	-	-	-
Twee Rivieren	6358	P	100	-	-	-	P	-
Vaal	152.69	P	100	-	-	-	-	-
Vaalhartz Weir	10.68	P	-	P	-	-	-	-
Vlugkraal	1.49	-	-	P	P	-	-	-
Wentzel	13.12	P	P	-	-	-	-	-
Witbank	15.69	10	25	-	-	P	-	-
Woodstock	3.56	-	-	-	P	-	-	-
Total No. of dams associated with cyanobacterial blooms (Chl a > 20 ug/L)		0	8	1	0	0	0	1

6.3 Discussion

Van Ginkel, Silberbauer and Vermaak (2000) compiled an assessment on the known seasonal and spatial distribution of cyanobacteria in South African surface waters. The study highlighted the fact that cyanobacteria are present in all water sources, but that the trophic status of an impoundment determines the dominance of the cyanobacteria during summer periods as well as the extent of cyanobacterial blooms that occur. However, the degree of cyanobacterial blooms can't be determined by the trophic status, as Hartbeespoort Dam, known to be the most serious case of cyanobacterial blooms, did not come up as the most serious eutrophication case determined by a prioritisation process done on South African dams (Van Ginkel *et al.* 2001a)

Downing and Van Ginkel (2003) also compiled the temporal distribution of cyanobacteria throughout the major dams of South Africa. The data indicated variability as to the spatial and temporal distribution of cyanobacteria. It is known that cyanobacteria are a seasonal phenomenon. The climatic conditions of South Africa and their effect on the occurrence of serious and toxic cyanobacterial blooms have not yet been established.

With the increasing number of water sources that are being included in the National Eutrophication Monitoring Programme (NEMP), an increasing number of cyanobacterial species are being found. During 2000 the first major cyanobacterial outbreak in the Orange River downstream of the confluence of the Vaal and the Orange River caused an uproar in the sparsely populated area (Van Ginkel & Conradie 2001). The findings of a study during this event indicated that the problem species originated in the Spitskop Dam. During high flows the cyanobacterial species were transported downstream causing problems for all the treatment works that was designed to handle high turbidity in the supply waters and not cyanobacterial or algal blooms. Since March 2003 to the present the Orange River has again shown a major *Oscillatoria* and *Cylindrospermopsis* bloom (Conradie Pers. Comm. 2003). The Orange River incident has resulted in the initiation of an eutrophication-monitoring programme in the Orange River itself, as well as in dams on the river.

It is expected that as phytoplankton composition monitoring increase in South Africa the presence of different species, not previously found, may become apparent. The monitoring of cyanobacterial species is thus essential to determine their effect on domestic, recreational and agricultural uses. Cyanobacteria pose a health risk to domestic and recreational users. In the agricultural field the specifications from overseas markets are also becoming stricter and in future water quality analyses may become a standard requirement if export fruits are to be accepted by the overseas market.

Chapter 7
CYANOBACTERIAL TOXIN PRODUCTION IN SELECTED IMPOUNDMENTS

7.1 Methods

7.1.1 *Site selection*

The five impoundments regularly monitored by Resource Quality Services were chosen as the regular sampling sites for assessment of cyanobacterial toxin production. These five impoundments are the Bon Accord, Hartbeespoort, Klipvoor, Rietvlei and Roodeplaat Dams.

When a cyanobacterial bloom was seen during the regular sampling of the impoundment a single sample was taken close to the dam wall, to determine the phytoplankton composition. As an impoundment was considered to be a single site the edges of the impoundment was scanned for algal accumulations or scums to select the cyanobacterial toxin-sampling site.

7.1.2 *Sampling frequency*

The five impoundments were sampled every two weeks during the study period. If a bloom was evident, then algal accumulations or scums around the edges of the impoundment had to be found for sampling purposes.

7.1.3 *Sample type*

A 1 liter grab sample was taken close to the cyanobacterial scum accumulation to include live cyanobacteria.

7.1.4 *Analysis methods*

An Elisa quick screening analysis was done on each sample to determine the presence or absence of the combination of cyanobacterial toxins, namely Microcystin-LR, -LA, -RR, -YR and nodularin.

Thereafter the HPLC method was used to confirm the specific toxin type.

7.1.5 *Variables in Cyanobacterial scum sample*

The presence of the combination of Microcystin-LA, -LR, -RR, -YR & nodularin were tested for, without quantification or specification of the toxins. The presence or absence of a toxin is thus only shown as 1 or 0 respectively in the results.

7.2 Results and discussion

The results of the cyanobacteria present in the five selected impoundments are discussed separately and in alphabetical order below.

7.2.1 *Temporal toxin production*

It is important to note that when looking for the cyanobacterial toxins in an impoundment, the impoundment should be seen as one single site. The patchiness of the presence of the cyanobacterial bloom and the toxins during the bloom situation, as well as the effects of climatic and wind conditions prior to sampling, dictates the sampling site during a sampling trip. The presence of cyanobacterial toxins will therefore, only be reported as per impoundment – although it might have been found in a small area of the impoundment and quite often not the same site. This sampling method may also lead to not finding toxins although the possibility did exist that there may have been toxic areas in the dam if the correct site could be found.

Bon Accord Dam

During the study period the Bon Accord Dam experienced extreme algal blooms as can be seen in Figure 4 with chlorophyll *a* concentrations exceeding 1000µg/ℓ during January to April 2002. The Bon Accord Dam has a mean chlorophyll *a* concentration of 248.6µg/ℓ (Table 4). The impoundment is hypertrophic with long periods of algal blooms, however very short periods of dominance by *Microcystis* and *Anabaena* prevailed in the impoundment. It would, therefore, not be expected that toxins would have been found.

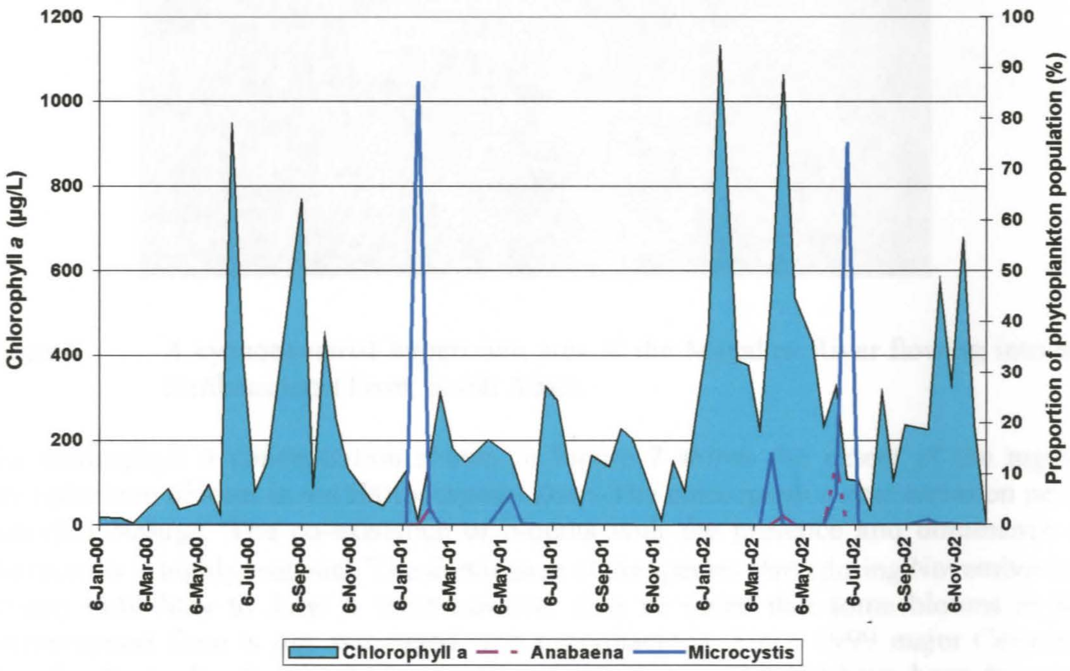

Figure 4 The temporal concentration of Chlorophyll *a*,and proportion of *Microcystis* and *Anabaena* in the Bon Accord Dam during the period 1999 to 2002.

No cyanobacterial toxins were found in the Bon Accord Dam during the period 2000 to 2002 associated with the occasional dominance of *Microcystis*. This is most probably because of the short periods of *Microcystis* being dominant in the dam as can be seen in Figure 4. *Anabaena* was present for very short periods during the study and was never dominant.

Hartbeespoort Dam

Although the Hartbeespoort Dam was identified in a study done in South Africa to be only sixth on the eutrophication list after prioritisation (Van Ginkel *et al.* 2001a), it is nationally and internationally known to experience the worst cyanobacterial blooms known. The impoundment has shown during the last three years (since 2001) extremely noxious cyanobacterial blooms (Figure 5 and 6).

Figure 5 A cyanobacterial hyperscum area in the Magalies River flowing into the Hartbeespoort Dam, South Africa

The chlorophyll *a* concentration shown in Figure 7 shows the extent of the regular phytoplankton blooms in the Hartbeespoort Dam. The chlorophyll *a* concentration never exceeded 500µg/ℓ. The co-existence of blooms with the presence and dominance of *Microcystis* is highly seasonal. The dominance of the species starts during November and persists until May to July. It must however also be noted that some blooms in the Hartbeespoort Dam is not associated with cyanobacteria. Since 1999 major *Ceratium hirundinella* (a dinoflagelate) blooms (Van Ginkel *et al.*, 2001b) have been found to occur in the Hartbeespoort Dam.

Cyanobacterial toxins have been found during the incidents of specifically *Microcystis* dominance in the phytoplankton population (Figure 8). Different cyanobacterial toxins, namely microcystin-LR, microcystin-LA, microcystin-YR, microcystin-RR and other unidentified toxins, were found. Microcystin-LA was the toxin found to occur most commonly during the study period.

Figure 6 A cyanobacterial hyperscum area showing the warning sign that was put up by a landowner at the Magalies River flowing into the Hartbeespoort Dam, South Africa.

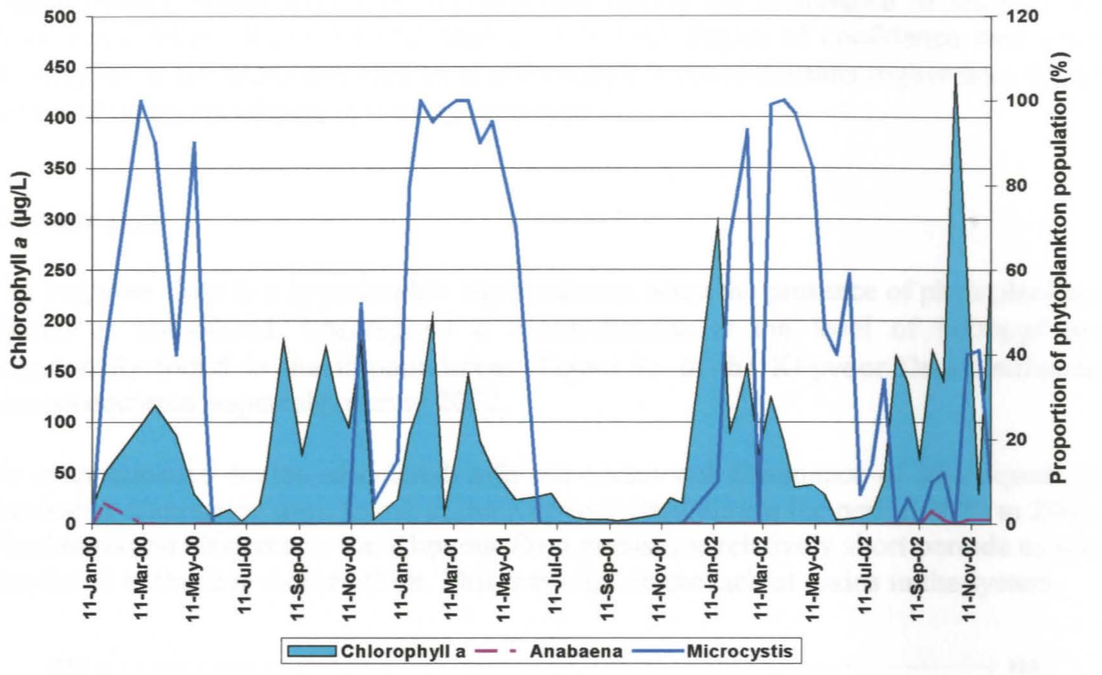

Figure 7 The temporal concentrations of Chlorophyll *a*, and proportion of *Anabaena* and *Microcystis* in the Hartbeespoort Dam during the period 2000 to 2002.

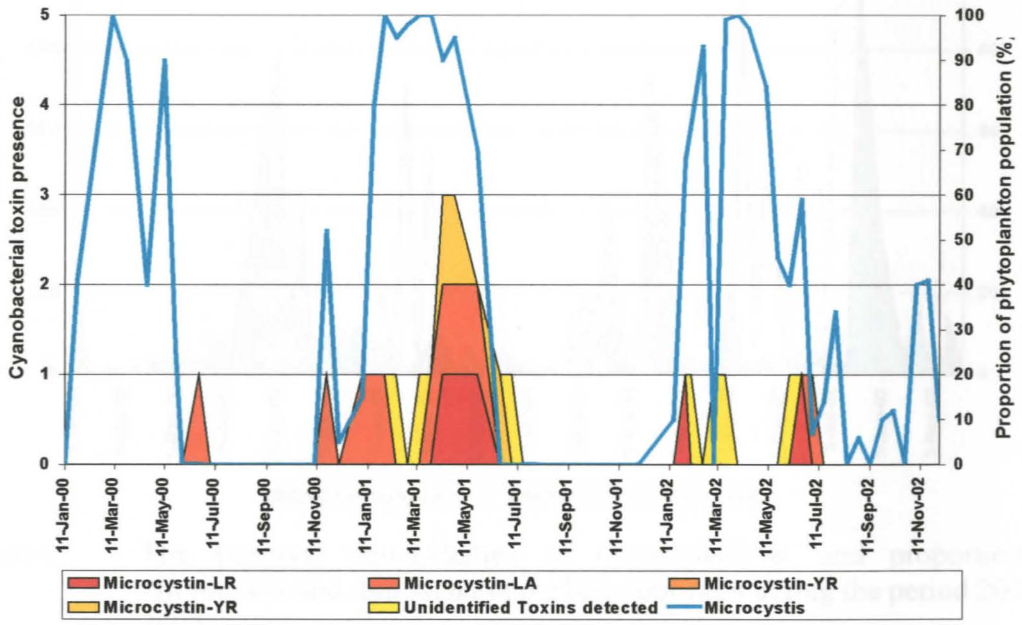

Figure 8 The temporal proportion of *Microcystis* and the presence of different cyanobacterial toxins in the Hartbeespoort Dam during the period 2000 to 2002

The sampling protocol for sampling cyanobacterial toxins is still in the development stage. The lack of proper sampling methods and protocols may be the reason for not always finding toxins within an impoundment during the dominance of *Microcystis*. From these results it can be said with a fairly high degree of confidence that when *Microcystis* is the dominant species at chlorophyll *a* concentrations higher than 30μg/ℓ there will be toxins present in the impoundment.

Klipvoor Dam

The Klipvoor Dam is a hypertrophic impoundment when the presence of phytoplankton blooms is considered. Chlorophyll *a* concentrations at the level of 1000μg/ℓ are occasionally found in the impoundment (Figure 9). In the Klipvoor Dam *Anabaena* blooms occurred, especially during 2002.

No cyanobacterial toxins associated with the occasional dominance of *Microcystis* or *Anabaena* dominance were found in the Klipvoor Dam during the period 2000 to 2002. The *Microcystis* blooms in the Klipvoor Dam persist for relatively short periods as was also found in the Bon Accord Dam. This may explain the lack of toxins in the system.

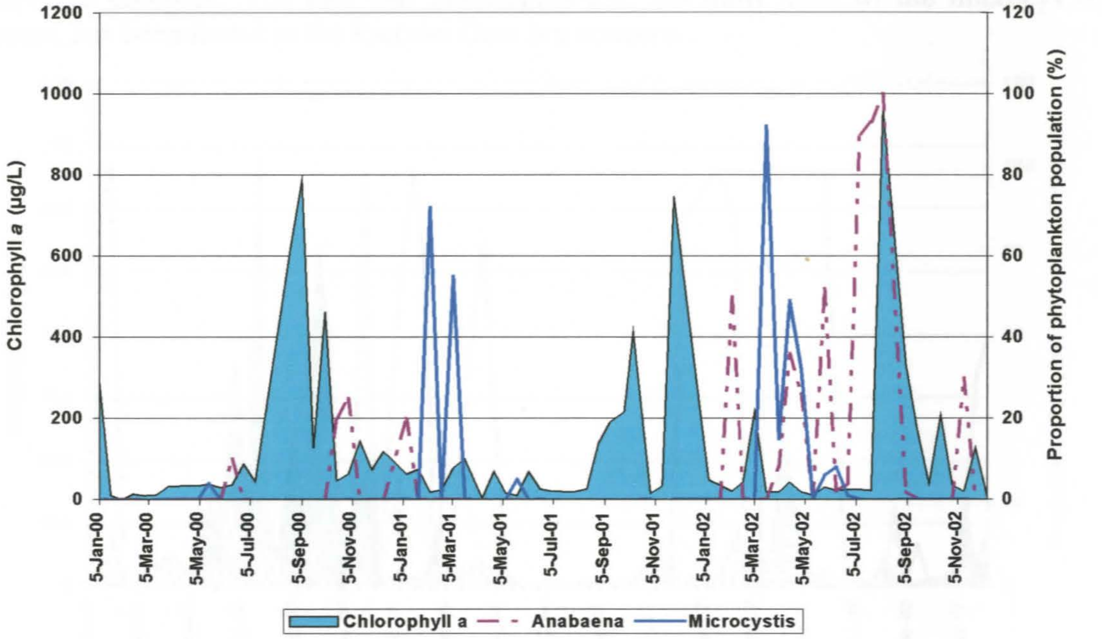

Figure 9 The temporal concentration of Chlorophyll *a*, and proportion of *Microcystis* and *Anabaena* in the Klipvoor Dam during the period 2000 to 2002.

Rietvlei Dam

Rietvlei Dam was identified in the study by Van Ginkel *et al.* (2001a) as the most eutrophied impoundment of all the impoundments monitored in South Africa. However, it does not have the same excessive cyanobacterial scum forming blooms as experienced in Hartbeespoort Dam. Chlorophyll *a* concentrations exceeded 650µg/ℓ during July 2000. The chlorophyll *a* concentration during 2000 was much higher when compared to the following year. However, the periods of extremely high concentrations of chlorophyll *a* did not correspond with the dominance by *Microcystis* (Figure 10). The mean annual chlorophyll *a* concentration for Rietvlei is 77.3µg/ℓ. This is in the same order as for Hartbeespoort Dam, but scum forming in the Rietvlei dam is not comparable to situations in the Hartbeepoort Dam.

Anabaena was found to contribute significantly on two occasions (January 2001 and April 2001) to the phytoplankton population in the Rievlei Dam. In the Rietvlei Dam algal blooms are not regularly dominated by cyanobacterial species.

Cyanobacterial toxin (Microcystin-LR) was only found on one occasion in the Rievlei Dam during March 2000 (figure 11). It cannot be said at this stage that high chlorophyll a concentrations associated with *Microcystis* in Rietvlei Dam is prone to cyanobacterial toxin production. It must be noted that Rievlei Dam is situated in the colder highveld area of Gauteng in contrast to the other impoundments that is situated in the much warmer bushveld complex. The fact that microcystin-LR, the most toxic of the microcystin toxins, has been found in the Rietvlei Dam is a concern.

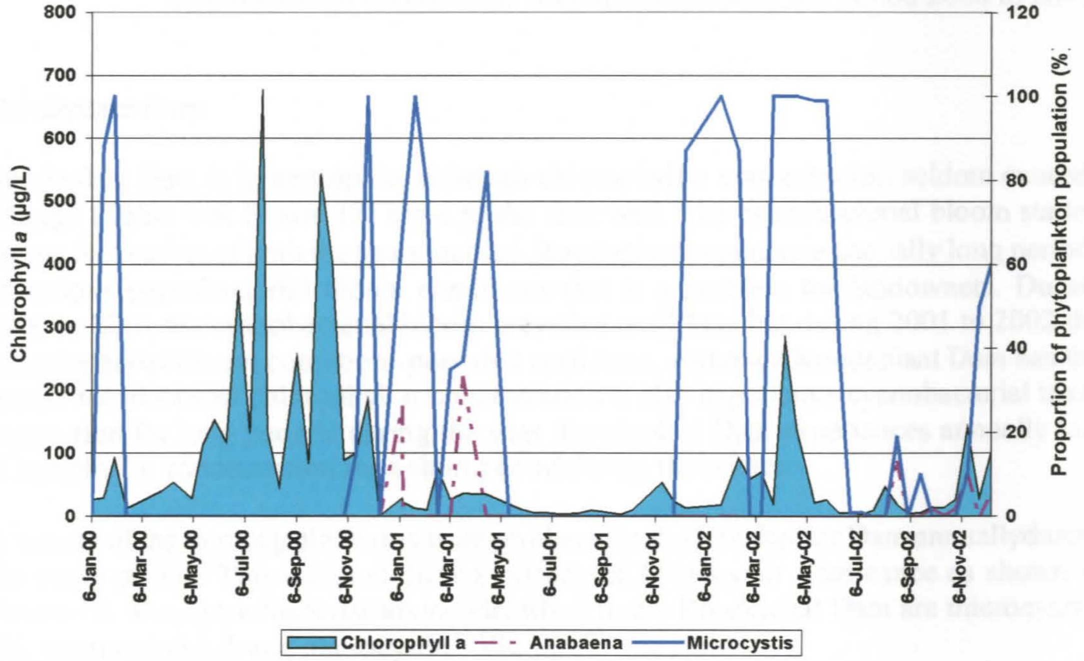

Figure 10 The temporal concentration of Chlorophyll *a*, and proportion of *Microcystis* and *Anabaena* in the Rietvlei Dam during the period 1999 to 2002.

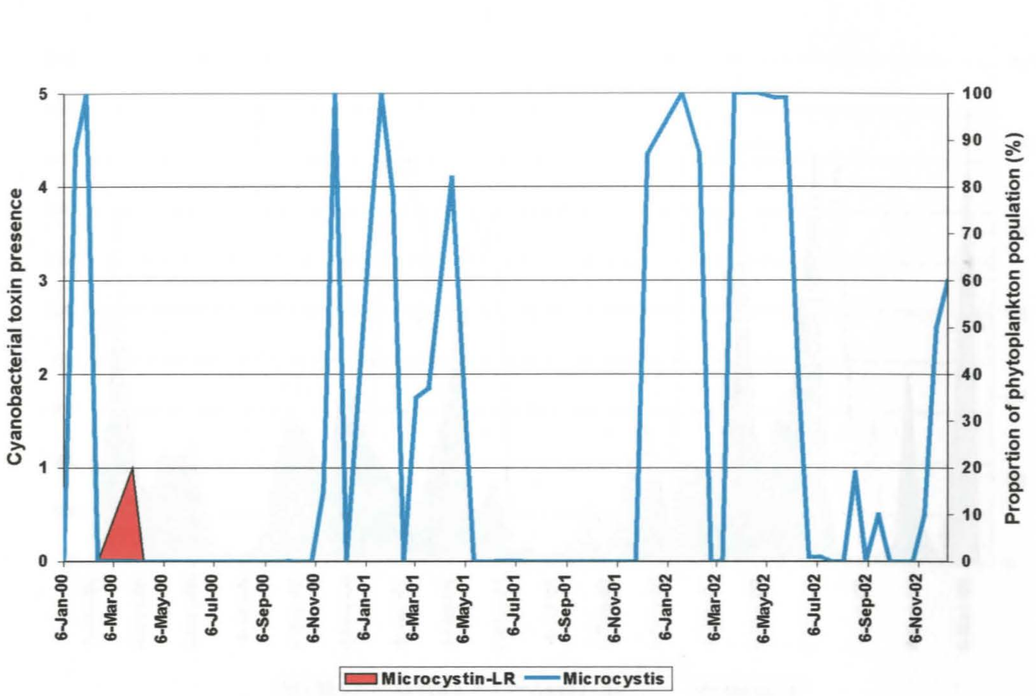

Figure 11 The temporal proportion of *Microcystis* and the presence of different cyanobacterial toxins in the Rietvlei Dam during the period 2000 to 2002

Roodeplaat Dam

Roodeplaat Dam is hypertrophic, although chlorophyll *a* concentration seldom exceeds 180µg/ℓ (Table 4 & Figure 12) close to the dam wall. The cyanobacterial bloom started during November of both the years studied. Roodeplaat experience annually long periods of serious cyanobacterial bloom conditions that is a problem for landowners. During 2000 to 2001 the cyanobacterial bloom prevailed until May but during 2001 to 2002 the cyanobacterial bloom conditions persisted until June. Although Roodeplaat Dam has the lowest mean annual chlorophyll *a* concentration it also experience cyanobacterial toxin production for long periods during the year. Roodeplaat Dam experiences annually low chlorophyll *a* concentration for a short period during the winter.

A variety of the microcystin toxins were produced in the Roodeplaar Dam annuallyduring the study period. This occured during periods of *Microcystis* dominance as shown in Figure 13. The cyanobacterial toxins identified in the Roodeplaat Dam are microcystin-LR, microcystin-LA and microcystin –YR.

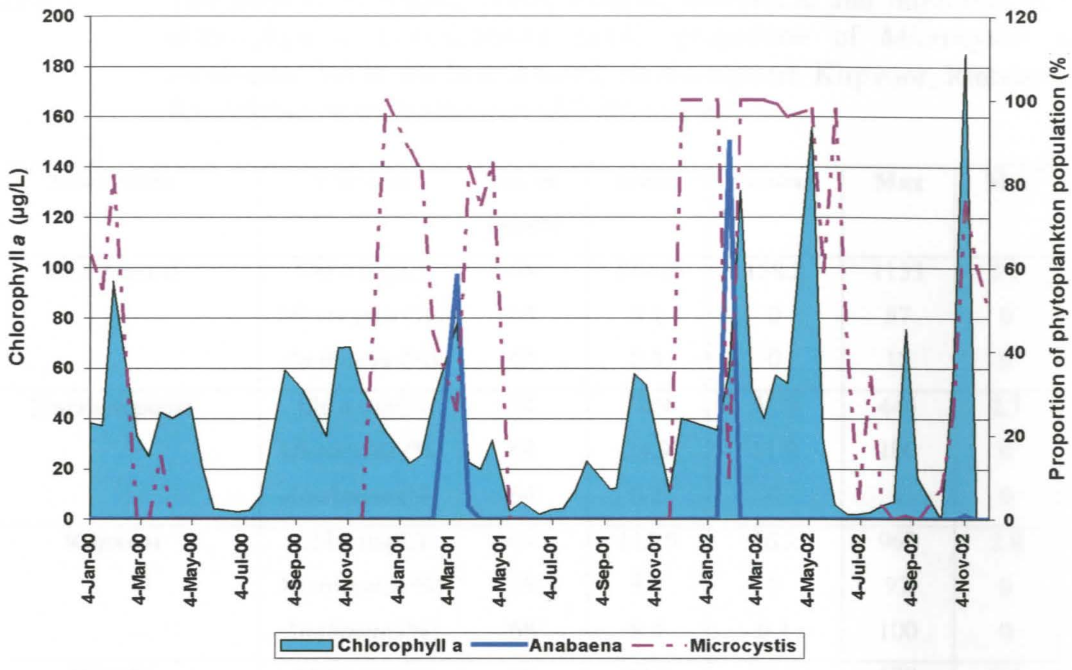

Figure 12 The temporal concentration of Chlorophyll *a*, and proportion of *Microcystis* and *Anabaena* in the Roodeplaat Dam during the period 1999 to 2002.

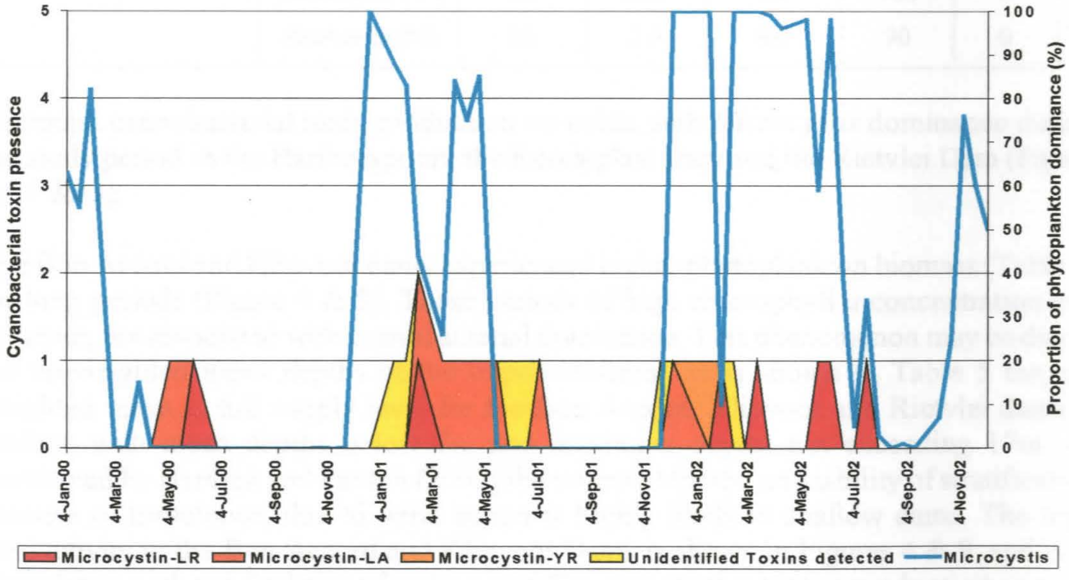

Figure 13 The temporal proportion of *Microcystis* and the presence of different cyanobacterial toxins in the Roodeplaat Dam during the period 2000 to 2002

Table 4. The number of results, mean, median, maximum, and minimum of the chlorophyll *a* concentration (µg/ℓ), proportion of *Microcystis* and *Anabaena* (%) in the Bon Accord, Hartbeespoort, Klipvoor, Rietvlei and Roodeplaat dams for the period 2000 to 2002.

Dam Name	Variable	No. of results	Mean	Median	Max	Min
Bon Accord	Chl *a* (ug/L)	64	244.6	158.2	1133	3.7
	Microcystis (%)	63	3.1	0	87	0
	Anabaena (%)	63	0.3	0	12	0
Hartbeespoort	Chl *a* (ug/L)	64	78.9	51.7	444	2.7
	Microcystis (%)	64	34.9	11.0	100	0
	Anabaena (%)	64	0.2	0	5	0
Klipvoor	Chl *a* (ug/L)	69	115.9	36.2	967	2.8
	Microcystis (%)	68	5.0	0	92	0
	Anabaena (%)	68	8.4	0.1	100	0
Rietvlei	Chl *a* (ug/L)	68	77.3	27.5	678	0.4
	Microcystis (%)	68	25.5	0.1	100	0
	Anabaena (%)	68	1.4	0	33	0
Roodeplaat	Chl *a* (ug/L)	60	37.6	32.4	185	2.1
	Microcystis (%)	63	32.7	3.0	100	0
	Anabaena (%)	63	2.4	0.0	90	0

Temporal cyanobacterial toxin production co-exists with *Microcystis* dominance during the study period in the Hartbeespoort, the Roodeplaat Dam and the Rietvlei Dam (Figure 8, 11 &13).

The Bon Accord and Klipvoor dams experienced higher phytoplankton biomass (Table 4) for long periods (Figure 4 & 9). These periods of high chlorophyll *a* concentration are, however, not associated with cyanobacterial dominance. This phenomenon may be due to the un-weighted mean depths of the impoundments. As is shown in Table 5 the un-weighted mean at full supply level for the Bon Accord, Klipvoor and Rietvlei dams is shallow with mean depths below 7m and maximum depths not exceeding 17m. As mentioned by Harding and Paxton (2002) the potential for the un-stability of stratification because of turbulence, due to wind action is highly likely in shallow dams. The high productivity in the Bon Accord and Klipvoor Dams is shown in Figures 4 & 9, and is in accordance with the finding of Harding (1997b), namely that higher productivity occurs in shallow turbulent conditions. It does not show long periods of dominance by cyanobacteria and therefore no toxicity either.

Table 5 The un-weighted mean and maximum gauge plate reading at full supply level of the Bon Accord, Hartbeespoort, Klipvoor, Rietvlei and Roodeplaat dams (Department of Water Affairs 1986).

Dam Name	**Bon Accord**	**Hartbeespoort**	**Klipvoor**	**Rietvlei**	**Roodeplaat**
Unweighted mean depth (m)	2.5	9.5	5.8	6.5	10.8
Maximum gaugeplate reading at dam wall	7.28	20.12	16.16	11.94	28.31

7.2.2 *Seasonality of toxin production*

The results show that cyanobacterial toxin production is highly seasonal (during spring to summer) in the Hartbeespoort, and Roodeplaat dams and to a lesser extent in the Rietvlei Dam. Rae *et al.* (1999) also found toxins during their sampling surveys (1995 – 1996) in the KwaZulu Natal Province in November, January, February and March. The screening survey for cyanobacteria was also done during the high summer season and showed that 20 percent of the samples taken were toxic.

These results show that with the presence of potentially toxic cyanobacteria (*Mirocystis*) the development of cyanotoxins is highly likely. There is still research needed in determining the set of driving forces behind the development of toxic cyanobacterial blooms.

7.2.3 *Cyanobacterial species responsible for known toxin production*

In the five dams studied no other toxins other than microcystins were found. It is, however not certain whether other toxins are present or not. It may be the unavailability of toxin standards that are essential to indentify the presence of the other toxins, e.g. anatoxin, anatoxin-a, etc (WHO, 1999) that led to this phenomenon.

The screening survey for cyanobacteria found that *Microcystis* is the dominant cyanobacterial specie in 83 percent of the cases that were toxic. *Anabaena* and *Oscillatoria* were the dominant species respectively in 8 percent of the toxic cyanobacterial incidents. Rae *et al.* (1999) found in their study that *Microcystis* is the dominant species when toxins are present in the raw water.

Microcystis was therefore identified as the dominant species when cyanobacterial toxins were found in the impoundments. However, the other cyanobacterial species that were found may also pose a health hazard to users of water sources. The lack of capability to determine the presence and concentrations of other cyanotoxins may skew the outcome of any aditional study undertaken.

7.2.4 *Conclusions*

- Sampling procedures need to be designed and standardized for South Africa to ensure comparable results.

- *Microcystis* may be used as an indicator of toxicity for hyper-trophic impoundments in South Africa due its dominance during blooms, although it may not be conclusive.

- Toxin production associated with the presence of *Microcystis* seems to be highly seasonal in especially the Hartbeespoort and Roodeplaat dams.

- Succession/presence of different microcystins need further investigation with special focus on the monitoring of the fresh water resources. The Bon Accord and Klipvoor dams experienced extremely high primary production during the study period without the presence of serious cyanobacterial scum forming blooms. This phenomenon needs further investigation to clarify the driving forces behind the cyanobacterial blooms and cyanotoxin production for prediction purposes.

Chapter 8
KNOWN DISTRIBUTION OF CYANOBACTERIA IN SOUTH AFRICA

8.1 Known Distribution of Cyanobacterial Species in South Africa

All the studies and known literature to date in South Africa was used to compile maps showing the distribution of different algal species in South Africa. *Anabaena* (Fig 14) and *Microcystis* (Fig 17) are most widely distributed. Of these two species *Microcystis* is the species that occurred more and was more associated with toxin production. The toxin-associated cyanobacteria are *Anabaena* (Fig 14), *Cylindrospermopsis* (fig 15), *Microcystis* (Fig 17), *Oscillatoria* (Fig 18) and *Lyngbya* (Fig 22). Other cyanobacterial species that were found at many sites are *Merismopedia* (Fig 16), *Pseudoanabaena* (Fig 19), *Chroococcus* (Fig 20) and *Spirulina* (Fig 21).

From these results it is shown that cyanobacteria are widely distributed in South Africa and blooms occur throughout South Africa. *Cylindrospermopsis* was for the first time found under bloom conditions in South Africa during the major cyanobacterial bloom event in the Orange River, the largest river in South Africa (Van Ginkel & Conradie 2001).

Figure 14 The known distribution of *Anabaena* spp. in South Africa.

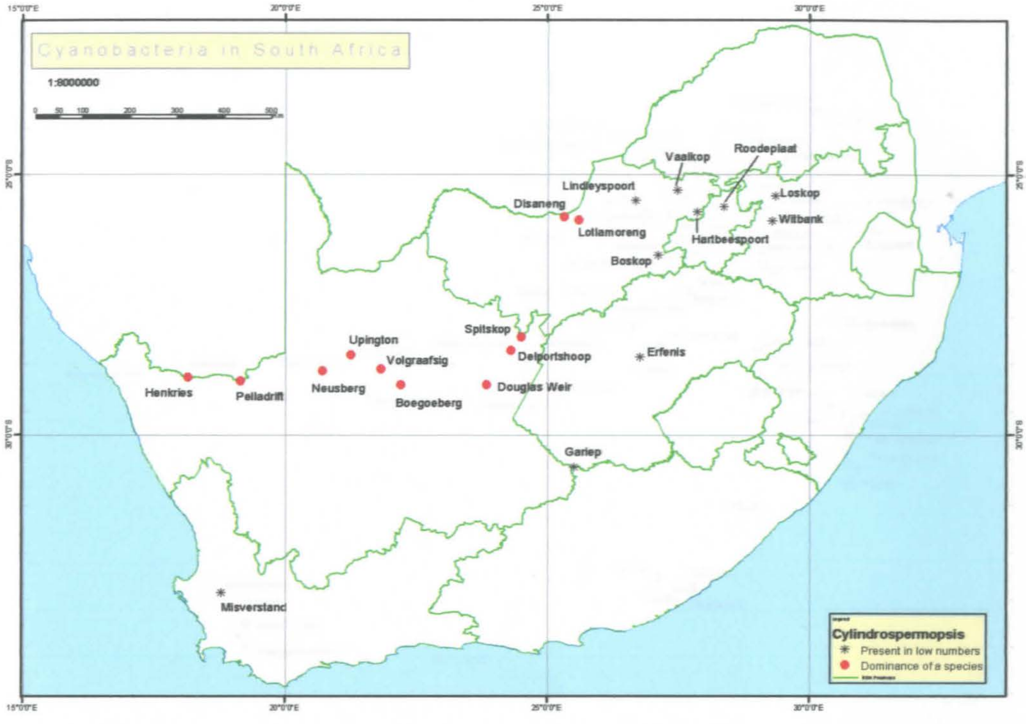

Figure 15 The known distribution of *Cylindrospermopsis* spp. in South Africa.

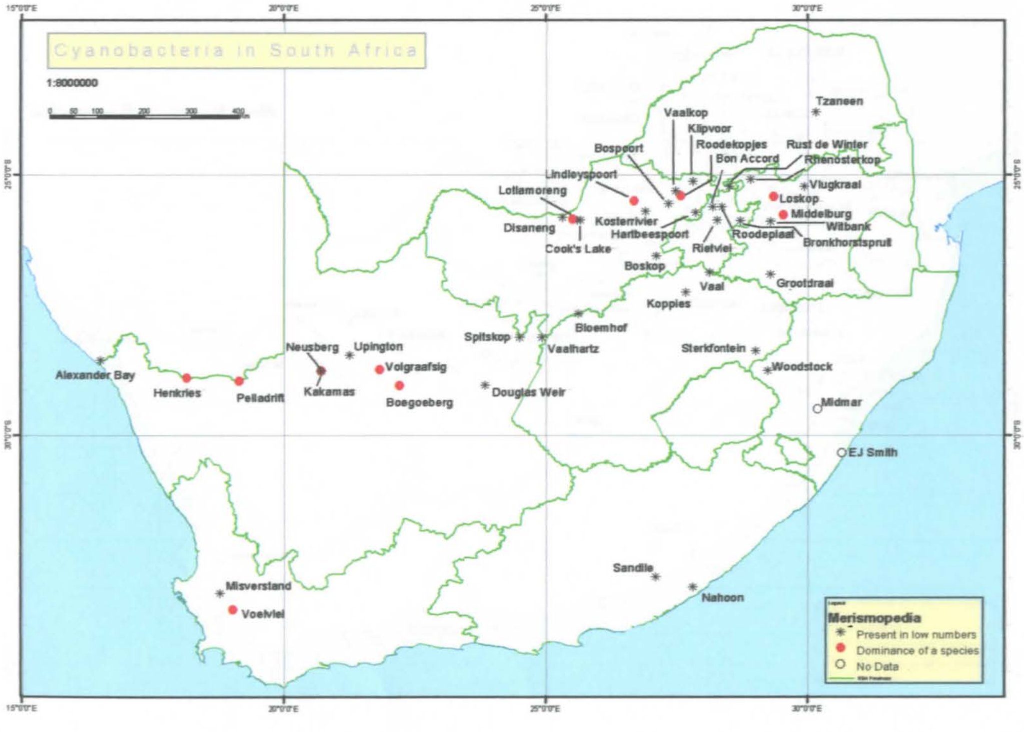

Figure 16 The known distribution of *Merismopedia* spp. in South Africa.

Figure 17 The known distribution of *Microcystis* spp. in South Africa.

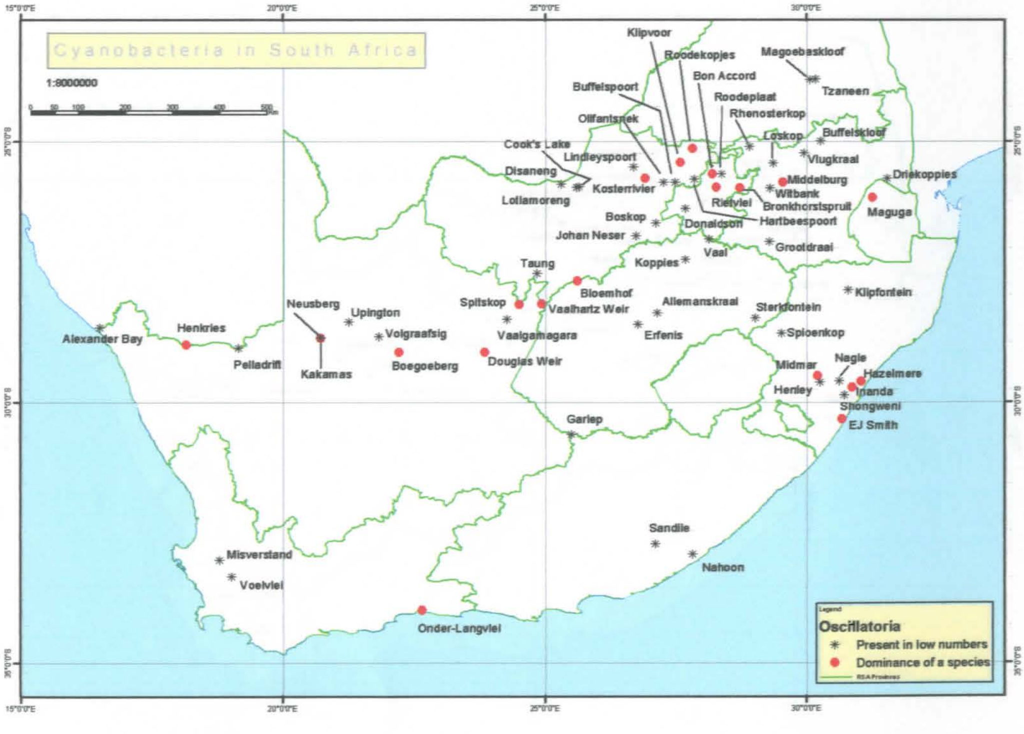

Figure 18 The known distribution of *Oscillatoria* spp. in South Africa.

Figure 19 The known distribution of *Pseudoanabaena* spp. in South Africa.

Figure 20 The known distribution of *Spirulina* spp. in South Africa.

Figure 21 The known distribution of *Chroococcus spp*. in South Africa

Figure 22 The known distribution of *Lyngbya* spp. in South Africa

8.2 Known extent of toxic cyanobacterial incidents

All the data available in SA literature as well as data from this study were used to compile a map showing all the sites where cyanobacterial toxicity have been found to date. Fig 23 shows that cyanobacteria have produced toxins in many cases and also throughout South Africa. The water users in South Africa are, therefore, at risk if the Department or local authorities do not start to take the necessary precautions when providing drinking water or facilities for recreational use. Users also need to be made aware of the potential hazard to their health in cases of extensive cyanobacterial blooms.

Figure 23 The known sites where toxic cyanobacterial incidents have been found until 2003

Chapter 9
CONCLUSIONS AND RECOMMENDATIONS

8.3 Conclusions

Cyanobacterial blooms and the effects are widespread, frequent and typically seasonal. The increasing number of events of cyanobacterial blooms in South African impoundments and rivers - with specific reference to the Vaal and the Orange Rivers - is a cause of concern to the Department of Water Affairs and Forestry. The increasing development of urbanised areas in the country with the resultant increase in nutrient influxes in the fresh water resources in the country has necessitated this study. There was a lot of drive during the last four years both internationally and nationally to increase our knowledge regarding the driving forces of cyanobacterial blooms and cyanotoxin production.

The lack of knowledge on the extent of cyanobacterial bloom development has been satisfied to a certain extent, however there is still a lack of complete understanding and predictability of the development of toxic cyanobacterial blooms. This lack of understanding initiated the study. It is, however, only showing that much more research is still needed to predict, control and manage all the problems with eutrophication and the associated toxic cyanobacterial blooms.

Toxic cyanobacterial blooms are a threat to the supply of safe drinking water to the whole population of South Africa, when the lack of knowledge and analyses capacity for cyanobacterial toxins in the country is considered.

There is still research needed to determine the driving forces of the toxin production of cyanobacteria.

8.4 Recommendations

The studies that were done during the past four years lead to the following recommendations.

- South Africa need to develop standardized sampling and analyses methods

- Analytical laboratories, both for algal identification and cyanobacterial toxin analyses, need to be established on a regional, provincial or CMA level for a more efficient dissemination of information.

- A National Cyanobacterial Monitoring Programme (which can possibly be developed as part of the National Eutrophication Monitoring Programme) should include all water resources.

- The integration of biological and meteorological research is needed to understand and estimate the consequences of climate variations on the ecosystem.

- Sampling surveys on small farm dams and irrigation systems should be initiated to determine the potential hazard to rural domestic water users and agricultural users.

- Eutrophication management strategies need to be developed and implemented to reduce toxic cyanobacterial bloom development in South Africa's freshwater resources and to ascertain safe domestic, agricultural and recreational water supplies.

Chapter 10
REFERENCE

Department of Water Affairs (1986) *Management of the Water Resources of South Africa*. CTP Book Printers, Cape Town. ISBN 0 621 11004 3.

Department of Water Affairs and Forestry (2002) *National Eutrophication Monitoring Programme. Implementation Manual.* Compiled by K Murray, M du Preez and C.E. van Ginkel. Pretoria. South Africa.

Downing TG and Van Ginkel CE (2002) *Cyanobacterial monitoring 1990 – 2000: evaluation of SA data.* Report No 1288/1/03 to the Water Research Commission. Pretoria. ISBN 1-77005-012-6.

Harding WR and Paxton BR (2001) *Cyanobacteria in South Africa: A review*. Report No TT153/01 to the Water Research Commission. Pretoria. ISBN 1 86845 7745.

Harding WR (1997a) New regional emergence of cyanobacterial toxicosis. *Harmful Algae News*, **16**, 12-13.

Harding WR (1997b) Phytoplankton primary production in a shallow, well-mixed, hypertrophic South African lake. *Hydrobiologia*, **344**, 87-102.

Janse van Vuuren S (2001) Environmental variables and the development of phytoplankton assemblages in the Vaal River between the Rand Water Barrage and Balkfontein. PhD Tesis at the Potchefstroom University for Christian Higher Education. Potchefstroom. South Africa.

Lawrence I, Bormans M, Oliver R, Ransom G, Sherman B, Ford P and Wasson B (2000) *Physical and nutrient factors controlling algal succession and biomass in Burrinjuck Reservoir*. Technical Report for the Cooperative Centre for Freshwater Ecology. ISBN 0967704844. 134pp

Namikoshi M and Rinehart KL (1996) Bioactive compounds produced by cyanobacteria. *Journal of Industrial Microbiology*, **17**, 373-384.

Quibell G; Badenhorst JE and Carelson CIC (1995) *A national toxic blue-green algal surveillance programme for South Africa.* Internal Draft Report No. N/0000/DPQ/1094. Resource Quality Services (Institute for Water Quality Studies), Department of Water Affairs and Forestry. Pretoria

Rae B, Moollan RW and Clark RC (1999) *Algal Toxins in drinking water supplies*. Water research Commission Report No. 549/1/99, Pretoria, South Africa.

Shapiro J (1990) Current beliefs regarding dominance by blue-greens: The case for the importance of CO_2 and pH. *Internat. Verein. Limnol.* **24**, 38-54.

Van Ginkel CE , Hohls BC and Vermaak E (1999) Fish kill in Hartbeespoort Dam South Africa, October 1999. Internal Report No. N/A210/02/DEQ/4299. Resource Quality Services (Institute for Water Quality Studies), Department of Water Affairs and Forestry, Pretoria

Van Ginkel CE and Conradie B (2001) *Potentially toxic algal incident in the Orange River, Northern Cape, 2000.* Internal Report No. N/D801/12/DEQ/0800. Resource Quality Services (Institute for Water Quality Studies), Department of Water Affairs and Forestry, Pretoria.

Van Ginkel CE; Hohls BC and Van Niekerk H (2000) *Pollution incident in the Roodeplaat Dam, May 2000.* Internal Report No. N/A230/01/DEQ/0600.Resource Quality Services (Institute for Water Quality Studies), Department of Water Affairs and Forestry. Pretoria.

Van Ginkel CE; Hohls BC; Belcher A; Vermaak E and Gerber A (2001a) *Assessment of the Trophic Status Project.* Internal Report No. N/000/00/DEQ/1799. Resource Quality Services (Institute for Water Quality Studies). Department of Water Affairs and Forestry. Pretoria.

Van Ginkel CE; Hohls BC and Vermaak E (2001b) A *Ceratium hirundinella* (O.F. Müller) bloom in Hartbeespoort Dam, South Africa. Water SA, 27 (2), 269-276.

Van Ginkel CE, Silberbauer MJ and Vermaak E (2000) The seasonal and spatial distribution of cyanobacteria in South African surface waters. *Verh. Internat. Verein. Limnol.* **27**, 871 – 878.

Vasconcelos VM, Sivonen K, Evans WR, Carmichael WW and Namikoshi M (1996) Hepatotoxic microcystins diversity in cyanobacterial blooms collected in Portugese freshwaters. *Wat. Res.*, **30** (10), 2377-2384.

Walmsley RD (2001) *Proceedings of a Workshop to Discuss Research and Capacity building within the field of Eutrophication.* WRC document.

Wnorowski AU (1992) *Taste and odour forming microorganisms in South African surface waters.* WRC Report No. 320/1/93. Pretoria. South Africa. ISBN 1 874858 95 0.

World Health Organization (1999) *Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management.* Edited by Chorus I and Bartram J. E&FN Spon. London. ISBN 0-419-23930-8.

Appendix A

Table A-1. List of impoundments selected to be included included in a National Cyanobacterial Survey.

Dam name	Mean PO_4-P (µg/L)	Urban (%)	Industrial (%)	Agriculture Irr/sugar (%)	Agriculture Dry/subs (%)	Natural (%)	Monitoring programmes	Included in this survey
Albert Falls Dam	1	58.5	0.0	9.2	7.1	25.2	Ongoing	Yes
Allemanskraal Dam	37	4.3	0.0	0.9	74.5	20.3	Ongoing	Yes
Arabie Dam	13	33.5	0.8	42.5	12.9	10.3	-	Yes
Armenia Dam	129	4.7	0.0	1.2	77.1	17.1	-	No
Babers Pan	33	14.5	18.4	12.3	34.5	20.3	-	No
Beervlei Daml	131	0.8	0.2	4.5	0.0	94.5	-	No
Bellair Dam	81	0.0	0.0	37.7	15.5	46.8	-	No
Binfield Dam	21	28.1	0.0	55.3	4.6	12.1	-	No
Bloemhof Dam	23	16.5	8.8	4.0	58.3	12.5	Ongoing	Yes
Blyderivierpoort Dam	12	0.6	0.0	88.3	0.5	10.6	-	No
Boegoeberg Dam	18	5.7	0.1	27.1	0.0	67.2	NC monitoring	Yes
Bo-Lang Vlei	46	11.7	0.0	53.9	1.8	32.5	-	Yes
Bon Accord Dam	37	85.7	0.2	12.3	0.7	1.1	Ongoing	Yes
Boskop Dam	14	18.4	42.1	6.4	20.7	12.3	Ongoing	Yes
Bospoort Dam	295	31.9	17.6	37.6	8.5	4.5	Ongoing	Yes
Bot River Wetland	20	6.7	0.0	65.5	21.9	5.8	-	No
Bridle Drift Dam	33	79.4	1.9	0.0	4.8	14.0	Ongoing	Yes
Bronkhorstspruit Dam	20	38.3	1.8	5.0	47.8	7.1	Ongoing	Yes
Buffelskloof Dam	17	0.0	0.0	62.8	5.8	31.4	Cyano Survey	Yes
Buffelspoort Dam	17	9.9	6.9	72.3	4.6	6.3	Elands River monitoring	Yes
Bulshoek Dam	12	7.2	0.0	37.5	42.7	12.6	-	No
Calitzdorp Dam	17	5.8	0.0	51.3	1.7	41.2	-	No
Craigie Burn Dam	14	0.0	0.0	0.0	33.3	66.7	-	No
Dap Naude Dam	14	0.0	0.0	0.0	0.0	100.0	-	No
Darlington Dam	104	0.0	0.0	9.4	0.0	90.6	-	No
Disaneng Dam	14	51.8	5.5	3.9	28.4	10.5	Ongoing, monthly	Yes
Doornrivier Dam	22	45.2	0.0	15.8	20.0	19.0	-	No
Douglas Storage Weir	21	12.2	6.1	22.7	20.4	38.6	NC Monitoring	Yes
Driel Barrage	21	3.4	0.0	81.1	7.5	8.0	Cyano Survey	Yes
Ebenezer Dam	13	0.0	0.0	0.0	0.0	100.0	TSP	Yes
Erfenis Dam	35	7.2	0.0	0.8	61.1	30.8	Ongoing	Yes
Floriskraal Dam	46	1.8	0.0	11.2	0.7	86.2	-	No
Gamkapoort Dam	73	7.7	0.0	47.5	0.9	44.0	-	No
Gariep Dam	30	8.7	0.2	11.2	25.1	54.9	Ongoing	Yes
Gcuwa Dam	22	74.0	0.0	0.0	17.6	8.4	-	No
Goedertrouw Dam	23	1.9	0.0	30.6	30.5	37.0	-	No
Grootdraai Dam	29	16.1	4.8	1.2	51.7	26.2	Ongoing	Yes
Hans Merensky Dam	13	8.7	0.0	14.0	29.1	48.2	-	No
Hartbeespoort Dam	31	67.9	2.9	22.7	3.2	3.3	Ongoing	Yes

Dam name	Mean PO_4-P (µg/L)	Urban (%)	Industrial (%)	Agriculture Irr/sugar (%)	Agriculture Dry/subs (%)	Natural (%)	Monitoring programmes	Included in this survey
Hazelmere Dam	2	9.8	0.0	43.9	33.8	12.5	Ongoing	Yes
Heyshope Dam	12	0.0	4.3	9.6	43.4	42.7	Started 2003	No
Howisonpoort Dam	14	0.0	0.0	0.0	13.2	86.8	-	No
Inanda Daml	1	59.8	0.1	30.6	3.1	6.4	Ongoing	Yes
Johan Neser Dam	91	3.8	2.2	14.0	58.5	21.7	Cyano Survey	Yes
Kalkfontein Dam	21	4.0	0.1	9.9	12.0	74.0	-	No
Katrivier Dam	31	21.3	0.0	2.3	4.3	72.0	-	No
Klipberg Dam	19	0.0	0.0	90.6	1.0	8.4	-	No
Klipdrift Dam	37	14.7	16.1	16.9	24.0	28.4	Cyano Survey	Yes
Klipfontein Dam	29	57.4	6.9	0.0	16.5	19.2	Ongoing	Yes
Klipheuwel Dam	30	4.5	0.0	0.0	55.7	39.8	-	No
Klipvoor Dam	235	80.6	0.0	0.6	11.6	7.2	Ongoing	Yes
Knellpoort Dam	26	0.0	0.0	8.4	45.6	46.0	-	No
Koppies Dam	18	7.1	0.0	2.1	60.8	29.9	Ongoing	Yes
Korinte-Vet Dam	35	0.0	0.0	29.3	14.1	56.6	-	No
Kosterrivier Dam	22	0.5	0.0	0.0	55.7	43.8	Ongoing; Elands River Mon.	Yes
Kouga Dam	14	2.7	0.0	68.0	2.8	26.5	-	No
Kwaggaskloof Dam	18	0.0	0.0	83.3	6.7	10.0	-	No
Kwena Dam	14	2.0	0.0	59.8	14.2	24.0	-	No
Laing Dam	45	79.3	0.9	1.4	7.1	11.3	Ongoing	Yes
Lake Arthur Dam	70	0.0	0.0	40.3	0.0	59.7	-	No
Leeugamka Dam	51	0.0	0.0	8.0	0.0	92.0	-	No
Leeukraal Dam	1196	97.2	0.2	0.5	0.8	1.3	Cyano Survey	Yes
Lindleyspoort Dam	21	10.7	10.5	2.0	56.9	20.0	Ongoing; Elands River Mon.	Yes
Little Fish River	69	6.9	0.0	51.2	0.0	41.8	-	No
Loerie Dam	19	2.7	0.0	77.3	4.8	15.3	-	No
Loskop Dam	18	37.5	24.7	1.7	20.7	15.5	Ongoing	Yes
Magoebaskloof Dam	14	8.7	0.0	14.0	29.1	48.2	Ongoing	Yes
Mgobezeleni Lake	21	0.4	0.0	8.8	20.1	70.7	-	No
Middelburg Dam	11	5.4	56.4	3.1	28.2	6.8	Ongoing	Yes
Middel-Letaba Dam	19	21.7	0.0	65.1	5.9	7.2	-	No
Midmar Dam	1	5.0	0.0	67.5	7.7	19.9	Ongoing	Yes
Misverstand Dam	32	5.9	0.4	72.1	19.0	2.5	Ongoing	Yes
Modimola Dam	21	51.8	5.5	3.9	28.4	10.5	Ongoing	Yes
Mokolo Dam	13	1.0	0.0	36.7	28.4	33.9	Cyano Survey	Yes
Molatedi Dam	15	39.4	3.7	18.9	9.9	28.1	Cyano Survey	Yes
Nagle Dam	1	1.1	0.0	91.2	2.6	5.0	Ongoing	Yes
Nahoon Dam	35	38.5	0.0	3.2	13.7	44.6	Started in 2002	Yes
New Doornpoort Dam	14	10.5	48.8	1.4	30.4	8.8	-	No
Nooitgedacht Dam	18	10.2	2.9	4.4	54.6	27.9	Cyano Survey	Yes
Nuwejaars Dam	23	7.5	0.0	8.5	1.0	83.0	-	No
Ohrigstad Dam	12	0.0	0.0	33.2	0.0	66.8	-	No
Onder-Lang Vlei	29	11.7	0.0	53.9	1.8	32.5	WCNC	Yes
Oukloof Dam	18	0.0	0.0	55.0	0.0	45.0	-	No

Dam name	Mean PO_4-P (µg/L)	Urban (%)	Industrial (%)	Agriculture Irr/sugar (%)	Agriculture Dry/subs (%)	Natural (%)	Monitoring programmes	Included in this survey
Pongolapoort Dam	12	5.0	1.2	39.7	21.0	33.2	-	No
Potchefstroom Dam	20	70.6	1.6	2.2	12.1	13.5	Cyano Survey	Yes
Rietvlei Dam	161	86.8	1.2	1.6	7.4	3.0	Ongoing	Yes
Rondevlei	100	11.7	0.0	53.9	1.8	32.5	WCNC	Yes
Roodekopjes Dam	18	12.1	4.6	77.6	1.0	4.8	Ongoing	Yes
Roodeplaat Dam	195	91.5	1.2	2.4	1.7	3.2	Ongoing	Yes
Serfontein Dam	48	18.9	0.0	1.1	59.1	20.9	Cyano Survey	Yes
Settlers Dam	13	0.0	0.0	0.0	13.2	86.8	Cyano Survey	No
Shongweni Dam	10	50.8	0.0	41.7	2.8	4.7	Ongoing	Yes
Sibayi Lake	12	0.4	0.0	8.8	20.1	70.7	-	No
Spioenkop Dam	22	2.8	0.0	79.2	9.2	8.9	Cyano Survey	Yes
Spitskop Dam	17	12.3	0.4	66.3	0.1	21.0	NC Monitoring	Yes
St Lucia Lake	31	0.9	0.7	25.4	30.4	42.7	-	No
Sterkfontein Dam	17	0.0	0.0	0.0	0.4	99.6	Ongoing	Yes
Susandale Dam	21	24.8	0.0	15.5	14.3	45.4	-	No
Taung Dam	17	25.5	0.0	14.3	41.4	18.8	NC Monitoring	Yes
Theewaterskloof Dam	14	1.4	0.0	92.4	1.5	4.7	CCT Monitoring	Yes
Tierpoort Dam	74	0.0	0.0	1.2	33.8	65.0	-	No
Tzaneen Dam	14	24.4	0.1	53.5	13.8	8.2	Ongoing	Yes
Umgababa Dam	28	8.6	0.0	81.0	5.2	5.1	-	No
Umtata Dam	32	74.8	0.0	0.0	13.1	12.0	Started 2002	Yes
Vaal Dam	34	15.0	12.9	2.2	50.2	19.6	Ongoing	Yes
Vaalkop Dam	19	55.0	10.4	7.9	4.4	22.3	Ongoing	Yes
Vaalrivier Barrage	156	70.5	12.6	1.1	11.9	3.9	Randwater	Yes
Van Ryneveldspas Dam	60	2.0	0.0	19.9	0.0	78.0	-	No
Vanderkloof Dam	22	2.5	0.0	9.7	0.3	87.5	Started 2002	Yes
Voelvlei Dam	18	7.6	0.0	87.1	2.9	2.3	Ongoing, CCT Monitoring	Yes
Vondo Dam	9	3.8	0.0	17.3	51.4	27.5	Started 2002	Yes
Warmbad Dam	17	49.5	0.0	8.9	27.4	14.2	-	No
Waterdown Dam	29	0.0	0.0	58.3	1.9	39.8	-	No
Wemmershoek Dam	10	4.0	0.0	87.4	0.0	8.7	Ongoing	Yes
Wolwedans Dam	33	4.5	0.0	0.0	55.7	39.8	-	No
Woodstock Dam	21	1.2	0.0	14.2	38.3	46.4	Cyano Survey	Yes
Wriggleswade Dam	18	29.5	0.0	17.9	7.7	44.9	Started 2002	Yes

Appendix B

Table B-1. List of people that attended talks and presentations on eutrophication and monitoring during the last two years for the National Cyanobacterial Survey. (NA = Not Available)

Date	Name	Site
2002/08/02	Pindela Sitandisile	Xilinxa
	Matho Wiserman	Kat River
	Abashoni Mefale	Grassridge
	Thabo Moloi	Vaal Dam
	Thandi Mthembu	Vaal Dam
	Dawid Thabona	Vaal Dam
	Basil Sandile Cele	Wagendrift Dam
	Niklaas Plaatjies	Vanderkloof Dam
	Jacob Erasmus	Koppies Dam
	Marius van Niekerk	Elandsdrift Dam
	Pieter Vermaak	Vaal Dam
2002/9/17	NA	
2003/5/14	Vuma Dlamini	KOBWA
	Vusi P Malinga	Swaziland
	Edward Mswane	Swaziland
	Michael Mamba	Swaziland
	Charles Ncube	Driekoppies Dam
	Austin Mgongo	Driekoppies Dam
	Angel Gwebu	Driekoppies Dam
	Mathokoza Manana	KOBWA
	Eric B Khoza	Maguga Dam
	Linda A Masuku	Maguga Dam