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

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Abstract

The Vaal Dam shows algal bioassay growth rates and algal growth potentials (AGP) as high as 1.6 d⁻¹ and 116 mg/l⁻¹ respectively using Selenastrum capricornutum as test algae. Addition of secondary treated sewage effluents to Vaal Dam water increased the AGP by between 7.4 and 11.2 mg/l⁻¹ for every one percent (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 1 400 x 10⁶ m³/d 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 present eutrophication level, despite the fact that algal blooms do occur in the dam from time to time (Stevan, 1973).

During the summers of 1912 and 1944 blooms of the alga Microcystis aeruginosa (Stephens, 1949) in the Vaal Dam caused extensive losses in livestock around the impoundment (Stevan, 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, 1919). After 1913 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 (Stevan, 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° 33′ south and a longitude of 28° 07′ east. The full supply level is 1 484 m above mean sea level. The catchment area occupies 37 100 km² 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 1 000 mm (Department of Water Affairs, 1964).

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The net capacity of the Vaal Dam is 2.330 × 10⁶ m³, covering an area of 29.260 ha at full supply level with a mean depth of 7.06 m. During the sampling period (1972-05-15 to 1973-01-08) the impoundment had an average capacity of 2.070 × 10⁶ m³ 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 (1972-03-15, 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 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, Toerien and Visser (1973a) and Steyn, Toerien and Visser (1973b) were used.

Results

Eutrophication status

The μₖ and AGP values are summarised in Table 1. The Vaal Dam has μₖ and AGP values as high as 1.6 d⁻¹ and 146 mg C⁻¹, respectively. Toerien (1973) suggested that AGP values in excess of 50 mg C⁻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 biostimulation of secondary effluents.

The Vaal Dam is a silt impoundment containing approximately 43 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., 1973a, 1973b and 1975), 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 at 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, th dissolved total nitrogen concentrations of filtered water were respectively 1.7 and 3.0 mg N l⁻¹. Assuming a yield coefficient (μ) of 0.3 for the growth of Schizothrix capricornutum, the bioassay organism (Steyn et al., 1973a, b; c; Toerien et al., 1973a), the above dissolved nitrogen concentrations could support only 5 and 30 mg AGP C⁻¹ whilst 1.38 and 82 mg AGP were actually recorded. This suggests that the rest of the nitrogen requirements must have been satisfied from organic compounds adsorbed onto clay (removed by filtration) and which had amounted to about 2.9 and 1.7 mg C⁻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). Combustion of these results indicated that:

AGP (mg C⁻¹) = 177.0 + 3.37 (% HTE) .................. 1
With r = 0.83 and n = 60

AGP (mg C⁻¹) = 139.3 + 11.22 (% SHTE) .................. 2
With r = 0.84 and n = 60

The AGP of the Vaal Dam water will consequently be increased by between 7.3 and 11.2 mg C⁻¹ for every per cent (v/v) 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., 1973a), Hartbeespoort Dam (7.2 and 13.0; Steyn et al., 1973b) and Roodeplaat Dam (7.17 and 12.4; Steyn et al., 1975a).

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., 1973a). Hartbeespoort (Steyn

| TABLE 1 |
| THE ALGAL GROWTH RATE, BATCH (μₖ), ALGAL GROWTH POTENTIAL (AGP) AND SOME CHEMICAL CHARACTERISTICS OF WATER SAMPLES FROM VAAL DAM. |

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<thead>
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<tbody>
<tr>
<td>AGP (mg C⁻¹)</td>
<td>138</td>
<td>115</td>
<td>82</td>
<td>146</td>
</tr>
<tr>
<td>μₖ (d⁻¹)</td>
<td>1.61</td>
<td>1.2</td>
<td>1.28</td>
<td>1.03</td>
</tr>
<tr>
<td>Total dissolved N (mg C⁻¹)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Total dissolved P (mg C⁻¹)</td>
<td>0.3</td>
<td>&lt;0.2</td>
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Water SA Vol. 2 No. 2 April 1976
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 mg/L for each 1% 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 to 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.
Biostimulation 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:

$$\text{AGP (mg/l')} = 19 + 20.5 \times (\text{mg N l'}^{-1})$$

with $r = 0.86$ and $n = 9$.

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

$$\text{AGP (mg/l')} = 42.3 + 18.2 \times (\text{mg N l'}^{-1})$$

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. Walsme 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 increased 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
1. The addition of secondary-treated sewage effluents to the Vaal Dam will increase the eutrophication level of the Vaal Dam. This is because it is possible that 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.

2. The Vaal Dam has μ0 and AGP values as high as 1.6 d⁻¹ and 146 mg/L⁻¹ respectively (recorded with S. capricornutum). In view of a suggestion by Toerien (1973) that AGP values in excess of 60 mg/L⁻¹ indicates eutrophic conditions under South African conditions, the Vaal Dam could be considered highly eutrophic.

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 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.

5. 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.

Conclusions

1. The Vaal Dam has μ0 and AGP values as high as 1.6 d⁻¹ and 146 mg/L⁻¹ respectively (recorded with S. capricornutum). In view of a suggestion by Toerien (1973) that AGP values in excess of 60 mg/L⁻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 mg AGP L⁻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.

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