

Eutrophication of Four Transvaal Dams[†]

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Abstract

A two year study of river waters in the catchment areas of the Buffelspoort, Hartbeespoort, Rietvlei and Roodeplaat Dams was conducted. Sources of eutrophying elements were detected by chemical analyses and algal bioassays. The degree of enrichment of each impoundment was compared by means of phosphorus surface loading rates. Treated sewage effluents which are discharged into the inflow waters of the Hartbeespoort, Rietvlei and Roodeplaat Dams are the main cause of their present enriched condition.

Introduction

Eutrophication, the process whereby water systems become enriched with plant nutrients, has become a world-wide lake management problem. Little research has been conducted on South African waters in order to quantify the extent of eutrophication in major water supplies. There is evidence to indicate that South Africa is currently experiencing most of the known problems associated with eutrophication (Toerien, 1975). In 1973, the National Institute for Water Research, under the auspices of the Water Research Commission, established a

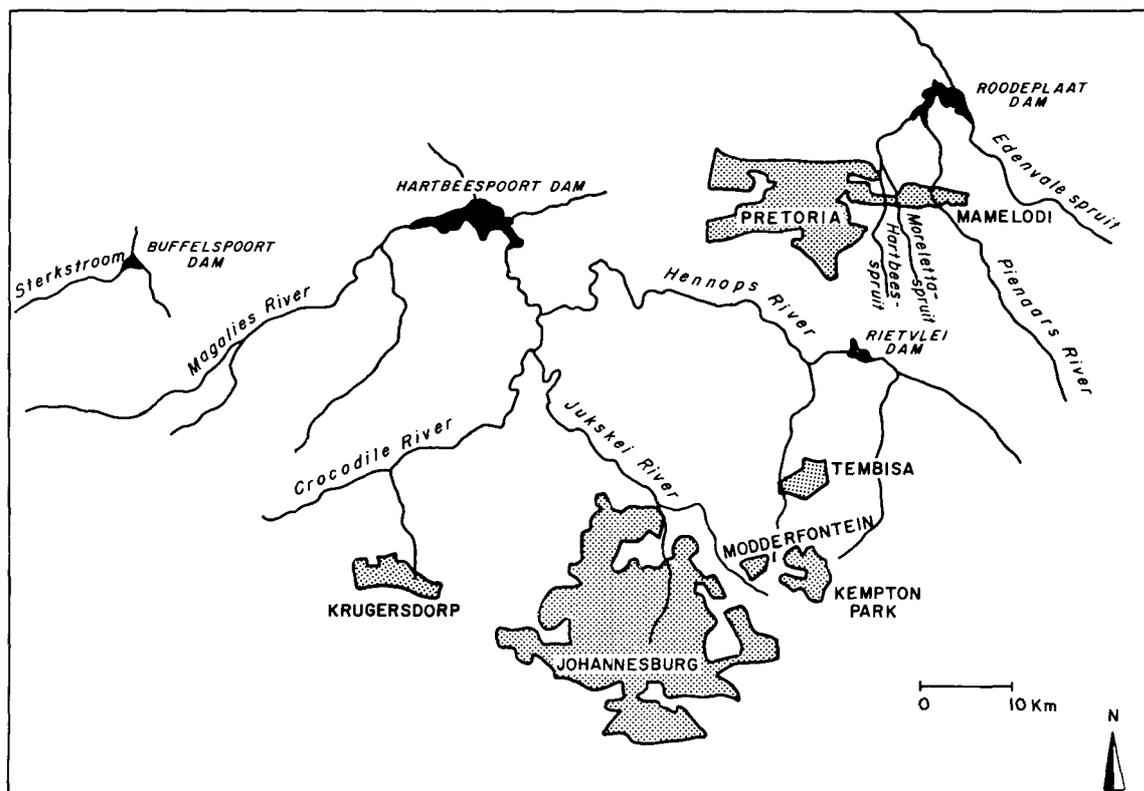


Figure 1
Map to show the position of the four dams and their catchment areas

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research programme to investigate the eutrophication of four impoundments in the vicinity of Pretoria. This paper presents basic characteristics which have been identified.

Description of Dams and Catchment Areas

The position of each dam and its catchment area in relation to Johannesburg and Pretoria is shown in Figure 1. These dams were selected in order to provide background information on as wide a spectrum of eutrophication characteristics as possible.

Buffelspoort Dam

Situated in a small secluded catchment (124 km²) of the Magaliesberg Mountains some 70 km west of Pretoria, this dam supplies water for irrigation. At full supply level, the dam has a capacity of $10,6 \times 10^6$ m³, an area of 135 ha and a mean depth of 7,9 m. Development in the catchment is minimal and land usage is restricted to agricultural small holdings. There are several holiday resorts in the catchment and the dam has become a popular recreational centre.

Geologically, the catchment lies within the Pretoria series and the sub-stratum consists of quartzites, shales and diabase (Du Toit, 1954). Perennial springs contribute to two inflows to the dam (Figure 2). These are the Sterkstroom, the major contributor, which flows the length of the catchment in a westerly direction, and an unnamed stream which flows in a northerly direction.

Hartbeespoort Dam

Hartbeespoort Dam, situated approximately 50 km west of Pretoria, serves as an irrigation supply for farmlands below the dam and also as a source of potable water for the towns of Brits, Kosmos and Schoemansville. In recent years the dam has become a widely used recreational centre. At full supply level, the dam has a capacity of $192,7 \times 10^6$ m³, an area of 1 998 ha and a mean depth of 9,6 m. The catchment area is large (4 144 km²) and contains numerous urban and industrial areas, notably northern Johannesburg, Kempton Park, Krugersdorp, Tembisa and Modderfontein. The geological structure of the catchment consists of quartzites, conglomerates and shales of the sedimentary rocks of the upper and lower Witwatersrand system, igneous rocks of the Ventersdorp lavas and granites, dolomitic belts and quartzites, shales and diabase of the Pretoria series (Du Toit, 1954).

Two rivers, the Jukskei and the Hennops, join the Crocodile River, the main source of inflow, before it enters the Hartbeespoort Dam. The other significant source of inflow is the Magalies River, whilst two minor, non-perennial streams, the Leeuspruit and the Swartspruit also flow into the dam (Figure 3).

Rietvlei Dam

Rietvlei Dam is situated approximately 20 km south of Pretoria in an indirect catchment of the Hartbeespoort Dam (Figure 1). The dam serves as a source of potable water for Pretoria and is

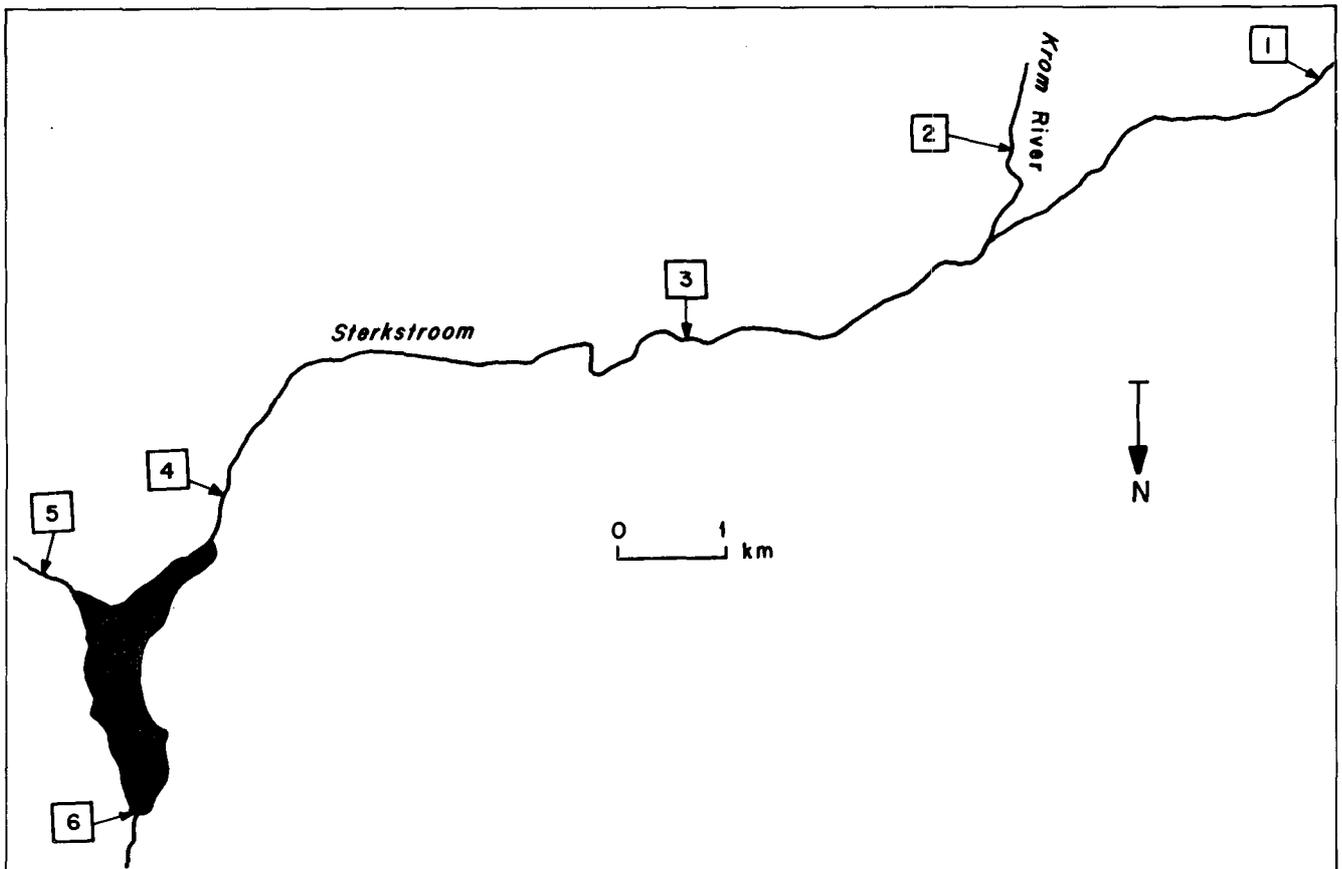


Figure 2
Sampling stations in the Buffelspoort Dam catchment area.

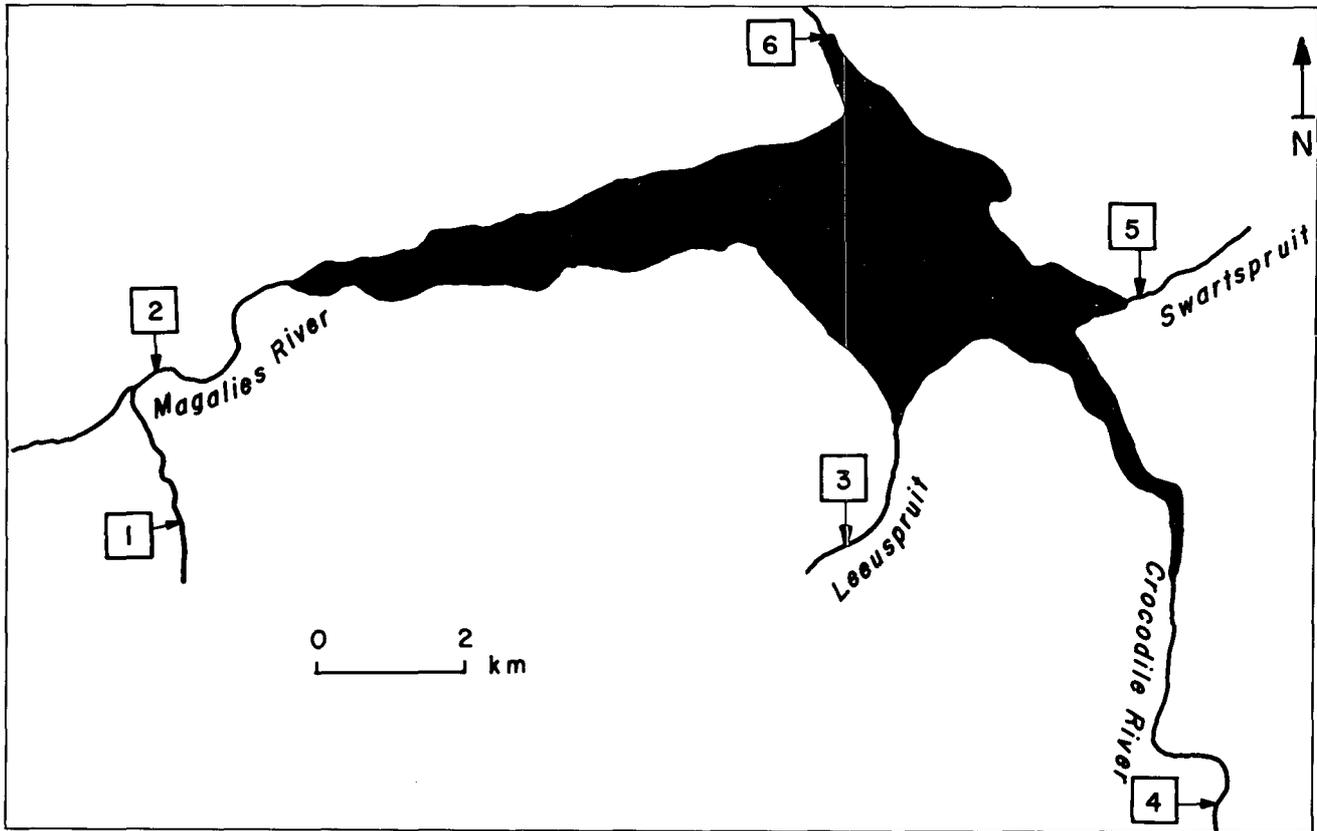


Figure 3
Sampling stations in the Hartbeespoort Dam catchment area

also used for fishing and sailing. At full supply level it has a capacity of $12,8 \times 10^6 \text{ m}^3$, an area of 204 ha and a mean depth of 6,3 m. The catchment area is 492 km² of which parts are dolomitic with shales, quartzites and conglomerates of the Pretoria series. Shales of the Dwycka and Ecca series also occur in isolated areas of the catchment (Du Toit, 1954).

The dam has one main source of inflow, the Hennops River, which rises in a swamp a few kilometres east of Kempton

Park. In its early reaches this river seeps through a marshy area in the Kempton Park sewage works (Figure 4) where it receives the entire discharge of treated sewage effluents from the works. Only after it leaves the sewage works does the river take a definite course and during its passage downstream, passes through two vlei systems and a small dam (Marais Dam) before entering Rietvlei Dam (Figure 4). The catchment area is utilized extensively for agriculture and use is made of river water for irrigation purposes.

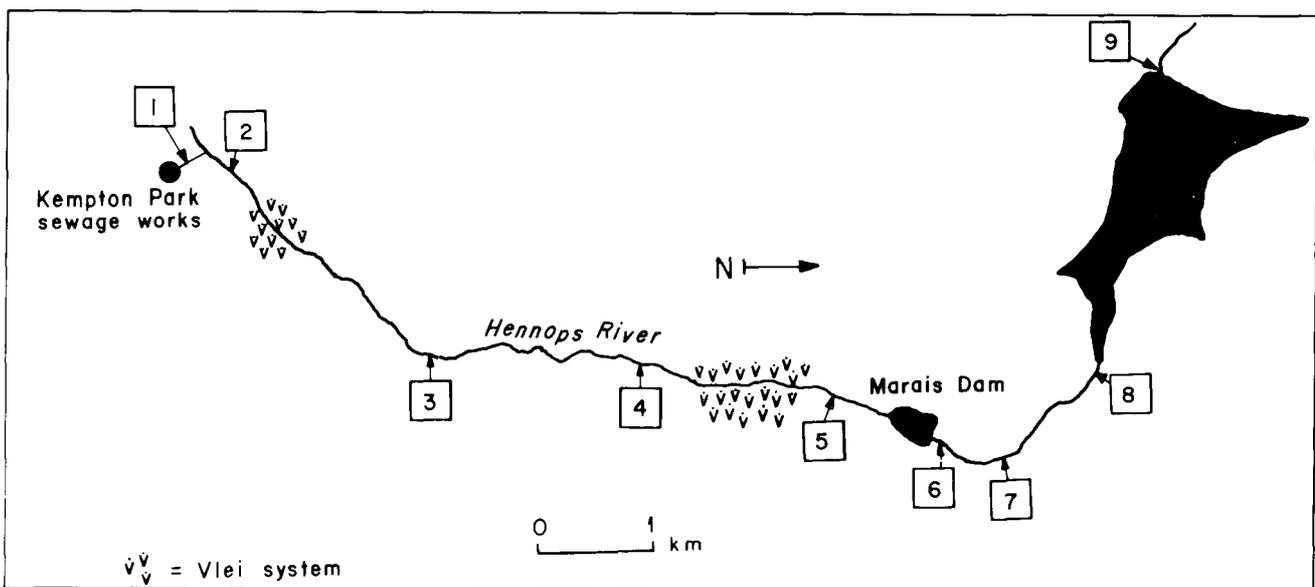


Figure 4
Sampling stations in the Rietvlei Dam catchment area

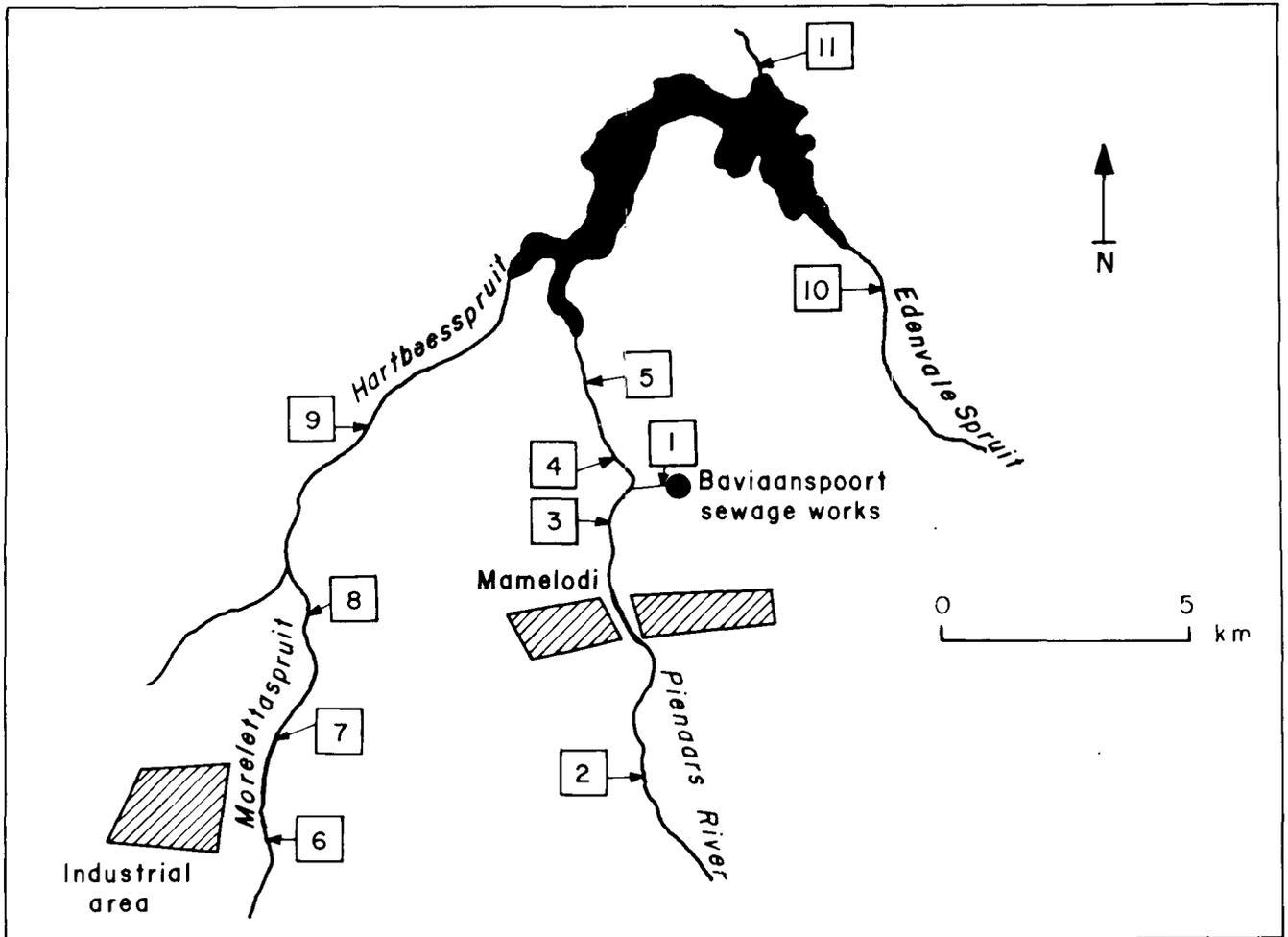


Figure 5
Sampling stations in the Roodeplaats Dam catchment area

Roodeplaats Dam

Roodeplaats Dam, an irrigation dam situated approximately 17 km north of Pretoria, has a catchment area of 668 km². The dam has a capacity of $41,9 \times 10^6$ m³, an area of 396 ha and a mean depth of 10,6 m. It is a popular recreational centre for fishing and boating.

The Hartbeesspruit, the Pienaars River and the Edenvale-spruit, all of whose flows are recorded, enter the dam at different points (Figure 5). The Hartbeesspruit and its tributary the Morelettaspruit, both rise in urban areas and the Morelettaspruit bypasses an industrial area before the confluence. The Pienaars River rises in a swampy area just north of the Rietvlei Dam catchment, drains agricultural land, flows through an urban area (Mamelodi) and then receives treated sewage effluents from the Baviaanspoort sewage works. The Edenvale-spruit on the other hand drains agricultural land to the east of Roodeplaats Dam and has no tributaries.

The geology of the catchment is fairly complex and country rock consists of shale and quartzite of the Magaliesberg stage, overlain by shale, siltstone and minor quartzite bands belonging to the Smelterskop stage of the Pretoria series (Verwoerd, 1967).

Sampling, Analysis of Water and Algal Bioassays

The localities of sampling stations in the catchment areas of each of the four dams are shown in Figures 2, 3, 4 and 5.

Water samples were collected from stations in the catchment of each dam at 14-day intervals during the period February 1973 to January 1974. In the following year (1974/75) sampling was limited to monthly intervals. Samples were transported to the laboratory in polyethylene bottles and stored at 2°C overnight. They were then filtered through prewashed Sartorius glass fibre filters and chemically analysed by the analytical services section of the National Institute for Water Research (NIWR). Analytical methods used were those described in the NIWR Manual — Analytical Guide, Part II (1974). Using the algal bioassay technique (Steyn, 1973) on unfiltered samples in the laboratory, the algal growth potential (AGP) was determined and expressed as the yield of *Selenastrum capricornutum* Printz in mg l⁻¹ produced by the test water after 14 days growth on a light box.

Results and Discussion

Although eutrophication is accompanied by increases in the

quantities of many elements and increased mineralization has been used as an index of eutrophication (Beeton, 1966), it is widely recognized that phosphorus and nitrogen are the most important elements (Stewart and Rohlich, 1967; Vollenweider, 1968; Schindler, 1974). Analysis of water samples included the determination of other elements, but only results for phosphorus and nitrogen are presented here. However, to illustrate the extent of mineralization in the respective catchments, conductivity characteristics are also given.

Buffelspoort Dam Catchment

Mean values for conductivity, phosphate and the combined

forms of nitrogen are presented in Figure 6. These waters had a low ionic content with mean conductivities ranging between 4,0 and 6,6 mS m⁻¹. This was to be expected from the geology of the catchment (Magaliesberg quartzite) and the fact that no urban or industrial centres were present. The nitrogen and phosphorus content of these waters was also low and indicated that no significant point source of nutrient supply existed in the catchment. This was also supported by the relatively low mean AGP values obtained for the same waters (Figure 7). These AGP values (approximately 30 mg l⁻¹) suggest that the waters of this reservoir may be considered mesotrophic since waters having an AGP greater than 25 mg l⁻¹ can be regarded as such (Toerien, 1975).

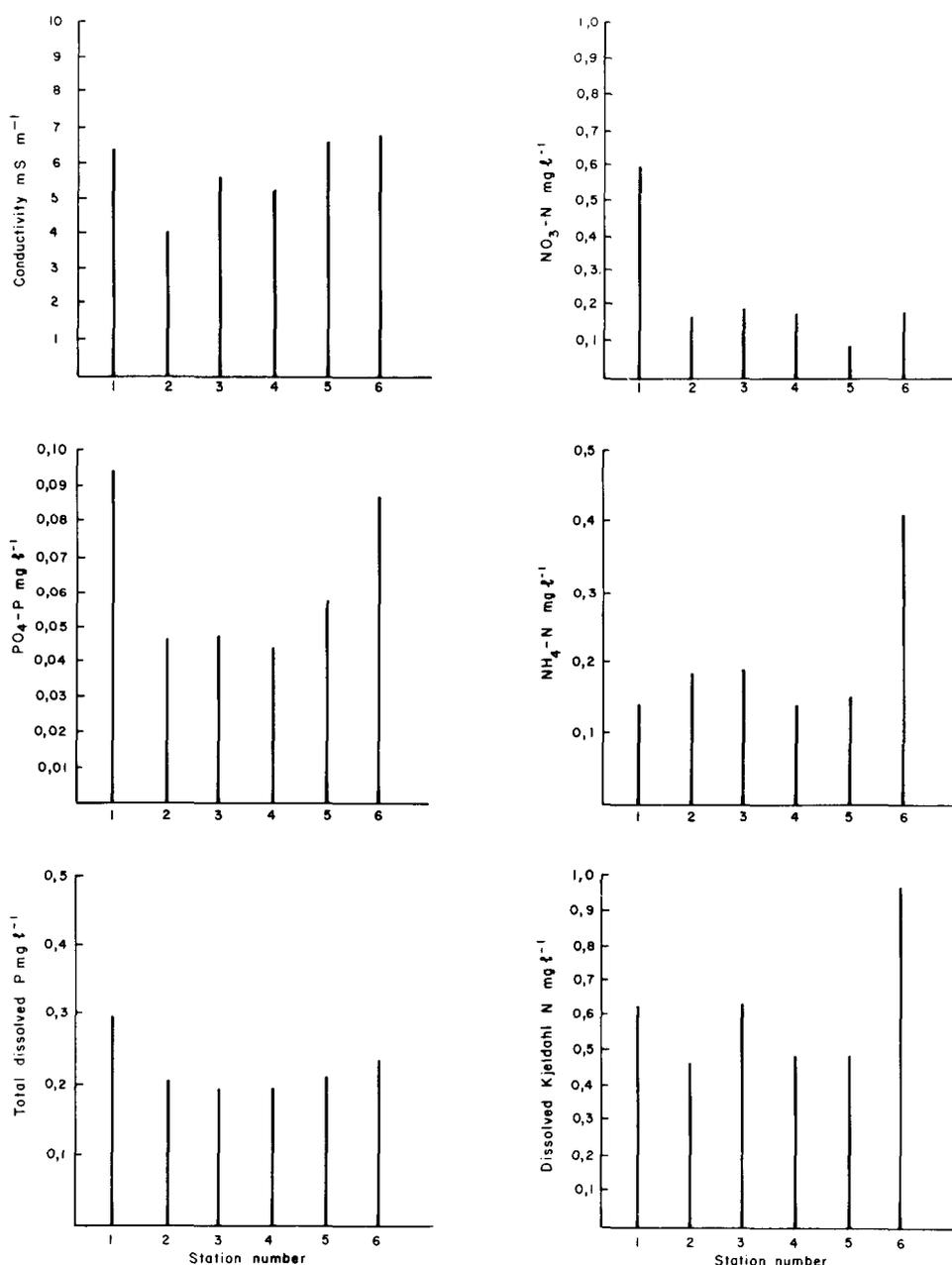


Figure 6
Mean values for conductivity, PO₄-P, total dissolved P, NO₃-N, NH₄-N and dissolved Kjeldahl N obtained for waters from stations in the Buffelspoort Dam catchment area

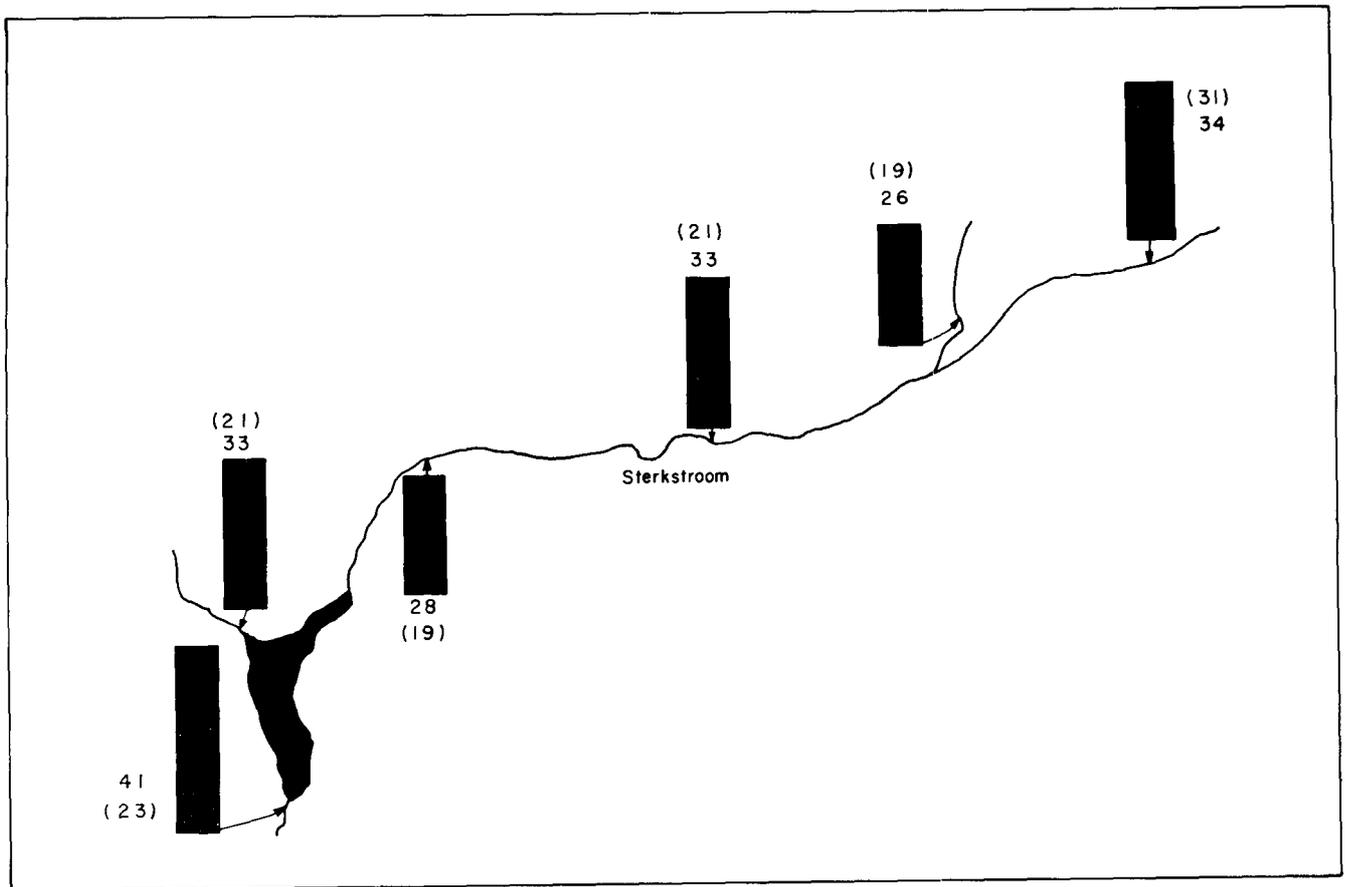


Figure 7
Mean AGP values for waters collected from stations in the Buffelspoort Dam catchment area. Figures in parentheses are standard deviation values

Hartbeespoort Dam Catchment

Compared with waters in the Buffelspoort catchment, rivers flowing into the Hartbeespoort Dam were highly mineralized. Mean conductivity values for all sources of inflow ranged between 37,3 and 63,5 mS m^{-1} (Figure 8). Waters of the Magalies River system, the Leeuspruit and the Swartspruit showed approximately the same degree of mineralization and nutrient content. The Crocodile River on the other hand had considerably higher mean values for conductivity and dissolved nitrogen and phosphate. The mean AGP value for waters of the Crocodile River (mean value of 570 mg l^{-1}) was over five times that of any of the other inflowing waters (Figure 9). These observations further confirm the conclusions of Allanson (1961) and Botha (1968) that the Crocodile River is a highly enriched water system.

Rietvlei Dam Catchment

The mean conductivity of water flowing into the Rietvlei Dam (Station 8) was high (68 mS m^{-1}) indicating high levels of dissolved minerals (Figure 10). With increasing distance of each

sampling station from the Kempton Park sewage works, there was a decrease in mean conductivity (from 88,0 mS m^{-1} at the sewage works to 68,0 mS m^{-1} at the dam inflow). This also applied to orthophosphate (from 7,0 mg l^{-1} to 1,6 mg l^{-1} as P), total dissolved phosphate (from 8,0 mg l^{-1} to 2,0 mg l^{-1} as P), dissolved Kjeldahl nitrogen (from 8,0 mg l^{-1} to 1,2 mg l^{-1} as N), and ammonia (from 5,5 mg l^{-1} to 0,3 mg l^{-1} as N). Nitrate showed a different trend in the early stages of the river in that mean levels increased. This may be attributed to nitrification which is common in such sewage-polluted waters (Allanson, 1961). There was a marked decrease in the mean concentration of total dissolved nitrogen between stations 2 and 3 and stations 4 and 5. From investigation of the river's course, it could be suggested that *Phragmites* reed beds, through which the river flows between these stations, had removed substantial amounts of available nitrogen and phosphorus. Unfortunately particulate nitrogen and phosphorus were not determined during this study and it is therefore not possible to comment on the efficiency of these reed systems as nutrient traps since nitrogen and phosphorus in the particulate form could still be flowing through them.

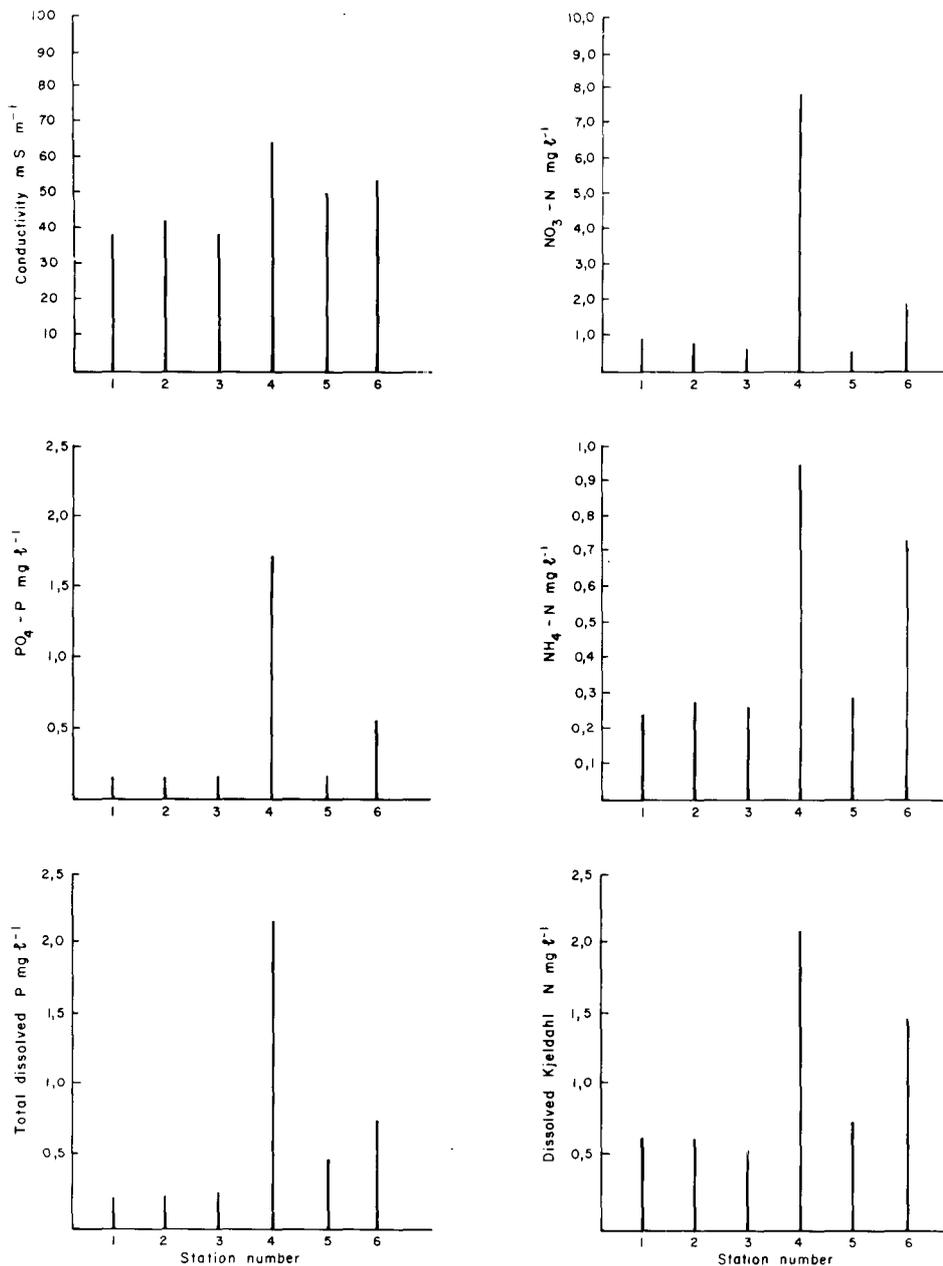


Figure 8
 Mean values for conductivity, PO₄-P, total dissolved P, NO₃-N, NH₄-N and dissolved Kjeldahl N obtained for waters from stations in the Hartbeespoort Dam catchment area

AGP results also supported the trend in nutrient content (i.e. mean AGP values decreased with distance from the sewage works) and showed up the effects of the reed beds (Figure 11). Since these waters had a low nitrogen to phosphorus ratio by weight (approximately 1:1), the mean AGP gave a measure of the available nitrogen present. On the basis of its phosphorus and nitrogen yield coefficients, *S. capricornutum*, the bioassay test

organism, requires a nitrogen to phosphorus ratio of approximately 24:1 for balanced growth. These waters may therefore be considered to be nitrogen-limiting to this organism. Toerien and Steyn (1973) have reported a similar trend in AGP values for this river system and Steyn (1973) has shown that the waters in Rietvlei Dam are nitrogen-limiting to *S. capricornutum*.

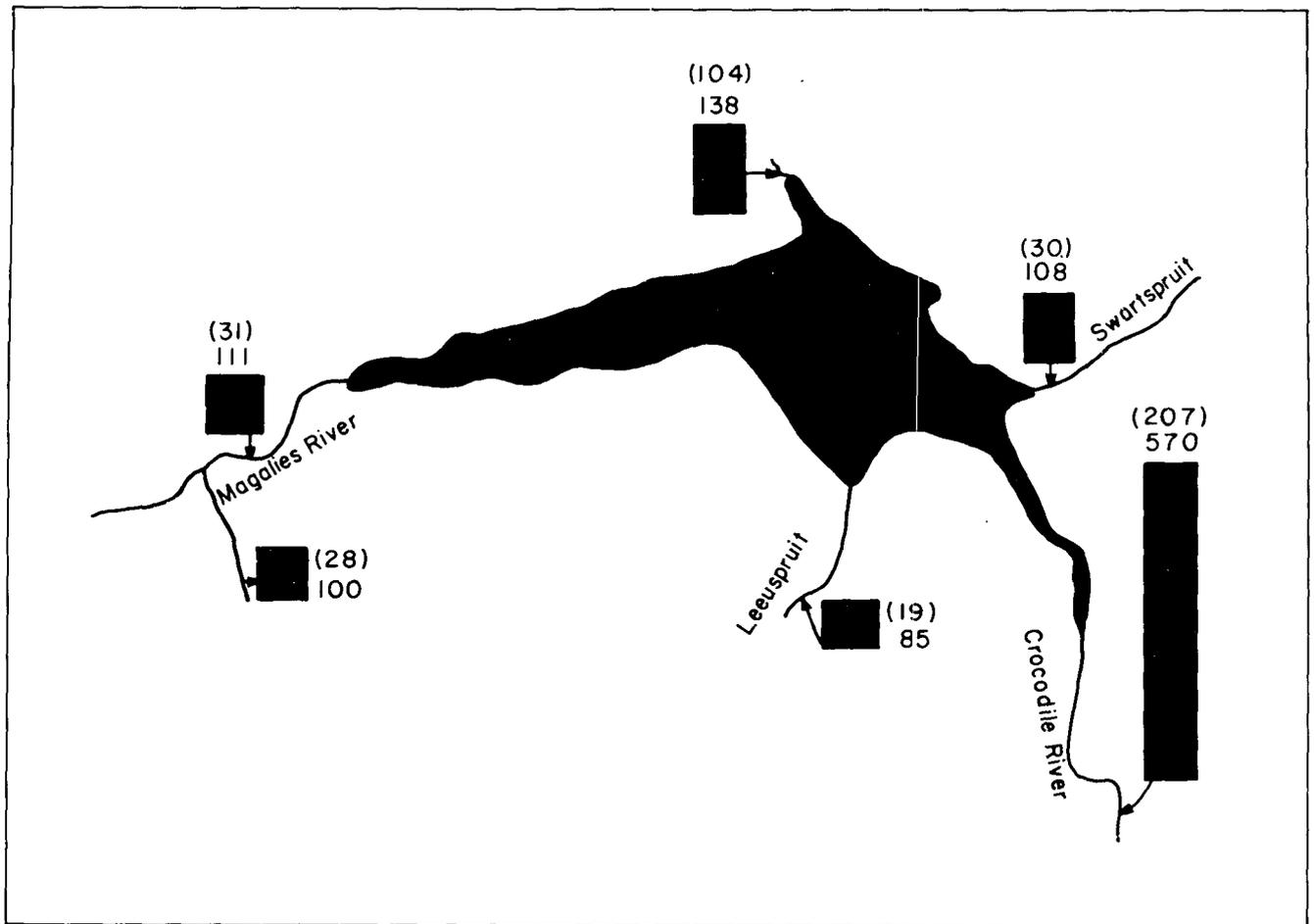


Figure 9
 Mean AGP values for waters collected from stations in the Hartbeespoort Dam catchment area. Figures in parentheses are standard deviation values

Roodeplaat Dam Catchment

Mean conductivity values of waters flowing into the Roodeplaat Dam showed that in some instances, mineralization of the waters by sewage and industrial effluents was more extensive than in the Rietvlei and Hartbeespoort catchments. Mean conductivity values ranged between 33 and 100 mS m^{-1} (Figure 12). A comparison of the three inflowing river systems provides an illustration of the differing effects of sewage and industrial effluents on river waters.

Waters from stations 2 and 3 on the Pienaars River showed little difference in conductivity, and dissolved phosphate and combined nitrogen levels were low. This showed that run-off from the Mamelodi Township itself had little effect on the Pienaars River. However, after receiving the effluents from the Bavianspoort sewage works, the chemical composition on the

Pienaars River was altered drastically, with large increases in combined nitrogen and phosphate levels. The sewage works can therefore be considered to be a major point source of nutrient supply in this catchment.

On the Hartbeespoort-Morelettaspruit system, it appeared that the industrial area at Silverton contributed large amounts of dissolved minerals to the Morelettaspruit. This was manifested by an increase in mean conductivity values between stations 6 and 7 (33 mS m^{-1} to 100 mS m^{-1}). There was also a slight increase in the dissolved combined nitrogen content, but no increase in phosphate between these two stations. Nutrient concentrations in the Edenvalespruit were low and mean values for conductivity, combined nitrogen and phosphate were comparable with those of the Morelettaspruit before it had passed the industrial area.

Algal bioassay results further confirmed the nutrient

analyses and showed that the Baviaanspoort sewage works discharged effluents which increased the AGP of the Pienaars River (Figure 13). As in the case of the Rietvlei inflow, these waters, on the basis of the nitrogen to phosphorus ratio (approximately 4:1), may be considered nitrogen-limiting to *S. capricornutum* and the AGP was also a measure of the available nitrogen content.

Nutrient loading and eutrophication significance

Eutrophication is a process which involves the increasing enrichment of water systems and can be a natural or artificial phenomenon (Hasler, 1947). In an attempt to quantify the eutrophication of lakes, Vollenweider (1968) introduced the nutrient loading concept model which related the eutrophication

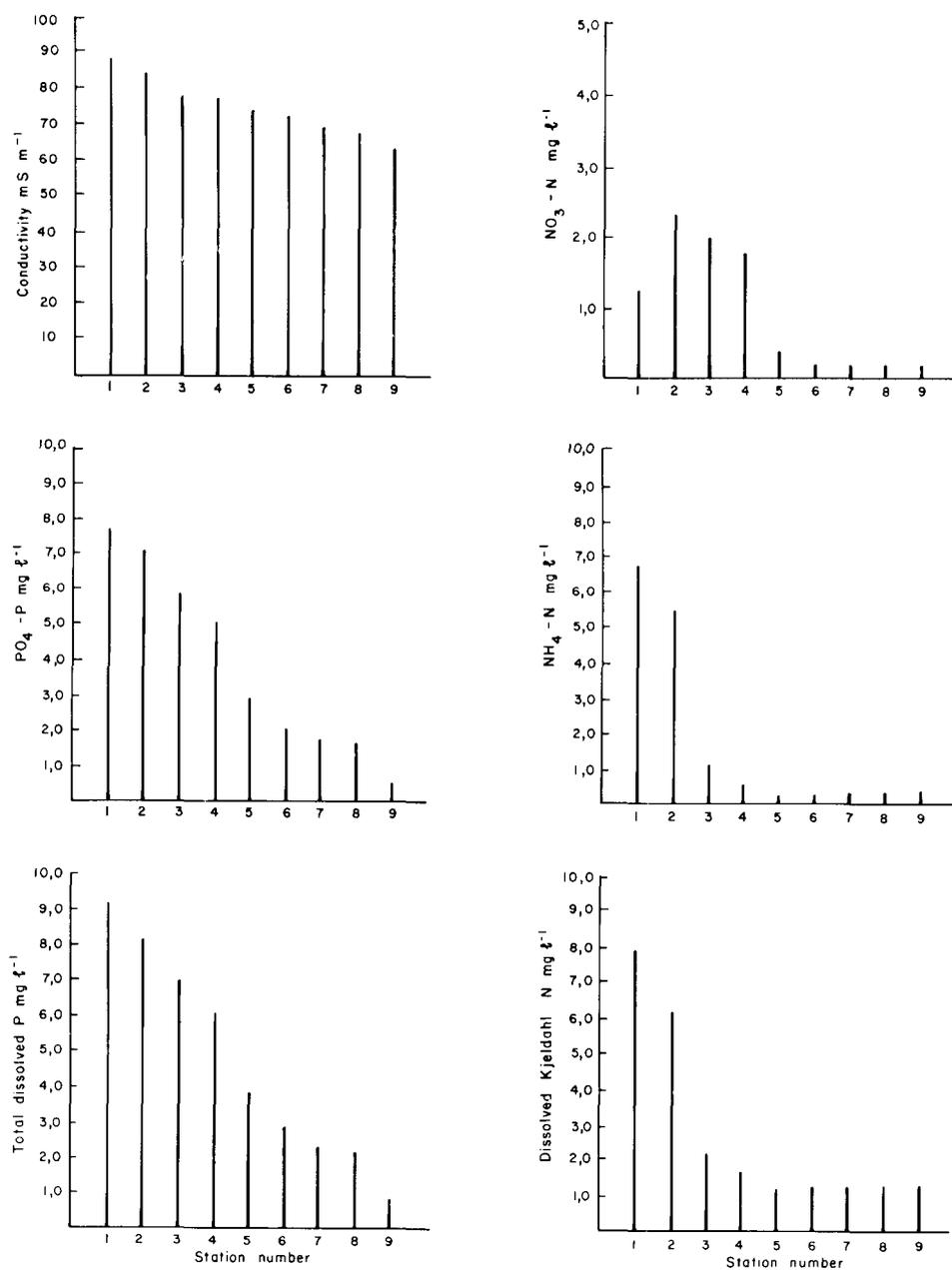


Figure 10
 Mean values for conductivity, PO₄-P, total dissolved P, NO₃-N, NH₄-N and dissolved Kjeldahl N obtained for waters from stations in the Rietvlei Dam catchment area

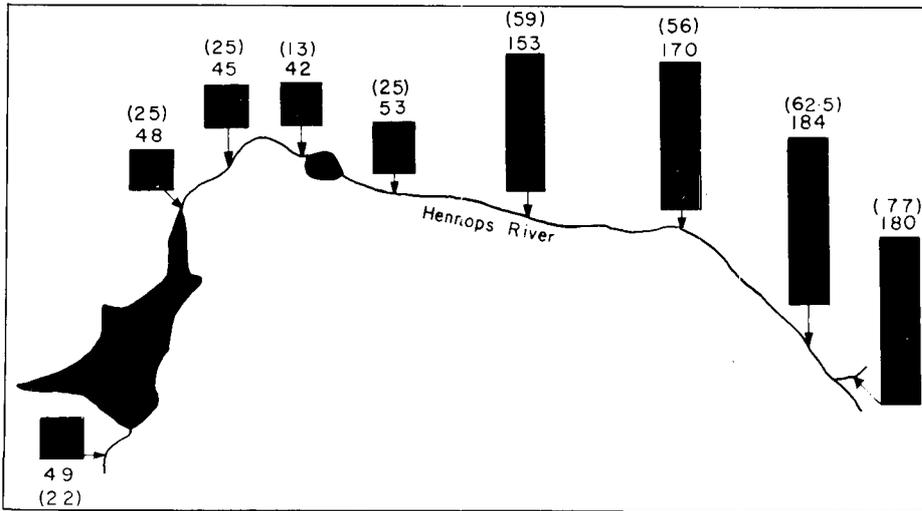


Figure 11
 Mean AGP values for waters collected from stations in the Rietvlei Dam catchment area. Figures in parentheses are standard deviation values

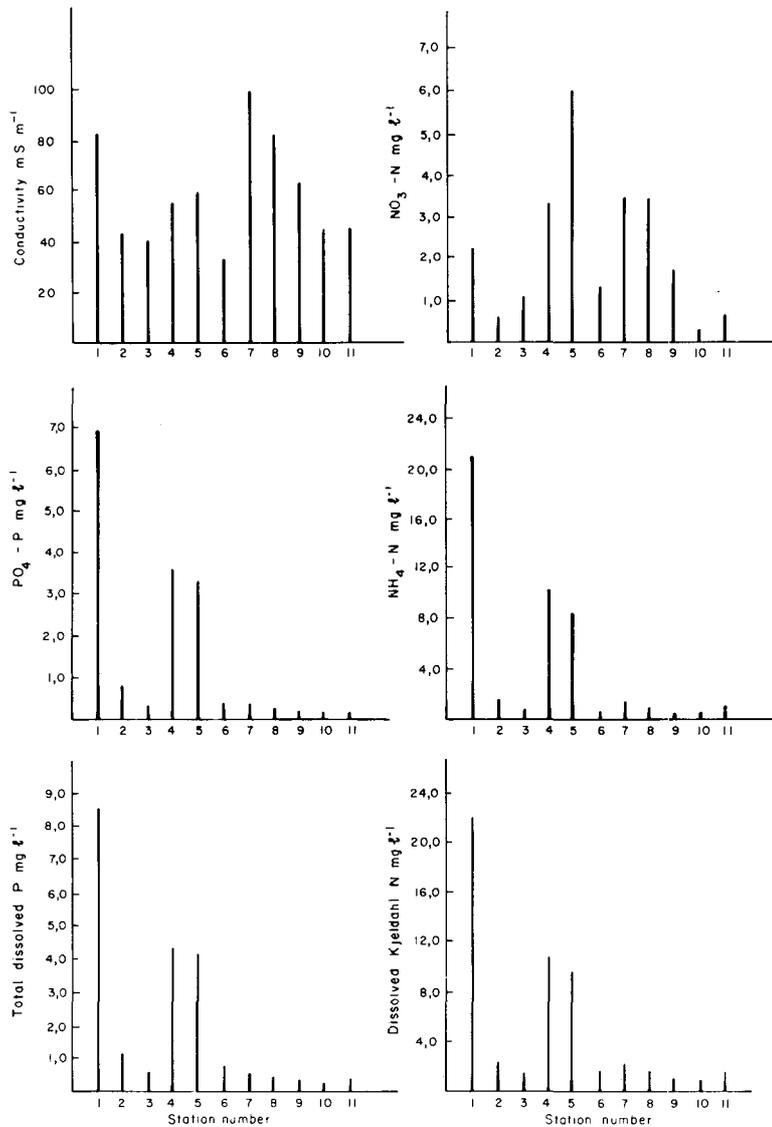


Figure 12
 Mean values for conductivity, $\text{PO}_4\text{-P}$, total dissolved P, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and dissolved Kjeldahl N obtained for waters from stations in the Rodeplaas Dam catchment area

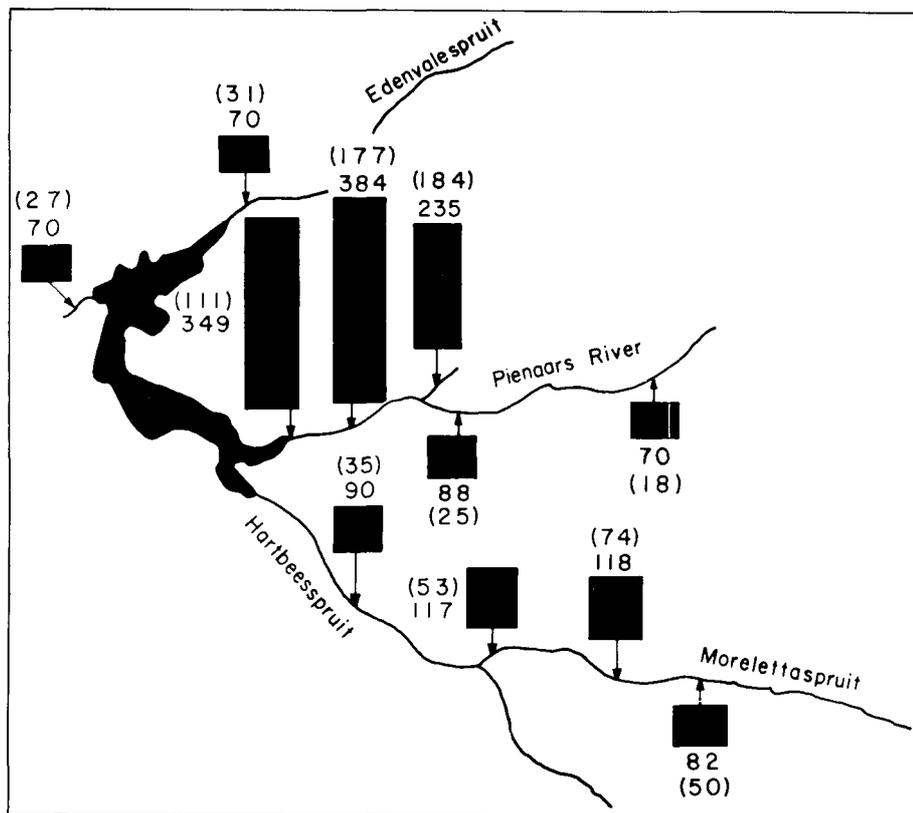


Figure 13
 Mean AGP values for waters collected from stations in the Roodeplaat Dam catchment area. Figures in parentheses are standard deviation values

TABLE 1
 HYDROLOGICAL AND NUTRIENT LOADING CHARACTERISTICS FOR BUFFELSPOORT DAM

	1973/74	1974/75
Mean capacity $m^3 \times 10^6$	4,767	9,492
Mean area ha	78	124
Mean depth m	6,0	7,6
Water outflow $m^3 \times 10^6$	9,4	19,5
Residence time a	0,50	0,48
Surface overflow rate $m a^{-1}$	12,0	15,8
PO_4 -P loading rate $g m^{-2} a^{-1}$	0,94	0,73
Total dissolved P loading rate $g m^{-2} a^{-1}$	3,60	2,70
Inorganic N loading rate $g m^{-2} a^{-1}$	5,71	4,42
Total dissolved N loading rate $g m^{-2} a^{-1}$	17,41	13,50
Vollenweider threshold rate total P $g m^{-2} a^{-1}$	0,57	0,67

status of a lake to its phosphorus and nitrogen surface loading rate ($\text{g m}^{-2} \text{a}^{-1}$ nitrogen or phosphorus) and its mean depth. This concept was further modified (Vollenweider, 1972) to include only the total phosphorus loading rate, the mean depth and the water retention time. In short, the concept is based on the fact that deep lakes with short residence times will be able to tolerate higher loading rates than shallow lakes with long residence times. Applying this concept to North American and

European lakes, Vollenweider (1968; 1972) has been able to predict the threshold phosphorus loading rate above which eutrophication problems may be experienced.

A comparison of the four dams described would not be realistic if only the nitrogen and phosphorus concentrations of the inflow waters were considered, since each dam had a different size and individual inflow systems contributed different inflow volumes. Therefore for each dam, the nutrient loading

TABLE 2
HYDROLOGICAL AND NUTRIENT LOADING CHARACTERISTICS FOR HARTBESPOORT DAM

	1973/74		1974/75	
Mean capacity $\text{m}^3 \times 10^6$	106,038		137,360	
Mean area ha	1 342		1 592	
Mean depth m	7,9		8,6	
Water outflow $\text{m}^3 \times 10^6$	121,899		187,051	
Residence time a	0,86		0,73	
Surface overflow rate m a^{-1}	9,18		11,71	
	Magalies River		Crocodile River	
	1973/74	1974/75	1973/74	1974/75
$\text{PO}_4\text{-P}$ loading rate $\text{g m}^{-2} \text{a}^{-1}$	0,07	0,19	13,29	13,68
Total dissolved P loading rate $\text{g m}^{-2} \text{a}^{-1}$	0,10	0,29	16,70	17,19
Inorganic N loading rate $\text{g m}^{-2} \text{a}^{-1}$	0,60	1,62	69,66	71,72
Total dissolved N loading rate $\text{g m}^{-2} \text{a}^{-1}$	0,78	2,10	78,99	81,32
Vollenweider threshold rate total P $\text{g m}^{-2} \text{a}^{-1}$	0,50	0,57	0,50	0,57

TABLE 3
HYDROLOGICAL AND NUTRIENT LOADING CHARACTERISTICS FOR RIETVLEI DAM

	1973/74	1974/75
Mean capacity $\text{m}^3 \times 10^6$	11,672	12,720
Mean area ha	190	202
Mean depth m	6,1	6,2
Water outflow $\text{m}^3 \times 10^6$	10,973	45,34
Residence time a	1,06	0,28
Surface overflow rate m a^{-1}	5,75	22,14
$\text{PO}_4\text{-P}$ loading rate $\text{g m}^{-2} \text{a}^{-1}$	10,13	25,73
Total dissolved P loading rate $\text{g m}^{-2} \text{a}^{-1}$	13,12	33,33
Inorganic N loading rate $\text{g m}^{-2} \text{a}^{-1}$	2,93	7,44
Total dissolved N loading rate $\text{g m}^{-2} \text{a}^{-1}$	8,85	22,48
Vollenweider threshold rate total P $\text{g m}^{-2} \text{a}^{-1}$	0,42	0,83

from each inflow system was estimated from the product of the mean concentration (nitrogen and phosphate) at the station nearest the dam and the total annual water flow. This annual loading was converted to an annual surface loading rate by dividing by the mean area of the reservoir for the same period. The water residence time was estimated by dividing the mean volume of the reservoir by the annual outflow. For the Hartbeespoort Dam, the contributions from the Swartspruit and the Leeuspruit have been ignored owing to the lack of flow data. Since these two streams are non-perennial their contribution to water flow and nutrient loading may, however, be considered negligible. In the case of Buffelspoort Dam where no flow data was available for the unnamed stream (i.e. station 5), estimates are based on total water flow into the impoundment and the mean nutrient concentrations at stations 4 and 5. Since these two stations showed little difference in mean nutrient concentrations (see Figure 6) it seems reasonable to assume that these estimates are fairly reliable. However, it is not possible to

quantify the relative contribution of these two streams to the nutrient loading of the Buffelspoort Dam.

The hydrological and nutrient loading characteristics for the respective dams and inflowing waters are given in Tables 1 to 4. In the case of the Rietvlei and Roodeplaat Dam catchments where samples were collected from sewage works, the potential nutrient contribution from each of the sewage works is expressed in terms of the phosphorus and nitrogen surface loading rate to the respective dam (Tables 5 and 6).

Since Vollenweider (1972) has indicated that phosphorus is the key element in the eutrophication process, the threshold total phosphorus loading rate value for his model under the respective hydrological conditions is also given. Vollenweider's value is based on total phosphorus determinations, whereas results from this study include only total dissolved phosphorus. It is therefore likely that the total phosphorus loading rate for each dam was actually higher than these values.

The hydrological characteristics show that the second

TABLE 4
HYDROLOGICAL AND NUTRIENT LOADING CHARACTERISTICS FOR ROODEPLAAT DAM

	<u>1973/74</u>		<u>1974/75</u>			
Mean capacity $m^3 \times 10^6$	40,440		41,470			
Mean area ha	383		391			
Mean depth m	10,5		10,5			
Water outflow $m^3 \times 10^6$	26,818		68,113			
Residence time a	1,50		0,60			
Surface overflow rate $m a^{-1}$	6,96		17,26			
	Edenvalespruit		Pienaars River		Hartbeesspruit	
	1973/74	1974/75	1973/74	1974/75	1973/74	1974/75
$PO_4 - P$ loading rate $g m^{-2} a^{-1}$	0,03	0,12	9,26	20,59	0,06	0,21
Total dissolved P loading rate $g m^{-2} a^{-1}$	0,20	0,32	11,59	25,76	0,07	0,89
Inorganic N loading rate $g m^{-2} a^{-1}$	0,12	1,10	42,35	94,16	0,60	5,07
Total dissolved N loading rate $g m^{-2} a^{-1}$	0,19	1,73	45,16	100,41	0,78	7,18
Vollenweider threshold rate total P $g m^{-2} a^{-1}$	0,45	0,71	0,45	0,71	0,45	0,71

TABLE 5
POTENTIAL CONTRIBUTION OF THE KEMPTON PARK SEWAGE WORKS TO THE NUTRIENT LOADING RATE OF RIETVLEI DAM

	1973/74	1974/75
Volume of flow from works $m^3 \times 10^6$	8,167	9,233
Per cent of inflow to dam	70,36	20,92
$PO_4 - P$ loading rate $g m^{-2} a^{-1}$	33,4	35,5
Total dissolved P loading rate $g m^{-2} a^{-1}$	39,4	41,9
Inorganic N loading rate	35,3	37,5
Total dissolved N loading rate	39,9	42,4

TABLE 6
POTENTIAL CONTRIBUTION OF THE BAVIAANSPOORT SEWAGE WORKS TO THE
NUTRIENT LOADING RATE OF ROODEPLAAT DAM

	1973/74	1974/75
Volume of flow from works m ³ × 10 ⁶	3,240	3,475
Per cent of inflow to dam	25,12	9,27
PO ₄ -P loading rate g m ⁻² a ⁻¹	5,88	6,18
Total dissolved P loading rate g m ⁻² a ⁻¹	7,26	7,63
Inorganic N loading rate g m ⁻² a ⁻¹	21,13	22,20
Total dissolved N loading rate g m ⁻² a ⁻¹	21,86	22,97

year of the study was much wetter than the first, and residence times in all four dams were shorter in the second year (Tables 1 to 4). The surface overflow rate value for each dam (mean depth/residence time) gives an idea of the tolerance of each dam to increased nutrient loading. The higher the surface overflow rate, the higher is the threshold phosphorus loading rate. Rietvlei Dam in the second year of study had the highest surface overflow rate of the four dams (22,1 m a⁻¹).

The nutrient loading rates for each dam evidently differ from year to year, depending on hydrological characteristics. These surface loading rate values, however, indicate that the Hartbeespoort, Rietvlei and Roodeplaat Dams may be considered highly eutrophic systems. These three dams had phosphorus surface loading rates over 30 times the proposed threshold value of the Vollenweider model and these values are based only on dissolved contributions. Buffelspoort Dam on the other hand had dissolved phosphorus loading rates which approached the Vollenweider threshold value more closely than the other three impoundments.

The role of sewage effluents in producing high nutrient loading rates is accentuated by the fact that the sewage-polluted Crocodile and Pienaars River contributed over 90 per cent of the annual phosphorus and nitrogen loads to the Hartbeespoort and Roodeplaat Dams respectively (Tables 2 and 4), whilst other inflowing streams (e.g. Magalies River, Edenvalespruit and Hartbeespruit) contributed negligible nutrient loads. In the case of the Rietvlei and Roodeplaat Dams where the potential nutrient contribution from sewage works has been able to be quantified (Tables 5 and 6), striking differences are apparent. The first is the difference between the percentage of the total dam inflow contributed by each sewage works, the second is the nitrogen to phosphorus ratio of the discharged effluents and the third is the actual percentage of this potential loading which enters the dam. Firstly, in the case of Rietvlei Dam, it can be seen that up to 70 per cent of the total water inflow may be derived from the Kempton Park sewage works whereas for Roodeplaat Dam only 25 per cent is derived from the Baviaanspoort sewage works. This figure depends on the amount of rainfall received in the catchment and, since during the second year of study abnormal floods were experienced, the flow figures of the first year are more representative. Secondly, the ratio of dissolved nitrogen:phosphorus in the Kempton Park sewage works' effluent was approximately 1:1 whilst that of the Baviaanspoort sewage works was 3:1. This is obviously caused by the composition of incoming effluents and suggests that in terms of

algal growth problems, blooms will become limited by nitrogen since algae require nitrogen and phosphorus in a ratio of approximately 15:1 (O'Kelley, 1968). Algal growth limitation studies on both Rietvlei and Roodeplaat Dam water have substantiated this suggestion (Toerien, Hyman and Bruwer, 1975; Steyn, Scott, Toerien and Visser, 1975; Steyn, Toerien and Visser, 1976). A third difference is that only a fraction of the dissolved nutrients from the Kempton Park sewage works reaches the Rietvlei Dam, whereas almost all of the nutrients discharged from the Baviaanspoort sewage works enter the Roodeplaat Dam (compare Tables 3 and 5; and 4 and 6). This accentuates the fact that it is not a good policy to site point sources of nutrient supply close to impoundments since considerable quantities of nutrients can be removed during the course of a river's flow through its catchment.

Studies and observations on the four dams have further established their trophic conditions. On the basis of plankton composition and certain dissolved minerals, the Hartbeespoort Dam was first described as an oligotrophic system (Hutchinson, Pickford and Schuurman, 1933). Studies on the chemical characteristics of the Hartbeespoort Dam some 30 years later showed that the system was highly eutrophic (Allanson and Gieskes, 1961). Allanson (1961) attributed this change to the fact that the Jukskei-Crocodile River system had stretches which were highly polluted by sewage and industrial effluents. More recent studies using algal bioassays (Steyn, Toerien and Visser, 1975; Toerien, Hyman and Bruwer, 1975) have also shown up the highly enriched condition of the Hartbeespoort Dam and its high potential to develop algal blooms. Both the Rietvlei and the Roodeplaat Dams have also been classified as highly eutrophic on the basis of their nutrient content and biological characteristics (Steyn, Scott, Toerien and Visser, 1975; Toerien, Hyman and Bruwer, 1975; Steyn, Toerien and Visser, 1976; Ashton, 1976; Walmsley and Toerien — in preparation). Buffelspoort Dam has not yet experienced any nuisance blooms of algae, but does exhibit certain eutrophic characteristics. The summer phytoplankton is dominated by *Microcystis aeruginosa* and the impoundment develops an anaerobic hypolimnion in summer (Walmsley and Toerien — in preparation). This impoundment probably represents a mesotrophic water body since nuisance conditions have not yet been experienced. Since the Buffelspoort Dam catchment represents a relatively undisturbed system (i.e. has not yet been subjected to discharges of sewage and industrial effluents), it is possible that most undisturbed South African reservoirs are naturally mesotrophic. However,

to extrapolate from the results obtained from only one system is dangerous, particularly as there is no past record for the Buffelspoort system.

The relative trophic condition of these four dams was therefore well reflected by their phosphorus loading rates and, from the Buffelspoort Dam situation, it is obvious by what degree the nutrient inputs into the Hartbeespoort, Rietvlei and Roodeplaat Dams should be reduced in order to accomplish rehabilitation. From the loading rates for the four impoundments (Tables 1 to 4), it is apparent that more than 90 per cent reduction in the nutrient loading to the eutrophic Hartbeespoort, Roodeplaat and Rietvlei Dams would be required in order for the loading to approach that of the mesotrophic Buffelspoort Dam.

Conclusions

1. Sewage and industrial effluents are the main cause of the eutrophication of the Hartbeespoort, Rietvlei and Roodeplaat Dams.
2. Enrichment of the Buffelspoort Dam appears to be due to natural rather than cultural activities.
3. The Crocodile River which drains urban and industrial areas, contributes over 95 per cent of the annual nutrient load into Hartbeespoort Dam.
4. Up to 70 per cent of the inflow into Rietvlei Dam may be derived from the Kempton Park sewage works. Reed beds in the catchment may remove dissolved nutrients.
5. The Pienaars River contributes over 90 per cent of the annual nutrient load into Roodeplaat Dam. Most of these nutrients are derived from the Baviaanspoort sewage works which can contribute up to 25 per cent of the total water inflow into the dam.
6. Hydrological characteristics for the impoundments varied considerably between the two years of study. This was due to different climatological conditions and more specifically rainfall differences.
7. Sewage effluents from the Kempton Park sewage works and the Baviaanspoort sewage works have a low nitrogen: phosphorus ratio. Effluents from these sewage works are therefore potentially nitrogen-limiting with respect to algal growth.
8. Determination of nutrient loading rates for important water bodies in South Africa is a prerequisite for the establishment of guidelines for eutrophication control.

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