The continued influence of organic pollution on the water quality of the turbid Modder River

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Abstract

The Modder River is a relatively small river which drains an area of 7 960 km^2, in the central region of the Free State Province, South Africa, and has a mean annual runoff of 184 x 10^6 m^3. Botshabelo is a city which was developed in the catchment area of the river and treated sewage is released into the Klein Modder River. This study determined seasonal and spatial patterns in the system as well as the continued influence that Botshabelo's treated sewage outflow has on the water quality of the river. It was determined that the Modder River and Klein Modder River follow distinctive seasonal patterns in terms of algal growth and physical factors. There were periods when the waters of the Modder River and Klein Modder River are of acceptable quality; however, outflows from Botshabelo have a detrimental effect on the water quality, in terms of nutrient concentrations and algal biomass. The inflow of the Klein Modder River into the Modder River caused on average, 112% increase in phosphate-phosphorus (PO_4-P), 171% increase in nitrate-nitrogen (NO_3-N) and a 50% increase in chlorophyll-*a* concentration in the Modder River. The long-term detrimental effect of Botshabelo on the system can clearly be seen by comparing predicted nutrient increases with measured values.

Introduction

South Africa is well endowed with natural resources, except for water. The total surface runoff in South Africa is only 51 x 10^9 m^3/a (Koch et al., 1990). Only 11% of the total rainfall reaches the rivers. The remainder is lost to evaporation and groundwater sources.

Due to ignorance by the major mines and factories, in spite of effluent quality regulations pollution, is having a negative impact on the quality of drinking water (Koch et al., 1990). Because the demand for potable water is increasing in South Africa, more research is needed to determine the best possible way to use, reuse and conserve freshwater.

The Modder River is a relatively small river which drains an area of 7 960 km^2, in the central region of the Free State Province, South Africa, and has a mean annual runoff of 184 x 10^6 m^3. Water from this river is stored in the Rustfontein, Mockes, Mazelspoort and Krugersdrift Dams (Grobler and Toerien, 1986; Grobbelaar, 1992). About 60% of the potable water supply of Bloemfontein is provided by the Modder River. The rest is pumped from the Caledon River which is about 150 km south-east of Bloemfontein (Grobbelaar, 1992). The Modder River is also a very turbid system, (modder means mud), for example the average sediment yield at Sannaspos was calculated to be 304 t/km^2·a (Rooseboom, 1978). The Modder River can be dry for long periods, particularly during the winter months and the impoundments are the only permanent sources of water (Grobbelaar, 1991). However, the river never ran dry during the study period, although the water levels were sometimes very low.

Botshabelo was founded in the 1970s and developed in the catchment of the Modder River, about 60 km east from Bloemfontein. The total population in 1995 was 243 855 (Pretorius and Viljoen, 1997). The majority of the residents reside in informal settlements and sanitation services are minimal. The sewage treatment facility at Botshabelo releases about 5 Mℓ treated effluent per day into the Klein (meaning small) Modder River. This may add contaminant concentrations of micro-organisms, minerals and nutrients to the Modder River system.

Grobler and Toerien (1986) conducted a study to predict the impact of Botshabelo's treated effluent on the river system by means of a simulation model. They concluded that the discharge of treated effluent into the Klein Modder River could result in undesirable eutrophic conditions in Mockes Dam and the Mazelspoort Barrage. To comply with the 1 mg/ℓ standard required for 95% of the time, an average concentration of 0.4 mg P/ℓ in the effluent would be required (Grobler and Toerien, 1986). They predicted that problems could arise before 1990, if a 1 mg/ℓ P standard for effluents was not enforced.

At present there is limited limnological information on the Modder River. Grobbelaar (1985; 1989) reported on the primary production and Jagals and Grabow (1996) on the effect of pollution on human health. Grobler and Toerien (1986) reported on some of the chemical characteristics of the river.

Using information from the literature, comparisons between different lotic ecosystems (for example a turbid system like the Barwon-Darling River in Australia and a polluted system like the Vaal River in South Africa) were made to put relationships between environmental variables and phytoplankton responses measured in the Modder River into perspective and to determine whether common characteristics could be found among the different systems. Because of limited availability, only some information regarding the Orange and the Caledon Rivers was given to gain a perspective on differences, if any, between rivers in the same catchment area.

The present study serves to determine whether Botshabelo has a detrimental effect (eutrophication and/or salinisation) on the water quality of the Modder River and what the self-purification potential of the river is. It also elucidates seasonal and spatial changes in the physical, chemical and biological characteristics of the water. The final objective is to contribute towards the limnological knowledge and resource management of the Modder River.

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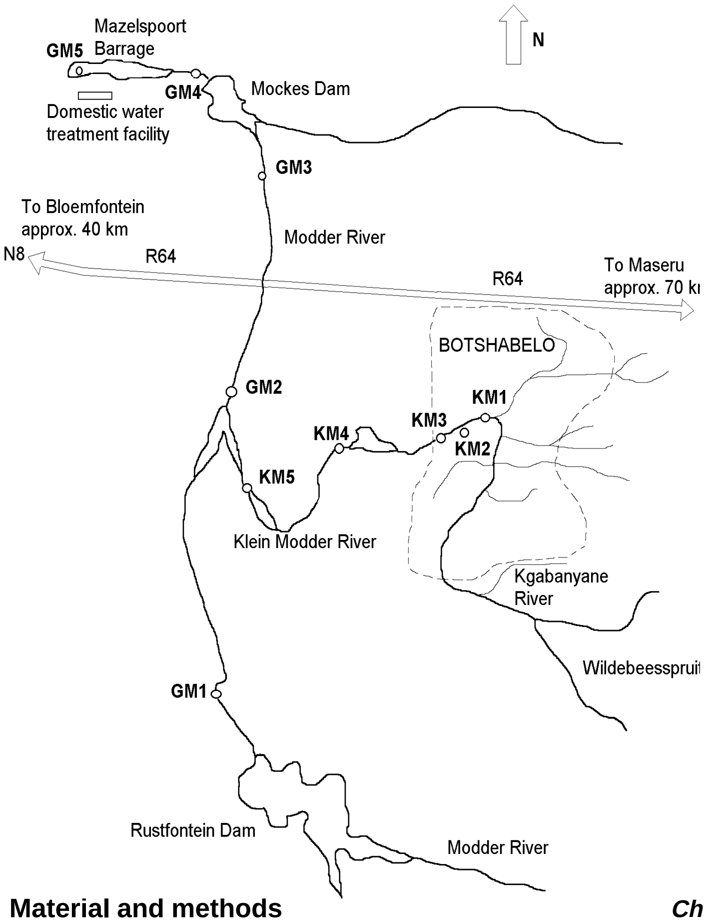

Figure 1
The different sampling sites in the Modder River study area

Klein Modder River
***KM1**: Reference point for Botshabelo's runoff before the treated sewage effluent is added.*
***KM2**: Outflow of the Botshabelo sewage treatment facility.*
***KM3**: Collective reference point (above Botshabelo Dam) for the city's total output/discharge of surface water runoff.*
***KM4**: In the river beneath Botshabelo Dam.*
***KM5**: On a farm (Vadersgift) above a damwall.*

Modder River
***GM1**: In the river near Palmietfontein Nature Reserve, below Rustfontein Dam. This site was used as an unpolluted reference point.*
***GM2**: Sannaspos - just after the confluence of the Modder and Klein Modder Rivers.*
***GM3**: A site about 12 km downstream from GM2 with rocky banks.*
***GM4**: A site below Mockes Dam.*
***GM5**: In Mazelspoort Barrage.*

Material and methods

Study site

The study was conducted in the upper part of the Modder River which included the region of the Modder River from Rustfontein Dam up to the Mazelspoort Barrage (Fig. 1), as well as the confluence of the Klein Modder River with the Modder River just before Sannaspos. Water samples were taken, fortnightly, from February 1996 to December 1996 at ten sampling points, five in the Klein Modder (KM1 - KM5) and five in the Modder River (GM1 - GM5) (Fig. 1). It is important to note that KM2 is not located in the Klein Modder River, but at the outflow of the Botshabelo treatment facility. Because GM1 is well above the populated area, it was considered to be the most unpolluted and used as a reference point.

Measurements

In situ measurements were made during sampling visits and subsurface samples (2 ℓ) were taken and transported to the laboratory for chemical analyses. The analyses were done within 48 h and were stored, in the dark, at about 4°C to limit chemical and biological changes.

Physical parameters

Water temperature (°C) was measured *in situ* using a YSI Model 50B dissolved oxygen meter (5739 probe).

Turbidity was measured using an Aqualytic Turbidimeter AL1000 and expressed as NTUs.

Daily flow data for the Modder River (at GM2 - Sannaspos) were obtained from the Department of Water Affairs and Forestry, Pretoria.

Chemical parameters

Conductivity was measured with a T and C Model 2001 conductivity meter as mS/m.

Nitrate-nitrogen (NO_3-N) was determined with a method described in Bausch and Lomb (1974). Phosphate-phosphorus (PO_4-P), total phosphorus (TP) and silica-silicon (SiO_2-Si), were determined by using the methods as described in S*tandard Methods* (1995).

The dissolved oxygen concentration (mg/ℓ) and percentage oxygen saturation (%) were measured *in situ* using a YSI Model 50B dissolved oxygen meter (5739 probe). The pH was determined *in situ* with a HANNA HI 9073C MICROCOMPUTER pH meter.

*Chlorophyll-*a *and algal identification*

Chlorophyll-*a* concentration was measured by using a modified ethanol extraction method similar to that of Sartory and Grobbelaar (1984) and expressed as µg/ℓ.

Because algal species can serve as biological indicators of water quality, the dominant algal species were identified using a Zeiss light microscope. Samples were examined after fixation with 2% formaldehyde.

Results

Turbidity and flow

The turbidity in both the Klein Modder and Modder Rivers ranged between 10 and 900 NTUs (mean = 60 NTUs). It increased during the rainy season with increased flow (September to May) but was low (<20) during the winter period (June to August). Once during the winter there was an increase in turbidity when snow and rainfall occurred. During the rainy season, the flow in the Modder River increased up to 10 m^3/s.

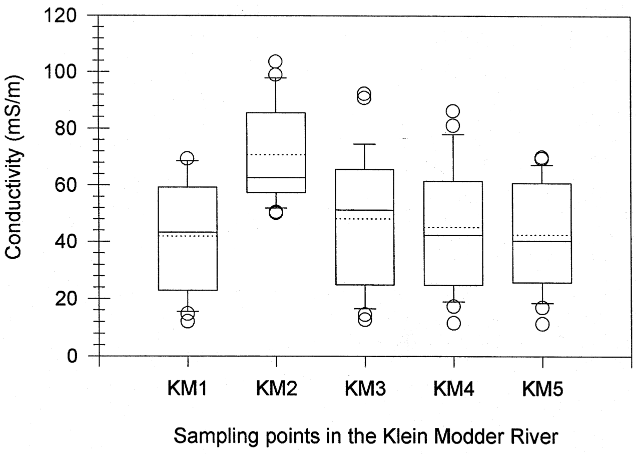

Figure 2

Box plot (data distribution) of conductivity (mS/m) in the Klein Modder River during the study period (Feb. to Dec. 1996). The box represents the 25th through to the 75th percentiles (thus 50% of the data values). The solid line in the box represents the median value and the dotted line the mean value.

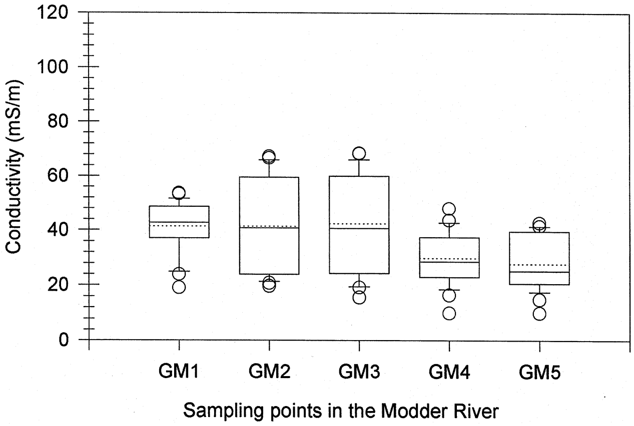

Figure 3

Box plot of conductivity (mS/m) downstream in the Modder River during the study period (Feb. to Dec. 1996).

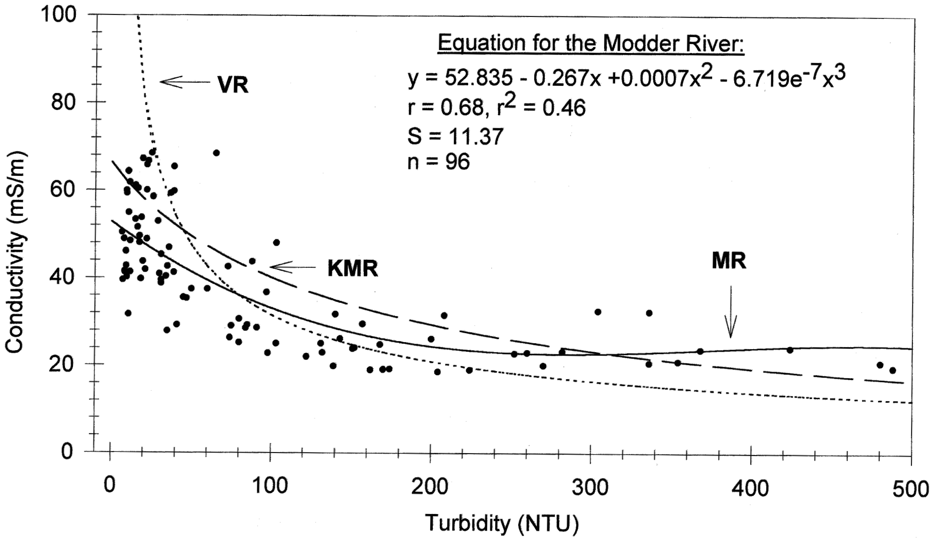

Figure 4

The relationship between turbidity and conductivity in the Modder River (MR) during the study period (solid line). The dotted line represents the relationship between conductivity and turbidity in the Vaal River (VR): Turbidity = conductivity$(3.4 * 10^4)^{(1/-1.69)}$ and the broken line the relationship between conductivity and turbidity in the Klein Modder River (KMR): $y = 1/(0.0151 + 0.00013x^{0.9431})$.

Conductivity

The minimum value of conductivity in the Klein Modder River was 12 mS/m and the maximum was 100 mS/m (mean = 52 mS/m) (Fig. 2). In the Modder River it was 10 mS/m and the maximum value was 60 mS/m (mean = 36 mS/m) (Fig. 3).

The mean conductivity at the sewage outflow, KM2 (72 mS/m), was higher than that of the sampling points in the river but it decreased from KM3 to KM5 (Fig. 2).

The average conductivity at GM1, GM2 and GM3 was nearly the same, being about 42 mS/m. However, there was a definite decrease in conductivity at GM4 and GM5 when compared to GM3 (Fig. 3).

Turbidity vs. conductivity

A statistically significant inverse correlation was demonstrated between conductivity and turbidity in the Klein Modder and Modder Rivers (Fig. 4). Forty-six per cent of the variation in conductivity was associated with the variation in turbidity (r^2 = 0.46).

Nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P) and silica-silicon (SiO_2-Si)

During the study period the NO_3-N concentration in the Klein Modder River displayed large variation with a mean of 860 µg/ℓ, excluding KM2. A maximum of more than 4 571 µg/ℓ was recorded at KM2 following storm events when the sewer system received large quantities of urban drainage with a probable overspill into the river. The NO_3-N concentration seems to have increased following rainfall at some of the sampling sites (Insert: Fig. 5). The NO_3-N concentration in the Modder River was on average 230 µg/ℓ (Fig. 5). The PO_4-P concentration in the Modder averaged 66 µg/ℓ (Fig. 6) and in the Klein Modder River it was 260 µg/ℓ. There was a definite increase in the NO_3-N and PO_4-P concentrations at GM2, compared with GM1 and were ascribed to inflow from the Klein Modder River (Figs. 5, 6).

The SiO_2-Si concentration in the rivers ranged between 2.6 to 5.4 mg/ℓ with an average of 3 mg/ℓ in the Modder River and 3.8 mg/ℓ in the Klein Modder River. The highest mean concentrations were at KM2 (6.4 mg/ℓ) and GM1 (5.2 mg/ℓ).

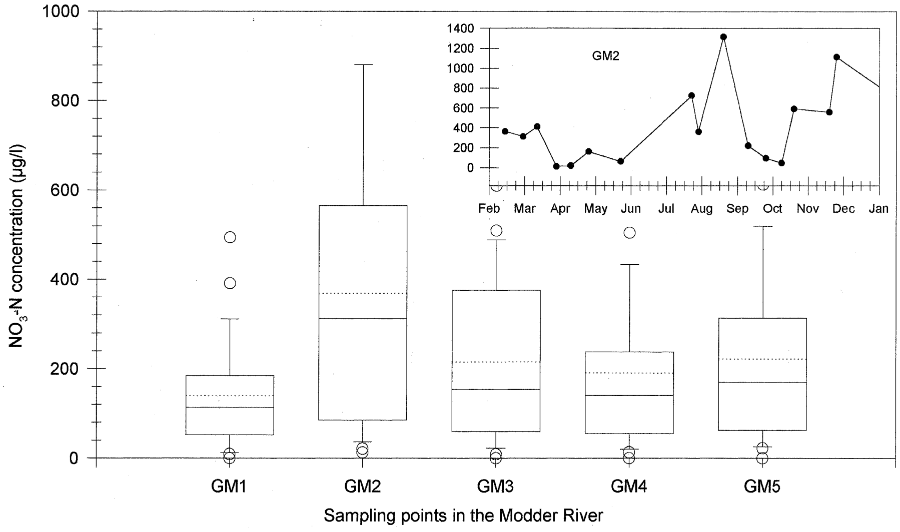

Figure 5
Box plot of NO$_3$-N concentration (µg/ℓ) downstream in the Modder River during the study period (Feb. to Dec. 1996). Insert show seasonal variation at GM2.

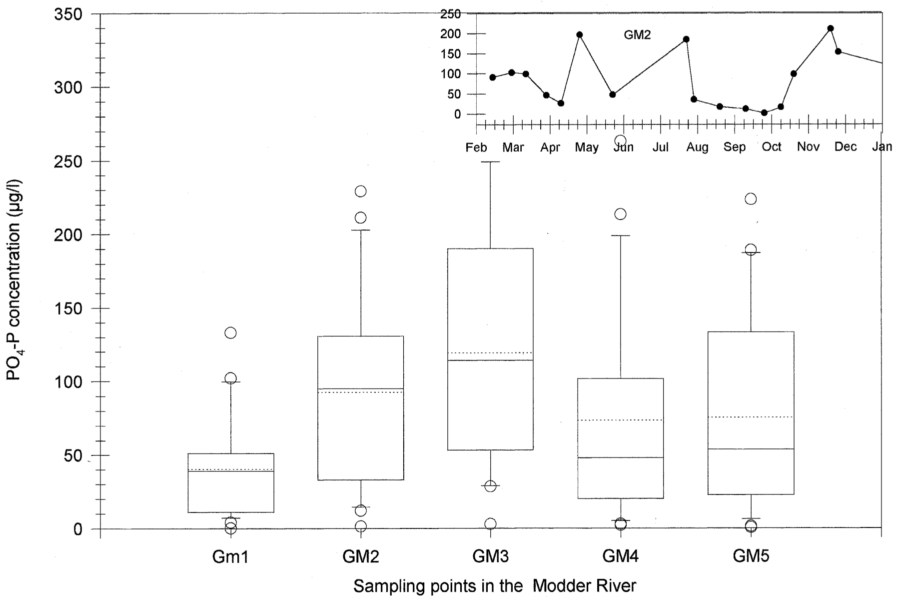

Figure 6
Box plot of PO$_4$-P concentration (µg/ℓ) downstream in the Modder River during the study period (Feb. to Dec. 1996). Insert show seasonal variation at GM2.

Oxygen, temperature and pH

The average dissolved oxygen, at the different sampling sites in the Modder River, varied between 3 and 7 mg/ℓ and in the Klein Modder River between 5 and 7 mg/ℓ. The mean percentage oxygen saturation varied between 60 to 80% in both rivers throughout the study period.

The temperature in both the Modder and Klein Modder Rivers followed the seasons being high (22 to 23°C) in the summer (September to May) and low (10 to 11°C) in the winter (June to August).

The pH in the Modder River (mean = 8.06) and the Klein Modder River (mean = 8), indicates that the water was mainly alkaline. It is important, however, to note that these measurements were made at a given time and that it can change rapidly during a diurnal period.

Chlorophyll-*a* concentration and algal species

The chl-*a* concentration of the Klein Modder River ranged between 1 and 180 µg/ℓ (mean = 30 µg/ℓ) and that of the Modder River between 1 and 83 µg/ℓ (mean = 15 µg/ℓ) (Figs. 7, 8). There was a 50% increase in the mean chl-*a* concentration in the Modder River from GM1 to GM2 (Fig. 8).

The seasonal changes in chl-*a* concentration at GM2 and GM3 can be summarised as follows (Fig. 9): During late autumn (May) an increase in chl-*a* concentration occurred. However, in the autumn, both day lengths and temperatures were dropping and the chl-*a* peak dropped off rapidly. During the winter period and especially during July and August the algal concentrations were low (mean < 20 µg/ℓ) in the Modder River. A spring increase began to develop during September and reached a maximum during mid-September (GM2, GM3) and a second peak during November (GM2, GM3). The maximum chl-*a* concentrations also occurred at these two sites (80 µg/ℓ) (Fig. 9).

The algal biomass in the sewage discharge (KM2) was very low throughout the study period. At the other sites in the Klein Modder River, the chl-*a* concentration showed comparable patterns with the Modder River.

Of all the algal species, *Phacus, Chlorococcum, Coelastrum* and *Chlamydomonas* were identified most often. There was also an abundance of pennate diatoms, mainly *Navicula* and *Nitzschia*.

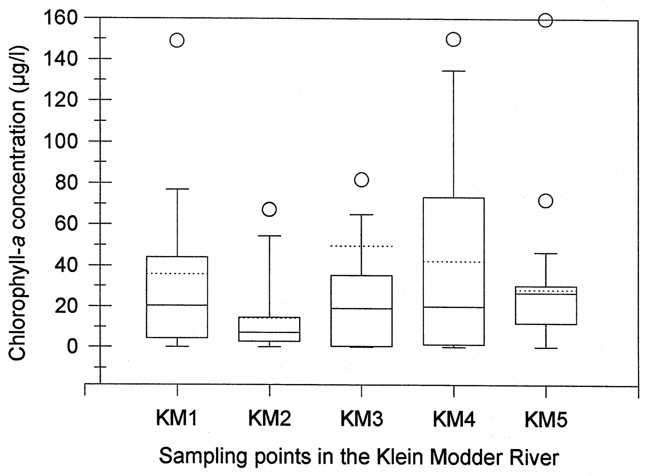

Figure 7
*Box plot of chlorophyll-*a *concentration (µg/ℓ) downstream in the Klein Modder River during the study period (Feb. to Dec. 1996).*

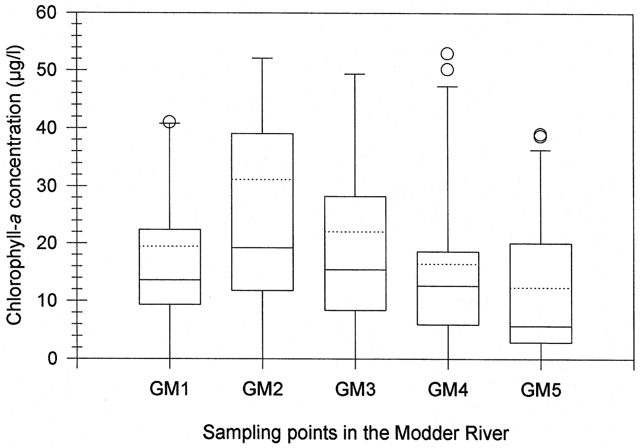

Figure 8
*Box plot of chlorophyll-*a *concentration in the Modder River during the study period (Feb. to Dec. 1996). Note difference in scale to Fig. 7.*

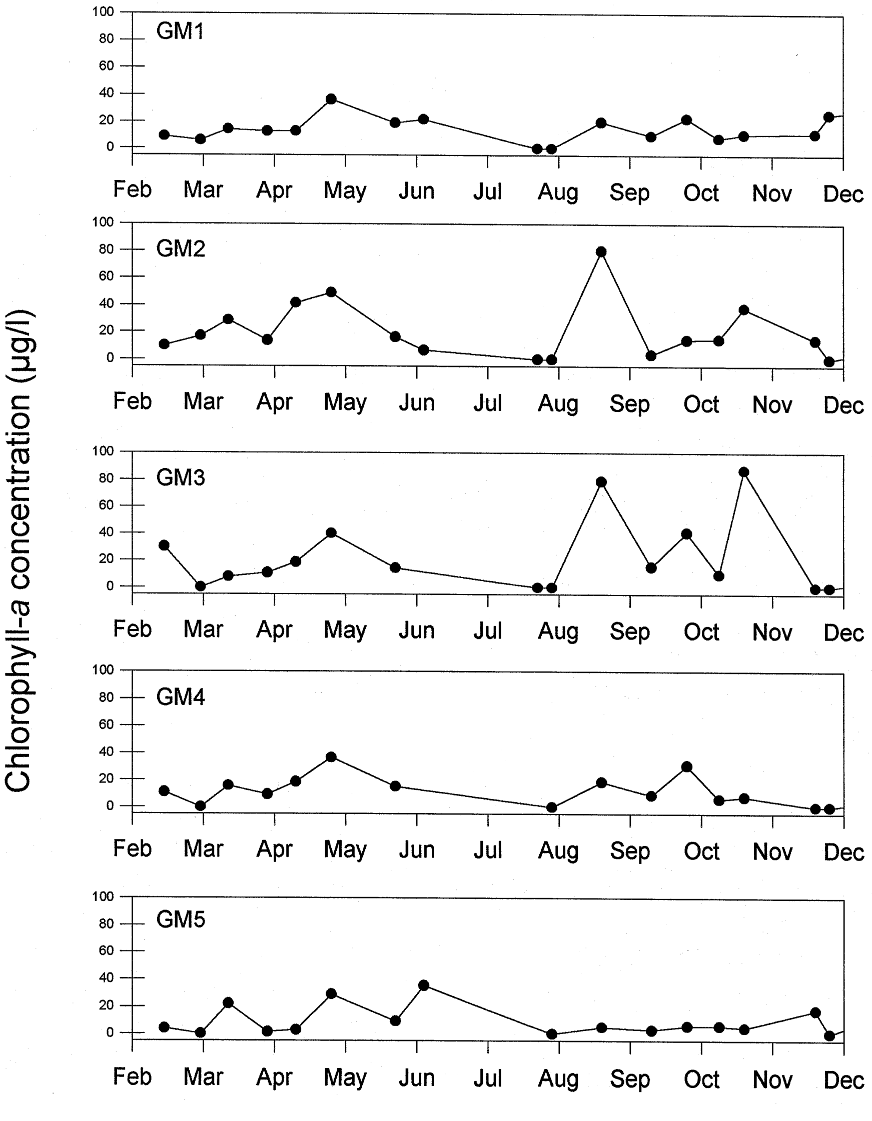

Figure 9
*Seasonal variation in chlorophyll-*a *concentration (µg/ℓ) in the Modder River (GM1 to GM5).*

Discussion

Turbidity and flow

The sediment loads of rivers, and the turbidity of their waters, are dependent on complex interactions, between soil characteristics and agricultural practices, within the catchment and the flow rates of rivers draining the catchment (Ferrar, 1989). An important feature of many South African reservoirs is high turbidity caused by the presence of suspended silt. Therefore, light and not nutrients is considered to be the primary limiting factor for algal growth in many South African aquatic ecosystems (Grobbelaar, 1985). Both the Klein Modder and Modder Rivers have an average of 60 and maximum NTU values of 900. These high turbidities of 900 NTU were recorded during high flows in November. This agrees with the Vaal River where the most important factor that influenced the turbidity, and thus the euphotic zone, is discharge (Roos and Pieterse, 1995b). The turbidity in the Barwon-Darling River was, however, much lower. It was usually less than 40 NTU at most localities at the time of sampling. It increased to above 200 NTU at some sampling sites following the passage of high flows in late December and early January (Bowling and Baker, 1996).

Conductivity

In general the conductivity of a stream is lowest in its catchment and, as it flows along its course, it leaches ions from the soils and also picks up organic material from biota and its detritus (Ferrar, 1989).

The average conductivity for the Klein Modder was 52 mS/m and for the Modder River it was 36 mS/m. The average value of typical, unpolluted rivers is approximately 35 mS/m. The conductivity of both the Modder and Klein Modder Rivers was much lower than for example that of the salinised Vaal River (Roos and Pieterse, 1995) with an average of 76 mS/m. However, it is well within the target guideline range proposed by the *South African Water Quality Guidelines*. No health, aesthetic or treatment effects are associated within this range (0 to 70 mS/m). When compared to the conductivity of the Barwon-Darling River, Australia, the conductivity of these rivers was in the same range - below 80 mS/m (Bowling and Baker, 1996). The average conductivity of the Orange and Caledon Rivers was 13.3 mS/m and 16.8 mS/m respectively (Keulder, 1979), much lower than the Modder River. The mean conductivity at KM2 (70 mS/m), was higher than at the other sampling points (Fig. 2) and can be ascribed to the salt content in the sewage. Although the degree of salinisation is less extreme than in mine effluents, treated sewage effluents contain much higher concentrations of salts than found in domestic water supplies (Ferrar, 1989). The conductivity decreased gradually downstream, probably due to dilution of the sewage outflow, from KM3 to KM5 (Fig. 2).

Mockes Dam is between sampling point GM3 and GM4, where a 47% decrease in conductivity was observed (Fig. 3). Impoundments store water from peak floods and this water is usually low in conductivity. The lentic conditions in this reservoir could also cause the salts to flocculate to the sediments, thus leading to a decrease in dissolved salts and conductivity.

The Modder River can thus be viewed as a typical, unpolluted river in terms of conductivity, while the Klein Modder River can be viewed as polluted.

The conductivity of the upper Modder River was relatively low (40 mS/m); however, it could increase in the near future due to the dissolved salts in the sewage effluent of Botshabelo (KM2) being high.

Conductivity vs. turbidity

The turbidity (suspension of particulate material) of a system also depends on factors other than the rainfall, such as total dissolved salts (TDS), water flow, geological formations and vegetation cover (Ferrar, 1989).

Conductivity was inversely related to turbidity in both the Klein Modder and Modder Rivers (Fig. 4). This relationship was also demonstrated by Roos and Pieterse (1995b) who found that salinity in the Vaal River displayed seasonal changes that were strongly influenced by turbid conditions following rainfalls. Fifty-six per cent of the variation in conductivity in the Vaal River was associated with the variation in turbidity. They also stated that most rivers exhibit decreasing conductivity with increasing flow. This is also in accordance with both the Orange and Caledon Rivers, where higher values of conductivity were measured during dry periods, when turbidity was low (Keulder, 1979).

Ferrar (1989) reported that immediately after the onset of a storm, the conductivity levels in rivers will increase sharply owing to salts being flushed down the system and as dilution occurs, they then return rapidly to pre-flood, or even lower, levels. The conductivity in the Modder River and Klein Modder Rivers decreased dramatically after rain (high flow conditions), while the turbidity increased. These measurements were, however, not taken after the onset of the storm, but days after heavy rains occurred.

Nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P) and silica-silicon (SiO_2-Si)

The average NO_3-N concentration of the Modder River (230 µg/ℓ) was much higher than the 100 µg/ℓ for unpolluted world rivers (Webb and Walling, 1992), but lower than the eutrophied Vaal River (400 µg/ℓ) (Roos and Pieterse, 1995a). However, the mean NO_3-N concentration in the Klein Modder River (860 µg/ℓ) was more than twice that of the Vaal River. In the Orange River, the NO_3-N concentration was 933 µg/ℓ and in the Caledon River 875 µg/ℓ (Keulder, 1979).

The mean PO_4-P concentration in the Klein Modder River (260 µg/ℓ) was much higher than in the eutrophied Vaal River (18 µg/ℓ) (Roos and Pieterse, 1995a) as well as in the Barwon-Darling River (9 µg/ℓ) (Bowling and Baker, 1996). It was also higher than the Orange River (59.8 µg/ℓ) and the Caledon River (63.5 µg/ℓ) (Keulder, 1979). The low NO_3-N:PO_4-P ratio of < 4 in the Modder River system indicates that nitrogen could be limiting to algal growth. The higher NO_3-N and PO_4-P concentrations in the Klein Modder River than in the Modder River, emphasise the effect of nutrient enrichment due to runoff from Botshabelo on the system.

Grobler and Toerien (1986) made predictions of the possible total phosphorus concentration in Mockes Dam assuming a P limitation of 1 mg/ℓ and runoff as 0.2 times the mean annual runoff. They predicted a TP concentration of 276 µg/ℓ in 1990 and 351 µg/ℓ in the year 2000. A mean value of 340 µg/ℓ was observed during 1996 at GM2 and GM3.

GM2 is the sampling point just below the confluence of the Modder and Klein Modder Rivers. The increase in concentration of NO_3-N and PO_4-P at this point, compared to GM1 (Figs. 5, 6), is a direct result of treated sewage which flows into the Modder River via the Klein Modder River. There was a tendency for the nutrients to decrease downstream, which is an indication of the self-purification capacity of the system. At KM2 (the sewage plant) there were always high nutrient concentrations but the algal biomass was low. This could be due to chlorine in the treated water which is toxic to living organisms.

The average silica concentration in the Modder River (3 mg/ℓ) and the Klein Modder River (3.8 mg/ℓ), is much lower than the world average of 9 mg/ℓ in rivers (Horne and Goldman, 1995) but comparable to other river systems, like the Vaal River (3 mg/ℓ). At some of the sites the silica concentration decreased when algal growth (chl-*a*) increased. It can be assumed that the silica was incorporated into the cell walls of diatoms, because of the presence of diatom species throughout the year. Silica concentrations are also dependent on temperature, having lower values at low temperatures (in the winter). This is demonstrated by the fact that the lowest SiO_2-Si values occurred in June in both the Klein Modder and the Modder Rivers.

In terms of the nutrient concentrations in the water of the Modder and Klein Modder Rivers, this section (the study site) of the systems can be classified as eutrophic (Mason, 1991).

Oxygen, temperature and pH

The mean percentage of oxygen saturation in the Modder and Klein Modder Rivers (which varied from 60 to 80%) showed that the water is of an acceptable quality. The highest dissolved oxygen concentrations coincided with maximum chl-*a* concentrations. For example, during the spring increase at GM2 and GM3 in September (80 µg/ℓ chl-*a*), the dissolved oxygen concentrations were 15 and 9 mg/ℓ respectively. This relationship was also found by Roos and Pieterse (1995a; 1996) in the Vaal River.

The different optimum temperatures for the species identified in the Modder River, were: *Nitzschia sp.* (pennate diatom); 27.5°C, C*hlamydomonas sp.*; 23°C and *Euglena sp.;* below 23°C (Kozitskaya, 1989). Thus, the low temperatures (10 to 15°C) during the winter could be a limiting factor for algal growth, despite the relatively high light availability (low turbidity). Algal growth also occurred when temperatures became more favourable e.g. during the spring increase.

Changes in pH influence the availability and toxicity of important plant nutrients, such as phosphate, ammonium, iron and trace elements. For example, ammonium is only toxic at very high concentrations or at elevated pH values (Horne and Goldman, 1995). The alkaline water of the Modder (8.06) and Klein Modder (8.0) Rivers is within the range of the prescribed water quality guidelines for recreational use (DWAF, 1993). High pH values concurred with high chl-*a* concentrations, thus high photosynthetic activity.

The pH of both the Modder and Klein Modder Rivers compares well with the mean pH of the Vaal River which varied between 6.3 and 9.2 (mean 8.1) and the pH of the Barwon-Darling River which exceeded 8.5 at all sites except two (Roos and Pieterse, 1995; Bowling and Baker, 1996).

Chlorophyll-*a* concentration and algal species

Algae are abundant in aquatic environments as primary producers and are an important part of water bodies, providing food for fish and other aquatic organisms. Excess algae or undesirable algal types can, however, become a nuisance and interfere with the uses of a water body. They can also cause taste and odour problems as well as gastro-enteritis and skin irritations (Bowling and Baker, 1996).

The predicted average chl-*a* concentration for Mockes Dam by Grobler and Toerien (1986) was 38 µg/ℓ in 1990 and 46 µg/ℓ for the year 2000. The measured value at GM3 (closest to Mockes Dam) in 1996 was 24 µg/ℓ. Thus, the prediction was an overestimation of the average measured concentration. However, at GM2 (just after the confluence of the two rivers) the average chl-*a* concentration was 32 µg/ℓ, much higher than at Mockes Dam.

The 100% higher mean chl-*a* concentration, in the Klein Modder River, can be ascribed to the higher nutrient concentrations and more favourable light conditions. High flow was associated with low chlorophyll-*a* concentrations.

The increase in chl-*a* at GM2 and GM3, compared to GM1 (Fig. 8), can be ascribed to the nutrient-rich water that flows from the Klein Modder River into the Modder River. The fact that two chl-*a* peaks occurred at GM2 and GM3, in September and November (Fig. 9), gives an indication of the degree to which the Klein Modder River enriches the Modder River with nutrients. There were sufficient nutrients for two algal blooms to occur. The dominant algae which caused these blooms were mostly diatoms. This was followed by a gradual decrease in chl-*a* from GM3 to GM5, probably due to dilution of the nutrients (Fig. 8).

GM5 showed a totally different seasonal pattern from any of the other points in the Modder River (Fig. 9). This could be due to the fact that this point was the Mazelspoort Dam which is lentic and a deep water-column.

Phacus, *Euglena* and *Chlamydomonas* were occasionally identified as dominant. These species are associated with polluted water and with water in which organic material is suspended (Canter-Lund and Lund, 1995).

Conclusion

The Modder River and Klein Modder River showed seasonal patterns in terms of algal growth and temperature and have periods where the water is of acceptable quality.

The nutrient concentrations in the Klein Modder River were consistently higher than in the Modder River, due to the nutrient-rich treated sewage effluent from Botshabelo, as well as from other sources, such as contaminated surface runoff and possible seepage of contaminated ground water and pit latrines. The nutrient concentration was the highest at GM2 and lower at GM5. This decrease could be due to dilution and/or self-purification through assimilation/sedimentation of pollutants. The impoundments could also make a small contribution towards the downstream "purification" of the system.

Algal blooms were caused by these high nutrient concentrations at some of the sampling sites during the spring and summer period. The chl-*a* concentration sometimes reached typically eutrophic levels in the Klein Modder River (> 100 µg/ℓ) and could cause aesthetic or environmental health problems. Algal growth in the Modder River is probably limited by light during the late summer (high flow, high turbidity), but the decrease in turbidity during the winter period improved the underwater light climate, thereby lifting the light limitation and permitting algal growth. Accordingly, the light penetration increases and causes more favourable light conditions for photosynthesis which stimulates primary productivity and leads to algal blooms (Toerien et al., 1983; Roos and Pieterse, 1995b).

From the results, it can be seen that temperature, nutrient concentrations and turbidity (all of which that are caused by seasonal changes) are the most important factors controlling algal growth in the Klein Modder and Modder Rivers. This is confirmed in the Barwon-Dowling River, Australia, where warm water temperatures, elevated pH, reduced turbidity and improved water transparency contributed to increased algal growth during spring (Bowling and Baker, 1996)

The negative influence of Botshabelo on the water quality of the Modder River is considerable. The inflow of the Klein Modder River into the Modder River caused 112% increase in PO_4-P, 171% increase in NO_3-N and 50% increase in chl-*a* in the Modder River from GM1 to GM2. It is important to remember that the dilution effect, observed during this study, could be ascribed to an above-average rainfall and high flush-out rate. However, given the hot, dry summer climate, the potential for drought and low flows, and the high nutrient concentrations of its waters, future blooms in the Modder River remain highly probable.

The long-term effect of Botshabelo on the system can be seen by comparing the observed values with those predicted by Grobler and Toerien (1986). The total phosphorus reached the predicted values, however, the chl-*a* concentration was lower than the predicted value. Though, it is important to note that higher chl-*a* values were measured upstream from Mockes Dam. Thus, the eutrophication of the system occurs not only in the reservoirs, but also in the river itself. Comparing the values obtained with those of 10 or 20 years ago, a definite increase can be seen. With increasing population numbers, the nutrient load to the Modder River system will continue to increase and the quality of the water will continue to deteriorate. Thorough integrated management of the system, like strict control over nutrient content in effluent as well as effluent volume, is necessary to control further eutrophication of the system that could lead to severe problems, such as noxious cyanobacterial blooms.

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