Potentially Toxic Algal Incident in the Orange River, Northern Cape, 2000

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EXECUTIVE SUMMARY

Purpose of the study

The purpose of this study is to assess the water quality situation and related climatological events in the Lower Orange River before, during and after the potentially toxic cyanobacterial bloom in the Lower Orange River during January to March 2000.

Study area

The Orange River, the largest river in South Africa, rises in the Drakensberg Mountains of Lesotho at an altitude of 3400 m. The main rivers contributing to the lower Orange River are the Harts-, the Vaal-, the Fish and the upper Orange rivers. The Lower Orange River catchment area is large and because of the arid nature of this section of the Orange River, falls within a low rainfall area.

Background and results

A massive cyanobacterial bloom occurred in the Lower Orange during January to March 2000. The DWAF Northern Cape Regional Office (Upington) and IWQS investigated the incident with assistance from many individuals and institutions in an attempt to understand the causes of the event for future management purposes.

The report highlights:

- The climatic conditions and impacts that occurred before, during and after the cyanobacterial bloom (rainfall, flow, etc.);
- The chemical water quality conditions in the Orange River catchment before, during and after the event (e.g. nutrients and salinity);
- The extent of the cyanobacterial bloom (chlorophyll a peaks, algal species, etc.);
- The impacts on all users during the event (domestic, recreational, industrial, agricultural and the aquatic environment);
- Comparison of available historical information to the situation in the Lower Orange River during the event; and
- The possible cause(s) of the cyanobacterial bloom.

Conclusions

From the study it can be concluded that there is a possibility that the cyanobacterial bloom was toxic, but no direct proof could be found.

- The rainfall and consequent flows from the Harts River, however small when compared to the contributions from the Vaal, the Upper Orange Rivers and

the Fish River, since December 1999 to February 2000 was the main reason for the influx of cyanobacteria found in the Lower Orange River. The composition of the cyanobacterial bloom in the Lower Orange River was the same as was found in the Spitskop Dam in the Harts River.

- The cyanobacterial bloom was of a passing nature, but can be repeated in future. The problem is that if *Cylindrospermopsis raciborskii* was not previously in the system, it might have been established now in the impoundments. Any future flooding events might, therefore, cause similar incidents.

- The fish kills in the Lower Orange River was caused by a combination of water quality factors (e.g. low oxygen concentrations, high pH and high ammonia concentrations) that could have been a secondary result of the cyanobacterial bloom.

- The effects of the cyanobacterial bloom did not cause any known health related problems, but did have major effects on the aquatic environment (fish kills), domestic water industry (filter clogging and difficulty in cyanobacterial biomass removal) and on the agricultural sector (irrigation water).

- There is a need to develop warning systems by way of regular monitoring to minimise the effect of similar incidents.

Recommendations

- The development of facilities in South Africa to determine cyanobacterial toxins is essential for the effective management of cyanobacterial bloom incidents.

- There is a need for monitoring programme(s) that include the indicator variables for eutrophication, including algal identifications. This will enable Water Care Works and other water management institutions to timeously detect problem causing algal species. This will increase WCW's and other water service provider's operational effectiveness. It will also enable other water management institutions to warn all users of the potential hazard of cyanobacterial toxin production of such waters.

- There is a need to develop a tool (e.g. a generic mathematical model) to predict algal blooms in surface water sources (not only impoundments).

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1. PURPOSE OF THIS DOCUMENT

The purpose of this document is to report on a study to assess the cyanobacterial bloom and related water quality situation in the Lower Orange River before, during and after the potentially toxic cyanobacterial bloom in the Lower Orange River which occurred during January to March 2000.

2. INTRODUCTION

2.1 Background to the study

This report originated from an urgent request by the DWAF Northern Cape Regional office in Upington, on 14 of January 2000, to IWQS, to investigate the state of the water in the Orange River. The Orange River water had turned completely green (Figure 4a), a state that is often referred to as "pea soup". The Upington Municipality was the first to report the incident to the DWAF office in Upington, due to problems at their Water Care Works (WCW), especially the carry over of algae to the final water. The whole lower Orange River catchment was affected. The situation must have prevailed for at least a week before the Department was contacted. Simultaneously large fish kills occurred in the middle and lower Orange River (ABRAHAMS, 2000) when *Labeo capensis* was mostly killed.

The Orange River, the largest river in South Africa, has not had any previous history of an algal bloom of this nature. Occasional algal problems do, however, occur in the WCW during low flow periods (DIPPENAAR 2000 and GOOSEN 2000).

Cyanobacteria is a frequent component of many freshwater and marine ecosystems. Under certain conditions, especially where waters are rich in nutrients (eutrophic conditions) and under warm climatic conditions, cyanobacteria may multiply to high densities to form blooms. The development of strains containing toxins is a common experience in polluted inland water systems all over the world, as well as in some coastal waters (CHORUS and BARTRAM 1999).

The cyanobacteria (blue-green algae) that are known to produce toxins can be harmful to human and animal life. The species that are well known to cause incidents in South Africa, due to their incidence and associated toxic effects on animals, are *Microcystis* spp, and *Oscillatoria* spp. Both species have previously caused large numbers of animal deaths in other impoundments (e.g. Vaal Dam,

Erfenis Dam and a farm dam in the Kareedouw area) in South Africa (QUIBELL *et al.* 1995, VAN GINKEL unpublished data). In the Orange River incident a cyanobacterial species that is internationally known to produce saxitoxin (neurotoxin) and hepatotoxins (liver toxin), namely *Cylindrospermopsis raciborskii* were found for the first time in South Africa, and in bloom conditions. The species occurred as dominant species in co-existence with *Oscillatoria* sp.

Hydrological differences between rivers and impoundments have important consequences for nutrient concentrations and, therefore, for cyanobacterial growth. Rivers have a significant flushing rate. The term 'self-purification' is used extensively in river environments to describe the rapid degradation of organic compounds where turbulent mixing effectively replenishes consumed oxygen. The process does not remove all undesirable substances (e.g. phosphorus) from the water, as many of the substances are adsorbed on the sediments and can be released later to be washed away. In lakes, with longer water retention times when compared to rivers, undesirable substances (e.g. phosphorus) accumulate in the sediments. This process is particularly important for phosphorus, one of the main nutrients that cause eutrophication symptoms. Sediments, therefore, acts as a sink for important nutrients such as phosphorus. However, if the conditions change, especially during summer periods the sediments may then serve as a nutrient source, that stimulate the growth of cyanobacteria and algae.

Cyanobacterial and algal blooms are thus more a phenomenon in impoundments and lakes than in rivers. The incident in the Orange River needs, therefore, to be explained also in terms of the climatic and seasonal situation of the upper catchment before and during the period that the bloom prevailed in the river.

2.2 Study Area

The Orange River, the largest River in South Africa, rises in the Drakensberg Mountains of Lesotho at an altitude of 3400 m (PALMER 1996). The Orange River mouth is considered to be the 6th most important coastal wetland in SA (RDM manuals 1999). The Orange River mouth was declared a RAMSAR site on 28 June 1991.

The main rivers contributing to the lower Orange River are the Harts-, the Vaal-, the Fish (in Namibia) and the upper Orange rivers (Figure 1). The extent of the catchment area is large and because of the arid nature of the lower Orange River falls within a low rainfall area. The upper reaches of the Orange River are,

however, in a much higher rainfall area. The impoundments in the upper Orange, the Vaal and the Harts Rivers made the development of intensive agricultural activities along the lower Orange River, even in the extremely dry areas, possible.

According to DWAF (1999) the flow pattern in the Lower Orange River is artificial, due to the impoundment of the upper catchment, to a large degree and peak seasonal flows occur much later in summer than usual. The winter flows have been increased to a large extent at the expense of summer flows. The Gariep and Vanderkloof dams have adverse effects on biota 200 km downstream by influencing water temperatures 180 km downstream. The large quantities of sediment trapped in the dams resulted in changed channel geomorphology and aquatic habitat. Since regulation of the flow, reed growth has increased. Increased flooding of agricultural land occurs during high flows.

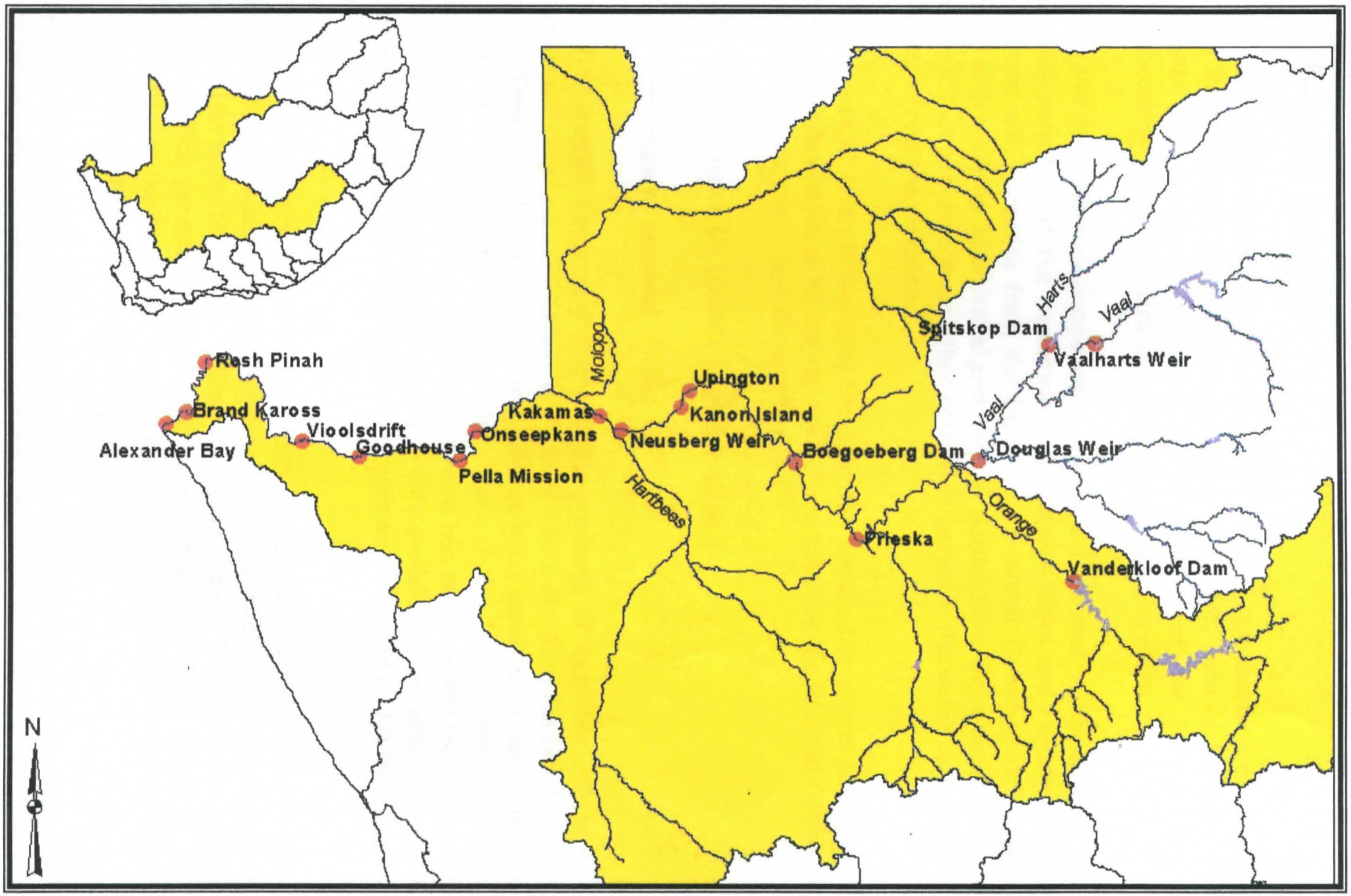
The Orange River water quality is generally very good and the system is characterised by very turbid water.

The increases in reed growth stimulated the occurrence of the blackfly (*Simulium chutterri)* (CAMBRAY *et al.* 1986, PALMER 1996) also due to more stable flow regimes with less floods and periods of low flow. Intensive irrigation areas resulted in little natural vegetation in the riparian zone.

Downstream of the Augrabies falls a fish species endemic to the Orange River is *Barbus hospes.* The blackfly, *Simulium gariepense,* is also endemic to the river downstream of the Augrabies falls.

During the incident, sampling was conducted from Boegoeberg Dam to Alexander Bay (see Figure 1). This sampling exercise excluded the situation within the three tributaries of the Lower Orange River.

Figure 1. The sampling sites in the middle and lower Orange River during the algal bloom in January and February 2000.



3. APPROACH TO THIS STUDY

3.1 Purpose of this section

Previous authors have referred to the occurrence of cyanobacteria (blue-green algae) in the Orange River system. However, an event, such as the one that happened in January and February 2000, reminding of the Murray Darling cyanobacterial bloom in Australia, could not have been foreseen.

Since the first user problems were reported from the Upington area, the Regional personnel of the Department of Water Affairs and Forestry (in co-operation with expertise from the Institute for Water Quality Studies) were faced with a number of logistical problems. By documenting these experiences, it is hoped that personnel from other regions or people in the water care industry can learn from the experience.

The purpose of this section is to highlight the consecutive events and actions during the cyanobacterial bloom and the actions taken by the Regional Office of DWAF (RO), Northern Cape during the event.

3.2 Actions taken by DWAF: Northern Cape

3.2.1 First reports received

The first report concerning the **possible** presence of cyanobacteria in the system was received on Tuesday, 11 January 2000. Mr Jaco Goussard of JCG Water Treatment (a consultancy firm), who supplies services to many concerns along the river, reported that the sand filters of the Topline Community were blocked. He wanted to find out if anybody else had reported the incident and if the Department's Regional Office had any data available on the possible species that may have been present. Negative answers were supplied in this incidence by the RO.

On Friday, 14 January 2000 a distinct taste was present in treated water from the Upington Municipality. Mr Gert Meiring of the office of the Town Engineer requested an inspection at the Water Treatment Works. DWAF Northern Cape Regional Office personnel at Upington investigated. The green colour of the river itself and the "pea-soup" appearance of the water in the irrigation canals required immediate attention of the RO.

The importance of this report should be seen in light of the fact that **all** water care works along the Orange River are designed to treat turbid water. Only very small works may still employ slow sand filtration units which may be most suited

where more advanced technology for algae removal does not exist. The potential effect of a toxic cyanobacterial bloom can, therefore, be quite serious for such treatment works that have not been designed to treat algal-laden waters.

Since no sampling and filtration equipment, bottles and preservatives were available in Upington, Regional personnel requested assistance from experts at the Institute for Water Quality Studies (IWQS) in Pretoria. Ms Carin van Ginkel arranged to be in Upington on Monday, 17 January 2000.

3.2.2 Assessment of the situation

The objectionable taste to the water had already caused concern amongst the public in the Upington Municipal area (receiving treated water), during the first reports of the event that were received by the RO. Large numbers of temporary employees were also in the area during the harvest season, many of whom use untreated water.

The first step in the process was, therefore, to identify the algal species and, based on this knowledge recommend appropriate actions to water users - especially those who do not have access to partially treated water. A summary of the specific monitoring rationale is presented in paragraph 3.3.

During this assessment, it was also important to identify the cause(s) of the problem. High rainfall occurred in the Harts River catchment area resulting in both the Taung and Spitskop Dams overflowing. Given the recent generally high rainfall in most of the catchment area of the Lower Orange River, the resultant wash-off of pollutants that accumulated during previous years of less-than-average rainfall events, were also considered as a possible aggravating factor to the situation.

The water quality contributions should be seen in the light of land-use patterns in the area. A limited number of point source (Sewage Treatment Works) contributions to the Orange River exist. The area is dominated by especially irrigation land use with extensive irrigation canal systems and irrigation return flow facilities where alluvial land close to the river is drained to prevent over-saturation of soils. Apart from the individual homesteads of landowners and their employees, a large number of communities are also situated close to the river. In these smaller communities and on the individual farms, on-site sewage disposal systems are used. A typical pollutant-wash-off pattern during the first heavy rains in a season, is therefore a definite contribution to the nutrients of the system.

Given the design constraints of WCW's in the area, it was also necessary to get the status (regarding treatment design) of WCW's upstream of Upington and those downstream of Upington in order to target specific groups for a warning system and to ensure continuous monitoring of the situation. To assist in this task the inputs from water treatment technology and chemicals suppliers and the Environmental Health Officers (National, Provincial and Local Authorities) were obtained.

3.2.3 Information distribution and recommendations during the event

By Tuesday, 18 January 2000, a written document to brief both the public and media on the subject was approved by the Regional Director: Northern Cape Region. This media brief contained information about the cyanobacteria (blue-green algae), its typical characteristics of bad odours and tastes, the potential to form toxins, the potential causes of the event (as discussed above) as well as practical recommendations to guide the public. These recommendations included a recommendation that, should alternative water sources be available, these should be given preference on the short-term. Filtration of the water was also recommended as a possible treatment. The document included the Region's intention to design and implement an early warning system to prevent or minimise a recurrence of the situation in future.

The information was regionally widely distributed - also amongst personnel working in sections other than water quality (e.g. Water Control Officers, Area and Scheme Managers and their personnel) to assist us in answering all the inquiries. Some of the other groups specifically targeted, were the Environmental Health Officers and Local Authorities to ensure that the largest possible group in communities could be reached.

A request to utilise water storage capacity to the fullest was also directed at water users not already affected by the situation (especially downstream of Augrabies). The communities of Witbank, Vioolsdrift and Rooiwal followed this approach with success.

The Trans Hex Ltd. mining company provided potable water distribution sites at their Reuning and Baken communities. Water was not only treated in the conventional manner but micron filtration units and activated carbon filtration units were also used to help in the treat the water for cyanobacterial toxins.

3.3 Monitoring before, during and after the event

As stated above, no algal-monitoring program existed in the Lower Orange River system. The only eutrophication status monitoring done by the Department is at

major impoundments in catchment areas where the Special Standard for Phosphate used to be applicable and impoundments known to have regular algal blooms.

The unnatural state of the river as reflected by the first set of results (e.g. 150ug/l chlorophyll a at Upington) required emergency incident actions. Added to this state were the types of cyanobacterial species present in the samples. *Microcystis* is the best known problem causing cyanobacterial species in South Africa. *Microcystis* toxins were studied internationally in different situations. *Anabaena, Oscillatoria and Cylindrospermopsis* present in all samples at various stages have not been studied to the same extent as *Microcystis*, and can, therefore, be classified as relatively unknown species regarding their toxins and toxin production.

A very conservative approach was, therefore, selected by the RO. The monitoring of the river itself and the individual water reticulation networks of communities were considered to be crucial to ensure that any potential danger would be avoided as soon as it is detected. Variables analysed for are discussed in section 4 of this report.

By the end of the first week (during which extensive fish kills between Keimoes and Blouputs were investigated), the monitoring was expanded to provide data **before**, **during** and **after** the event. This was done with the help of various individuals and companies as indicated in the beginning of this report.

A significant contribution was made by the RO Water Control, Area and Scheme Manager offices to predict the movement of the cyanobacterial bloom. When the "beginning" of the algal mass was detected on Sunday, 23 January 2000 at Onseepkans, the RO Water Control, Area and Scheme managers provided field workers with a daily briefing of water levels. It was also significant as a larger release of Vanderkloof Dam water followed the batch of unhealthy water.

On Monday, 24 January 2000, arrangements were made to monitor the effect of the water on both the macro-invertebrate and fish species of the Orange River downstream of Augrabies. Separate reports of these results were obtained and were used to compile this report.

3.4 Action plan

The design of an action plan for the Northern Cape Region was formally started during the compilation of information documents for the public and the media. As with any other action plan, it was continuously amended as new information

was obtained during the site inspections and as data became available. At present, the following are seen as the key components of this plan:

3.4.1 Development of a monitoring programme to determine the eutrophication status of impoundments, algal types and occurrence

Readers familiar with the "impoundments" of the Lower Orange River would agree that the Boegoeberg Dam is much smaller than some weirs (e.g. Neusberg) and the name "dam" stems from the folklore song. Since algae prefer clear, standing water and high temperatures to grow, the decision was taken to include all possible impoundments contributing to the system, namely those in the Vaal, Harts and Orange River systems as the influx of the cyanobacterial bloom had to come from a large impoundments with sufficient standing water to allow the development of a cyanobacterial bloom of such an extent as appeared in the Lower orange River.

Given the vast area which was affected it was decided to expand the "impoundment structures" monitoring points to include a number of river monitoring points as well. These sites were primarily selected to space observations equally along the length of the river and were selected at the intake of major water treatment facilities supplying water to more than one community.

Two balancing dams on canal systems were also selected mainly to investigate the effect that these facilities may have on the water quality (and specifically eutrophication-related problems). This is further explored in paragraph 3.4.2 below.

The selected monitoring points (Figure 1) were registered as such at the Institute for Water Quality Studies as a project for **at least** one year:

- Taung Dam (Harts River);
- Spitskop Dam (Harts River);
- Bloemhof Dam (Vaal River) is already part of the Department's National Programme;
- Vaalharts Weir (Vaal River);
- Vaalgamagara (Vaal River just downstream of the Vaal and Harts confluence) to use as a Departmental facility also in the design of the early warning system;
- Douglas Weir (Vaal River) just upstream of the Vaal and Orange confluence;
- Vanderkloof Dam (Orange River) as a major source of turbid water;

- Boegoeberg Dam (Orange River), downstream point for Orange/Vaal confluence;

4. SAMPLING AND ANALYSIS METHODS

Existing monitoring of biological variables in the Lower Orange River is limited to non-existent. The National Chemical Monitoring Programme of DWAF determines only major inorganic chemical variables.

The original reporting of the incident on 14 January 2000 initiated the first initial biological and chemical sampling that took place on 17 January 2000. Doing more ad hoc monitoring of the Lower Orange River when and where monitors were available extended the sampling during the cyanobacterial bloom in the Lower Orange River. This *ad hoc* monitoring eventually led to the development of a registered monitoring programme for the Lower Orange River. This registered monitoring programme included the impoundments in the Orange (Van Der Kloof Dam), Vaal (Vaalharts Weir) and Harts (Spitskop and Taung Dams) Rivers upstream of the confluence's of these three rivers as discussed above.

4.1 Sampling methods

Grab samples were taken at sites during the initial and *ad hoc* sampling. These water samples were then poured into the appropriate sampling bottles, preserved and transferred to the laboratories. Samples were collected to do major inorganic chemical (macro)- and biological analyses. Samples for chlorophyll *a* and suspended solids (SS) were filtered in the field onto filter paper. The chlorophyll *a* sample was preserved in 10 ml ethanol and the SS sample was stored in the filter holder that was supplied.

Physical measurements were taken *in situ* with the exception of pH on 2000/01/17. The temperature and oxygen readings were taken with a YSI 95 oxygen and temperature meter and the pH reading was determined in the Macro Elements Laboratory at the IWQS and at the TRANSNET Laboratory in Kimberley.

4.2 Analysis methods

4.2.1 Macro chemical samples including Kjeldahl nitrogen (KN) and total phosphorus (TP) analysis were taken at most of the sites on the Orange River. Analyses included are pH, ammonium (NH_4-N), nitrate and nitrite (NO_3 + NO_2 as N), fluoride (F), alkalinity as calcium carbonate (ALK), sodium (Na), magnesium (Mg), silicon (Si), ortho-phosphorus (PO_4-P), sulphate (SO_4), chloride (Cl), potassium (K), calcium (Ca), electrical

conductivity (EC), and total dissolved salts (TDS). The methods used to determine these variables are discussed in detail in the IWQS (1999) document.

4.2.2 Biological samples were analysed by the biological laboratory of the IWQS. Samples were tested for chlorophyll *a*, phaeophytin *a*, total suspended solids (TSS) and algal identifications were done under an inverted microscope with 10 ml chambers. The methods used to determine the results are discussed in detail in the IWQS (2000a) document.

4.2.3 The microcystin analyses to determine algal toxins were done by the Organic Laboratory of the IWQS, using two methods. Firstly, the ELISA screening method was used. This method is a quick screening method to test for microcystins-LR, -YR, -RR and nodularin. Secondly, the determination of the specific cyanobacterial toxin was done on a High Pressure Liquid Chromatograph (HPLC). Note that no facilities were available in South Africa for the determination of cylindrospermopsin, the toxin produced by one of the dominant species

4.2.4 Bioassay tests (mouse bioassay), for the presence of cyanobacterial toxins, were conducted by Onderstepoort Toxicology Laboratory. The mice were injected intra-peritoneal (into the abdomen) and were then observed for between 1 and 48 hours to note any reactions. The time period to observe the mice were extended from 1 to 48 hours after the algal species was identified (Roos 2000) and on advice from Dr. Humpage (2000) from Australia that mentioned that the normal bio-assay period for testing for cylindrospermopsin presence is 7 days.

4.2.5 Fish monitoring and a fish kill investigation undertaken by the Northern Cape Nature Conservation Service included a distance of approximately 700 km (ABRAHAMS 2000). This study included mainly telephone interviews with local residents and information communicated by local observers. This information included: the date and site where fish kills were recorded, the species composition of the dead fish, the colour of the gills, the presence/absence of blood at the fin bases and if possible the behaviour of swimming fish. ABRAHAMS (2000) also used the data collected by the Northern Cape Regional Office for the algal investigation in his report.

5. RESULTS AND DISCUSSION

The results are discussed and divided into three main sections. Firstly, the in-stream impacts assessment that highlights the water quality in the river during the incident and the phytoplankton concentrations measured as chlorophyll a in the Lower Orange River is discussed. The fish kills are discussed under this section and are summarised from ABRAHAMS (2000). Secondly, the available historical data of selected water quantity and quality variables and related eutrophication symptoms that prevailed within the river before the incident are discussed. Thirdly, the impacts on water users within the system during the cyanobacterial event are discussed.

5.1 In-stream Impact Assessment

The in-stream impact assessment include firstly, the climatological impacts in the form of a discussion on the rainfall within South Africa before and during the cyanobacterial bloom event and the daily flow measurements at selected sites. Secondly, the phytoplankton population, the chlorophyll a concentrations and the dominant cyanobacterial species within the river are assessed.

5.1.1 Rainfall and in-stream Flow impacts

The tropical cyclone season in South Africa is from November to April, with the peak frequency in January and February. Only tropical cyclones moving into the Mozambique channel influence South Africa's weather. When this happens, South Africa usually experiences dry weather over the interior because of the subsiding air surrounding a tropical cyclone. Only a few move in over or close enough to the land to cause destruction, and then usually north of the 25 ° S latitude. In such cases, the Northern Province, Mpumalanga and KwaZulu-Natal may experience destructive winds and the risk of flooding (WWW 2).

Since December 1999 to January 2000 high rainfall (See Figure 2) already filled impoundments in the Vaal- and the Harts River catchments. The flood conditions that prevailed since December 1999 to February 2000 in the upper catchment of the Harts and the Vaal Rivers should be kept in mind during all the discussions. Extensive flooding and subsequent damage had been recorded throughout the Northern Province and Mpumalanga and parts of North-West Province and Gauteng. The rivers barely had a chance to subside when again a tropical cyclone, Eline, caused extensive rainfall over northern Mpumalanga and the Northern Province (WWW 1,). The Fish River that contributed from Namibia also experienced floods during the incident and might have added an enormous load of silt with their associated nutrients.

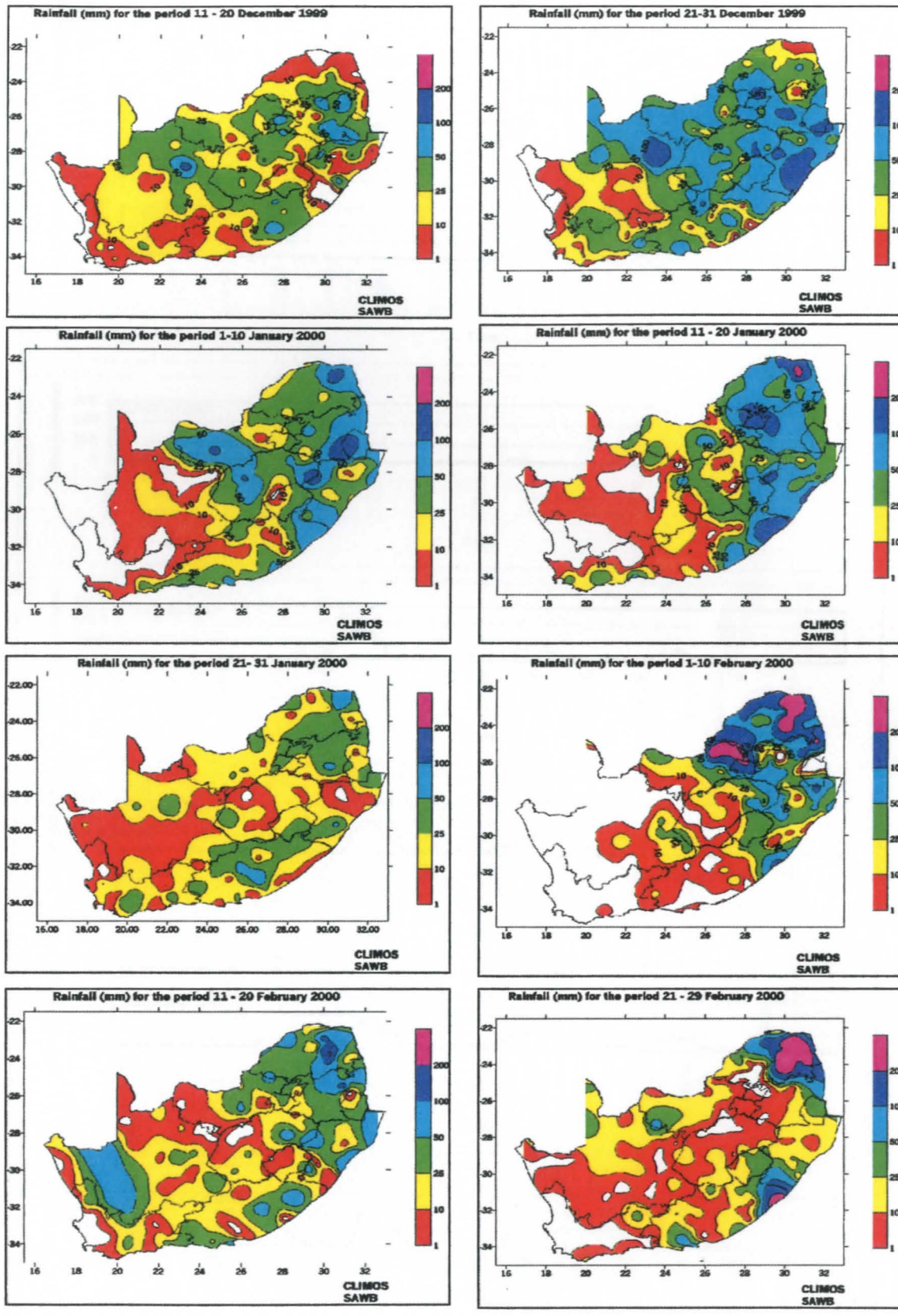


Figure 2. Ten-day rainfall patterns in South Africa from 11 December 1999 to February 2000 (WWW 7).

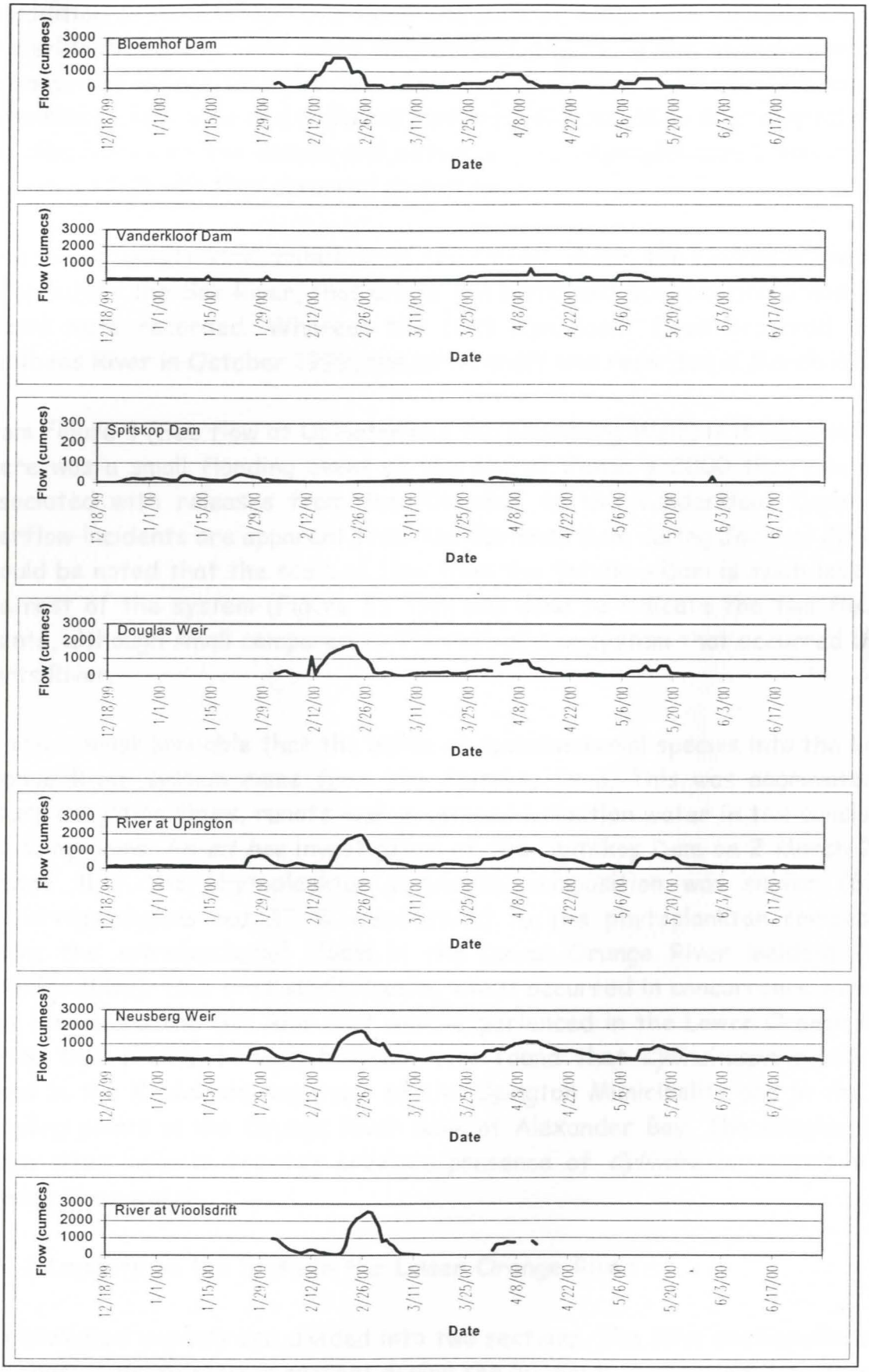


Figure 3. Flow measurements at selected sites on the Vaal and Orange River from December 1999 to June 2000.

In addition to natural dam overflows and rainfall, water was released from the Vanderkloof and Bloemhof dams respectively (Figure 3) for normal operational reasons. The effect that the increased flow levels had on the system was thus extensive (volume wise and sediment load wise) and should be kept in mind during the discussions on the nature and extent of the phytoplankton bloom and the associated fish kills that occurred downstream.

Even in the usually "dry" tributary of the Orange River, the Hartbees River and its tributary the Sak River, that drains the Karoo and Boesmanland areas, flood events were recorded. Whereas the first significant flows occurred in the Hartbees River in October 1999, the main runoff was recorded in March 2000.

From Figure 3 (See flow at Upington and the Neusberg Weir) it is apparent that there was a small flooding event at the end of January 2000 that cannot be associated with releases from the Bloemhof or the Vanderkloof Dams. Two overflow incidents are apparent from the Spitskop Dam during January 2000. It should be noted that the scale of flow from the Spitskop Dam is much less than the rest of the system (Figure 3). This was done to indicate the two flooding events, although small compared to the rest of the system that occurred in the Harts River.

It seems most probable that the influx of cyanobacterial species into the Lower Orange River system came from the Spitskop Dam. This was aggravated by return irrigation flows, runoff and un-utilised irrigation water in the canals and balancing dams. An *ad hoc* investigation of the Spitskop Dam on 2 March 2000 showed that the phytoplankton population composition was similar (63 % *Cylindrospermopsis* and 37 % *Oscillatoria*) to the phytoplankton composition during the cyanobacterial bloom in the Lower Orange River incident (VAN GINKEL 2000). This first small flooding event occurred in concurrence with the algal bloom and the fish kills that were experienced in the Lower Orange River during that period. It was, however, also found that *Cylindrospermopsis* was found in the Keidebees Reservoir of the Upington Municipality and in the well sampling points in the Orange River Bank at Alexander Bay. The samples from these sites indicate towards previous presence of *Cylindrospermopsis* in the Orange River water.

5.1.2 Impacts on the biota in the Lower Orange River

The biological impacts are divided into two sections. The first section discusses the phytoplankton species present during the incident. The second discusses the fish mortality that took place during January 2000.

5.1.2.1 The phytoplankton population in the Lower Orange River

The phytoplankton concentrations found in-stream in the Lower Orange River during the cyanobacterial bloom are discussed and all the sites, where data was available, are discussed in more detail.

At the time that the bloom was reported in the Upington area, the phytoplankton concentrations in Boegoeberg Dam (chlorophyll a concentrations never exceeded 50 µg/ℓ) seem to have already been much lower than what was found in the rest of the system. This phenomenon also indicates that the incident could have been flood related.

The maximum chlorophyll a concentration (240 µg/ℓ) was recorded at the Ernest Oppenheimer Bridge at Alexander Bay on 2 February 2000 (See Figure 5B). This high concentration indicates that similar concentrations could have prevailed at all the other sites earlier on in the bloom.

At the Upington, Neusberg North and Pelladrift sites, where measurements were done over a period of time, two chlorophyll a peaks showed in the results (see Figure 5). Volgraafsig and Kanoneiland sites are two balancing dams that are situated close to the river and are filled from the system. The chlorophyll a results at these two dams indicate the effect of the deterioration in water quality due to the impoundment of the river water (Figure 5A).

The dominant phytoplankton species that were recorded during the cyanobacterial bloom in the lower Orange River are *C. raciborskii* (Figure 4c) and an *Oscillatoria* sp (Figure 4d). Both cyanobacterial species have previously been implicated in toxic cyanobacterial incidents (CHORUS and BARTRAM, 1999; WILSON *et al.* 2000). *C. raciborskii* is infamous for its association with a human poisoning incident on Palm Island, Australia, in 1979 (HAWKINS *et al.* 1997). During the incident 148 victims were treated for hepatitis-like symptoms that lasted for between 4 and 26 days.

C. raciborskii is a cosmopolitan species found in tropical, subtropical, and temperate climatic regions. *C. raciborskii* is known to produce saxitoxins (neurotoxins) and an alkoloid hepatotoxin, cylindrospermopsin. The saxitoxins block nerve cell sodium channels, while cylindrospermopsin blocks protein synthesis with a major impact on liver cells (CHORUS and BARTRAM 1999). In pure form, cylindrospermopsin mainly affects the liver, although crude extracts of *C. raciborskii* injected or given orally to mice also induce pathological symptoms in the kidneys, spleen, thymus and heart (HAWKINS *et al.* 1985, 1997). Cylindrospermopsin is also produced by other cyanobacterial species (WILSON *et al.* 2000).

C. raciborskii is identified by the presence of gas vacuoles and by the shape and dimensions of terminal heterocysts, vegetative cells, and trichomes. Two distinctive morphological types, namely strait and coiled trichomes have been described. Both these forms were seen in the water samples taken during the bloom.

Unlike *Microcystis* and *Anabaena* (Figure 4e), *Cylindrospermopsis* does not form a surface scum, where concentrated livestock can consume cells. However, algal cell densities may be very high, and located in a band several metres from the surface in a reservoir (FALCONER, 1997). The cyanobacterial bloom in the Lower Orange River did not form a significant scum (Figure 4a), except at Neusberg Weir (Figure 4f). The slight scum that formed here might have been due to the decomposition of the cyanobacterial bloom.

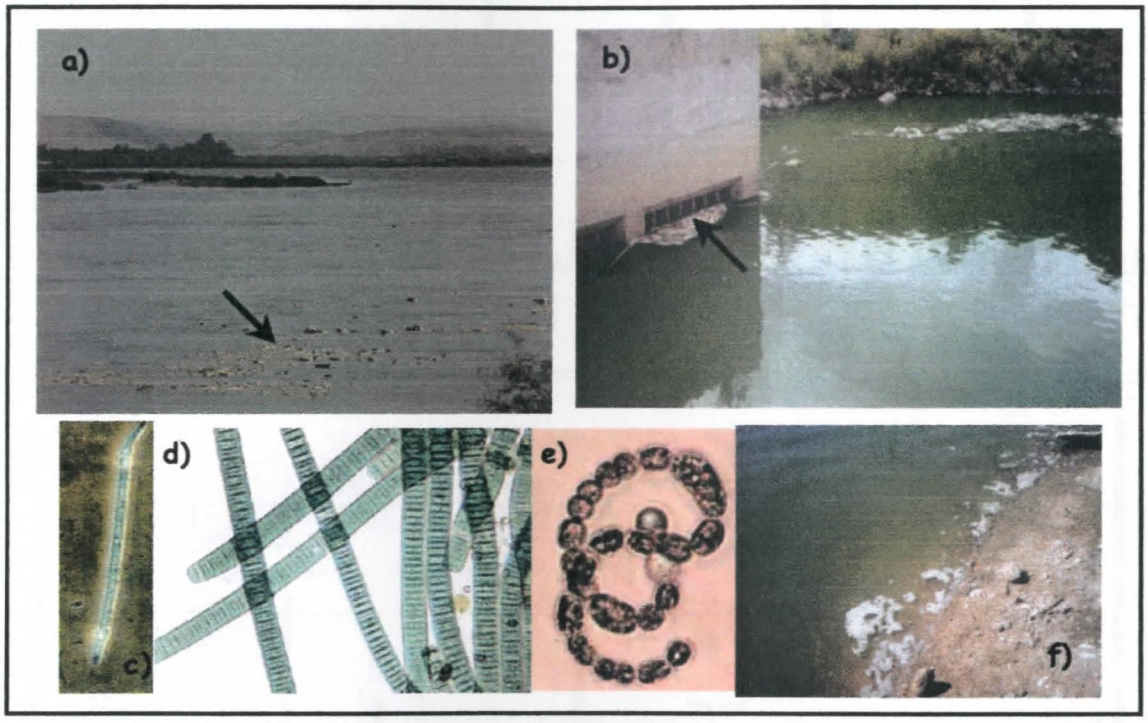


Figure 4. a) The Orange River during the cyanobacterial event close to the Orange River mouth, indicating scum on the water (Photograph by C.E. van Ginkel). b) The fish kill at the Neusberg Weir near the outlet tower (Photograph by B. Conradie). c) *C. raciborskii* (WWW 3). *d) Oscillatoria* species (WWW 4). e) *Anabaena circinalis* (WWW 5). f) Scum near the shore at Neusberg Weir (Photograph be B. Conradie) during the fish kill.

There are a number of synonyms to the species *C. raciborskii*: namely *Anabaena raciborskii* Woloszynska 1912, *Aphanizomenon kaufmanni* Schmidle in Brunnthaler 1914, *Cylindrospermum doryphorum* Bruhl et Biswas 1922, *Anabaenopsis raciborskii* (Woloszynska) Elenkin 1923, *A. seriata* Prescott 1955, *A. koganii*

Obuchova 1964, *A. maksimilianii* Obuchova 1964 or *A. wustericum* Obuchova 1964 (HINDÁK 1988). This indicates also the difficulty with which the specie was identified. The species was unknown to the analysis teams as it has never before been found in South Africa.

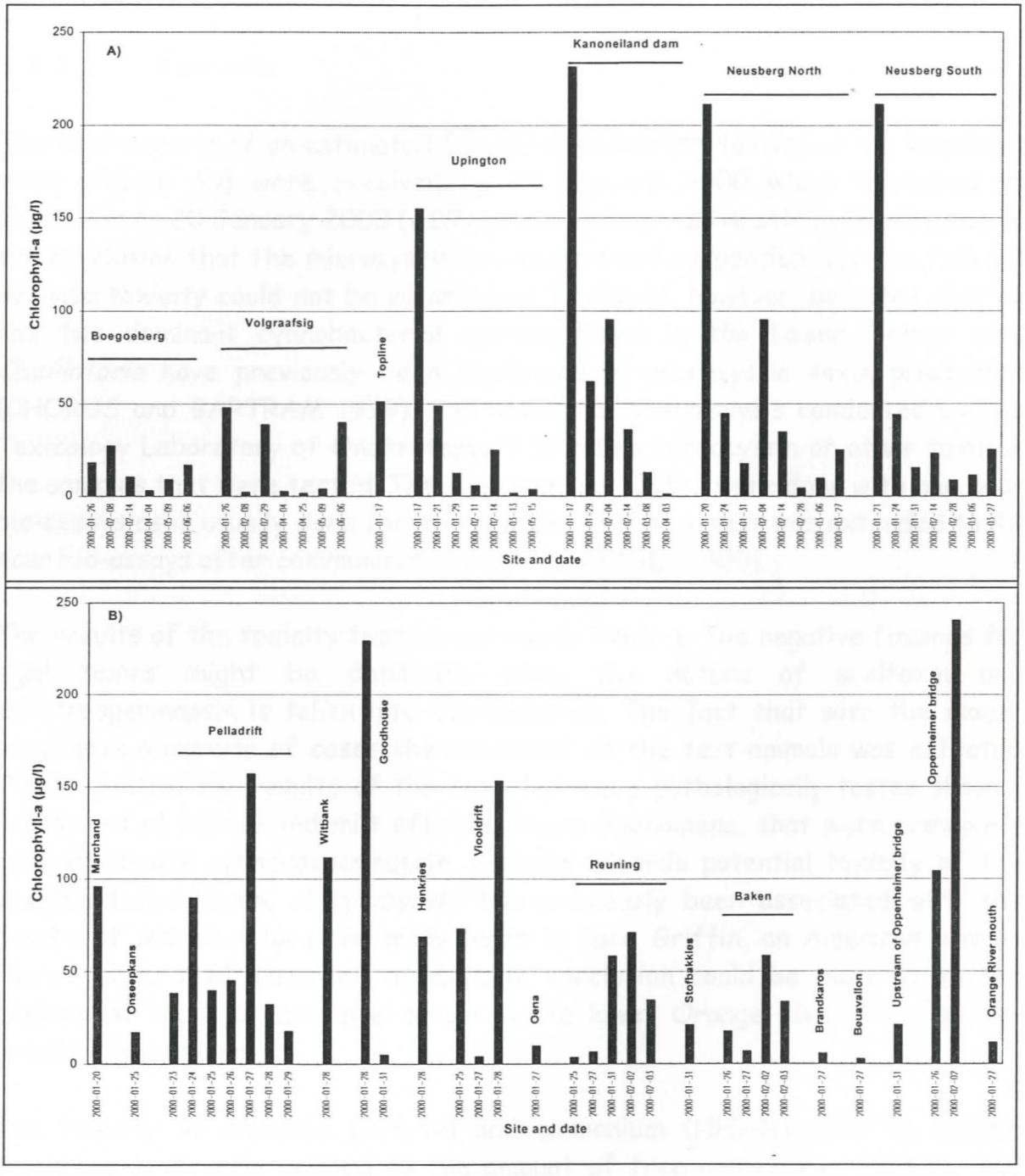


Figure 5. The chlorophyll a concentrations in the Lower Orange River during the phytoplankton bloom in January 2000 and thereafter.

Raw water samples, studied by HINDÁK (1988), had cyanobacterial blooms. In these blooms *C. raciborskii* was found in association with other cyanobacterial species including *Oscillatoria agardii.* MOHAMMED *et al.* (1989) also found in the

Aswan High Dam Lake in the Nile River, that an *Anabaenopsis* sp. and *Oscillatoria* sp occurred in maximum concentrations at below 5 m. Therefore the *C. raciborskii* and *Oscillatoria* species seem to be adapted to survive in light limited conditions. The lower Orange River is known to experience high turbidity. The *Oscillatoria* species in the Lower Orange River bloom was not identified to species level.

5.1.2.2 Fish kills

The first reports of an estimated few hundred fish mortalities at the Neusberg Weir (Figure 4b) were received on 19 January 2000 which increased to thousands on 20 January 2000 (ABRAHAMS 2000). ABRAHAMS (2000) came to the conclusion that the microcystin toxins were not responsible for the fish kill because toxicity could not be established. It should, however, be noted that of the two dominant cyanobacterial species found in the Lower Orange only *Oscillatoria* have previously been implicated in microcystin toxin production (CHORUS and BARTRAM 1999). The results of the analysis conducted by the Toxicology Laboratory of Onderstepoort found no microcystin or other toxin in the samples that were tested. The first samples tested were done with one hour bio-assays as is usually done for microsystin. This hour test was extended to 48 hour bio-assays after communication with HUMPAGE (2000).

The results of the toxicity tests are shown in Table 1. The negative findings for algal toxins might be debatable when the nature of saxitoxin and cylindrospermopsin is taken into consideration. The fact that with the mouse bio-assays a number of cases the movement of the test animals was affected (Table 1). Also the results of the fish that were pathologically testes showed indications of kidney and milt effects. These phenomena, that were previously associated with cylindrospermopsin, indicate towards potential toxicity of the cyanobacterial bloom. *C. raciborskii* has previously been associated with the deaths of 160 alligators and many birds in Lake Griffin, an American lake in Florida (WWW 6). However, no definite conclusion could be made as to the toxicity of the cyanobacterial bloom in the lower Orange River when all the results are considered.

The toxicity of ammonia (NH_3-N) and ammonium (NH_4-N) salts to aquatic organisms is directly related to the amount of free ammonia in solution. The most significant factors that affect the proportion and toxicity of NH_3-N in the aquatic ecosystem are water temperature and pH (DWAF 1996c). Additional environmental factors that also increase the effects of the NH_3-N toxicity are the concentrations of dissolved oxygen (DO), carbon dioxide and total dissolved salts (TDS), and the presence of other toxicants.

Table 1. Results of the Toxicology Laboratory of Onderstepoort done on Orange River water and dead fish during the cyanobacterial event showing the reactions of the mice.

Sample	Date	Liver:mouse (%)	Remarks
River at Upington (water)	2000/1/28	6.2	Uncomfortable (25 min)
Keimoes Network (water)	2000/1/20	6.5	Not affected (50 min)
River at Upington (water)	2000/1/21	6.7	Not affected (50 min)
Keimoes Network (water)	2000/1/20	6.3	Not affected (50 min)
Upington Network (water)	2000/1/21	5.6	Look off colour after 15 min. Move sluggishly after 25 min.
Upington Treatment Works	2000/1/21	6.1	Not affected (50 min)
Neusberg Weir	2000/1/20	5.8	Look off colour after 15 min. Move sluggishly.
Kakamas Network (water)	2000/1/20	6.8	Stomach spasms after 15 min. and move sluggishly
Neusberg North Weir (water)	2000/1/21	5.9	Abdomen breathing after 15 min with severe abdomen spasms.
Neusberg left water	2000/1/21	6	Uncomforable and sluggish after 20 min. Abdomen spasms to one side
Neusberg middle (water)	2000/1/21	5.8	Not affected 35 min.
Sample	**Date**	**Sample no. and remarks**	
Post mortem on fish from Neusberg	2000/1/20	2000/0080 - moderate to severe decomposition, lips oedematous and swollen, milt congestic 2000/0081 - Lightly decomposed; gills extremely congestive, kidneys moderately congestive and fluid in abdomen. 2000/0082-84 - Moderate to severe decomposition, gills congestive, kidneys lightly congestive	

Table 2. The water quality variables implicated in a fish kill at three of the sites in the Lower Orange River in January 2000.

Site	Date	NH_4-N (mg/ℓ)	Calculated NH_3-N (µg/ℓ)	Temp. (°C)	pH	EC (mS/m)	TDS (mg/ℓ)	DO (%)
Neusberg Weir: north	2000-1-19	0.7	51	27.6	8.1	47	306	47.9
Marchand	2000-1-20	1.2	29	28.6	7.2	48	312	43.4
Blouputs	2000-1-22	1.7	41	28.1	7.2	50	325	52.0

NH_3-N affects the respiratory systems of many animals. The Chronic Effect Value (CEV) is 15 µg/ℓ and the Acute Effect Value (AEV) is 100 µg/ℓ (DWAF 1996c). From Table 2 it is apparent that the NH_3-N concentrations at the time of sampling have not reached AEV concentrations but the concentrations were definitely higher than the CEV. If the low concentrations of dissolved oxygen

present at the sites is taken into consideration the fish kills could have been caused by a combination of high NH_3-N, low DO and potentially also the toxicity of the cyanobacterial biomass. The die-off of the phytoplankton population (See the Phaeophytin a concentrations in Figure 6) may have released nutrients into the system that would have increased the NH_3-N concentrations in the system as well. The conclusion of ABRAHAMS (2000) "The most likely cause of the fish mortality, are sudden changes in water quality parameters (NH_3-N and DO) resulting from the high incidence of blue-green algae" is, therefore, supported, although the potential toxicity of the cyanobacterial bloom can not be ignored.

The fish mortality data indicated that the large cyprinid, *Labeo capensis*, was most commonly killed in the incident. Other fish species amongst which mortality occurred are *Barbus aeneus*, *B. Kimberleyensis*, *Clarias garipinus*, *Cyprinus carpio* and *Mesobola brevianalis* (ABRHAMS 2000).

5.1.3 Water quality related impacts in the Lower Orange River

The Lower Orange River is not known to experience eutrophication problems. Whenever water quality issues were described in earlier reports, only salinity was addressed (DWAF 1999) as it was the major water quality concern. As the Lower Orange River is known to be a turbid system, eutrophication has not previously been a water quality concern, and, therefore, the algal bloom that occurred in the river was unexpected.

Selected water quality variables in the Orange River as well as the symptoms of eutrophication that prevailed in the river during the incident, and in some cases where monitoring was continued thereafter, are discussed. This section are subdivided into different sites that will be discussed in terms of chemical characteristics (nutrients and salinity) and biological characteristics (chlorophyll a, algal species and fish kills.

The chemical characteristics comprise of the nutrients and the salinity of the Lower Orange River and are compared to the prevailing chlorophyll a concentrations at specific sites on the River from Boegoeberg Dam downstream to Pelladrift.

5.1.3.1 Boegoeberg Dam

Boegoeberg dam wall is 9 m high and the impoundment has a capacity of 21×10^6 m^3 live storage capacity. Boegoeberg Dam (Figure 6) was sampled from 26 January 2000 and monitored until 6 June 2000. The total phosphorus concentrations showed a peak (1000 $\mu g/\ell$ P) during mid February. Thereafter the

concentrations decreased to very low concentrations and started increasing again towards June.

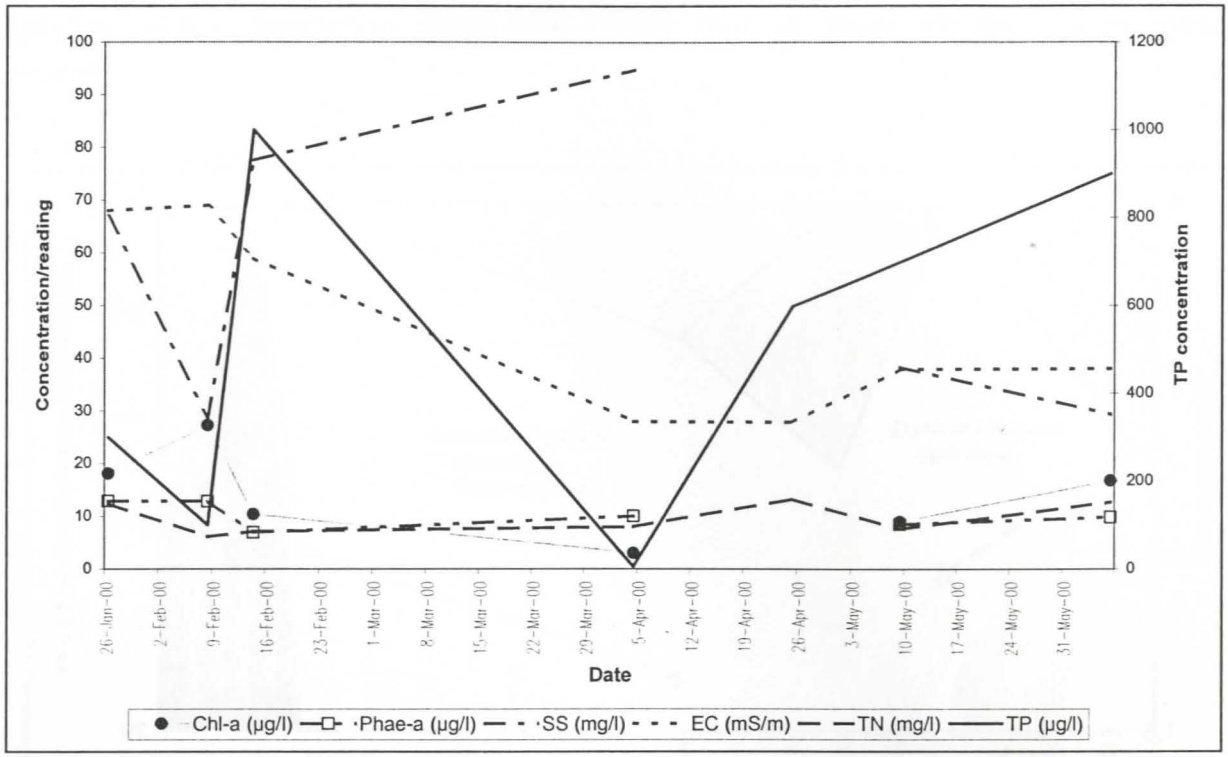


Figure 6. Comparison of the chlorophyll a, phaeophytin a, suspended solids (SS), electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP) in the Boegoeberg Dam from 26 January to 6 June 2000. Measurement units are shown in the legend.

The highest chlorophyll a concentration (27.3 µg/ℓ) in the Boegoeberg Dam occurred when the total phosphorus levels were low (on 14 February 2000). The EC concentration was highest during the peak in chlorophyll a concentration in the Boegoeberg Dam. The SS concentration was at its lowest during the peak chlorophyll a concentration indicating that the increase in light penetration due to lower turbidity might be responsible for the higher phytoplankton concentration. The actual cause of the lower SS concentration is not known, but may be due to increased volumes of water with lower turbidity.

High TN concentrations also prevailed during the sampling period (Figure 6). The TN:TP ratios in the impoundment were consistently above 10 except during 14 February 2000 when the ratio was 7.1. Whenever the ratio is below 10 it has been indicated to favour the development of cyanobacterial dominated blooms (WETZEL 1983).

The composition of the phytoplankton population during the sampling period is shown in Figure 7 and it is evident that the cyanobacterial bloom was caught in its final stage as it disappeared from the site during mid February 2000. The

phytoplankton population changed from cyanobacterial dominance to being dominated by Chrysophyta species, namely *Melosira* and other diatoms and then later by *Cyclotella* (Figure 7). There was, therefore, a significant change in the phytoplankton population since the Lower Orange River phytoplankton bloom event.

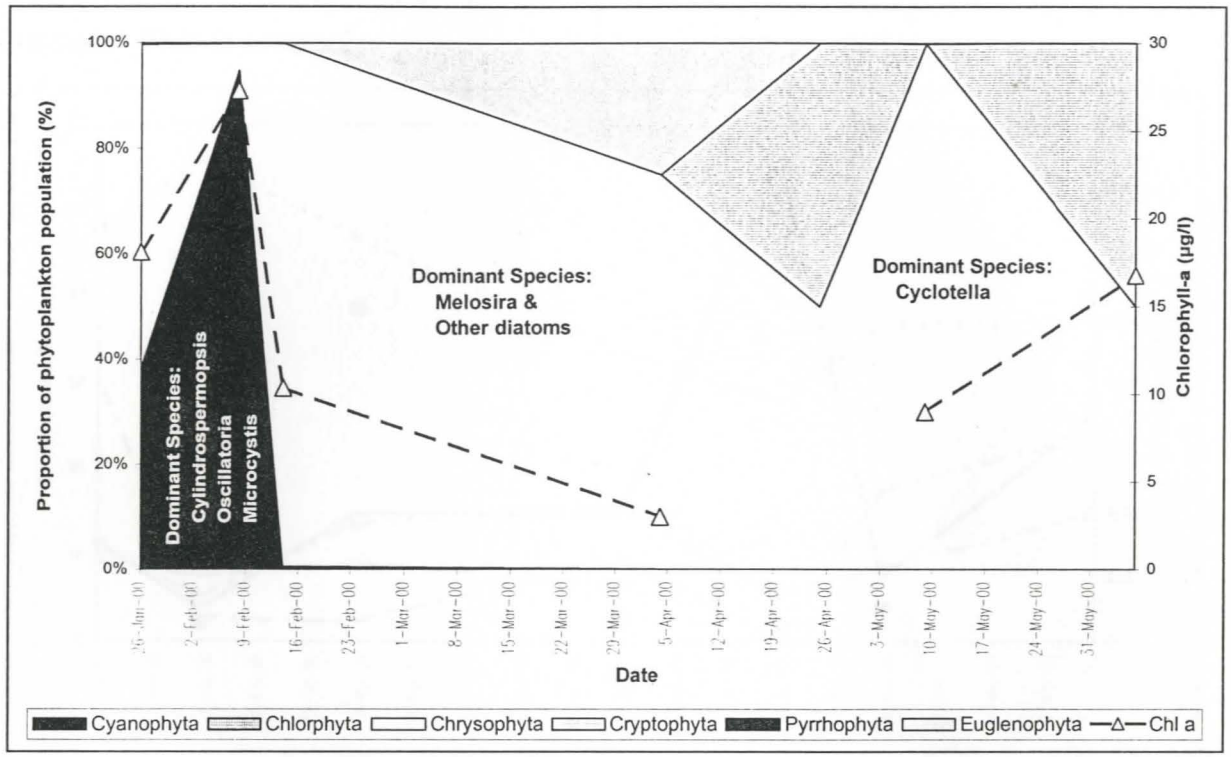


Figure 7. The phytoplankton composition in the Boegoeberg Dam from 26 January 2000 to 6 June 2000 compared to the chlorophyll a concentrations.

5.1.3.2 Volgraafsig Dam

The Volgraafsig Dam is situated downstream of the Boegoeberg Dam and is used as a storage reservoir for irrigation purposes. This site is, therefore, not reflecting the situation within the river but might show delays due to the fact water is stored in this dam for the irrigation purposes.

The total phosphorus concentrations (Figure 8) show a peak (1500 µg/ℓ P) during April 2000. Before and thereafter the concentrations were low when compared to the peak, but still indicated eutrophic conditions.

Three peaks in chlorophyll a concentration (> 30 µg/ℓ) are evident in Figure 8. The impoundment can therefore be classified as eutrophic when the phosphorus and the chlorophyll a concentrations are considered.

The EC readings vary between 28 mS/m and 54 mS/m. This phenomenon is not indicative of a saline system.

The TN concentrations in the Volgraafsig Dam vary between 6.3 and 14.4 mg/ℓ. These are very high concentrations. The TN:TP ratios were only once during sampling lower than 10 on 25 April 2000. Therefore, the TN:TP ratio was indicative of a phosphorus limited system during the cyanobacterial bloom incident. This is unusual

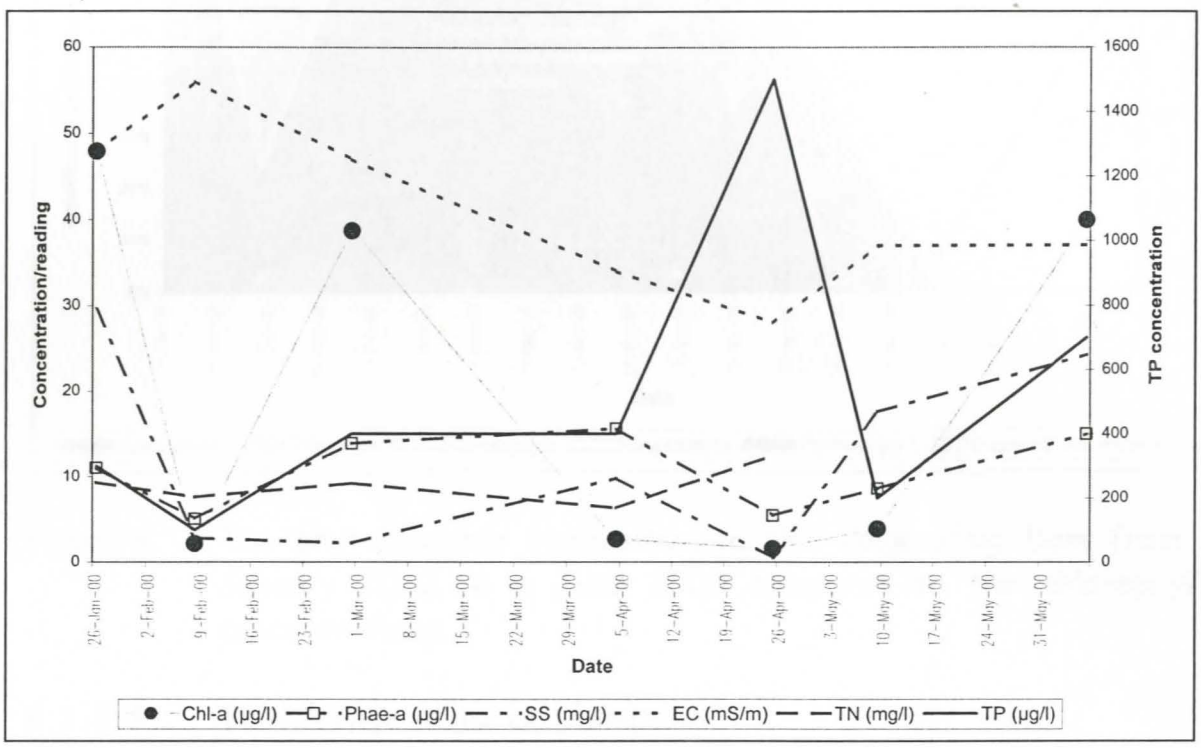


Figure 8. Comparison of the chlorophyll a, phaeophytin-a, suspended solids (SS), electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP) in the Volgraafsig Dam from 26 January to 6 June 2000.

The phytoplankton population composition in the Volgraafsig Dam is shown in Figure 9. The cyanobacterial bloom prevailed in the Volgraafsig Dam until April 2000. The dominant species in the system during this bloom was again *C. raciborskii* and an *Oscillatoria* species. During May 2000 the cyanobacterial dominance was replaced by a Chlorophyta increase and then a Chrysophyta species, *Cyclotella* dominated.

This period, when compared to other sites, of much longer presence of the cyanobacterial species is due to the relative stagnant nature of an impoundment like the Volgraafsig Dam. The algal species were not transported downstream by high flows, but did manage to develop further in the impoundment. This phenomenon might also react as a feeding system of the nuisance cyanobacterial

species that prevailed in the system for a much longer period while water were continuously discharged back into the river.

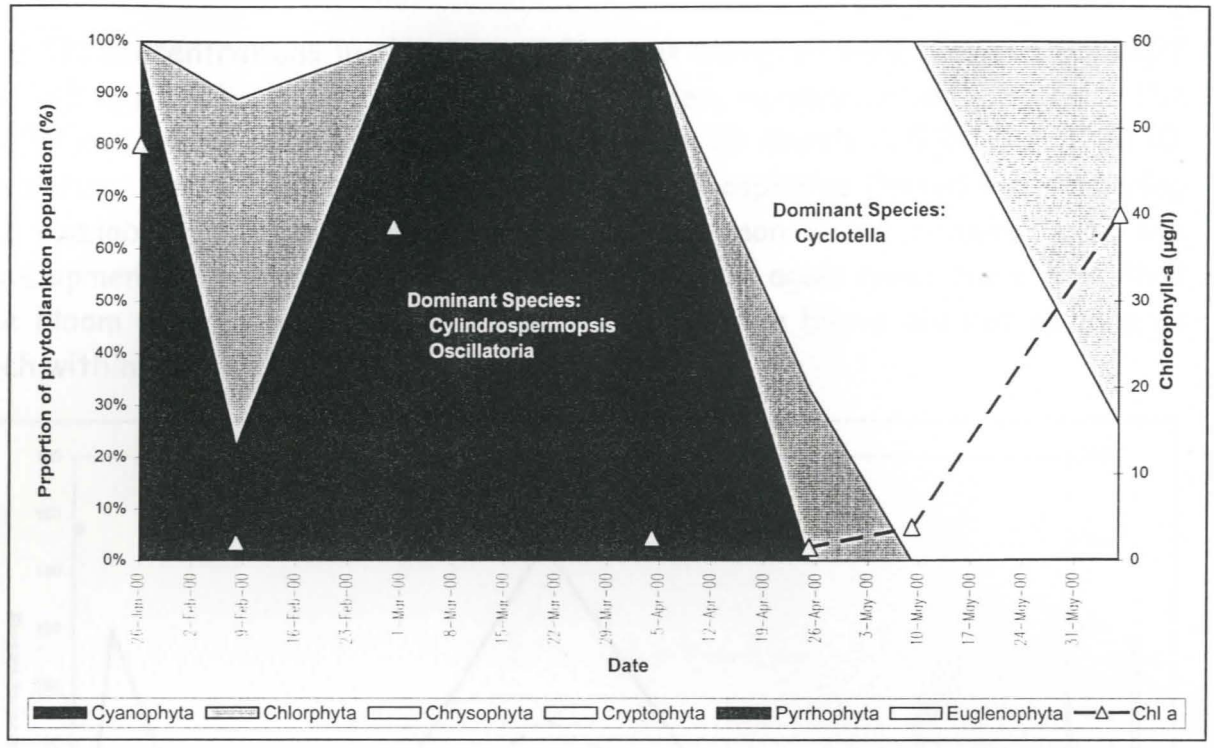


Figure 9. The phytoplankton composition in the Volgraafsig Dam from 26 January 2000 to 6 June 2000 compared to the chlorophyll a concentrations.

5.1.3.3 The Orange River at Upington

The sampling site on the Orange River at Upington is situated at the bridge crossing the river to Groblershoop. This is a river site and the nature of the site is therefore not comparable to an impoundment or a weir. The river is wide and often flowing at low velocities.

The TP concentrations showed two peaks (Figure 10). The first peak (800 µg/ℓ) was prevalent in January 2000 and the second peak (1000 µg/ℓ) passed through the system during March 2000. The second peak is not associated with high flow, but rather with lower flows that occurred in March 2000.

The chlorophyll a concentrations showed a peak (150 µg/ℓ) on the 17 January 2000. Concentrations decreased thereafter to 5.51 µg/ℓ. A second peak was prevalent on 14 February 2000 at 24.8 µg/ℓ.

The EC readings vary between 28 mS/m and 75 mS/m. These readings show that the system is not saline, but that there is saline discharges into the river

between Boegoeberg and Upington. The cause of this increase in salinity is most probably due to irrigation return flows.

The TN concentrations in the Orange River at Upington vary between 0.2 mg/ℓ and 4.3 mg/ℓ. The peak should not cause major, eutrophication problems. The TN:TP ratio were only once during sampling (on 13 March 2000) lower than 10. Therefore, the TN:TP ratio was indicative of a phosphorus limited system during the cyanobacterial bloom incident. This phenomenon is not favourable to the development of cyanobacterial species and indicates again towards the fact that the bloom was a flood related incident and that the bloom did not develop as such within the river.

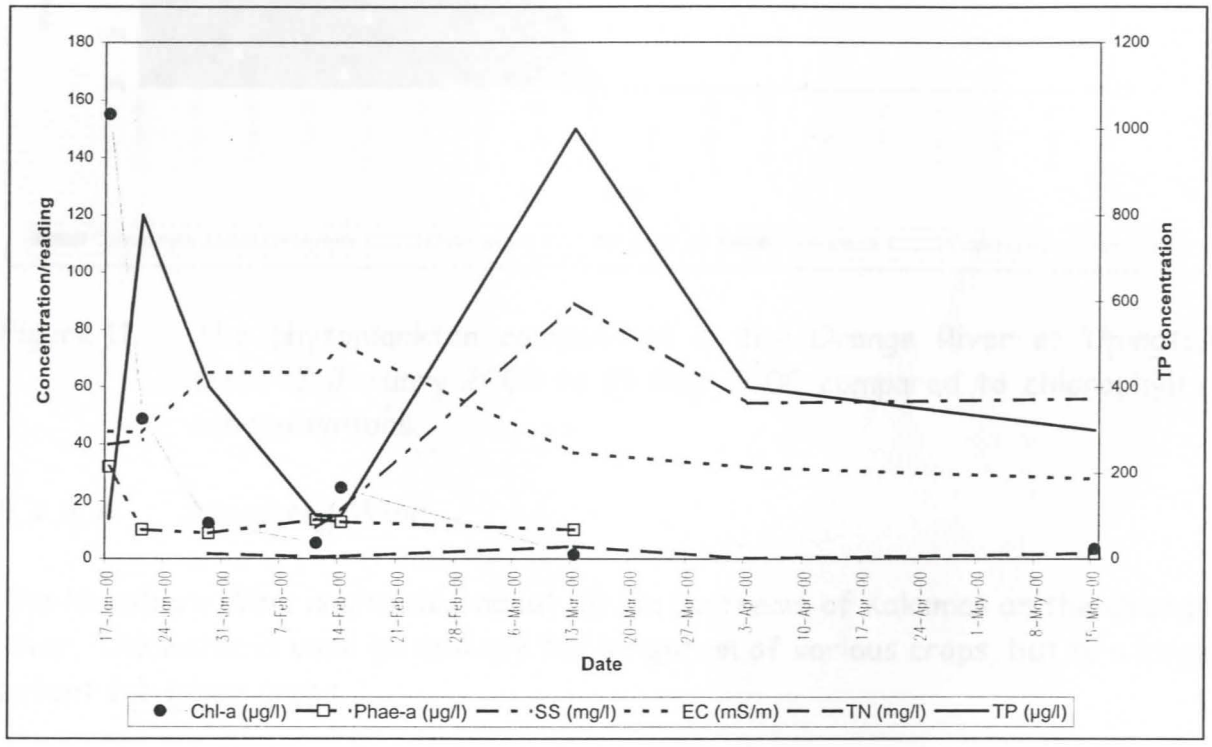


Figure 10. Comparison of the chlorophyll a, phaeophytin a, suspended solids (SS), electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP) in the Orange River at Upington from 26 January to 6 June 2000.

The phytoplankton population in the Orange River at Upington is shown in Figure 11. It is apparent that two peaks of cyanobacterial dominance was associated with the two chlorophyll a peaks that occurred in the Lower Orange River. *C. raciborskii* was again in association with *Oscillatoria* responsible for the peak chlorophyll a concentrations.

The cyanobacterial species was replaced successively by *Euglena* and *Cyclotella* as the dominant algal species since 13 March 2000 when the chlorophyll a concentrations decreased to 1.44 µg/ℓ.

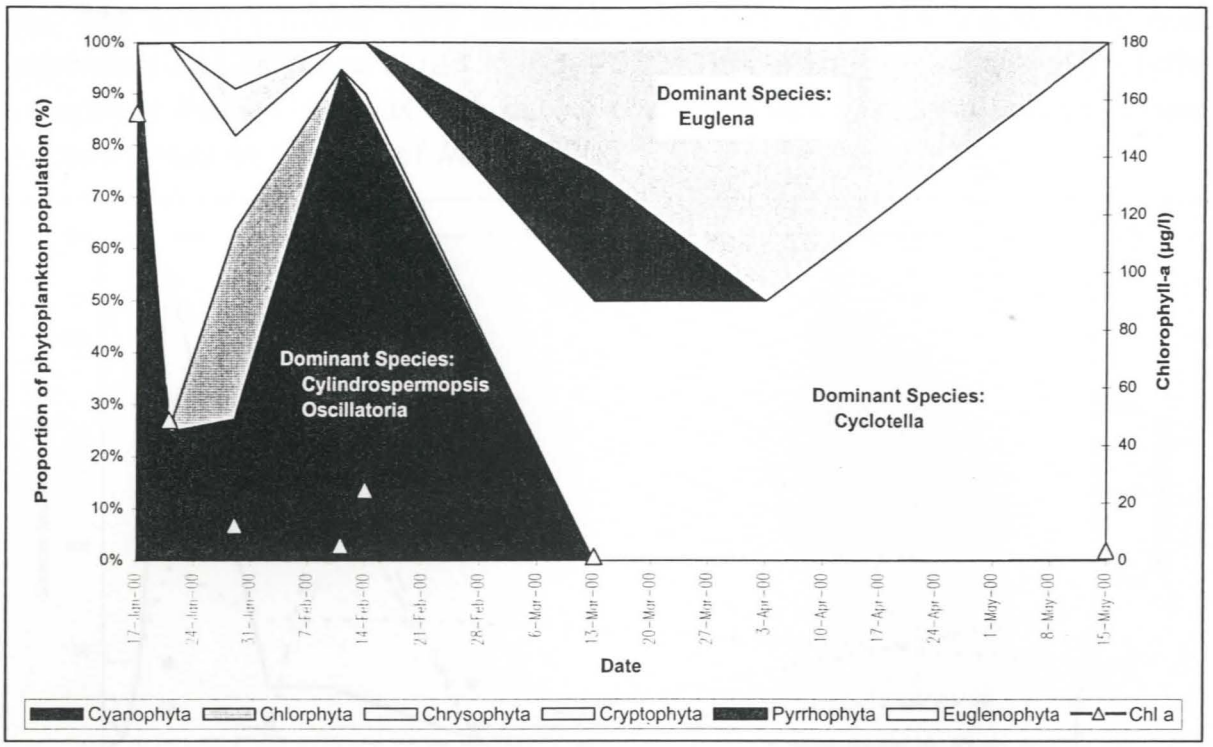


Figure 11. The phytoplankton composition in the Orange River at Upington from 17 January 2000 to 15 May 2000 compared to chlorophyll a concentrations.

5.1.3.4 Neusberg Weir

The Neusberg Weir is situated about 20 km upstream of Kakamas on the Orange River. The water is used intensively for irrigation of various crops, but to a large extent for grape crops.

TP concentrations (See Figure 12) at the Neusberg Weir peaked (2800 µg/ℓ P) on 21 January 2000 and decreased thereafter to below 500 µg/ℓ P. These concentrations are still very high. TP concentrations of such a nature would lead to nuisance algal bloom development, if the nutrient concentrations are not managed to acceptable levels and is not light limited.

The chlorophyll a concentrations showed two peaks, namely the first peak (211 µg/ℓ) on 20 January 2000. The second peak (95 µg/ℓ) in chlorophyll a concentrations occurred on 4 February 2000. These peaks are associated with the first flooding event that was measured at the Neusberg Weir (See Figure 3).

The EC measurements at the Neusberg Weir peaked (91 mS/m) on 24 January 2000 after which it decreased to below 40 mS/m. The highest salt content was, therefore, associated with the first flood during the end of January 2000.

The TN concentrations vary between 3.6 mg/ℓ and 13.4 mg/ℓ. The peak concentration was found on 28 March 2000. This is thus an indication that the nitrogen in the system was high during the event but increased only to serious concentrations at the end of March 2000.

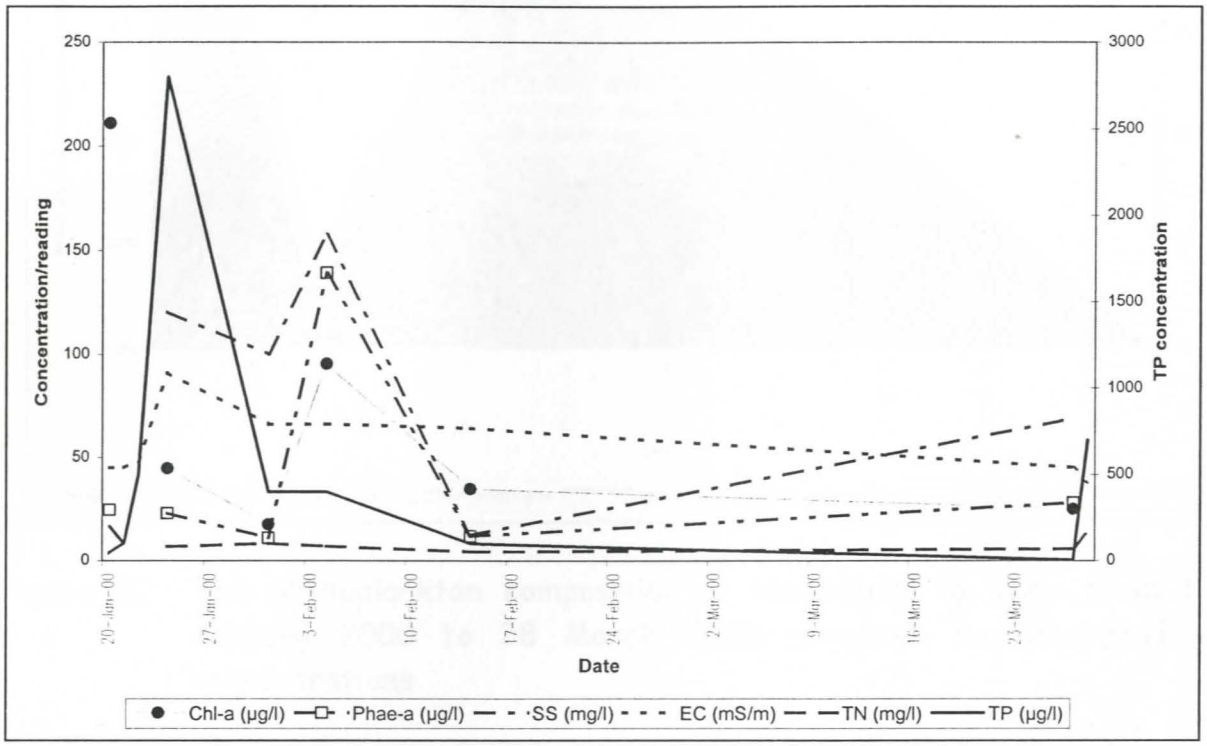


Figure 12. Comparison of the chlorophyll a, phaeophytin a, suspended solids (SS), electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP) at the Neusberg Weir from 26 January to 6 June 2000.

The phytoplankton population during the time of the cyanobacterial event and the consecutive sampling are shown in Figure 13. Again as in the phytoplankton population at Upington two peaks in cyanobacterial blooms are indicated.

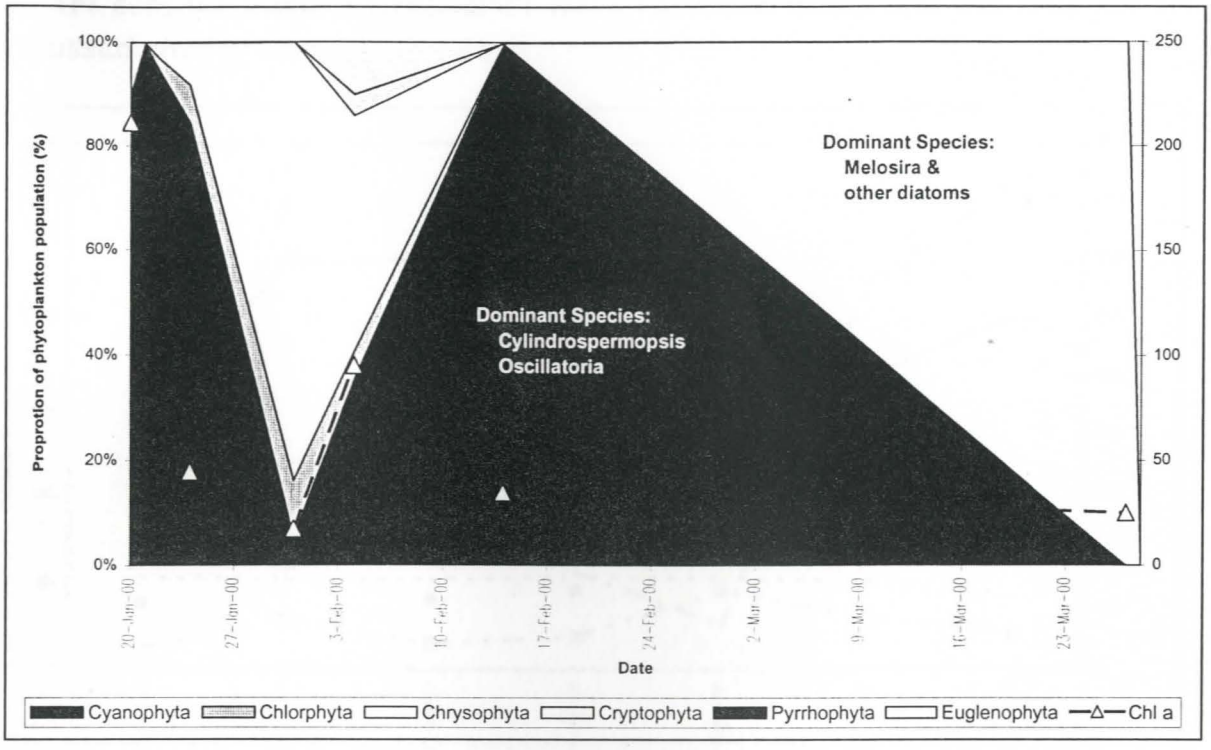


Figure 13. The phytoplankton composition at the Neusberg Weir from 17 January 2000 to 28 March 2000 compared to chlorophyll a concentrations.

5.1.3.5 Pelladrift

Pelladrift Water Board is situated between Upington and Alexander Bay on the Orange River. There is a WCW located at this site that provides treated water to Pella and the surrounding mining communities.

The sampling at Pelladrift was done over a week period during the main algal bloom incident at the end of January 2000.

The TP concentrations (see Figure 14) were high and varied between 400 µg/ℓ and 800 µg/ℓ. These concentrations would support large algal blooms if located within an impoundment, where the more stagnant nature of the water will favour algal development.

The chlorophyll a concentrations (Figure 14) in the Orange River at Pelladrift peaked twice. The first time on 25 January 2000 (89,7 µg/ℓ) and the second time on 27 January 2000 (157.1 µg/ℓ).

The EC readings in the Orange River at Pelladrift varied between 41 mS/m and 53 mS/m and showed no significant changes during this period.

The TN concentrations at Pelladrift were not determined and will thus not be discussed any further.

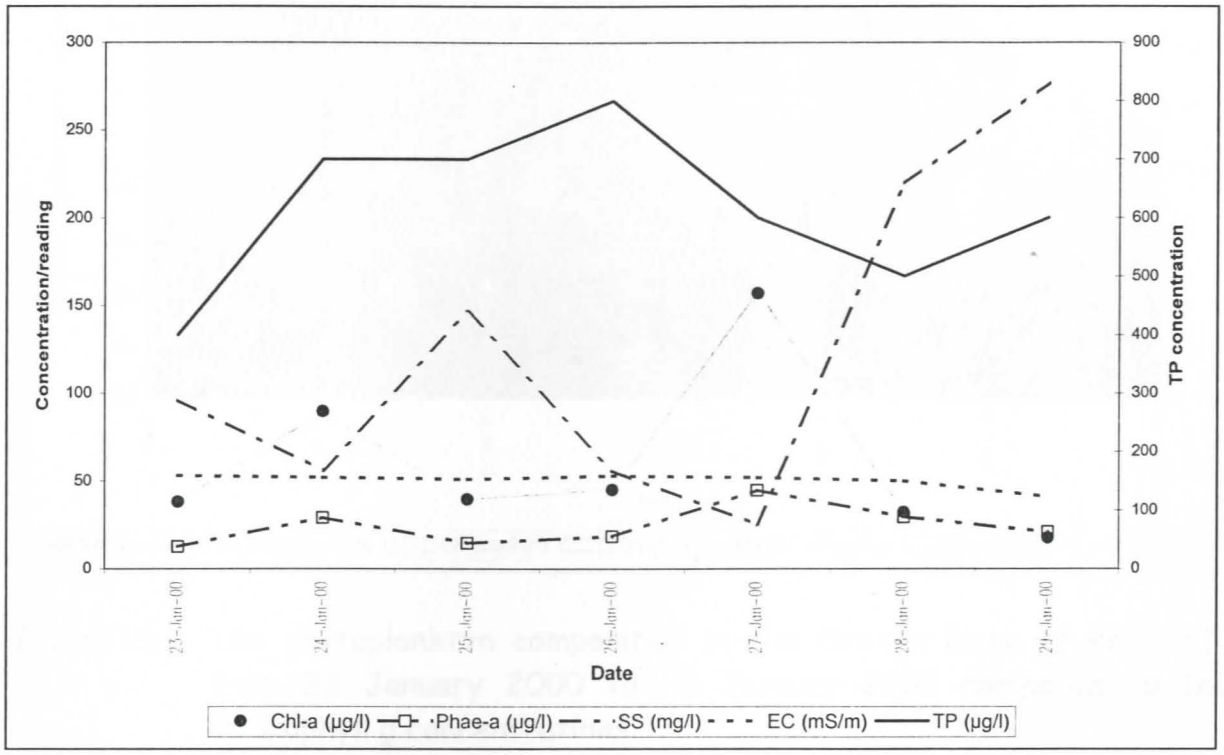


Figure 14. Comparison of the chlorophyll a, phaeophytin a, suspendid solids (SS), electrical conductivity (EC) and total phosphorus (TP) in the Orange River at Pelladrift from 23 January to 29 January 2000.

The composition of the phytoplankton population changes at Pelladrift is shown in Figure 15. During most of this period the dominant species in the Orange River was again *C. raciborskii* and the *Oscillatoria* species. The dominance of the cyanobacterial species was replaced by a variety of other algal groups at much lower chlorophyll a concentrations (17 µg/ℓ). Throughout this week the chlorophyll a concentrations present were indicative of nuisance eutrophication symptoms.

According to ABRAHAMS (2000) a fish kill was also reported at this site.

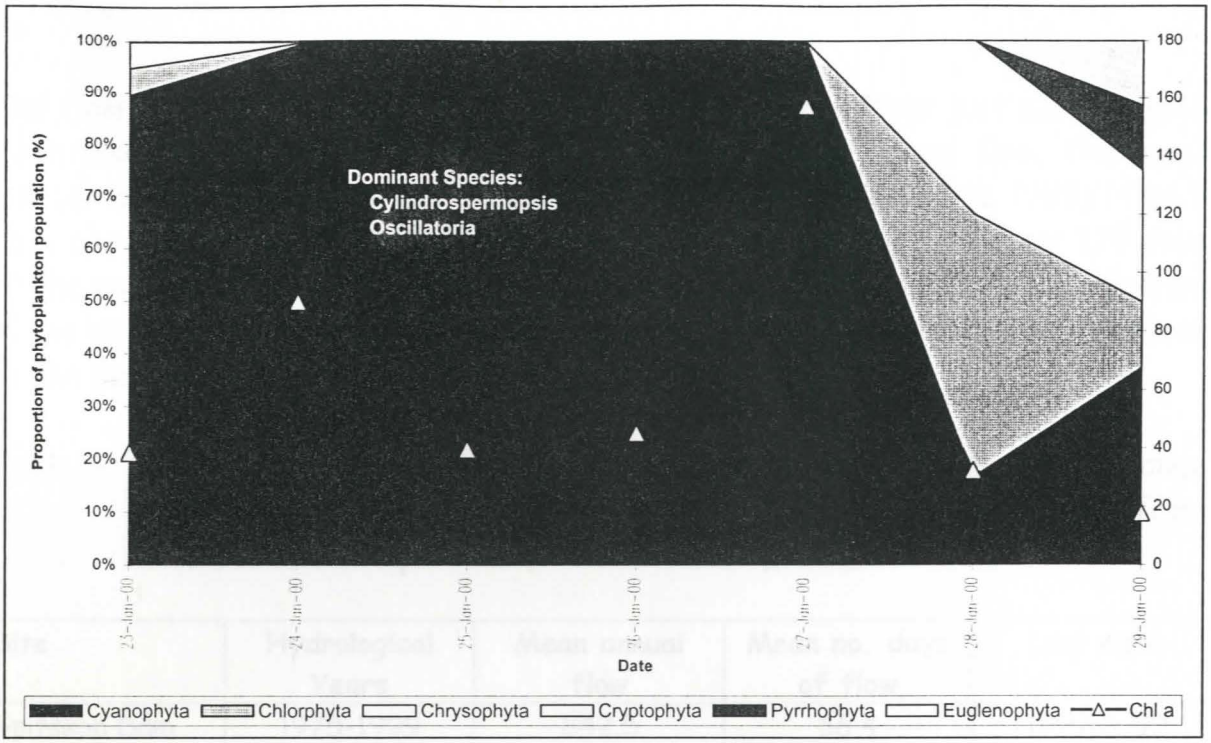


Figure 15. The phytoplankton composition in the Orange River at Pelladrift from 23 January 2000 to 29 January 2000 compared to the chlorophyll a concentrations.

5.2 Historical Data Analysis

Historically no eutrophication related problems occurred in the Lower Orange River. This section of the report addresses the historical situation in the Harts, Vaal and the Orange Rivers, related to all relevant water quality variables. The section includes the assessment of the historically available flow and chemical data.

5.2.1 Historical Flow Data

The historical flows in the tributaries and in the Orange River are discussed briefly to determine the potential for the incident in terms of the cyanobacterial bloom to re-occur.

Table 3 indicates clearly that the mean annual flow from the Spitskop Dam is half of the flow that was measured from 1999-10-01 to 2000-7-13. It was, therefore, an exceptionally high rainfall year. The number of days that flow was recorded at the Spitskop Dam is also 343.4 % of the normal.

The flow in the Lower Orange River at Upington was not exceptionally high when compared to the mean annual flow that was determined for a period of 57 years. The mean annual flow was actually slightly lower than normal. The Lower Orange River is a perennial river and flows throughout the year (Table 3).

The flow in the Fish River that enters the Lower Orange River just east of Rosh Pinah also had flows that were double the normal mean annual flow. The mean number of days that flow was measured in the Fish River (1927 to 1999) is 24.2 days per year. Since 1999-10-01 to 2000-05-10 flow was found to occur 179 days of the year. However, because the Fish River only enter the Lower Orange System in the last stretch before it flows into the ocean, it could only have had an effect at the Baken and the Orange River mouth sites.

Table 3. The historical flow statistics for the Spitskop Dam, the Orange River at Upington and the Fish River compared to the flow from 1999-10-01 to present (and as available).

Site	Hydrological Years	Mean annual flow	Mean no. days of flow	Last date
Spitskop Dam	1975-1999	842.5	66.4	1999-9-30
	1999-2000	1770.1	228.0	2000-7-13
Orange River at Upington	1942-1999	99999.7	355.1	1999-9-30
	1999-2000	94800.1	354.0	2000-9-18
Fish River (Namibia)	1927-1999	161.9	24.2	2000-9-30
	1999-2000	339.8	179.0	2000-5-10

Only some of the rivers in the Lower Orange catchment experienced much higher than normal flow when compared to historical data, specifically the Harts River (Spitskop Dam data) and the Fish River. In the Hartbees River flow was also measured for the first time since 1988.

5.2.2 Historical Chemical Data

5.2.2.1 Salinity

Salinity has been considered the major water quality problem in the Orange River system (DWAF, 1999). A comparison of the available historical data to the South African Water Quality Guidelines, indicate that the target water quality guidelines for domestic use, irrigation use and industrial use are exceeded from time to time at all monitoring stations.

Since the mean or median concentrations should be compared to the guidelines, a summary of median concentrations for monitoring points in the Harts, Vaal and Orange Rivers are presented in Figure 16.

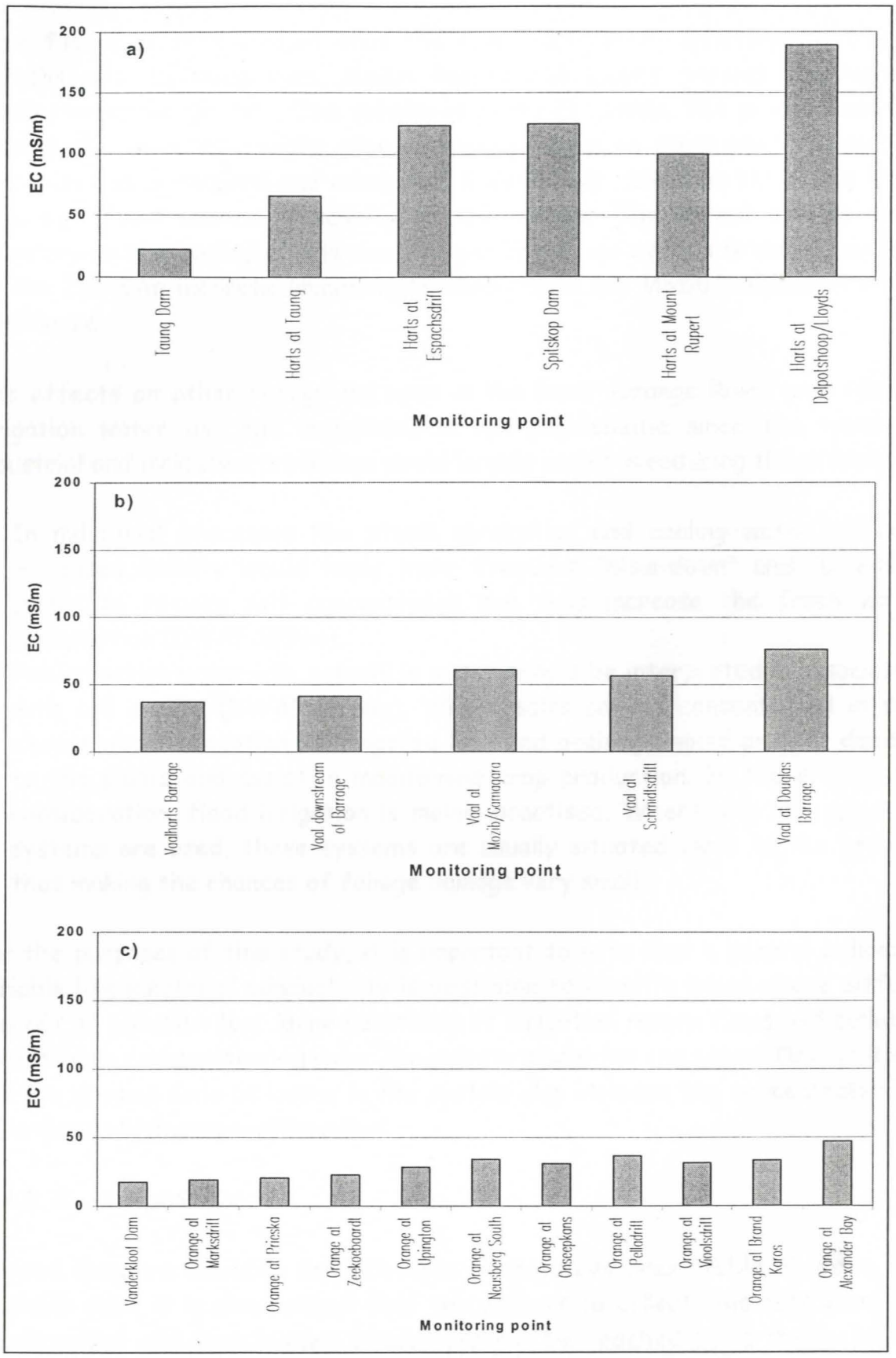


Figure 16. Historical median EC (mS/m) concentrations in the a) Harts River, b) the Vaal River and c) the Orange River. All available data were used.

From Figure 16 it is evident that the four Harts River Monitoring points at Espachsdrift, Spitskop Dam, Mount Rupert and Lloyds present the highest salinity recorded to date. The salinity is worst at Lloyds. The yellow class for potable use indicates a slight adverse taste problem at times when the median concentration is reached and exceeded, it definitely identifies the Harts River as a significant source of salinity to the system. The effect of this small tributary on the quality of the much larger Vaal River system is clearly evident by the 20mS/m increase immediately downstream (at Mozib/Gamagara) of its confluence.

The effects on other recognised uses in the lower Orange River area (mainly irrigation water use and industrial) is not problematic since the types of industrial and irrigation processes would largely assist in reducing the effects:

- In industrial processes like steam generation and cooling water systems, increased salinity would imply more frequent "blow-down" and "bleeding" cycles to remove salt concentrates and thus increase the fresh water consumption (DWAF 1996a).
- For irrigation water use, salinity in water should be interpreted in association with soil quality (DWAF 1996b). Where salts can be concentrated in soil, excess water allocation to irrigated land and drainage would prevent damage to the plants and assist in maintaining crop production. In the area under consideration, flood irrigation is mainly practised. Where drip and sprinkler systems are used, these systems are usually situated close to the ground, thus making the chances of foliage damage very small.

For the purposes of this study, it is important to note that a general indicator variable like electrical conductivity is best able to identify areas where diffuse sources of pollution (e.g. large quantities of irrigation return flows and polluted runoff from communities) occurs. The salinity model for the Lower Orange River and the studies done on losses in the system also included the concentration of salts due to high evaporation rates.

5.2.2.2 Nutrients

Limited data are available for nutrients in the study area (Table 4). From the available data, it is also evident that the efforts to collect this data were not synchronised and thus limited conclusions can be reached using the historical data. One question (almost an accusation from frustrated and concerned City Engineers of local authorities and operators of WTW's) to the Department, was whether the event of January/February 2000 could have been predicted. From

the available data, it is evident that no description of extended periods of high nutrient concentrations could be supplied.

Table 4. Statistics of the TN:TP ratio at selected sites in the Lower Orange River catchment for full record available on WMS.

Site	Minimum	Median	Maximum	Number of data (n)
Taung Dam	14.9	23	28.7	4
Spitskop Dam	6.8	10.2	21.4	5
Vaal Downstream of Barrage	9.90	17.8	44.45	15
Vaalharts Barrage	6.89	15.2	27.92	16
Mozib/Gamagara	2.6	15.9	41.6	18
Douglas Barrage	14.3	21.0	21.4	3
Van Der Kloof	14.5	20.1	25.4	11
Boegoeberg	-	6.31	-	1
Upington	3.9	11.5	29.9	102
Brandkaros	9.41	9.64	9.93	3
Pelladrift	4.79	8.0	9.44	7
Vioolsdrift	2.3	8.7	55.3	298

Harts River Monitoring Points

Of the selected monitoring points, only the data records of Taung and Spitskop Dams in the Harts River contain nutrient data. Four weekly samples were taken in September 1979 in the Taung Dam. The TN:TP ratios in all samples were above 10, although just two of these were (very slightly) above 25. These values are used to determine whether a system is impacted or not through nutrients where a ratio of less than 10 indicates eutrophic or hyper-eutrophic conditions and ratios higher than 25 and 40, can be considered not yet too much impacted upon (DWAF 1996c).

At Spitskop Dam, sampling was only done on three days in October 1997. Although the first two samples have ratios more than ten, the ratios were less than 25. Three samples taken at 0m, 2m and 4m in the impoundment had ratios less than 10.

Vaal River Monitoring Points

The records of Vaal Barrage and the monitoring point downstream of the Barrage contain fifteen records each. Most of these were taken late in 1979. Three of the samples (two in the Barrage record and one in the river record) have ratios less than 10. Very few records (and mainly those at the river points) have ratios more than 25.

Eighteen records (summer 1988/89) are available for the Mozib/Gamagara monitoring point in the Vaal River immediately downstream of the confluence of the Harts and Vaal Rivers. Ratios, from August to the beginning July, were mainly below 10. Only four ratios exceeded 25.

Three records are available for Douglas Barrage, with none containing ratios below 10 or above 25. The data were collected in 1984 (2 samples) and 1999.

Orange River Monitoring Points

The record for Vanderkloof Dam contains eleven analysis results for nutrients (mainly in 1986). None of these had ratios less than 10, but only one reached the 25 ratio.

For Boegoeberg, only one sample was taken in 1986 with a ratio less than 10.

The records of Upington contain one hundred and two records for total nutrients. This data were taken from 1993 to 2000. The TN:TP ratio was less than 10 in 37 of the samples.

Data at Brand Karos were collected in 1995. Three samples were analysed for nutrients of which all contained ratios of less than 10.

The latest data available, is for the Pelladrift monitoring point where analysis results are available for May and June 2000. All these samples have ratios less than 10.

The data record for the Orange River at Vioolsdrift contains two hundred and ninety eight records for total nutrients over the period 1980 to 2000. Of these samples one hundred and eighty seven have ratios less than 10.

5.2.3 Historical Biological Data

5.2.3.1 Algal identification and quantification

No historical information on the phytoplankton population of the Lower Orange River could be found. The nearest site to the lower Orange River where algal data have been collected is the Bloemhof Dam in the Vaal River. Although Bloemhof Dam is known for toxic algal blooms (VAN GINKEL *et al.* 2000) *C. raciborskii* was not historically present (or might have been wrongly identified as *Oscillatoria*) in the impoundment. The cyanobacterial species responsible for the historical toxic blooms in Bloemhof Dam is *Microcystis auriginosa*, a species that were only found in small concentrations in the Orange River at Upington during the bloom.

The Vanderkloof Dam is not known to have major algal blooms and, therefore, most probably did not cause the cyanobacterial bloom downstream in the Lower Orange River. However, it must be noted that no recent algal monitoring was conducted on this impoundment.

The Spitskop Dam in the Harts River was the only impoundment where similar phytoplankton compositions were found during a preliminary, once-off cyanobacterial screening survey in March 2000. The bloom that occurred in the Orange River thus originated not from the Vaal or the Orange River but from the Harts River.

5.2.3.2 Macro-invertebrate data

PALMER (1996) conducted an intensive literature survey on the invertebrates in the Orange River listing all the species found and can be used in future investigations as a reference list. This study concluded that the river is characterised by low numbers of species. The fauna was dominated by filter-feeders. None of the taxa was considered to be endemic, although *Simulium gariepense* is believed to be restricted to the Orange River (PALMER 1996).

Of the invertebrate species found in the Orange River one is a serious pest (*Simulium chutteri*) and at least fourteen are potential disease vectors.

5.2.3.3 Fish data

The Orange River fish fauna is well adapted to the unpredictable flow regime of the system. Increased flow rates and floods occur mostly during spring and summer (CAMBRAY 1984, BENADE 1993, ABRAHAMS 2000) as the river is regulated by man-made impoundments in the upper catchment.

Benade (1993) conducted a comprehensive fish survey in 1989 and ABRAHMS (2000) followed this up with a survey of the Lower Orange River with a seine net during January 2000.

The Orange River system has a low, ichtyo-faunal diversity. The Lower Orange River contains 12 of the 16 indigenous freshwater species found in the Orange River system (See Table 2).

According to ABRAHAMS (2000) the once-off sampling survey of the fish fauna in January 2000 is insufficient to determine the health of the fish population in the Lower Orange River. He recommended that freshwater fish species should be included in any long-term biomonitoring programme for the Middle and Lower Orange River.

Table 2. A summary of the indigenous fish species inhabiting the Lower Orange River (Taken from ABRAHAMS 2000).

Common Name	Scientific Name	Conservation Status
Smallmouth yellowfish	*Barbus aeneus*	Endemic (Orange-Vaal)
Namaqua barb	*B. hospes*	Endemic (Lower Orange)
Largemouth yellowfish	*B. kimberleyensis*	Endemic (Orange-Vaal)
Straightfin barb	*B. paludinosus*	Indigenous
Threespot barb	*B. trimaculatus*	Indigenous (isolated)
River sardine	*Mesobola bevianalis*	Indigenous (isolated)
Moggel	*Labao umbratus*	Indigenous
Orange River labao	*L. capensis*	Endemic (Orange-Vaal)
Rock catfish	*Austroglanis sclateri*	Endemic (Orange-Vaal)
Sharptooth catfish	*Clarias gariepinus*	Indigenous
Banded tilapia	*Tilapia sparmanii*	Indigenous
Southern mouthbrooder	*Pseudocrenilabrus philander*	Indigenous

5.3 Impact on water users

The cyanobacterial bloom that occurred in the Lower Orange River impacted severely on the different uses within the system for the period that the algal bloom persisted in the river. The effects on the different users will be discussed separately and briefly.

5.3.1 Aquatic ecosystems

The cyanobacterial bloom conditions, the concurrent fish kills and the biomonitoring that were conducted reflects the effect of the incident on the aquatic ecosystem to some degree of detail. The ecosystem was thus largely

affected and will not be discussed any further as it was discussed in detail in Section 5.1.2.

5.3.2 Domestic water use

The domestic drinking water industry in the Lower Orange River system was greatly affected by the cyanobacterial bloom. The main impacts on users were the objectionable taste and odour of the water. Due to the inability of treatment systems (either of WCW's serving communities or small works serving individual households) to remove all the algae effectively, the amount of algae remaining in the treated water was enough to give a distinct taste and odour to the water.

The cyanobacteria was also present in the Groblershoop water reticulation network even as late as almost two weeks after the Upington Local Authority has reported the incident. The local authority did not report any problems and water care suppliers could not assist us either in determining to what extent this community was affected, since the local authority was in the process of changing their supplier of chemicals and expertise. The exact impact on this water user is thus not known.

Upstream of Upington, the person providing water treatment expertise to the District Council for a number of smaller communities, replaced the sand in the filters of Wegdraai and Topline. The other three communities had the sand replaced late in 1999 and did not report any problems.

Downstream of Upington, specific reports were received from Karsten Boerdery, Keimoes Municipality, Kakamas Municipality and the Augrabies Waterfall National Park. All of these facilities experienced carry-over of algae into their networks. Numerous reports and requests for information were received from concerned individuals and even from schools.

The major concern of the Department, were the persons who did not have access to treated water supplies since the health risk would have been reduced significantly even if treatment could not be fully effective.

Upington Municipality was the first to report difficulty in removing the cyanobacterial biomass from their WCW. The bottled drinking water industry was affected positively, as the sales of bottled drinking water increased during the period of the cyanobacterial bloom.

- Sales of small micron and activated carbon filters also increased in the period and the local newspaper carried numerous advertisements to this effect.

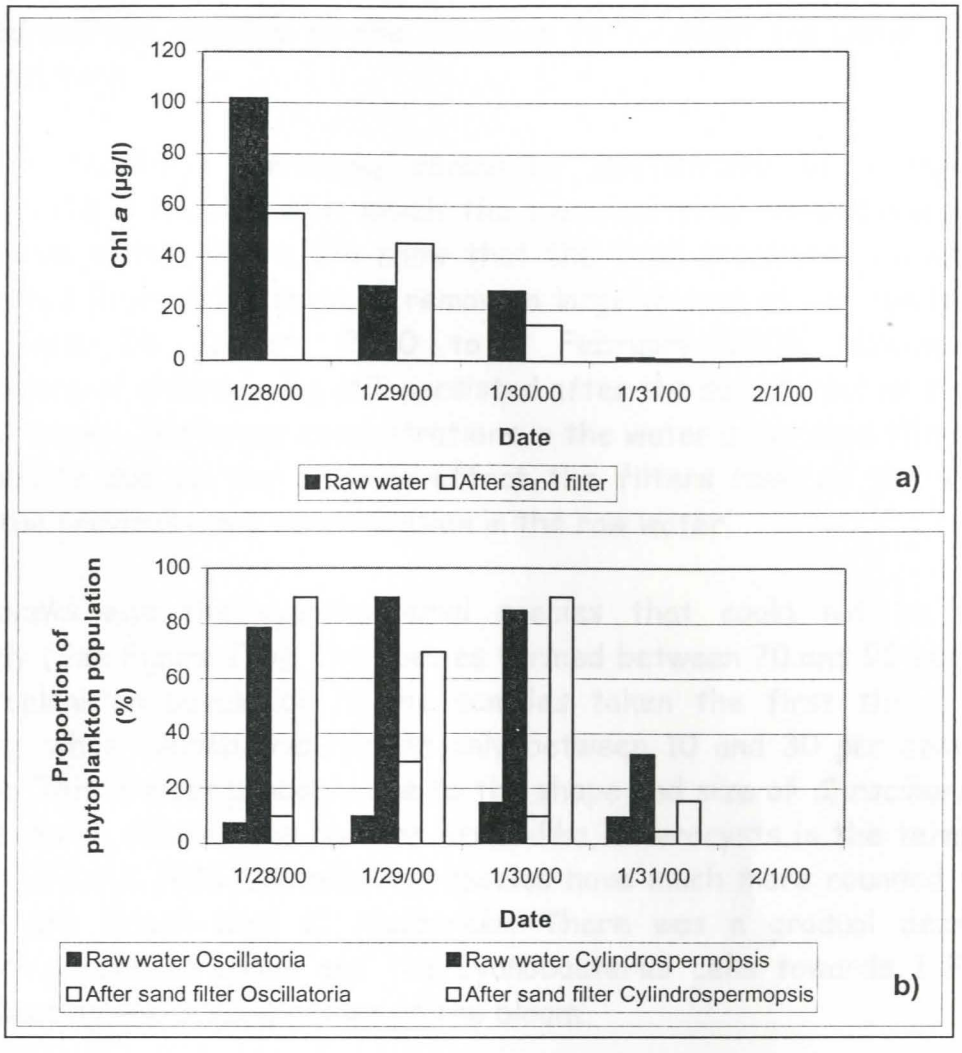


Figure 17 a) The raw water and after sand filtration chlorophyll a concentrations in Namakwa Water WCW's during cyanobacterial bloom in the Lower Orange River area. b) The proportion of *Oscillatoria* and *C. raciborskii* in the raw water and after sand fitration in Namakwa Water WCW's in the Lower Orange River during the cyanobacterial bloom in the Lower Orange River.

- When personnel visited Onseepkans community, it was realised that a recommendation of "filter the water" may not suffice in poorer communities, since no filter paper (as used in percolators) are readily available or affordable.
- Some people bought cold drink concentrates (e.g. "Oros") in huge quantities to try and hide the taste of the water. This might have been a problem as cyanobacterial toxins were present in the water.
- Micron and activated carbon filters were installed by the Trans Hex Limited mining company for their personnel at Reuning and Baken to serve as potable water points.

- Where possible, communities (e.g. Pella, Witbank, Rooiwal and Vioolsdrift) utilised storage capacity to the maximum to "by-pass" the water containing the algal mass.

During the incident monitoring conducted downstream of Upington also highlighted the difficulty with which the cyanobacterial species was removed form the raw water. Figure 17a show that the small treatment facility in the Lower Orange River did manage to remove a large amount of the cyanobacterial biomass from 28 January 2000 to 1 February 2000. However, large concentrations of chlorophyll a still persisted after the sand filtration step in the treatment works. The larger concentrations in the water after sand filtration are most probably due to the delaying effect the filters have on the water. It reflects the previous day's concentration in the raw water.

C. raciborskii was the cyanobacterial species that could not be removed effectively (See Figure 17b). The species formed between 70 and 90 per cent of the phytoplankton population in the samples taken the first three days of monitoring, while *Oscillatoria* formed only between 10 and 30 per cent of the population. This is most probably due to the shape and size of *C. raciborskii*. The species is short, filamentous and has arrow-like heterocysts in the terminal cell position (HINDÁK 1988). *Oscillatoria* species have much more rounded terminal cells and are larger than *C. raciborskii*. There was a gradual decrease in chlorophyll a concentrations and the cyanobacterial cells towards 1 February 2000, indicating the passing nature of the bloom.

From these results it is apparent that the cyanobacterial bloom affected the drinking water industry in the Lower Orange River to a large extent.

5.3.3 Agricultural water use

No large-scale effects in the form of animal deaths as is often associated with cyanobacterial blooms, were found in the agricultural sector. The major affect on the farming communities was the fact that it was peak harvest season. At such periods the population quite often triples. Therefore, when domestic water for these populations is considered, the farming communities was also affected to a large extent, as additional water supplies had to be found for domestic purposes.

5.3.3.1 Irrigation water use

Irrigation water was definitely infected as can be seen from the infestation of the bloom in the Volgraafsig Dam and the Balancing Dam at Kanoneiland. No effects to crops as such have been reported.

5.3.3.2 Livestock watering

As mentioned, no animal deaths were reported, indicating towards the possibility that the bloom might not have been toxic. The fact that no animal deaths have been found may be due to the nature of the cyanobacterial species than is not scum-forming and would thus not have accumulated in masses arlang the shores of any water resources.

5.3.4 Industrial and mining water use

The KWV, Upington experienced excessive foaming in their boilers.

The OWK cellars all had to increase chemical dosing at their cooling systems to prevent foaling.

The Black Mountain Mine has a very sophisticated treatment plant for process water and could handle the algal mass.

Trans Hex mines using river water do not require good quality water.

The industrial and mining users were, therefore, largely affected.

5.3.5 Recreational water use

No known impacts of the cyanobacterial bloom on the recreational uses of the Lower Orange River have been reported.

6. CONCLUSIONS

The assessment of the situation in the Lower Orange River before, during and after the extensive cyanobacterial bloom during January to February 2000. From the report we can conclude that:

6.1 There is a possibility that the cyanobacterial bloom was toxic, but no direct proof could be found.

6.2 The rainfall and consequent flows of the Harts River, however small when compared to the contributions from the Vaal and the Upper Orange Rivers, since December 1999 to February 2000 were the main reasons for the influx of cyanobacteria into the Lower Orange River.

6.3 The cyanobacterial bloom was of a passing nature, and may re-occur in future. The problem is that if *C. raciborskii* was not previously in the system, it might have been established now in the impoundments/weirs. Any future flooding events might, therefore, cause similar incidents.

6.4 The fish kills in the Lower Orange River were caused by a combination of water quality factors that could have been a secondary effects of the cyanobacterial bloom in association with the possible addition of cyanobacterial toxins. The large population of cyanobacteria and the decomposition of the algal biomass causes oxygen depletion in the water and can contribute to fish kills.

6.5 The effects of the cyanobacterial bloom did not cause any health related problems, but did have major effects on the aquatic environment (fish kills), domestic water industry (filter clogging and difficulty of cyanobacterial biomass removal), agricultural sector, industrial and mining sectors.

6.6 There is a need to develop warning systems by way of regular monitoring to minimise the effect on all water users during similar incidents.

7. RECOMMENDATIONS

The cyanobacterial bloom highlighted the following:

7.1 The development of facilities in South Africa to determine the presence of cyanobacterial toxins is essential to the effective management of cyanobacterial bloom incidents.

7.2 There is a need for monitoring programme(s) that include the indicator variables for eutrophication, including algal identifications. This will enable WCW's to timeously detect problem causing algal species and will increase their operational effectiveness.

7.3 A tool (model or other suggestions) to predict algal blooms in surface water sources (not only impoundments) need to be developed.

8. REFERENCES

ABRAHAMS, A.A.M. (2000) *Fish mortality and distribution during an episodic high flow in the middle and lower Orange River.* Internal report to Northern Cape Nature Conservation Service, Kimberley, South Africa. 17pp.

BENADE, C. Studies on fish populations in the regulated Orange River system within the borders of the Cape Province. MSc Thesis. University of the Orange Free State, Bloemfontein.

CAMBRAY, J.A. (1984) Fish populations in the middle and lower Orange River, with special reference to the effects of stream regulation. *J. Limnol. Soc. sth. Afr.* 10(2): 37-49.

CAMBRAY, J.A., DAVIES, B.R. and ASHTON, P.J. (1986) The orange-Vaal system. *In* B.R. Davies and K.F. Walker (eds). The ecology of river systems. Dr W. Junk Publishers, Dordrecht: 89-122.

CHORUS, I and BARTRAM, J. (eds.)(1999) *Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management.* E & FN Spon. London. 416 pp.

DWAF (1996a) South African Water Quality Guidelines Volume 1: Domestic Use. 1st edition. Pretoria.

DWAF (1996b) South African Water Quality Guidelines Volume 3: Industrial Use. 1st edition. Pretoria.

DWAF (1996c) South African Water Quality Guidelines Volume 7: Aquatic Ecosystems. 1st edition. Pretoria.

DWAF (1999) Orange River Replanning Study: Main Report. Ed. M.S. Basson. A report by BKS and Ninham Shand for the Department of Water Affairs and Forestry, Directorate: Water Resource Planning. Pretoria.

FALCONER, I.R. (1997). Harmful effects of blue-green algae on human health. *Australian Biologist,* 1:2, pp 107-110.

GOOSEN, J. (2000). Operator of Henkries Water Care Works. Personal communication during August 2000.

HAWKINS, P.R., CHANDRASENA, N.R., JONES, G.J., HUMPAGE, A.R. & FALCONER, I.R. (1997). Isolation and toxicity of *Cylindrospermopsis raciborskii* from an ornamental lake. *Toxicon*, 35, 341-346.

HAWKINS, P.R., RUNNEGAR, M.T., JACKSON, A.R. & FALCONER, I.R. (1985). Severe hepatotoxicity caused by the tropical cyanobacterium (blue-green) alga) *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya and Subba Raju isolated from a domestic water supply reservoir. *Applied and Environmental Microbiology*, 50, pp 1292-1295.

HINDÁK, F. (1988). Planktic species of two related genera *Cylindrospermopsis* and *Anabaenopsis* from Western Slovakia. Arch. Hydrobiol. Suppl. 80, 1-4, pp 283-302.

HUMPAGE, A.R. (2000) Personal communication via e-mail.

IWQS (1999). *Macro Elements Laboratory Test Methods and SOP Manual.* Revised edition. Institute for Water Quality Studies. Department of Water Affairs and Forestry. PRETORIA. South Africa.

IWQS (2000). *Biology Laboratory Test Methods and SOP Manual.* Revised edition. Institute for Water Quality Studies. Department of Water Affairs and Forestry. PRETORIA. South Africa.

PALMER, R.W. (1996). Invertebrates in the Orange River, with emphasis on conservation and management. *Sth, Afr. J. aquat. Sci.* 22 (1/2), pp 3-51.

QUIBELL, G., BADENHORST, J.E. & CARELSEN, C.I.C. (1995). *A national toxic blue-green algal surveillance programme for South Africa.* IWQS, DWAF Report N/0000/DPQ/1094, PRETORIA.

ROOS, J. (2000) Personal communication.

VAN GINKEL, C.E., HOHLS, B.C., BELCHER, A., VERMAAK, E. and GERBER, A. (2000). Assessment of the trophic status project. Final Draft Report No. N/0000/00/DEQ/1799. Institute for Water Quality Studies, Department of Water Affairs and Forestry. PRETORIA. South Africa.

VAN GINKEL, C.E. (2000) Unpublished data. Institute for Water Quality Studies, Department of Water Affairs and Forestry. PRETORIA. South Africa.

WILSON, K.M., SCHEMBRI, M.A., BAKER, P.D. & SAINT, C.P. (2000) Molecular charaterization of the toxic cyanobacterium *Cylindrospermopsis raciborskii* and design of a species-specific PCR. *Applied and Environmental Microbiology,* Jan 2000, pp 332-338.

WWW 1:
http://dwaf-www.pwv.gov.za/hydrology/weather.htm, 2000-10-12
https://www.dwa.gov.za/hydrology/weather.htm

WWW 2:
http://www.weathersa.co.za/wfacts/Cyclones.htm, 2000-10-12

WWW 3:
http://www-cyanosite.bio.purdue.edu/images/lgimages/CYLINDP5.JPG, 2000-11-15

WWW 4:
http://www-cyanosite.bio.purdue.edu/images/lgimages/oscisp2.jpg, 2000-11-15

WWW 5:
http://wwwcyanosite.bio.purdue.edu/images/lgimages/CIRCIN1.JPG, 2000-11-15

WWW 6:
http://www.sun-sentinel.com/news/daily/detail/0%2C1136%2C23000000000110296%2C00.html, 2000-11-16

WWW 7
http://www.weathersa.co.za/, 2000-03.