

# Eutrophication Levels of some South African Impoundments. IV. Vaal Dam

D.J. STEYN\*, D.F. TOERIEN\*\*

[NATIONAL INSTITUTE FOR WATER RESEARCH, COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, P.O. BOX 395, PRETORIA, 0001, REPUBLIC OF SOUTH AFRICA]

AND

J.H. VISSER

[DEPARTMENT OF BOTANY, UNIVERSITY OF PRETORIA, HATFIELD, PRETORIA, 0002, REPUBLIC OF SOUTH AFRICA]

## Abstract

The Vaal Dam shows algal bioassay growth rates and algal growth potentials (AGP) as high as  $1.6 \text{ d}^{-1}$  and  $146 \text{ mg} \ell^{-1}$  respectively using *Selenastrum capricornutum* as test alga. Addition of secondary treated sewage effluents to Vaal Dam water increased the AGP by between 7.4 and  $11.2 \text{ mg} \ell^{-1}$  for every one per cent (v/v) added. Nitrogen and phosphorus were the important algal growth-limiting nutrients in the impoundment. Plant nutrients adsorbed onto clay particles could be important in the eutrophication of the impoundment, indicating the importance of soil conservation techniques in eutrophication control. The significance of the impoundment and the paucity in knowledge of its physical, chemical and biological characteristics suggest that such studies should be undertaken as a matter of urgency.

## Introduction

South Africa is a semi-arid country and, therefore, the water quality of its impoundments is of extreme importance in maintaining a favourable balance between water supply and demand. As in many other countries, South Africa is plagued by the existing and potential threat of cultural eutrophication as a water quality problem.

The Vaal Dam is the largest single source of water used for potable and industrial purposes in the country, serving the Pretoria-Witwatersrand-Vereeniging urban-industrial complex. Some  $1400 \times 10^3 \text{ m}^3 \text{ d}^{-1}$  was supplied to about four million people in 1972 (Rand Water Board, 1972; South African Municipal Yearbook, 1971/72). Yet very little is known about its pre-

sent eutrophication level, despite the fact that algal blooms do occur in the dam from time to time (Steyn, 1973).

During the summers of 1942 and 1944 blooms of the alga *Microcystis toxica* (Stephens, 1949) in the Vaal Dam caused extensive losses in livestock around the impoundment (Steyn, 1945). These blooms were probably caused by the inundation of fertile agricultural land after the completion of the dam with a resultant release of nutrients from decaying plant matter (Stephens, 1949). After 1945 the blooms were successfully eradicated by the application of copper sulphate (Louw, 1950). However, during the past decade algal blooms in the impoundment have been on the increase (Steyn, 1973).

The purpose of this study was to determine the present eutrophication level of the Vaal Dam; to determine how it might be affected by increased discharges of secondary treated sewage effluents or discharges of low nutrient effluents; and to identify those plant nutrients which control the growth of algae in the impoundment. Algal bioassays were used for this purpose.

## Materials and Methods

### Vaal Dam

The Vaal Dam is situated in the Heilbron magisterial district with a latitude of  $26^{\circ} 53'$  south and a longitude of  $28^{\circ} 07'$  east. The full supply level is 1484 m above mean sea level. The catchment area occupies  $37\,100 \text{ km}^2$  and consists of highveld grassland. The geology of the catchment consists mainly of the shales, mudstones, sandstones and limestones of the Ecca and Beaufort Series of the Karroo system, with isolated areas of the basalt, sandstones and shales of the Stormberg Series (Karoo system) and andesitic lavas of the Ventersdorp System (du Toit, 1954). The catchment covers large areas of the eastern Transvaal and the northeastern Orange Free State. The average annual rainfall over the catchment ranges from 650 to 1000 mm (Department of Water Affairs, 1964).

\*Present address: Hydrological Research Unit, Department of Water Affairs, Private Bag X313, Pretoria, 0001.

\*\*Present address: Department of Microbiology, University of the Orange Free State, P.O. Box 339, Bloemfontein, 9300.

The net capacity of the Vaal Dam is  $2\,330 \times 10^6 \text{ m}^3$ , covering an area of 29 260 ha at full supply level with a mean depth of 7.96 m. During the sampling period (1972-05-15 to 1973-01-08) the impoundment had an average capacity of  $2\,070 \times 10^6 \text{ m}^3$  with an area of 27 970 ha and a mean depth of 7.42 m.

### Sampling

Samples were taken on four occasions over a period of one year (1972-05-15, 1972-07-09, 1972-08-13 and 1973-01-08) and more or less represented the four seasons of the year. Owing to the large size of the impoundment, sampling was restricted to the water at the dam wall. Samples were taken at different depths (surface, 10 m, 20 m and 30 m) and equal volumes of these were composited. All samples were obtained with a 5 ℓ van Dorn sampling bottle.

### Algal bioassays and experimental design

The techniques and experimental design of Steyn, Scott, Toerien and Visser (1975a) and Steyn, Toerien and Visser (1975b) were used.

## Results

### Eutrophication status

The  $\mu_b$  and AGP values are summarised in Table 1. The Vaal Dam has  $\mu_b$  and AGP values as high as  $1.6 \text{ d}^{-1}$  and  $146 \text{ mg} \ell^{-1}$  respectively. Toerien (1975) suggested that AGP values in excess of  $60 \text{ mg} \ell^{-1}$  indicate eutrophic conditions under South African conditions. This suggests that the Vaal Dam could be considered highly eutrophic, which is further supported by the occasionally high nitrogen and phosphorus concentrations in the water (Table 1).

The Vaal Dam is a silty impoundment containing approximately 45 mg of suspended material per litre. Since the highest AGP values were registered in summer, in contrast to Rietvlei, Hartbeespoort and Roodeplaat Dams (Steyn *et al.*, 1975a, 1975b and 1976), when the highest inflows of silt-laden water are experienced, it can be postulated that the suspended clay must contain adsorbed plant nutrients available for algal growth. This suggests that agricultural practices resulting in soil erosion could be extremely important in the eutrophication of the Vaal Dam. However, this postulate needs further investigation.

### Identity of the growth-limiting nutrients

Nitrogen and phosphorus were each primary growth-limiting on two occasions, (nitrogen on 1972-05-15 and 1972-08-13 and phosphorus on 1972-07-09 and 1973-01-08) (Fig. 1). When nitrogen was primary growth limiting, phosphorus was secondary growth-limiting and *vice versa*. These two nutrients are, therefore, the two most important nutrients regulating algal growth in the Vaal Dam.

When nitrogen was the primary growth limiting nutrient, the dissolved total nitrogen concentrations of filtered water were respectively 1.7 and  $1.0 \text{ mg N} \ell^{-1}$ . Assuming a yield coefficient ( $Y_N$ ) of 30 for the growth of *Selenastrum capricornutum*, the bioassay organism (Steyn *et al.*, 1975a, b, c; Toerien *et al.*, 1975a), the above dissolved nitrogen concentrations could support only 5 and  $30 \text{ mg AGP} \ell^{-1}$  whilst 138 and  $82 \text{ mg AGP}$  were actually recorded. This suggests that the rest of the nitrogen requirements must have been satisfied from nitrogen compounds adsorbed onto clays (removed by filtration) and which must have amounted to about 2.9 and  $1.7 \text{ mg N} \ell^{-1}$  respectively.

### Biostimulation by secondary effluents

Addition of humus tank effluent (HTE) or synthetic humus tank effluent (SHTE) to Vaal Dam water caused the AGP to increase linearly ( $p = 0.01$ ) on each sampling date (Fig. 2 and 3). A combination of these results indicated that:

$$\text{AGP (mg } \ell^{-1}\text{)} = 177.0 + 7.37 (\% \text{ HTE}) \dots \dots \dots (1)$$

With  $r = 0.88$  and  $n = 60$  and

$$\text{AGP (mg } \ell^{-1}\text{)} = 159.3 + 11.22 (\% \text{ SHTE}) \dots \dots \dots (2)$$

with  $r = 0.84$  and  $n = 60$

The AGP of the Vaal Dam water will consequently be increased or reduced by between 7.3 and  $11.2 \text{ mg} \ell^{-1}$  for every per cent (1 volume) increase or decrease (respectively) of humus tank effluent discharged directly into the impoundment. These values compare favourably with the respective values for Rietvlei Dam (8.37 and 14.3; Steyn *et al.*, 1975a), Hartbeespoort Dam (7.4 and 13.0; Steyn *et al.*, 1975b) and Roodeplaat Dam (7.17 and 12.4; Steyn *et al.*, 1975c).

Vaal Dam water with the addition of 10 per cent (v/v) HTE was limited throughout by nitrogen (Fig. 1). This was also the case for Rietvlei (Steyn *et al.*, 1975a), Hartbeespoort (Steyn

**TABLE 1**  
THE ALGAL GROWTH RATE, BATCH ( $\mu_b$ ), ALGAL GROWTH POTENTIAL (AGP) AND SOME CHEMICAL CHARACTERISTICS OF WATER SAMPLES FROM VAAL DAM.

Sampling date	1972-05-15	1972-07-09	1972-08-13	1973-01-08
AGP ( $\text{mg} \ell^{-1}$ )	138	115	82	146
$\mu_b$ ( $\text{d}^{-1}$ )	1.61	1.2	1.28	1.03
Total dissolved N ( $\text{mg} \ell^{-1}$ )	1.6	1.5	1.0	1.8
Total dissolved P ( $\text{mg} \ell^{-1}$ )	0.5	<0.2	<0.2	0.2

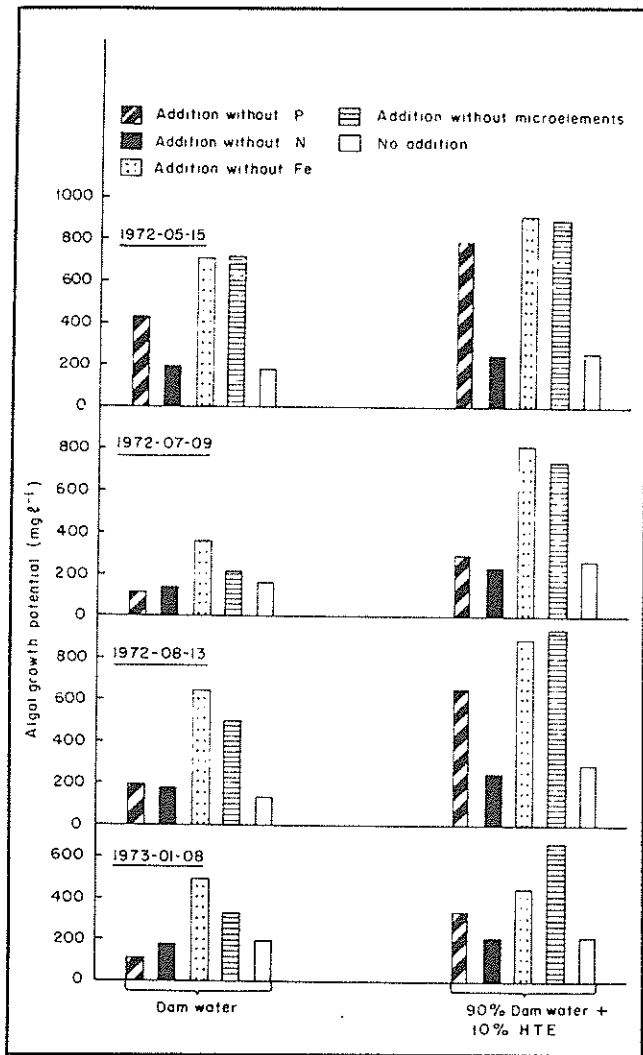


Figure 1

Identification of the growth limiting nutrients in Vaal Dam water with or without humus tank effluent (HTE)

al., 1975b) and Roodeplaat (Steyn *et al.*, 1976) Dams. Since secondary treated sewage effluents contain more phosphorus than nitrogen (in terms of growth requirements), any impoundment which receives substantial inputs of such effluents will become nitrogen growth-limited. Such impoundments will exhibit an increased growth potential for nitrogen-fixing algae (Walmsley and Toerien, 1975).

#### Dilution with low nutrient water

Dilution of Vaal Dam water with low nutrient water (distilled and deionized) resulted in significant ( $p = 0,01$ ) linear decreases in the AGP of the dam water (Fig. 4). Depending on the time of the year, the AGP decreased by between 1,38 and 1,68  $\text{mg}/\ell^{-1}$  for each one per cent (v/v) of low nutrient water added. The eutrophication level of the dam would consequently be decreased if low nutrient water were to enter the dam.

The earlier results suggested that suspended silt particles onto which plant nutrients are adsorbed may be an important source of nutrients to the dam. To create low nutrient inflows the development of better soil conservation techniques in the catchment of the Vaal Dam might be necessary.

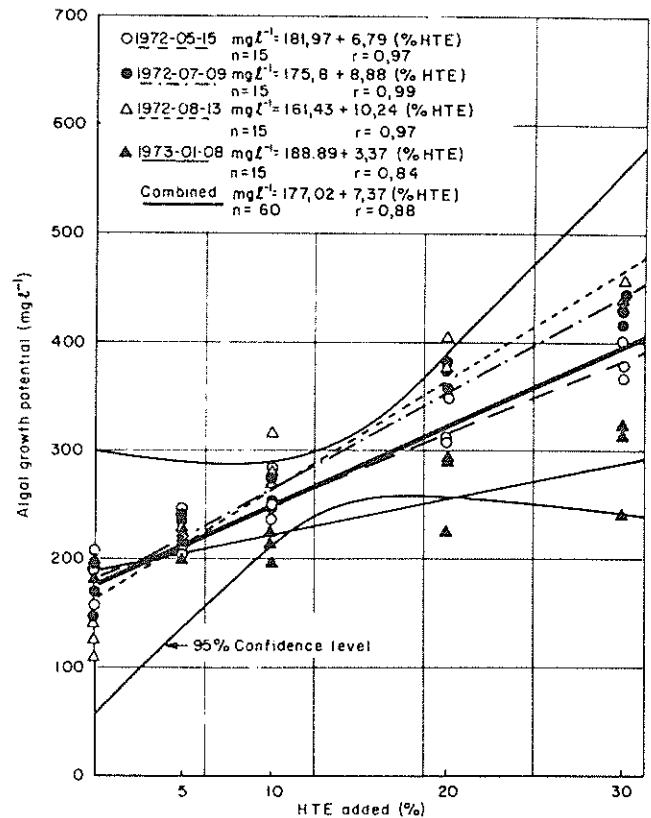


Figure 2

Stimulation of the algal growth potential of Vaal Dam water by humus tank effluent (HTE)

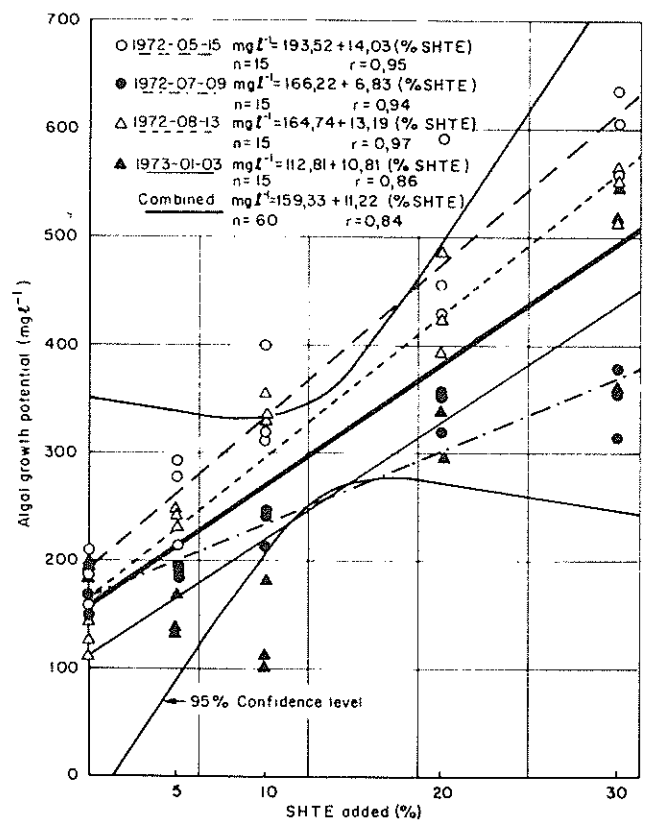


Figure 3

Stimulation of the algal growth potential of Vaal Dam water by synthetic humus tank effluent (SHTE)

## Bio-stimulation of Vaal Dam water by nitrogen and phosphorus

Addition of different concentrations of nitrogen to Vaal Dam water obtained on 1972-08-13 linearly increased the AGP (Fig. 5) according to:

$$\text{AGP (mg/l)} = 19 + 20,5 (\text{mg N l}^{-1}) \dots\dots\dots (3)$$

with  $r = 0,86$  and  $n \times 9$ .

Similar additions to Vaal Dam water enriched with all nutrients except nitrogen (to a concentration of 150% PAAP-medium) also linearly increased the AGP according to:

$$\text{AGP (mg/l)} = 42,3 + 18,2 (\text{mg N l}^{-1}) \dots\dots\dots (4)$$

with  $r = 0,89$  and  $n = 12$ .

The water in the above cases was nitrogen growth-limited (Fig. 1) and increased concentrations of nitrogen resulted in higher AGP values. Addition of phosphorus to these waters did not increase the AGP responses of *S. capricornutum*, the bioassay alga. Walmsley and Toerien (1975) have shown that when nitrogen is primary growth-limiting to *S. capricornutum*, additions of phosphorus will not alter the *S. capricornutum* response but an increased AGP for nitrogen-fixers is created. Therefore, although the bioassay responses of this study did not indicate an increased eutrophication level after the addition of phosphorus, it is possible that an increased eutrophication level was created in terms of an increased growth potential for nitrogen-fixing algae.

## Discussion

The AGP results of this study suggest that the Vaal Dam is eutrophied and that the eutrophication level will be further in-

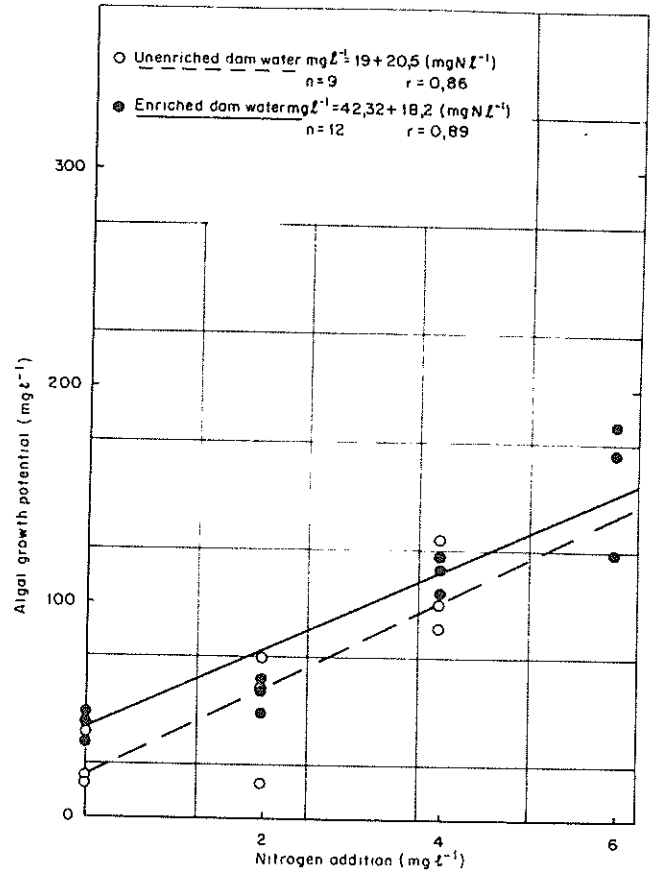


Figure 5  
Nitrogen stimulation of the algal growth potential of Vaal Dam water with or without nutrient enrichment

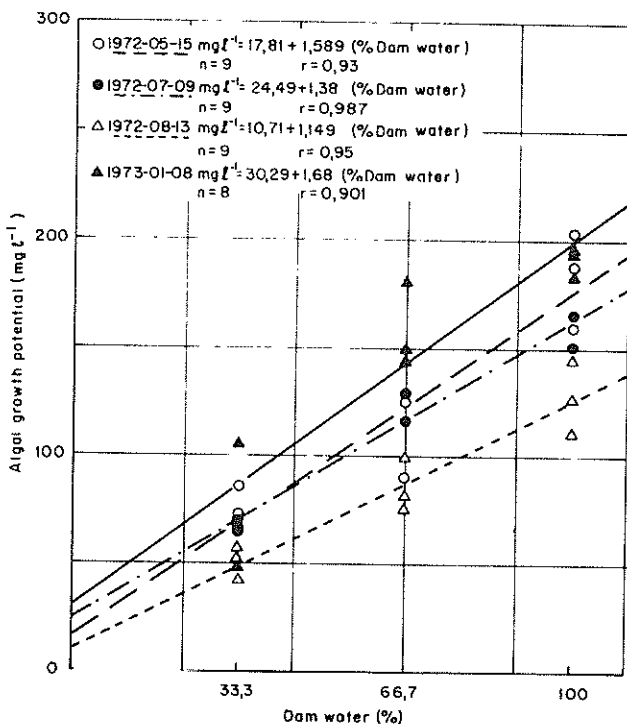


Figure 4  
Effect of dilution with low nutrient water on the algal growth potential of Vaal Dam water

creased by the discharges of nutrient rich effluents into the dam. At present little is known about the reasons for the eutrophied state of the dam although it appears that nutrients adsorbed onto silt may play an important role.

Because of the paucity in knowledge of the physical, chemical and biological characteristics of Vaal Dam it is difficult to predict the future behaviour of this impoundment in terms of algal growth. Algal blooms occurred in the dam in the years following its completion (Stephens, 1949). In December 1940 livestock losses, caused by a toxic *Microcystis*, occurred and in 1942, 98 per cent of the whole water surface was covered by a bloom of *Microcystis* (Stephens, 1949). The apparent reason for this growth was the decay and release of plant nutrients from drowned vegetation of the fertile valley inundated by water (Stephens, 1949; Steyn, 1949).

The algae occurred in the impoundment in large quantities and were found to depths of 6 m or more. On the surface large drifting masses accumulated and were blown and concentrated towards the edges by the wind. Decomposition of these accumulations resulted in a terrible stench which caused problems to riparian owners (Steyn, 1949).

Control of algal growth through the dosing of copper sulphate was initiated in 1942 and this control method was maintained through the years. However, it appears that in the late forties and the fifties the problems due to algal growth decreased but in recent years an increase was noted. For instance, control with

copper sulphate during the period 1963 to 1967 necessitated the expenditure of R1 000, but in the period 1968 to 1972 R37 000 was needed (Collins, J. - personal communication).

Development is taking place in the catchment of the Vaal Dam. Towns like Standerton, Bethlehem and Harrismith are expanding, the new SASOL II complex will be situated in the catchment and increased agricultural production necessitates increased fertiliser application. Consequently it can be expected that the eutrophication level of the Vaal Dam will increase.

An increase in nutrient inputs would result in increased algal growth since the earlier experiences have indicated that the natural turbidity of the water is not sufficient to prevent algal blooms. It is possible that such blooms may restrict the uses of water from this impoundment. The importance of the Vaal Dam as a water supply is such that impairment of its use cannot be tolerated. Therefore, studies on the physical, chemical and biological characteristics of this impoundment in relation to eutrophication and the sources of eutrophying elements must be undertaken urgently.

## Conclusions

1. The Vaal Dam has  $\mu_0$  and AGP values as high as  $1,6 \text{ d}^{-1}$  and  $146 \text{ mg } \ell^{-1}$  respectively (recorded with *S. capricornutum*). In view of a suggestion by Toerien (1975) that AGP values in excess of  $60 \text{ mg } \ell^{-1}$  indicates eutrophic conditions under South African conditions, the Vaal Dam could be considered highly eutrophic.
2. Part of the nutrients available for algal growth appears to be adsorbed onto silt particles which causes high AGP values in summer when the summer rainfall results in silt-laden inflows. Agricultural practices resulting in soil erosion could be extremely important in the eutrophication of this dam.
3. Nitrogen and phosphorus are the most important algal growth-limiting nutrients in the impoundment. For a better understanding of the reasons why the dam is eutrophied the sources of these nutrients along with their quantitative contributions should be determined.
4. The addition of secondary-treated sewage effluents to the Vaal Dam water increased the AGP by between 7,4 and 11,2  $\text{mg AGP } \ell^{-1}$  for every one per cent (v/v) of effluent added. Should substantial inflows of such effluents enter into the dam, nitrogen could become the sole primary growth-limiting nutrient leading to an increased growth potential for nitrogen-fixing algae.

5. Addition of low nutrient water decreased the AGP of the dam water. Since nutrients might be associated with silt inputs, soil conservation techniques may be important in the creation of low nutrient inflows.
6. The determination of the physical, chemical and biological characteristics, and the tolerance of the impoundment for nitrogen and phosphorus is necessary to allow well planned developments of the catchment for urban, industrial and agricultural purposes.

## Acknowledgement

This paper is published with the approval of the National Institute for Water Research. This paper formed part of an M.Sc. thesis submitted to the University of Pretoria by the senior author.

## REFERENCES

- DEPARTMENT OF WATER AFFAIRS (1964). *Hydrographic Survey Publication No. 8*, Vol. 1. The Government Printer, Pretoria.
- DU TOIT, A.L. (1954). *The Geology of South Africa*, 3rd Ed., Oliver and Boyd, Edinburgh.
- LOUW, P.G.J. (1950). The active constituent of the poisonous algae, *Microcystis toxica* Stephens. *S. Afr. Industr. Chem.* 4, 62-66.
- SOUTH AFRICAN MUNICIPAL YEARBOOK (1971-72). Ed. W. Albertyn. S. Afr. Society of Municipal Workers, Pretoria.
- STEPHENS, E.L. (1949). *Microcystis toxica* sp. nov.: A poisonous alga from the Transvaal and Orange Free State. *Trans. Royal Soc. S. Afr.* 32, 105-112.
- STEYN, D.G. (1945). *Poisoning of animals by algae (scum or water-bloom) in dams and pans*. Bull. Dept. Agric. and Forestry, Pretoria.
- STEYN, D.G. (1949). *Vergiftiging van mens en dier met gifplante, voedsel en drinkwater*, Van Schaik, Pretoria.
- STEYN, D.J. (1973). *Die eutrofikasiepeile van vier Transvaalse damme*. M.Sc.-thesis, University of Pretoria.
- STEYN, D.J., SCOTT, W.E., TOERIEN, D.F. and VISSER, J.H. (1975a). Eutrophication levels of some South African impoundments I. Rietveld Dam. *Water S.A.*, 1, 45-52.
- STEYN, D.J., TOERIEN, D.F. and VISSER, J.H. (1975b). Eutrophication levels of some South African impoundments. II. Hartbeespoort Dam. *Water S.A.*, 1, 93-101.
- STEYN, D.J., TOERIEN, D.F. and VISSER, J.H. (1976). Eutrophication levels of some South African impoundments. III. Roodeplaat Dam. *Water S.A.*, 2.
- TOERIEN, D.F. (1974). South African Eutrophication Problems. A perspective. *Wat. Pollut. Control*, 74, 134-142.
- TOERIEN, D.F., STEYN, D.J. and KOHLMAYER, S.I. (1975a). The nitrogen yield coefficient of the green alga, *Selenastrum capricornutum* Printz. *S. Afr. J. Sci.*, 71, 217-218.
- TOERIEN, D.F., HYMAN, KATHY L. and BRUWER, MARIAAN, J. (1975b). A preliminary trophic status classification of some South African impoundments. *Water S.A.*, 1, 15-23.
- WALMSLEY, R.D. and TOERIEN, D.F. (1975). Algal bioassays and nitrogen fixation. *S. Afr. J. Sci.*, 71, 313-314.