The Phosphorus-Chlorophyll Relationship in Roodeplaat Dam

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Abstract

Since eutrophication is a serious potential water quality problem in South Africa, decision making for the rational control of eutrophication problems requires information on the relationship between algal growth and nutrient concentration and nutrient loading. The authors have demonstrated the following statistically significant correlation (P = 0,01) between average chlorophyll *a* and phosphate phosphorus concentrations in $\mu g\ l^{-1}$ at 6 sampling stations for a two year period in Roodeplaat Dam:

$$\log_{10} \text{Chl}\ a = 1{,}232\ (\log_{10} PO_4 - P) - 0{,}509$$
$$(r = 0{,}98;\ n = 6)$$

Analysis of the standard deviation and maximum chlorophyll *a* concentration values of surface waters at different sampling stations suggested that the upper standard deviation level of a particular average chlorophyll *a* value will be exceeded for ca. 20% of the time.

On the basis of results on the more productive western and less productive eastern sections of Roodeplaat Dam and the above regression line it is suggested that 26 $\mu g\ l^{-1}\ PO_4 - P$ represent a level beyond which algal nuisance conditions may develop in Roodeplaat Dam and possibly other impoundments. It might be possible to utilize the chorophyll *a* and $PO_4 - P$ concentrations in the eastern and western sections in conjunction with eutrophication models based on phosphate phosphorus loading to arrive at allowable phosphate phosphorus loadings for this and other South African impoundments.

Introduction

Eutrophication is a serious potential water quality problem in South Africa (Toerien, 1975) and problems due to the excessive growth of algae and/or macrophytes are already experienced at a number of dams in the country (Toerien and Walmsley, 1977).

It is well known that increased nutrient loading frequently results in increased phytoplankton standing crop with undesirable blue-green algal species becoming the dominant populations. Little is known, however, about the phytoplankton standing crop response in relation to a given change in nutrient loading.

The decrease of the supply of phosphate phosphorus to the aquatic environment has been suggested as a long term solution for the control of eutrophication problems (e.g. Vallentyne, 1972), an approach that was used with remarkable success in the case of Lake Washington (Edmondson, 1969). This approach was also suggested for South Africa (Toerien and Walmsley, 1977).

Eutrophication models based on this concept and with the purpose of defining the 'critical' phosphorus loadings, i.e. those loadings which, when exceeded, would lead to the appearance of excessive algal or macrophyte growth (and its associated problems) have been developed for lakes of the temperate zone (e.g. Vollenweider, 1968, 1972, 1975; Imboden, 1974; Brezonik and Shannon, 1971). These models, however, do not predict the intensity of problems which will be associated with loading increases beyond the 'critical' level. This information, which is often required in planning and decision-making, could be obtained from predictive models of the relationship between chlorophyll and phosphorus concentrations (e.g. Sakamoto, 1966; Dillon and Rigler, 1974). It is not known whether models developed in the temperate zone on natural lakes are applicable to man-made lakes in sub-tropical areas like Southern Africa.

The purpose of this paper is to evaluate the relationship between phosphate phosphorus ($PO_4 - P$) and chlorophyll *a* in Roodeplaat Dam, an eutrophic impoundment near Pretoria (Walmsley, Toerien and Steÿn, 1978) and to consider its implications for the control of eutrophication.

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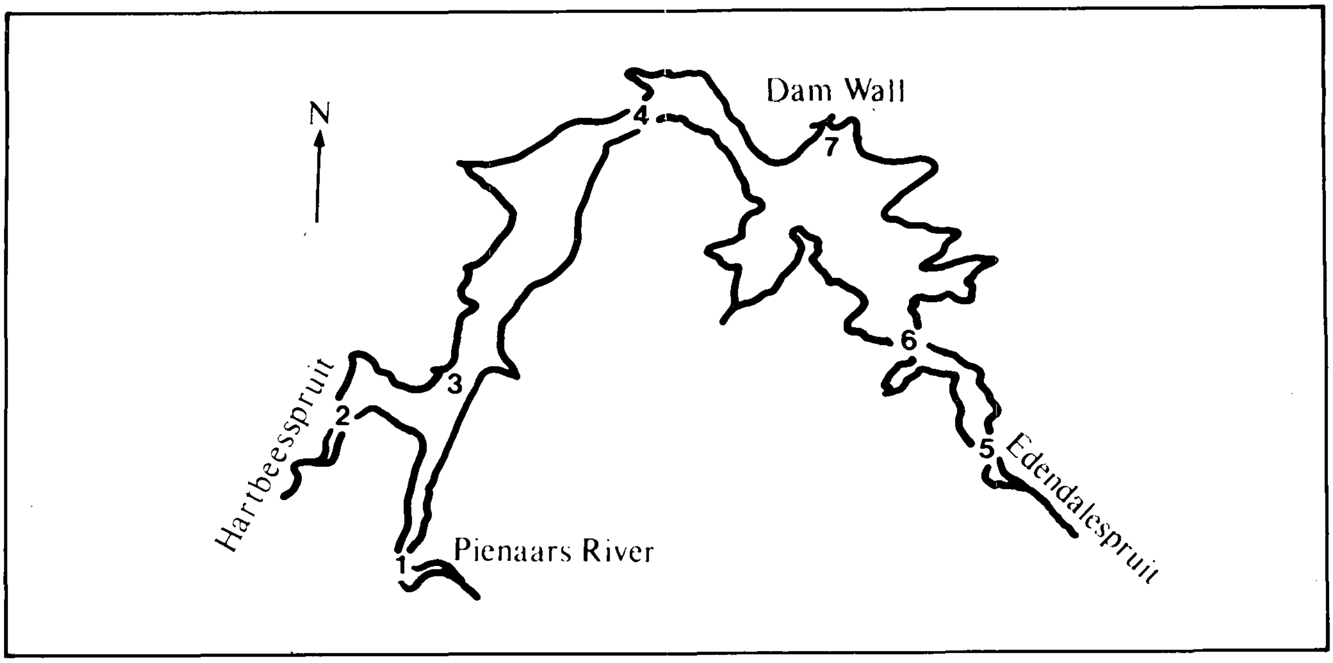

Figure 1
Roodeplaat Dam showing sampling stations

Materials and Methods

Study Area

The Roodeplaat Dam is situated in the Pretoria district at a latitude of 25° 37' south and a longitude of 28° 23' east. Full supply level is 1 314 m above mean sea level. The area of the catchment is 668 km^2 and consists of grassland, shrub-covered ridges and bushveld. The impoundment has a net capacity of $41{,}9 \times 10^6$ m^3 and covers an area of 396 ha at full supply capacity with a mean depth of 10,6 m and a maximum depth of 43 m.

The impoundment was completed in 1959. Since that time the use of the dam for irrigation purposes has been curtailed, and the dam has become an important recreation site. Potable water from the dam is prepared by the Baviaanspoort Prison and the Department of Water Affairs. Three inflowing streams enter the impoundment, namely the Edendalespruit, the Hartbeesspruit and the Pienaars River (Figure 1). The Pienaars River receives treated sewage outflow from the Baviaanspoort Sewage Treatment Plant which is the primary nutrient source of the Roodeplaat Dam and which can contribute up to 29 per cent of the total water inflow of the dam (Walmsley, Toerien and Steÿn, 1978).

Sampling

Thirty-six surface samples (0,5 m) were taken every second or third week from January 1976 to December 1977 at seven sampling stations (Figure 1) by means of a Van Dorn sampler.

Analyses

The concentrations of inorganic nitrogen and phosphorus ions (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}) were determined on samples filtered through pre-washed Sartorius glass fibre filters by the automated techniques of the Division of Water Quality, National Institute for Water Research (1974). Chlorophyll *a* concentrations were determined according to Talling and Driver (1963).

The mean values and standard deviations of chlorophyll *a*, inorganic nitrogen and PO_4-P were calculated for each of the sampling stations during the study period. These values were utilized in linear regression analyses of the relationship between chlorophyll *a* and nutrient concentrations. The upper standard deviation levels were plotted against average PO_4-P concen-

TABLE 1
THE MEANS** AND STANDARD DEVIATIONS OF CHLOROPHYLL *A*, INORGANIC NITROGEN AND PO_4—P CONCENTRATIONS ($\mu g\ l^{-1}$) OF DIFFERENT STATIONS IN ROODEPLAAT DAM

Sampling station	Chlorophyll *a*		PO_4—P		Inorganic nitrogen***	
	Mean	S.D.*	Mean	S.D.*	Mean	S.D.*
1	36,8	26,6	286,5	264,9	1 198,1	845,2
2	46,0	41,7	52,6	52,2	685,8	445,3
3	48,3	47,4	60,9	60,0	619,7	460,0
4	27,5	18,2	40,3	30,2	627,1	381,3
5	16,2	16,0	22,8	16,6	564,9	361,3
6	15,1	12,5	23,6	15,8	540,7	336,3
7	19,7	12,5	32,4	17,6	592,2	351,9

* S.D. = standard deviation
** n = 36
***$NO_3^- -N + NO_2^- -N + NH_4^+ -N$

trations for each sampling station and a curve was fitted by eye. A similar procedure was followed to develop a curve for the maximum observed chlorophyll *a* concentrations against average PO_4-P concentrations.

Results and Discussion

Chlorophyll and Nutrient Concentration

The mean values and standard deviations of chlorophyll *a* and the mean values of dissolved inorganic nitrogen and PO_4-P are summarized in Table 1. The highest mean chlorophyll *a* concentration occurred at station 3 and not at station 1 as might be expected from the mean PO_4-P and inorganic nitrogen concentration (Table 1). The lower mean algal standing crop at station 1 which receives the inflow of the Pienaars River could be due to suspended particulate matter carried into the dam by the Pienaars River resulting in light-limiting conditions, the presence of an algal growth inhibitor, predation, increased sedimentation of algal cells, or to a short retention period of water (and nutrients) in this part of the impoundment with the consequence that algal growth is not nutrient limited.

The lowest mean chlorophyll *a* values were encbuntered at sampling station 6 where the Edendalespruit enters the dam. Walmsley *et al.* (1978) reported that low amounts of nutrients, especially dissolved inorganic nitrogen and PO_4-P, enter the dam via the Edendalespruit.

The chlorophyll *a*, inorganic nitrogen and PO_4-P values of the other sampling stations were between that of sampling stations 3 and 6 and represented a gradient from sampling station 3 to 6, in agreement with the results of Toerien and Walmsley (1978).

Inspection of Table 1 indicates that sampling stations 5, 6 and 7 (eastern section of the dam) group together. Similarly, sampling stations 2 and 3 (western part of the dam) group together whilst station 4, in the section connecting the eastern and western sections of the dam, had an intermediate position. Roodeplaat Dam can therefore be divided into a more productive western section and a less productive eastern section. This division is also supported by the results of Toerien and Walmsley (1978).

This study was not designed to quantify algal nuisance conditions such as increased costs in potable water production, interference with the recreational use of the impoundment, increased health hazards towards recreational uses, etc. However, conditions such as foul smells due to the excessive growth of *Microcystis aeruginosa* and *Anabaena circinalis* were experienced for up to three weeks at a time during the warmer months at stations 2, 3 and 4 by the sampling team. The mean concentration of PO_4-P at these stations were 52,6, 60,9 and 40,3 $\mu g\ l^{-1}$ respectively (western section). On the other hand, in the less productive eastern section, station 7 exhibited less intensive smelling conditions only occasionally and stations 5 and 6 rarely if ever. The mean PO_4-P concentration in the eastern section was only 26,3 $\mu g\ l^{-1}$. Consequently it can be postulated that the eastern section represents threshold conditions of acceptability with regard to algal growth, whereas the western section exceeds such conditions.

If the above is interpreted in terms of PO_4-P levels, it can be suggested that the mean PO_4-P concentration of 26,3 $\mu g\ l^{-1}$ in the eastern section would represent the mean upper PO_4-P level beyond which increased algal growth accompanied with the occurrence of increased intensity in algal nuisance conditions will occur. The average PO_4-P concentration at station 4 was 40,3 $\mu g\ l^{-1}$, and this station as described above, experienced foul smells. The upper average PO_4-P level therefore lies somewhere between 26 and 40 $\mu g\ l^{-1}$. A conservative approach would at present indicate that 26 ug $PO_4-P\ l^{-1}$ be used as the critical PO_4-P level.

It must be emphasized that the above approach suffers from the obvious limitation that algal nuisance conditions have not yet been quantified in terms of producing water for potable purposes or in providing acceptable conditions for recreation, etc. Research projects must therefore be developed to provide pertinent information on problems associated with the excessive growth of algae under eutrophied conditions.

Various other authors have related chlorophyll concentration to the phosphate phosphorus concentration and suggested comparable levels beyond which blue-green algal blooms could be expected to develop, e.g. 20 $\mu g\ PO_4-P\ l^{-1}$ for the Occoquan River (Sawyer, 1970), 30 $\mu g\ l^{-1}$ for river estuaries (Pritchard, 1969) and 25 $\mu g\ l^{-1}$ for the Potomac estuary (Jaworski, Lear and Villa, 1972). Some authors suggested lower levels e.g. 15 $\mu g\ l^{-1}$ (Sawyer, Lackey and Lenz, 1945) and 10 $\mu g\ l^{-1}$ (Sawyer, 1947), but Toerien and Walmsley (1977) concluded that eutrophic conditions could set in under South African conditions if the phosphate concentration exceeds 25 $\mu g\ l^{-1}$, while Toerien (1975), employing yield coefficient and algal growth potential results with *Selenastrum capricornutum* as test species, estimated that 30 $\mu g\ PO_4-P\ l^{-1}$ would represent the upper limit of oligotrophic conditions.

Relationship Between Chlorophyll *a* and Nutrients

Regression analysis carried out on all the averaged data except for that of station 1 yielded the following equations (Figures 2 and 3):

$$\log_{10} \text{Chl } a = 1{,}232\ (\log_{10} P) - 0{,}509 \quad \ldots\ 1$$

(r = 0,98; n = 6)

and

$$\text{Chl } a = 0{,}24\ (N) - 116{,}43 \quad \ldots\ 2$$

(r = 0,82; n = 6)

where

Chl a = μg chlorophyll $a\ l^{-1}$

P = $\mu g\ PO_4^{3-} - P\ l^{-1}$

N = $\mu g\ NO_3^- - N + NO_2^- - N + NH_4^+ - N\ l^{-1}$

The correlation between chlorophyll *a* and PO_4-P concentration was highly significant at the P = 0,01 level whilst that for chlorophyll *a* and inorganic nitrogen was significant at the P = 0,05 level. It appears that algal growth in the major part of the impoundment was limited by PO_4-P rather than by inorganic nitrogen. This is in contrast to the suggestion of Toerien, Hyman and Bruwer (1975) that Roodeplaat Dam is growth-limited by nitrogen.

Sakamoto (1966) and Schindler, Fee and Ruszczynski (1978) found that the mean chlorophyll concentration of lake

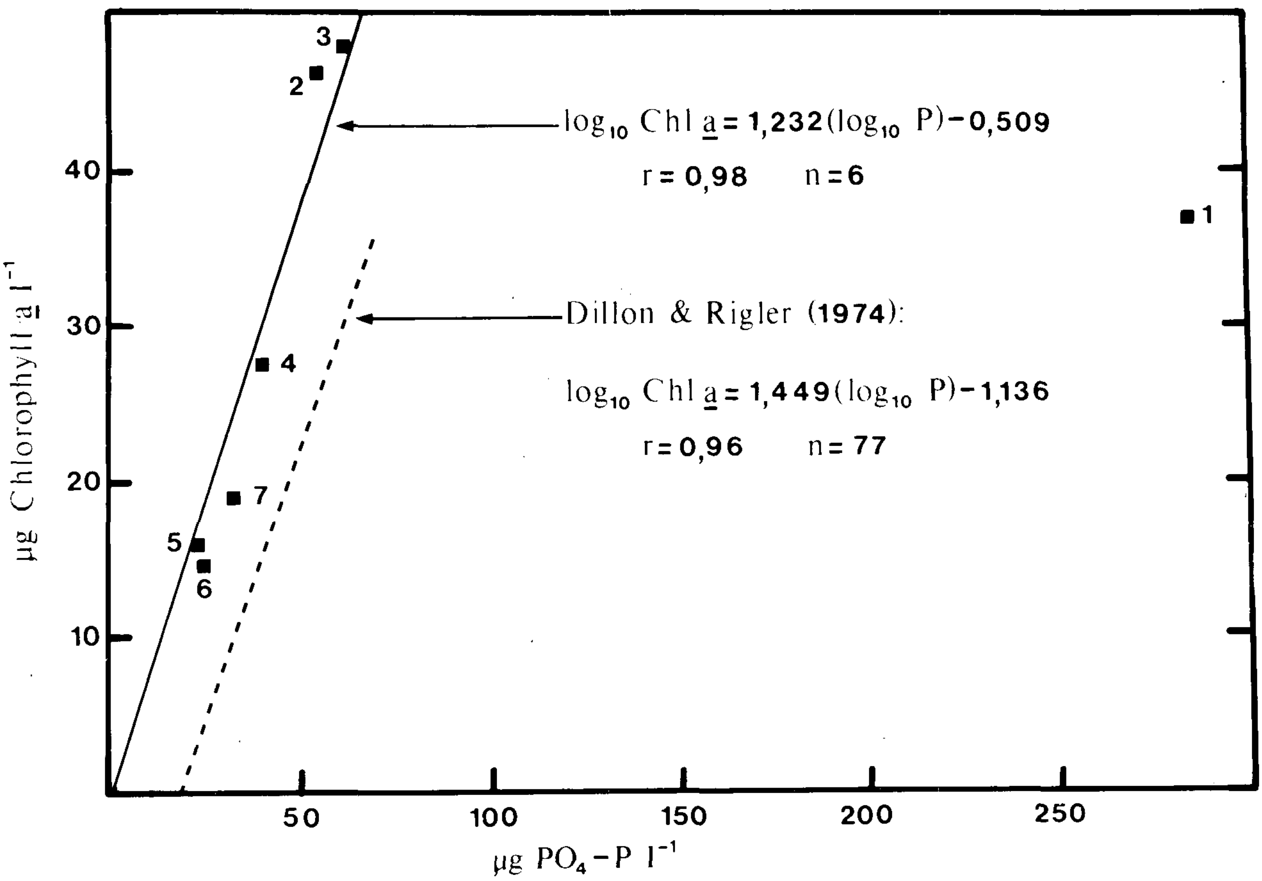

Figure 2
*The relationship between chlorophyll **a** and phosphate phosphorus at the various sampling stations (1 to 7)*

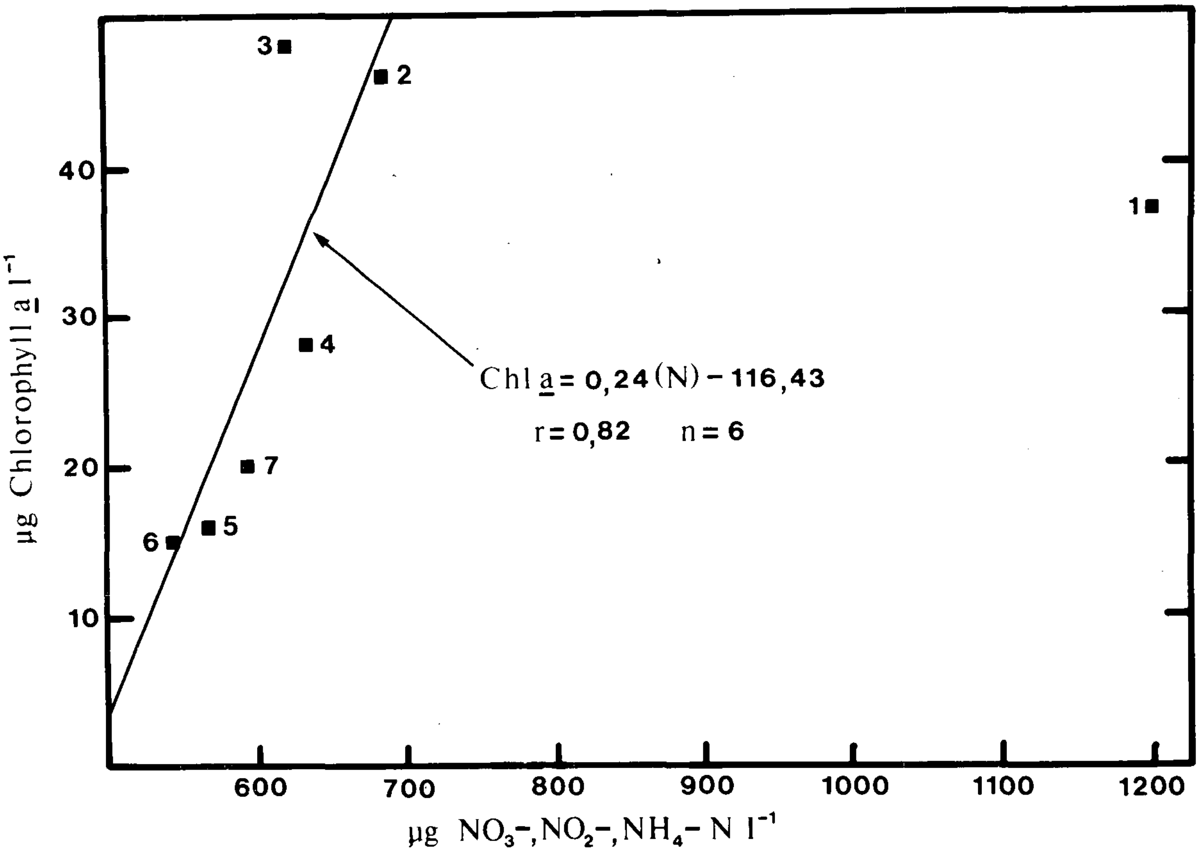

Figure 3
*The relationship between chlorophyll **a** and inorganic nitrogen at the various sampling stations (1 to 7)*

water is closely correlated with the mean concentration of total phosphorus provided that the N/P ratio is in excess of 12 (Sakamoto, 1966). It is significant firstly that a similar situation was found in Roodeplaat Dam (although based on PO_4-P) and secondly that this relationship may be utilized for predictive purposes, e.g. a reduction in the PO_4-P concentration will result in a decline in algal standing crop.

Dillon and Rigler (1974) reported the following relationship between the mean summer chlorophyll *a* concentration and mean spring total phosphorus concentration of natural lakes in the temperate zone:

$$\log_{10} \text{Chl}\ a = 1{,}449\ (\log_{10} \text{Total P}) - 1{,}136 \quad \dots\dots\dots\dots \quad 3$$
$$(r = 0{,}96,\ n = 77)$$

Although the slope of equation 1 (on PO_4-P data) is lower than that of equation 3 (on Total P data) the predictions of the two lines are very similar due to the differences in the points of intersection on the abscissa. The lower slope of the regression line of the Roodeplaat Dam data (equation 1) may be due to the fact that PO_4-P concentrations instead of Total P concentrations were used. However, the point of intersection on the abscissa of this equation is closer to zero than that of equation 3, which is what would be expected theoretically, i.e. no chlorophyll *a* at a zero PO_4-P concentration.

The above suggests that if long term results (e.g. one or two years of observations) are utilized in deriving regression lines, PO_4-P values may be more applicable to Southern African conditions than Total P values. This is gratifying since under the conditions of high turbidity due to silt in many South African impoundments total phosphorus values can not be used because of the large amount of phosphorus which is associated with the silt particles and therefore unavailable for algal growth (R.D. Walmsley, personal communication). PO_4-P is easily determined and the use of this parameter for predictive purposes therefore presents few, if any, analytical problems.

Models relating algal standing crop (i.e. chlorophyll concentration) to phosphorus concentration (even in water bodies where phosphate phosphorus is the primary limiting nutrient) do not take processes like mineralization, uptake of phosphorus by organisms, loss of phosphorus to the bottom sediments, supply of phosphorus from the catchment, etc., into account. Vollenweider (1975) pointed out that the concentration of phosphate phosphorus in the water is affected by loading, biological transformation and elimination rates. Based on this Toerien (1977) concluded that (phosphorus) concentration values are meaningless in defining eutrophic conditions, pointing out that this type of model cannot be advocated for general use and suggesting that this type of criterion for eutrophication control should be replaced by criteria based on loadings.

The above objections to models based on nutrient concentrations are, however, largely eliminated by basing the model on average concentrations over long periods of time, one or two years, because these average values would, for example, take into account occasions when the chlorophyll concentration was high but the phosphate concentration low (ca 1 $\mu g\ PO_4-P\ l^{-1}$ at all sampling stations in Roodeplaat Dam, Figure 4) and *vice versa*. The fact that a highly significant relationship existed between the chlorophyll *a* and PO_4-P concentrations (equation 1) at the various sampling stations (except for station 1) indicates the soundness of this approach.

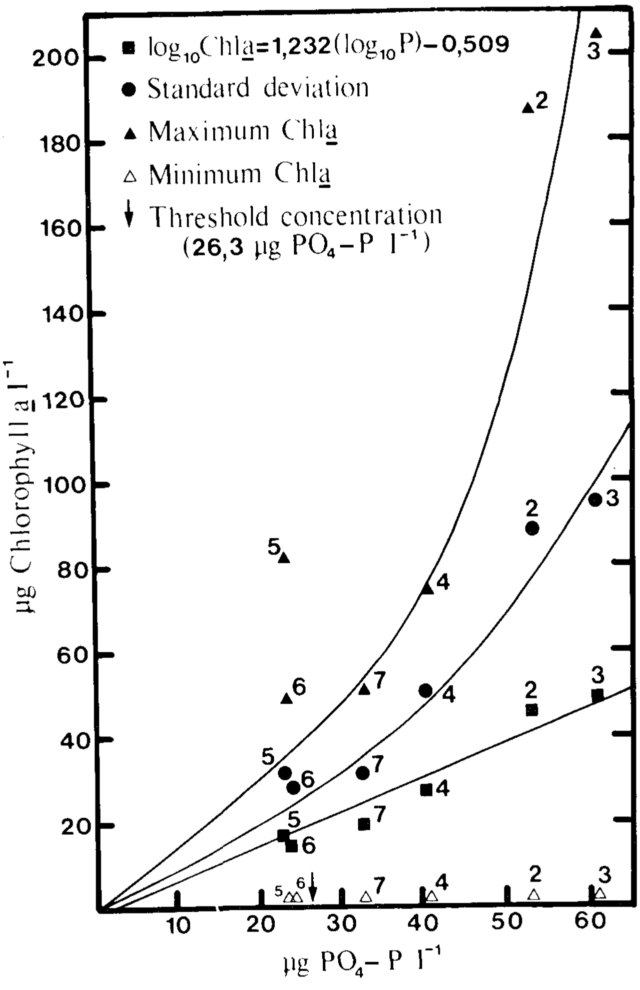

Figure 4
The relationship between phosphate phosphorus and mean, maximum, minimum as well as upper standard deviation levels of chlorophyll ***a***

Another aspect of models based only on concentration must be considered. Lake Washington is, like Roodeplaat Dam, a water body of which the primary productivity is determined by available phosphate. Edmondson (1969) showed that the growth of *Oscillatoria* species in Lake Washington decreased PO_4-P concentrations from spring to summer and a maximum algal concentration was reached at a time when PO_4-P concentration was at its minimum. The summer concentration of algae was determined by the spring concentration of PO_4-P. The authors feel that in Roodeplaat Dam summer chlorophyll *a* concentration is probably not determined only by spring or winter PO_4-P concentration because Roodeplaat Dam, being in the subtropical zone, has higher productivity in the winter and spring, resulting in more nutrients (i.e. phosphorus) being removed from the euphotic zone at these times than in Lake Washington. The difference in temperature between the surface and deep water is also smaller in Roodeplaat Dam than in Lake Washington, resulting in less stable thermal stratification which might increase the supply of phosphorus from deep water. Anaerobic conditions did not develop to the same extent in Lake Washington as in Roodeplaat Dam, where the anaerobic part of the water column sometimes extended into the epilimnion, which would increase nutrient supply to the euphotic layer. Lake Washington, occurring in a glacier valley, has a smaller ratio of shallow water to surface area than Roodeplaat Dam. There is a relatively larger surface area of bottom sediments where mineralization occurs in direct contact with the euphotic zone at Roodeplaat Dam. The internal supply of nutrients, including phosphate, is therefore probably greater in Roodeplaat Dam than in Lake Washington, even and perhaps particularly in winter when the temperature is higher in Roodeplaat Dam.

Since Lake Washington is a deep, clearwater lake in the temperate zone some or all of the above mentioned differences between this lake and Roodeplaat Dam may also contribute to the differences between the regression line of Dillon and Rigler (1974; equation 3 above) for temperate waters and that of Roodeplaat Dam (equation 1).

Because different rates of nutrient re-cycling occur both in winter and summer in Roodeplaat Dam as compared to Lake Washington, and because average chlorophyll *a* concentrations at various sampling stations in Roodeplaat Dam were linearly related to phosphate phosphorus concentrations, it is felt that the model represented in equation 1 can be used for predictive purposes in Roodeplaat Dam relating phosphate phosphorus to algal standing crop, thus providing a criterion for the evaluation of the trophic status of the water body or parts of the water body. Roodeplaat Dam can be considered representative of clear water South African impoundments. The threshold value of 26 $PO_4-P\ l^{-1}$ above which algal nuisance conditions can be expected to occur in Roodeplaat Dam is similar to threshold values suggested by Sawyer (1970), Jaworski *et al.* (1977) and Toerien and Walmsley (1977) and the authors are confident that the Roodeplaat Dam results can be used as a guideline for similar water bodies.

Predicting the Intensity of Eutrophication Problems

From equation 1 and with the threshold value of 26 $\mu g\ PO_4-P\ l^{-1}$, an upper average threshold value of 17,3 μg chlorophyll *a* l^{-1} for the absence of intensive algal nuisance conditions can be predicted when *Microcystis* and *Anabaena* are the dominant algal species. However, it is not sufficient for planning and decision-making only to predict the average chlorophyll *a* value. Some information is needed about the variation of chlorophyll *a* concentrations around this mean.

To gain this information the maximum, minimum and upper standard deviation levels of chlorophyll *a* were plotted against the average PO_4-P concentration for each sampling station. Curves to the maximum chlorophyll *a* concentrations and the upper standard deviation levels were then fitted by eye, forcing them through the O-point (Figure 4). Since these curves were fitted by eye they may underestimate the maximum chlorophyll *a* concentration as well as the upper standard deviation limits, especially in the lower PO_4-P concentration range. Further information would be needed to plot the curves more precisely.

The upper standard deviation curve was used to determine a corresponding chlorophyll *a* concentration for each sampling station. The latter were used in conjunction with plots of chlorophyll *a* concentration against time (not presented here) for each sampling station to determine the per cent of total time during which the actual chlorophyll *a* concentrations exceeded the upper standard deviation curve values (Table 2).

The percentages at stations 2 to 6 were very similar, but station 7 had a much lower value. The reason for this is not obvious at present and in order to present a conservative figure the mean value, derived from the results of stations 2 to 6, was used. This indicated that the chlorophyll *a* concentration at any sampling station would be less than the upper standard deviation level for 79 to 82 per cent of the time and higher (between the upper standard deviation and the maximum levels) for 18 to 21 per cent of the time.

TABLE 2
PER CENT OF TOTAL TIME DURING WHICH CHLOROPHYLL CONCENTRATIONS AT SOME ROODEPLAAT DAM SAMPLING STATIONS EXCEEDED THE UPPER STANDARD DEVIATION LEVEL

Sampling Station	Per cent
2	20,8
3	17,1
4	17,9
5	19,3
6	20,2
7	8,7
Average (2 to 7)	17,3 (4,4*)
Average (2 to 6)	19,1 (1,6*)

*Standard deviation

In the less productive eastern section of the impoundment the average chlorophyll *a* value would be 17,3 $\mu g\ l^{-1}$. For 80 per cent of the time the value would be below 28 $\mu g\ l^{-1}$ but for 20 per cent it would be between 28 and 42 $\mu g\ l^{-1}$. In the more productive western section of the impoundment the average chlorophyll *a* concentration would be 39,6 $\mu g\ l^{-1}$, for 80 per cent of the time it would be below 71 $\mu g\ l^{-1}$ and for 20 per cent it would be between 71 and 132 $\mu g\ l^{-1}$.

It is possible that this model can be applied successfully to other clear water South African impoundments, should their average long term phosphorus concentrations be known or be predictable from other information.

To illustrate the above, a hypothetical impoundment (where algal growth is primarily limited by available phosphate phosphorus) with an average PO_4-P concentration of 50 $\mu g\ l^{-1}$ would maintain an average chlorophyll *a* concentration of 38 $\mu g\ l^{-1}$ (equation 1). For 80% of the time the chlorophyll *a* concentration would be below 70 $\mu g\ l^{-1}$, but for 20% of the time it would be between 70 and 120 $\mu g\ l^{-1}$ (Figure 4).

If chlorophyll concentrations in excess of 70 $\mu g\ l^{-1}$ accompanied by *Microcystis* and *Anabaena* dominance are unacceptable as far as the specific requirements for optimum utilization of the impoundment is concerned, remedial action will be needed.

Phosphate Phosphorus Loading and Concentration in Impoundments

Eutrophication models based on the loading of phosphorus have been proposed (e.g. Brezonik and Shannon, 1971; Imboden, 1974; Vollenweider, 1975). It is therefore important to relate the PO_4-P concentration of Roodeplaat Dam to the PO_4-P loading.

Oglesby (1977) demonstrated a relationship between the mean summer chlorophyll *a* concentration ($\mu g\ l^{-1}$) and the input of biologically available phosphorus (L'_{sp}; mg $PO_4-P\ m^{-2}\ a^{-1}$) for several temperate zone lakes:

$$\log_{10} \text{Chl}\ a = 1{,}38\ (\log_{10} L'_{sp}) - 2{,}69 \qquad (r = 0{,}97;\ n = 10) \qquad 4$$

Based on the average summer chlorophyll *a* concentration (November to April) for the eastern (19,9 $\mu g\ l^{-1}$) and western (55,2 $\mu g\ l^{-1}$) sections of Roodeplaat Dam, the phosphorus loadings for these sections were respectively 0,78 and 1,63 g P $m^{-2}\ a^{-1}$. Based on the earlier suggestion that the eastern section represents upper threshold conditions for the onset of nuisance algal growth, the maximum allowable phosphorus loading for Roodeplaat Dam is, therefore, 3 089 kg P a^{-1}. Using the Vollenweider (1975) model as modified by Toerien and Walmsley (1977) on the data for Roodeplaat Dam during 1973 to 1975 (Walmsley *et al.*, 1978) the maximum allowable phosphorus loading is estimated to lie between 1 624 and 3 049 kg P a^{-1} for years of different residence times. The modified Vollenweider model is therefore apparently more conservative than the Oglesby (1977) model in estimating maximum allowable phosphorus loadings on impoundments. This could indicate that the Oglesby model may also be useful as a predictive method in eutrophication analyses.

The mean PO_4-P concentrations at stations 1 and 3 were 286,5 and 60,9 $\mu g\ l^{-1}$ respectively (Table 1) corresponding to respective loadings of 5,9 and 1,5 g P $m^{-2}\ a^{-1}$ according to equations 1 and 4. This would indicate that a large portion of the PO_4-P load originating via the Pienaars River becomes unavailable for further algal growth before it reaches the confluence with the Hartbeesspruit. The mechanism of this process may be not only biological in nature. There is a possibility that suspended allochthonous material settling out between stations 1 and 3 removes dissolved phosphate. The fact that the average concentration of total suspended solids at station 1 is much higher than that of station 3 (A.J.H. Pieterse, unpublished data) indicates that the concentration of the suspended solids is reduced by sedimentation between stations 1 and 3. There is furthermore a significant correlation (P = 0,01) between chlorophyll *a* and total suspended solids concentration at the sampling stations if data for station 1 is ignored (A.J.H. Pieterse, unpublished data) suggesting that allochthonous suspended material primarily contributed to the total suspended solids concentration at station 1.

It is also interesting to consider the above-mentioned loading at station 1 (5,9 g P $m^{-2}\ a^{-1}$) in relation to the PO_4-loadings of 9,3 and 20,6 g P $m^{-2}\ a^{-1}$ contributed by the Pienaars River to the dam as a whole during the years 1973/1974 and 1974/1975 respectively (Walmsley *et al.*, 1978). This seems to indicate that the PO_4-P load entering the impoundment by way of the Pienaars River is considerably diminished before it reaches station 1. The same mechanism(s) for removing dissolved phosphate between stations 1 and 3 visualized above could be operative in the section of the dam above station 1.

Concluding Remarks

Numerous attempts have been made to define relationships that would be useful in predicting the productivity of lake communities, especially as far as their phytoplankton components are concerned. Walmsley and Toerien (1977) pointed out that many criteria have been developed in order to classify the trophic status of a waterbody, and various models have been proposed to predict the reaction of the waterbody to increased nutrient supply (Toerien, 1977). These criteria have been established by examining either one or two parameters (e.g. Dillon and Rigler, 1974; Carlson, 1977), or by a multi-parameter approach (e.g. Lee, 1970; Brezonik and Shannon, 1971; Imboden, 1974; Vollenweider, 1975). Walmsley and Toerien (1977) concluded that each approach is limited in its usefulness because too many or too few parameters are used and that there is no single criterion or combination of criteria which can be used successfully to assess the trophic status of impoundments.

A relationship between mean phytoplankton standing crop and phosphate phosphorus concentration has been derived for six sampling stations in the Roodeplaat Dam. This single criterion (phosphate phosphorus concentration) successfully predicted trophic status and the intensity of the eutrophication problem in this impoundment. The model is subject to improvement dependent on information for other South African impoundments.

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