A contribution to the knowledge of South African coastal vleis: The limnology and phytoplankton periodicity of Princess Vlei, Cape Peninsula

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Abstract

This paper summarises the water chemistry regime, phytoplankton assemblage and periodicity in Princess Vlei, between April 1989 and March 1991. Princess Vlei is a small (29 ha), shallow (mean depth 2,4 m) and eutrophic freshwater coastal vlei situated on the Cape Flats adjacent to the Cape Peninsula. Mean annual concentrations of nitrogen and phosphorus are 2,0 and 0,16 mg·ℓ⁻¹, respectively, with chlorophyll *a* concentrations averaging 63 μg·ℓ⁻¹. Hydraulic flushing during the winter plays a significant role in controlling phytoplankton biomass in this system. The phytoplankton assemblage exhibits a low generic diversity composed of Cyanophyta, Chlorophyta and Bacillariophyta. Prior to the development of an *Anabaena circinalis* bloom during the summer of 1991, cyanophyte species had not dominated the phytoplankton assemblage since 1983. Princess Vlei has recreational amenity value for the Cape Town municipal area, and the results of this work are directed towards the management of this urban-impacted system.

Study area

Princess Vlei is a small (29 ha), shallow (*ca.* 2,4 m), permanent, freshwater coastal lake (as defined by Davies and Day, 1986), situated in the Southfield area of Cape Town, South Africa (latitude 34° 03'S; longitude 18° 28'E; (Fig. 1). It was classified in the 1920s as alkaline (Stevens, 1929) and during the 1940s as being alkaline and eutrophic (Harrison, 1962). Princess Vlei lies on sandflats which were originally submerged beneath the sea (Shand et al., cited in Hutchinson et al., 1932). Details of the geology of the area are described in Gardiner (1988). Of the four largest vleis on the Cape Peninsula, viz. Zeekoevlei, Zandvlei, Rondevlei and Princess Vlei, the latter is the smallest and probably the oldest (Hutchinson et al., 1932). With the exception of Rondevlei, which has been developed as a nature reserve, Zeekoevlei and Zandvlei are extensively utilised by the public for a variety of recreational pursuits (City of Cape Town, 1988; 1990a), and together with Princess Vlei, form the only substantial, naturally-occurring areas of inland water suitable for recreation within the Cape Town municipal area, serving a population of 940 000 people (City of Cape Town, 1990b). In a regional context, i.e. inclusive of neighbouring municipalities forming part of the Greater Cape Town area, this figure would exceed 2 million people.

Princess Vlei's inflow emanates from the Southfield Canal (Fig. 1) which drains an urban catchment of approximately 800 ha. An outlet weir, constructed during 1990 (crest height, 6,6 m above mean sea level, AMSL), lies to the south-east and drains into a canal linking Princess Vlei to Rondevlei (Fig. 1). Prior to this, a temporary weir (crest height, 6, 45 m AMSL) restricted the outlet. A flood-prevention overflow weir (crest height, 7,4 m AMSL), is positioned to the south-west and drains into the Sand River, terminating ultimately in Zandvlei (Fig. 1).

The vlei is bordered to the north by residential and small-scale industrial areas, to the east and west by public open space and to the south by a small residential development. In addition to the inflow from the Southfield Canal, several stormwater pipes enter the vlei at various points around its perimeter. Outflow from Princess Vlei usually occurs between April and October during the winter rains. The Cape Town City Council (CCC) has three sewage pumping stations in the Princess Vlei catchment which, during time of malfunction or overloading, are designed to overflow into the Southfield Canal.

Prior to 1985, such overflows were relatively frequent during the winter months but subsequent modifications have greatly reduced the incidence of overflow events, so that only two overflows have been recorded between January 1986 and December 1990 (City of Cape Town, Sewerage Branch records, unpublished).

Vegetation bordering the vlei is sparse, with grass and stands of semi-aquatic reeds (*Typha capensis*) as was previously recorded by Harrison (1962). The inlet bay has dense fringes of *Typha*, and is subject to year-round infestation by water hyacinth (*Eichhornia crassipes* (Mart) Solms). Control of these plants is carried out at intervals using glyphosate herbicides and physical removal.

Princess Vlei is utilised on a regular basis by casual and club anglers, especially during the winter months. Water is abstracted from the vlei by the City Council for irrigation of the surrounding public open space. According to the terms of reference of an ecological management survey of Cape Peninsula waters (Howard-Williams, 1976), Princess Vlei was accorded a low priority with respect to research needs. At that time, attention was directed towards the removal of water hyacinth.

Princess Vlei was dredged between March and July 1983, to remove a shallow sand-bar, running from north-west to south-east across the middle of the vlei. This restrictive sill effectively divided the vlei into two stilling-basins and precluded effective hydraulic flushing, thereby allowing dense phytoplankton populations and blooms with chlorophyll *a* concentrations of up to 600 μg.ℓ⁻¹ to develop (City of Cape Town, Scientific Services Branch records). Sludge accumulation, with fine, black, organically-rich silt overlying white to buff coloured medium-grained sands in these basins, was, on average, between

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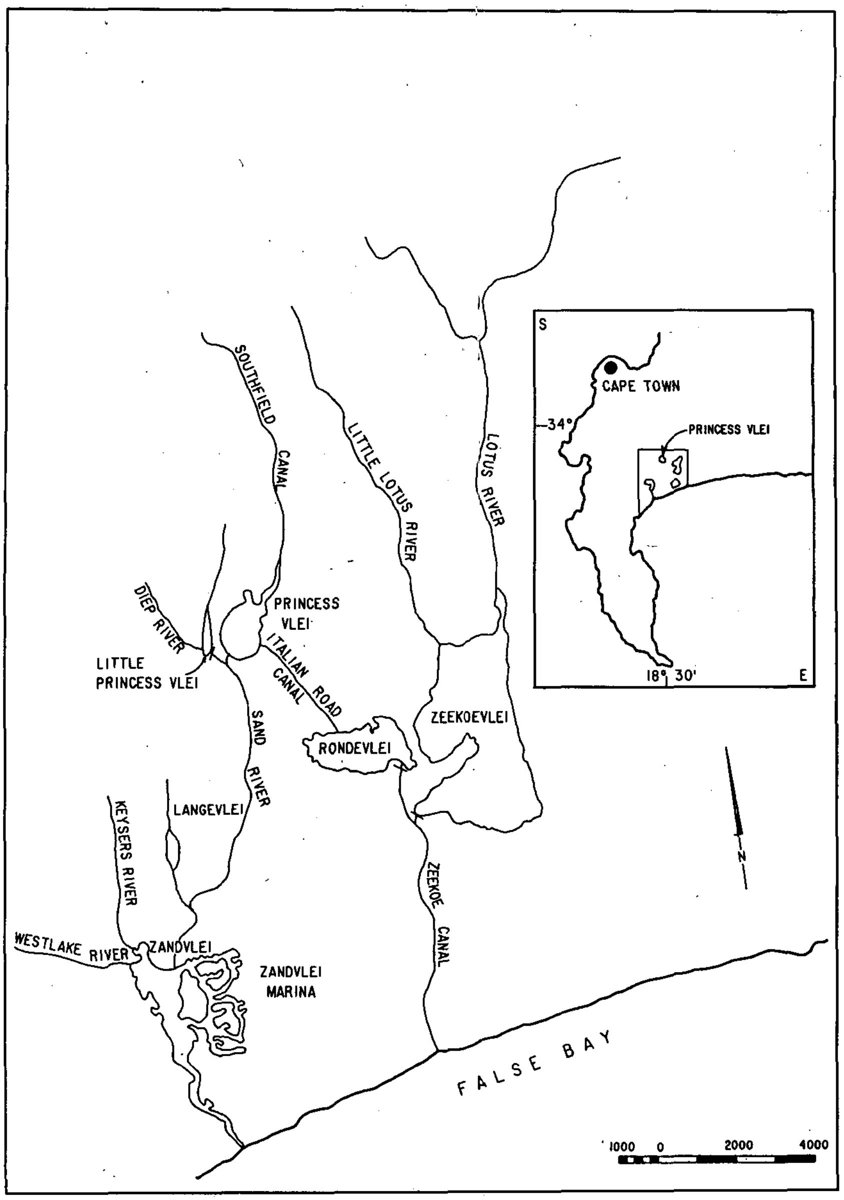

Figure 1

Map showing the position of Princess Vlei in relation to the Cape Peninsula (insert) and to the other Cape Flats lakes referred to in the text. Scale bar indicates distances in meters.

2 and 3 m thick, reaching as much as 5 m deep in places (Hill, Kaplan and Scott, 1980). The bathymetry of Princess Vlei was recently resurveyed and the results showed that the sill has been replaced by a central deepening of the vlei and some redistribution of the sediments. The volume of the vlei was calculated as 715 000 m^3, with the sediments accounting for approximately 150 000 m^3 or 21% thereof (Harding, 1991a).

This paper reports on conditions at Princess Vlei between April 1989 and March 1991, and constitutes the first long-term published summary of aspects of the ecology of this system. Princess Vlei currently exhibits seriously perturbed benthic macroinvertebrate (see McShane, 1989; Henderson and Davies, 1990) and fish populations (Harding, unpublished data). Details of the perturbation in the fish population and the underlying casual reasons will be published elsewhere. Princess Vlei has been monitored by the Cape Town City Council since 1982, and the result have been summarised by Harding (1991b). Details of the zooplankton diversity and periodicity are currently being investigated (Combrink, unpublished data).

Methods

General

This study comprised fortnightly limnological monitoring and phytoplankton collections with monthly water chemistry monitoring coinciding with one of the fortnightly visits. Monthly heavy metal analyses of the water and sediments commenced during December 1989. Except for the plankton, the influent Southfield Canal (Fig. 1) was similarly monitored at a point approximately 1 km north of the vlei. Four vlei stations were sampled from a boat and sampling was invariably carried out between 09:00 and 11:30.

The physico-chemical methodologies employed in the monitoring of Princess Vlei are listed in Table 1. Water temperature, pH, dissolved oxygen, conductivity and wind speed were measured in the field, while all other analyses and measurements were made on return to the laboratory.

Water chemistry, chlorophyll *a* and phytoplankton samples

TABLE 1
ANALYTICAL METHODS

Parameter	Method	Reference
pH	Hanna Model HI8424 pH meter with thermistor probe	—
Temperature	YSI Model 57 DO meter or Hanna pH meter thermistor probes	—
Windspeed	Deuta hand-held anaemometer	—
Water transparency	0,20 m perforated Secchi disc	—
Total alkalinity	Sulphuric acid titration	DWA, 1988
Dissolved oxygen	YSI 57 DO meter	—
Conductivity	WTW LF196 conductivity meter	—
Heavy metals	Atomic absorption spectro. for As, Cd, Cu, Ni, Cr, Fe, Zn, Pb, Al, Hg & Mn using a GBC Model 902 AAS.	— — NIWR, 1974
Water hardness	Atomic absorption spectro. for Ca & Mg, converted to $CaCO_3$	NIWR, 1974
Sediment composition	Sedigraph analysis	TMH, 1986
Kjeldahl-N	Digestion and conversion to ammonium sulphate	EPA, 1979
Ammonia-N	Boric acid distillation	EPA, 1979
Nitrate and nitrite-N	Cadmium reduction and autoanalyzer colorimetry	EPA, 1979
Silicon, reactive	Molybdate reduction	NIWR, 1974
Total and total-dissolved-P	Persulphate digestion followed by SRP analysis	EPA, 1979
Total-P (sediments)	Ignition method	Andersen, 1976
Soluble-P (SRP)	Ascorbic acid method	EPA, 1979
Suspended solids	Gravimetric analysis	EPA, 1979
Chlorophyll *a*	Ethanol extraction, results corrected for phaeophytins	DWA, 1988

were collected using a 2 x 0,4 m perspex tube sampler fitted with an airtight valve at the upper end. Sediment samples for heavy metal analysis were collected using a stainless-steel Birge-Ekman grab with a bite area of 0,0225 m^2. Samples were then transported in plastic buckets to the laboratory and aliquots thereof dried at 105°C prior to digestion and analysis. Water samples for heavy metal analysis were collected as integrated samples and transported in acid-rinsed high density polyethylene bottles to the laboratory. These samples were preserved with nitric acid prior to analysis.

Meteorological

Rainfall data were obtained from a CCC rainfall gauge situated on the northern shore of the vlei. On-site wind recordings were limited to surface speed and direction measurements made at the time of sampling.

Supplementary wind, rainfall, sunshine and incident solar radiation data were obtained from the meteorological office of the South African Transport Services, DF Malan Airport, Cape Town.

Phytoplankton

The samples for subsequent identification and counting were preserved with Lugol's solution (Vollenweider, 1975) immediately after collection, and examined using the inverted microscope techniques described by Utermohl (1958) and Lund et al. (1958). All of the phytoplankton cells present in pre-calibrated sedimentation-chamber transects were identified and counted. Colonial species such as *Microcystis* spp. were disrupted prior to counting using the method of Zohary and Pais Madeira (1987). With certain exceptions, identifications were to genus level only, although a comprehensive photo-micrographic record of the genera observed was compiled using a Zeiss Photomicroscope. Phytoplankton biomass was calculated using the gravimetric method described by Young (1986). Organic content (as percentage volatiles) was determined by combusting the dried samples at 500°C for 1 h and expressing the mass loss as a percentage of the dry weight.

Results

Meteorological measurements

During this study the monthly average sunshine period measured at DF Malan Airport ranged between 6,0 and 11,1 $h \cdot d^{-1}$, with minima during June and July and maxima during January. Wind speed measurements made at the time of sampling gave a mean surface wind speed of 7,3 $m \cdot s^{-1}$ over a range of 0 to 25 $m \cdot s^{-1}$. Calm conditions, representing speeds <1 $m \cdot s^{-1}$, were recorded on 9 out of 45 occasions. The Cape Peninsula experiences highest wind speeds (southerly) during the summer, and lowest speed and greatest incidences of calm during the winter (Fuggle, 1978).

Annual rainfall totals for the individual years of this study were 636 and 715 mm, respectively. The bulk of the rainfall was measured between April and August of each year with peak falls during April, July and August. The water level of the vlei fluctuated between 6,17 and 6,95 m AMSL, with a mean level of 6, 43 m AMSL during the study.

TABLE 2
PRINCESS VLEI WATER CHEMISTRY DATA FOR THE PERIOD APRIL 1989 TO MARCH 1991

Parameter	Mean, x	Min	Max	x - SD	x + SD	n
Temperature, °C	18,0	11,6	24,8	14,5	22,2	192
Dissolved oxygen, mg·ℓ$^{-1}$	8,7	4,6	17,8	7,2	10,5	192
Oxygen saturation, %	92	52	208	74	115	188
Water transparency, m	0,48	0,15	1,55	0,28	0,84	190
Suspended solids, mg·ℓ$^{-1}$	24	3	165	8	72	84
pH	8,7	7,1	9,9	8,0	9,.5	188
Conductivity, mS·m^{-1}	55	28	81	45	68	192
Kjeldahl-N, mg·ℓ$^{-1}$	2,0	0,8	4,0	1,4	2,9	90
Ammonia-N, mg·ℓ$^{-1}$	0,11	nd	0,8	0,02	0,48	90
Nitrate-N, mg·ℓ$^{-1}$	0,12	0,01	1,61	0,04	0,38	84
Total-P, mg·ℓ$^{-1}$	0,16	0,05	0,30	0,11	0,23	90
Soluble-P, mg·ℓ$^{-1}$	0,37	0,01	0,16	0,02	0,08	88
Ortho-P, mg·ℓ$^{-1}$	0,02	nd	0,15	0,01	0,06	92
Reactive silicon, mg·ℓ$^{-1}$	0,38	0,03	2,49	0,13	1,09	76
Total alkalinity, mg·ℓ$^{-1}$	101	41	162	82	126	76
Chlorophyll *a* µg·ℓ$^{-1}$	63	2	302	22	176	92

SD = One standard deviation
n = number of samples
x = mean
Nitrate-N expressed as sum of nitrite- and nitrate-N
Soluble-P = total filterable phosphorus
nd = not detected

TABLE 3
SOUTHFIELD CANAL WATER CHEMISTRY DATA FOR THE PERIOD APRIL 1989 TO MARCH 1991

Parameter	Mean, x	Min	Max	x -SD	x + SD	n
Temperature, °C	19,7	12,7	28,4	16,0	24,1	49
Dissolved oxygen, mg·ℓ$^{-1}$	8,6	6,3	12,4	7,3	10,0	49
Oxygen saturation, %	94	61	148	76	117	49
Suspended solids, mg·ℓ$^{-1}$	12	3	206	3	46	21
pH	7,9	6,9	9,5	7,4	8,5	48
Conductivity, mS·m^{-1}	60	19	89	48	76	50
Kjeldahl-N, mg·ℓ$^{-1}$	1,7	0,7	4,3	1,1	2,9	23
Ammonia-N, mg·ℓ$^{-1}$	0,10	nd	0,82	0,02	0,47	23
Nitrate-N, mg·ℓ$^{-1}$	3,30	0,59	6,31	1,91	5,64	22
Total-P, mg·ℓ$^{-1}$	0,15	0,07	0,45	0,08	0,28	24
Soluble-P, mg·ℓ$^{-1}$	0,08	0,04	0,34	0,04	0,15	24
Ortho-P, mg·ℓ$^{-1}$	0,06	0,03	0,21	0,03	0,11	24
Reactive silicon, mg·ℓ$^{-1}$	3,19	1,10	9,73	1,86	5,50	21
Total alkalinity, mg·ℓ$^{-1}$	99	37	289	67	146	19

SD = One standard deviation
n = number of samples
x = mean
Nitrate-N expressed as sum of nitrite- and nitrate-N
Soluble-P = total filterable phosphorus
nd = not detected

Physico-chemical measurements

Data for Princess Vlei and the influent Southfield Canal are summarised in Tables 2 and 3, respectively. The vlei was visited 49 times during the two years of the study, and the results are expressed as the mean value of all four stations. No chemical or thermal stratification was detected (see Harding, 1991b) apart from some transient microstratification during calm periods. All the data were log-transformed for statistical analyses.

Water temperatures reached their maxima by February, decreasing to below 12°C in July. Dissolved oxygen concentrations consistently exceeded half-saturation, pH levels ranged between 7 and 10, and conductivities showed a mean of 55 mS·m^{-1} (range, 30 to 80 mS·m^{-1}). Peak concentrations of inorganic nitrogen, orthophosphate and reactive silicon coincided with the peak winter rainfall period from July to August (see Fig. 2). During this time, chlorophyll *a* and suspended solids concentrations reached their annual minima (see Tables 2 and 3) and, correspondingly, Secchi disk transparencies showed a marked increase (Fig. 2). Chlorophyll *a* concentrations ranged between 2 and 300 µg·ℓ$^{-1}$ with a mean concentration of 63 µg·ℓ$^{-1}$. An uncharacteristic increase in the concentration of chlorophyll *a* was recorded towards the end of the survey period (Fig. 2), when concentrations exceeded 100

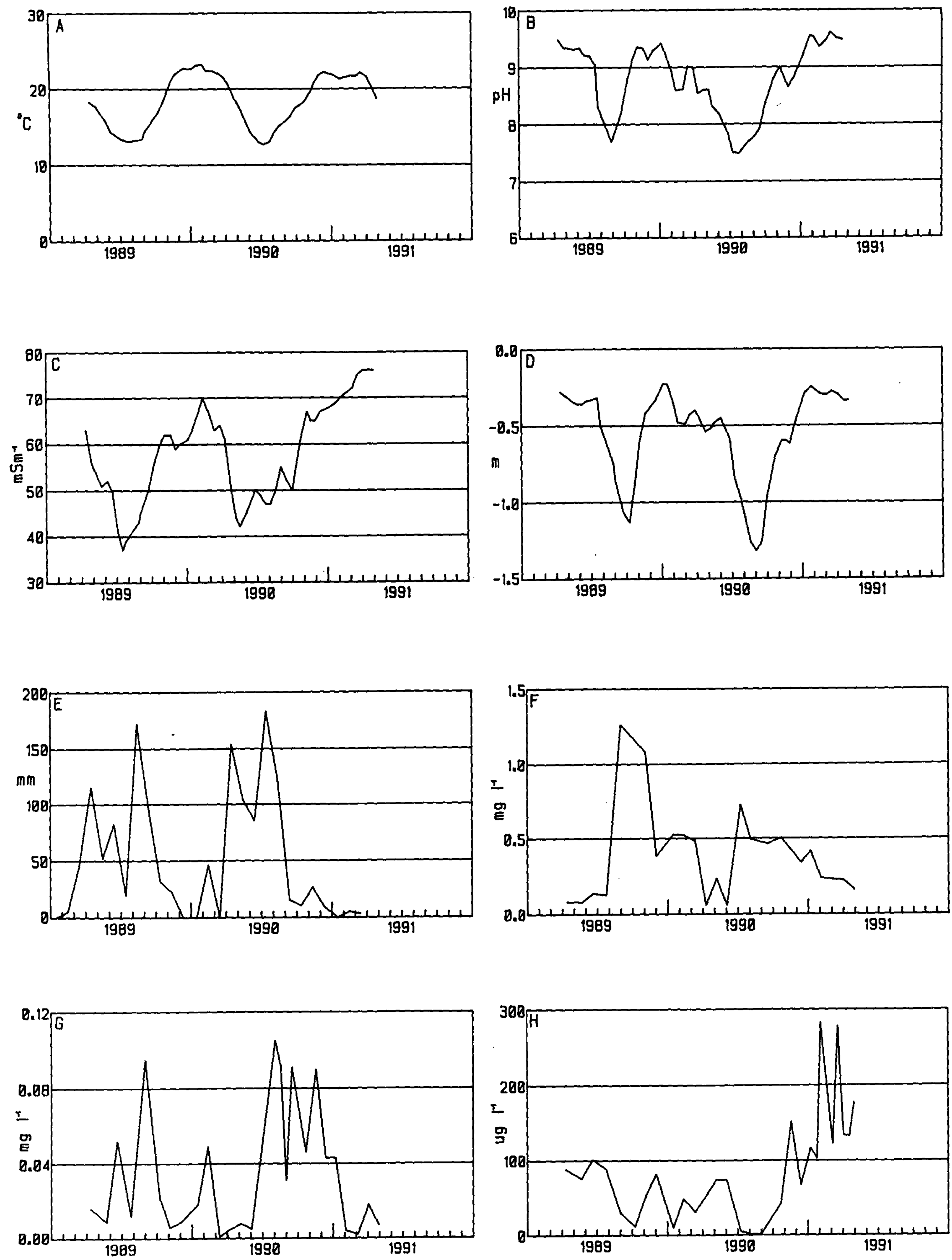

Figure 2

Trends of certain physical and chemical parameters for Princess Vlei. (A) Water temperature (B) pH (C) Conductivity (D) Water transparency (E) Rainfall (F) Inorganic nitrogen (G) Orthophosphate (H) Chlorophyll a.

TABLE 4
HEAVY METAL CONCENTRATIONS IN PRINCESS VLEI WATER AND SEDIMENTS AND A COMPARISON WITH LEVELS IN THE SEDIMENTS OF OTHER WATER BODIES

Sample	Concentration of metal (water= $\mu g \cdot \ell^{-1}$, sediments= $mg \cdot kg^{-1}$)							
	Cd	Cu	Ni	Cr	Fe	Zn	Mn	Pb
Sediments								
Princess Vlei	1,0	14	5	11	1 950	150	40	90
Zeekoevlei (1)	1,6	21	14	19	3 100	154	87	nd
Zandvlei (2)	0,9	6	6	10	nd	50	23	34
Wilderness-Lakes (3)	0,2	4	4	5	5 800	15	50	nd
Water								
Princess Vlei	1,0	3	4	5	340	10	25	10

SOURCE (1) - Harding (1991b) (2) - Harding (unpublished data)
(3) - Watling (1977) nd = no data

$\mu g \cdot \ell^{-1}$ for the first time since 1983 (see Harding, 1991b).

Heavy metal analyses of the water and sediments of Princess Vlei were carried out on 10 occasions between December 1989 and December 1990 and the results are presented in Table 4, together with some comparative values for other western and southern-Cape systems. Analyses of the sediment composition revealed a 30 to 50% silt content with a particle size range 0,001 to 0,1 mm, the remainder being fine to medium sand with a particle size range of 0,1 to 0,43 mm. The average water and organic material contents of these sediment samples were 80% and 14%, respectively.

Aluminium, mercury and arsenic concentrations in the sediments had mean concentrations, respectively, of 2 400, <0,3 and 1,1 $mg \cdot kg^{-1}$. The mean concentration of aluminium in the water was 320 $\mu g \cdot \ell^{-1}$. The water hardness, expressed as calcium carbonate, was <150 $mg \cdot \ell^{-1}$.

Phytoplankton assemblage

A list of the phytoplankton genera recorded in Princess Vlei is presented in Table 5. A range of 5 to 24 genera was recorded and the lowest diversity was observed coinciding with the peak of the rainfall period during August and September of each year. This was most evident during September 1990 when the total number of genera was reduced to 5, compared with a minimum of 13 genera during the corresponding period of 1989.

The major components of the phytoplankton comprised genera of Cyanophyta, Chlorophyta and Bacillariophyta (diatoms, division Chrysophyta). Low levels of cryptomonads were recorded between June and September 1989, and isolated occurrences of dinoflagellates and euglenophytes were observed between November and December of 1989. *Staurastrum* sp. (desmids, division Chlorophyta) were rare, appearing on only five occasions. The ranges of total cell counts for the three divisions were very similar: Chlorophyta 60 to 20 000 $cells \cdot m\ell^{-1}$; Cyanophyta 0 to 27 000 $cells \cdot m\ell^{-1}$, and Bacillariophyta 0 to 25 000 $cells \cdot m\ell^{-1}$. Median counts for each division during the two-year study were, respectively, 3 200, 290 and 540 $cells \cdot m\ell^{-1}$. In terms of numbers, the Chlorophyta were the dominant division, comprising in excess of 50% of the total cell count on 71% of 49 sampling occasions.

Phytoplankton periodicity

This phytoplankton study commenced at the end of the summer of 1989 when water temperatures, conductivity and nutrient concentrations were decreasing. The phytoplankton periodicity for each of the dominant divisions is shown in Fig. 3.

The diatom genera, *Cyclotella, Nitzschia* and *Navicula*, as well as an isolated, short-lived appearance of a small centric diatom, *Thalassiosira nana*, were recorded during June 1989. The filamentous bacillariophyte *Melosira* spp. were ubiquitous throughout the study, occurring mostly as short fragments (<100 μm).

Microcystis sp. was the dominant Cyanophyte, with *Anabaena circinalis, A. solitaria, Aphanocapsa* sp., *Merismopedia* sp. and *Sprirulina* sp. also present. *Pseudanabaena* sp. cells were commonly associated with the *Microcystis* colonies. *Microcystis* cells were present in numbers ranging from 1 000 to 5 000 $cells \cdot m\ell^{-1}$ from the start of the study until November 1989, at which time they almost disappeared from the assemblage before reappearing during the winter of 1990. Although not

TABLE 5
COMPOSITION OF THE PRINCIPAL PHYTOPLANKTON DIVISIONS PRESENT IN PRINCESS VLEI

Chlorophyta	Cyanophyta	Bacillariophyta
Actinastrum	*Anabaena*	*Cocconeis*
Ankistrodesmus	*Anabaenopsis*	*Cyclotella*
Carteria	*Aphanocapsa*	*Fragilaria*
Chlamydomonas	*Chroococcus*	*Melosira*
Chlorella	*Merismopedia*	*Navicula*
Chodatella	*Microcystis*	*Nitzschia*
Coelastrum	*Pseudanabaena*	*Thalassiosira*
Golenkinia	*Raphidiopsis*	
Gloeocystis	*Spirulina*	
Micractinium		
Oöcystis		
Pediastrum		
Phacotus		
Scenedesmus		
Schroederia		
Selenastrum		
Sphaerocystis		
Tetraedron		

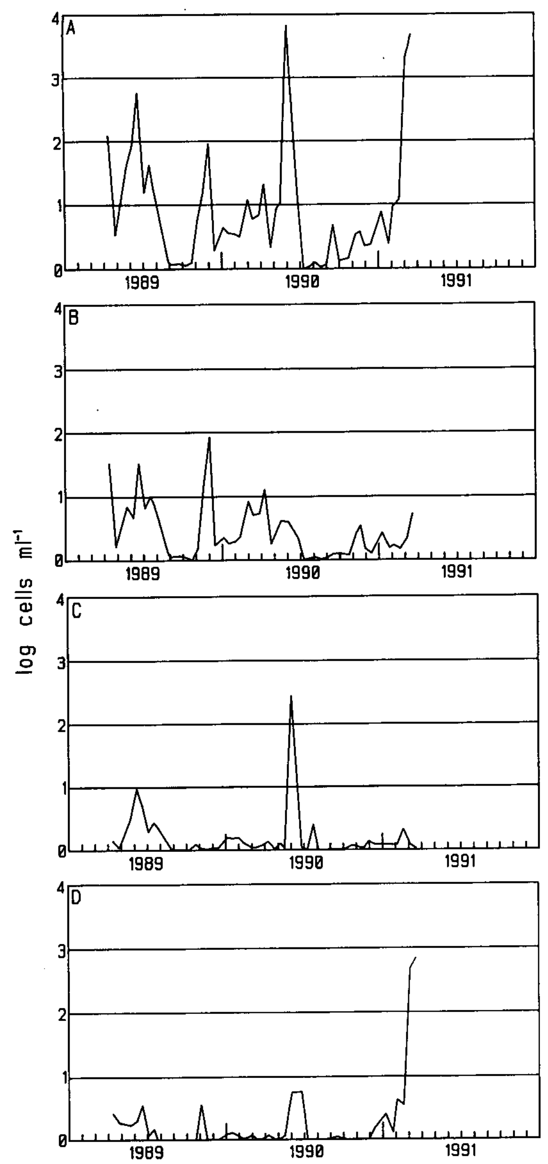

Figure 3
Periodicity of the dominant phytoplankton divisions present in Princess Vlei. (A) All combined (B) Cyanophyta (C) Bacillariophyta (D) Chlorophyta.

dominant in the open water phytoplankton assemblage, *Microcystis* formed dense populations of clumped colonies along the west and south-western shores during the late summer and winter months. This assemblage prevailed until the onset of increased water clarity (Fig. 2), whereupon it was replaced by low numbers of *Schroederia* sp. (up to 600 cells·mℓ⁻¹). With the onset of spring 1989 the assemblage reverted to one dominated by chlorophyte species of *Pediastrum, Gloeocystis, Sphaerocystis, Actinastrum* and *Tetraedron* (Fig. 4).

A second peak of naviculoid-diatom development was observed during the 1990 summer, together with an increase in *Aphanocapsa* sp., the latter reaching maximum numbers during mid-January. The *Gloeocystis-Sphaerocystis* chlorophyte assemblage was replaced during February 1990 by one composed of *Chodatella, Micractinium, Scenedesmus* and *Ankistrodesmus* spp. This assemblage persisted until the middle of 1990 when the small centric diatom, *Thalassiosira*

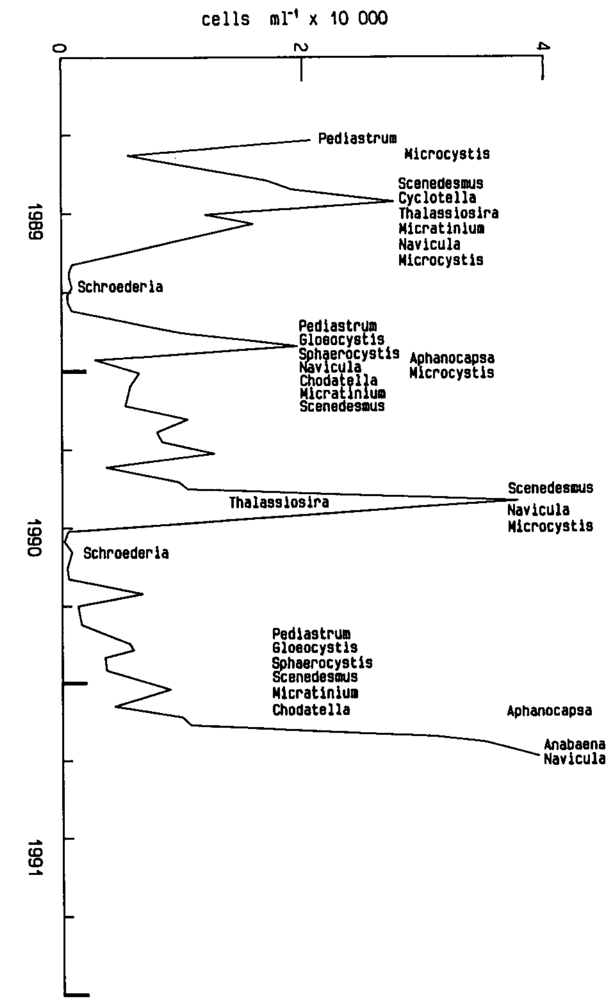

Figure 4
Composition of the phytoplankton assemblages as recorded during the two years of the Princess Vlei study.

nana reappeared in large numbers for a short period of less than 14 days, peaking at 24 000 cells.mℓ⁻¹. This winter assemblage was again followed by a clear water period, during which *Schroederia* sp. reappeared. The spring of 1990 saw the re-emergence of an assemblage of *Gloeocystis* sp. cells, together with increasing numbers of *Pediastrum, Sphaerocystis, Chodatella, Micractinium, Actinastrum and Tetraedron* spp. as well as some naviculoid diatom species.

The 1991 summer assemblage was marked by the sudden and prolific development of *Anabaena circinalis*, replaced soon after by *Anabaena solitaria*. Total counts of these cyanophyte species reached 25 000 filaments.mℓ⁻¹. *Microcystis* numbers also increased at this time, with maxima reaching 8 000 cells.mℓ⁻¹. As was the case during the previous summer, *Aphanocapsa* sp. reached peak number during January 1991. The collapse of this cyanophyte-dominated assemblage was coincident with an increae in naviculoid and nitszchioid species of diatoms (Fig. 3).

Phytoplankton biomass

A mean phytoplankton biomass concentration of 20,5 mg (dry weight) mg·ℓ⁻¹, over a range of 0,0 to 67,0 mg·ℓ⁻¹ was recorded the study, with no detectable biomass recorded during the clear water phase during August 1990. The organic content of the dried samples varied between 44 and 93%, with highest values during late summer and lowest during the winter.

Discussion

Although flow data were not available, the effect of rainfall-induced flushing on this small vlei was readily apparent, as seen by the dramatic increase in water clarity (Fig. 2), and the decrease in phytoplankton numbers (Fig. 3) and chlorophyll *a* concentration (Fig. 2). This physical forcing factor appears to function as an important control in the dynamics of the water body. Flushing occurs annually, at a time when the nearby, hyper-eutrophic Zeekoevlei (Fig. 1), which is not subject to observable (transparency) wash-out, experiences maximal nutrient concentrations as well as marked increases in phytoplankton numbers (Harding, in prep.). In addition to the flushing effect, the annual winter rains introduce nutrients into Princess Vlei, increasing the ambient concentrations of inorganic nitrogen, orthophosphate and reactive silicon (Fig. 2). Nutrient concentrations in the water of Princess Vlei are typically lowest during the summer months, and the high spring-summer levels of orthophosphate which persisted after the winter of 1990 (Fig. 2) are uncharacteristic, having last been recorded during the 1986/1987 summer (Harding, unpublished data). Zeekoevlei experienced a significantly higher (44%) hydraulic throughput during 1990 than was the case during 1989 (Harding, 1991b), and given the proximity of the two catchments, it is probable that a similarly increased flow occurred in Princess Vlei, resulting in greater removal of viable phytoplankton propagules from the vlei. This would, in turn, have retarded the rate of regrowth of the phytoplankton assemblage during the following spring (see comments below on water hyacinth development), with concomitantly slower removal of the available nutrients from the water column.

Application of the trophic state index (TSI) formulae of Carlson (1979) to the mean water transparency, chlorophyll *a* and total phosphorus levels of Princess Vlei yielded a TSI range of 70 to 80. On Carlson's "continuum" scale of 0 to 110 (0 = ultra oligotrophic) this is indicative of a eutrophic system. According to the parameters for trophic state laid down by the OECD (1982), Princess Vlei is eutrophic with respect to concentrations of phosphorus, nitrogen and chlorophyll *a*. With respect to other South African water bodies, Princess Vlei exceeds the eutrophic limits for chlorophyll *a* as described by Walmsley (1984).

The presence of a timber treatment plant in the industrial area north of Princess Vlei has been implicated in high levels of chromium measured in the ground water drawn from nearby boreholes (City of Cape Town, 1990c;d). Although these elevated concentrations were subsequently shown to be localised to the area of the timber yard (Dick, CCC, 1991), the fact that timber treatment preservatives, typically chrome-copper-arsenic or pentachlorophenol-tributyltin mixtures, can be particularly destructive to life in aquatic systems (e.g. McNeill, 1989), prompted the investigation of trace metal concentrations in Princess Vlei reported on here.

This investigation revealed that the concentrations of trace metals in the Princess Vlei sediments were very similar to those recorded for the adjacent Zeekoevlei. Elevated iron levels, such as those recorded here (Table 4) are generally regarded as non-critical with respect to toxicity (e.g. Forstner aad Wittman, 1981). The concentrations of metals in Princess Vlei comply with the benchmark levels of the Dutch Guidelines for Soil Sanitation (Rang and Schouten, 1989). In addition, heavy metal concentrations in the water of Princess Vlei do not exceed the limits specified by the EC Guidelines for the Protection of Freshwater Life (Mance, 1986). The analysis of trace metals in sediment cores collected in and around Princess Vlei revealed no evidence of any heavy metal accumulation during the recent past (Van der Heyden, 1990).

The phytoplankton divisions which are present (this study), and the composition of the Cyanophyta and Chlorophyta, are characteristic of a eutrophic water body (Hutchinson, 1967). Historical data on the phytoplankton assemblage of Princess Vlei are limited to the *ad hoc* observations of Stevens (1929), Hutchinson et al. (1932) and Harrison (1962) on samples collected in the littoral zone during the 1920s and 1940s. Nonetheless, the profiles recorded by these researchers were similar to those recorded during this study. Algal blooms were reportedly common in Princess Vlei and this was still the case in more recent years as Furness (1979) reported a severe bloom of *Microcystis aeruginosa* during the winter of 1979. The available information indicates that blooms of *Micractinium* spp. occurred during the summer (Harrison, 1962). Summer blooms of phytoplankton have been recorded for the similarly-sized Rondevlei (Gardiner, 1988) and City Council officials have reported that Princess Vlei used to be green in colour all year round prior to its dredging. Algal blooms and the green colouration have not been recorded since 1983 (Harding, 1991b). The annual removal from the vlei of a significant fraction of viable algal biomass through hydraulic flushing appears to have prevented dense populations of nuisance species of cyanophyte algae from becoming firmly established during the summer.

Although representatives of the cyanophyte "nuisance" algae, e.g. *Microcystis* and *Anabaena* spp. were routinely present in the phytoplankton assemblage, they did not become dominant until the summer of 1991 when bloom conditions of *Anabaena* spp. were recorded. The only apparent reason for this sudden over-development of these species was the occurrence of a prolific spring/summer 1990/91 growth of water hyacinth which covered the surface of the small inlet bay to the north-east of the vlei (Fig. 1). Growth of this macrophyte has in the past been limited to a thin fringe of plants along the shoreline. The 1990/91 overgrowth of this floating weed may have been fuelled by the high orthophosphate concentrations prevailing after the 1990 winter (see earlier comments). Control of water hyacinth in Princess Vlei is usually effected by spraying with herbicide and/or manual removal. In this [1990/91] instance, the sheer volume of material precluded timeous removal and the bulk of the plant tissue was left to decay in the water, possibly providing the pulse of nutrients necessary to sustain increased phytoplankton growth during the otherwise nutrient-poor summer season.

The possibility of inundation of previously exposed shoreline, brought about by the 0,15 m increase in weir height (see **Study area**), and/or any changes in the hydraulics and water retention in Princess Vlei, are not considered to be implicated in the observed increased development of cyanophyte algae. Water levels in Princess Vlei only attained the new operating level of 6,6 m AMSL for the first time during the winter of 1991 .

Princess Vlei's phytoplankton periodicity demonstrated a repetitive trend as evident from the appearance of *Schroederia* sp. during the clear water phases of both years of the study; the coincident mid-winter timing of the small centric diatom species, *Thalassiosira*; and the almost identical composition and timing of the chlorophyte-asemblages during both years. The timing of the *Thalassiosira* growth coincided with a peak of the same species in Zeekoevlei (Harding, in prep.).

Conclusions

Princess Vlei is a small, well-mixed and eutrophic freshwater vlei which is subject to annual hydraulic flushing during the winter. The washout of phytoplankton from the system acts as a natural control mechanism preventing dense populations of nuisance algae such as *Microcystis* from becoming permanently established. Ecological conditions are such that phytoplankton blooms of cyanophyte species may occur during the summer months, although the recent bloom of *Anabaena* may have been fuelled by ineffective control measures applied in the eradication of water hyacinth. The phytoplankton diversity is poor, typical of an urban-impacted, nutrient-enriched water body.

Details of the nutrient loading processes, fish and benthic macroinvertebrate and zooplankton populations, and other biophysical interactions in Princess Vlei are inadequately understood at present. Princess Vlei has been described as a biologically disturbed system. An improved understanding of the physical and biological mechanisms prevailing in Princess Vlei may provide some insights pertinent to the future management of this and similar water bodies.

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