Nitrogen and Phosphorus Input to the Midmar Dam, Natal

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Abstract

From March 1973 to February 1974 the mass of nutrients carried to the Midmar Dam by surface drainage was equivalent to a surface loading rate of 0,62 g total phosphorus and 8,49 g total soluble nitrogen $m^{-2}a^{-1}$. The mean annual rate for phosphorus is probably approximately half this value. Throughout the same period algal growth in the dam water was limited by the amount of phosphorus available, and the dam was in an oligotrophic-mesotrophic condition. Atmospheric nutrient deposition in the dam catchment was measured during 1975-76 and this source probably provides a small but significant contribution to the total annual input. The vegetation and soil of the catchment retains most of the nutrients reaching the land surface. In view of possible development in the catchment the increase in phosphorus loading rate that could be permitted without development of algae-associated problems is discussed.

Introduction

Although not the largest drainage basin in Natal, the Umgeni catchment is undoubtedly the most heavily utilized water source in the Province and currently provides approximately $480 \times 10^3 m^3 d^{-1}$ of purified water. The present population of the area is 1,85 million and is expected to reach 5,6 million by the year 2005, and the region is currently responsible for about 20% of the industrial production of the Republic (Phelines, 1975).

The Umgeni River rises at around 1 800 m in the foothills of the Drakensberg and flows eastward to reach the Indian Ocean on the northern outskirts of the city of Durban. It has been impounded at three points along its course and a fourth and final impoundment before it reaches the coast is expected to be completed in the early 1980's.

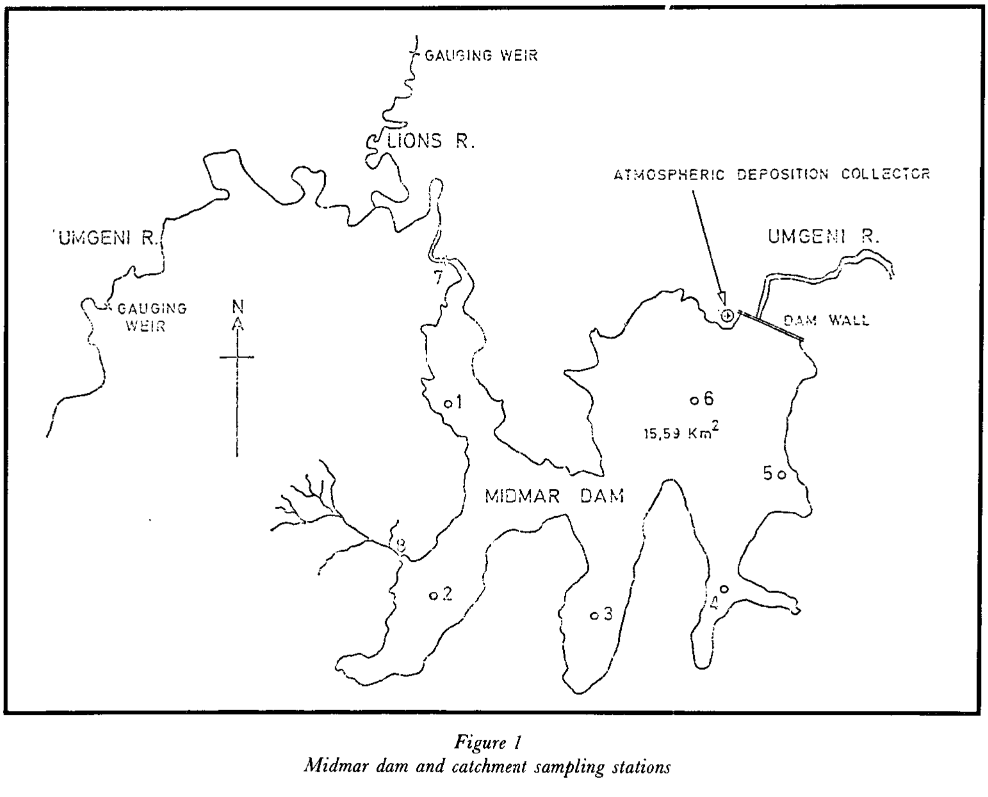

Figure 1
Midmar dam and catchment sampling stations

A survey by Brand *et al* (1967) showed the river water to be of generally good quality with little evidence of pollution, except in the lowest reaches. However, the present rapid rate of urban and industrial development in the drainage basin has made it necessary to assess the current extent of nutrient enrichment of the Umgeni impoundments. This paper provides some data on the present input of phosphorus and nitrogen to the Midmar Dam, the uppermost impoundment in the basin.

Materials and Methods

Midmar Dam and its catchment

The major part of the catchment is drained by the Umgeni and Lions Rivers which join about 3 river kilometres above their combined discharge to the dam. The flooded valleys that form the dam confer an irregular shape, as shown in Figure 1 and Table 1. Land use in the catchment is limited to agriculture, forestry and stock raising by the small rural communities, totalling about 25 000 people in 1967. The natural veld and cultivated pastures are utilized by approximately 25 000 cattle and 50 000 sheep and, apart from some production of potatoes and vegetables, most of the cultivated land is used to produce stock feed. A division of the area by land use is given in Table 2 which shows that more than half of the catchment is undeveloped hillside veld. A detailed account of land use and soil characteristics in the catchment has been given by Scotney (1970).

TABLE 1
MIDMAR DAM AND THE MIDMAR CATCHMENT (MORPHOMETRIC PARAMETERS OF DAM ACCORDING TO HUTCHINSON (1957))

Midmar Dam	
Dam surface	15,59 km^2
Volume (at F.S.L.)	177,2 × $10^6 m^3$
Maximum depth	20,7 m
Mean depth	11,36 m
Maximum width	3,35 km
Mean width	1,97 km
Maximum length	5,75 km
Length of shoreline	40,0 km
Development of shoreline	2,85
Midmar Dam Catchment	
Total catchment excluding dam	917 km^2
Umgeni River catchment above gauging weir	284,9 km^2
Lions River catchment above gauging weir	354,8 km^2

Water samples

Samples were collected at approximately 4-weekly intervals for a period of one year (March 1973-February 1974) from a number of points in the catchment and in the dam itself. The location of sample points providing data described in this paper is shown in Figure 1.

TABLE 2
LAND USE IN THE LIONS AND UMGENI RIVER CATCHMENTS ABOVE MIDMAR DAM

	%
Undeveloped hillside grassland	56,4
Dryland arable and grassland	19,2
Irrigated arable	3,9
Commercial forest plantations	14,3
Natural forest	2,5
Vleis and marshes	2,7
Small impoundments	0,8
Small population centres	0,2

A 5 litre Van Dorn sampler was used to collect samples from 1 m above the bottom, 1 m below the surface and at mid-depth at each point on the dam. A composite prepared from all the samples was used to represent the dam as a whole for determination of growth limiting nutrients. All samples were collected in prewashed polyethylene bottles and the same bottle was used to sample at the same station on each occasion. Samples were immediately cooled to about 5°C with a mixture of water and solid carbon dioxide in insulated boxes to reduce chemical changes during transit. Samples were then stored at -20°C and were normally analysed within a few days of collection.

Analytical methods

Kjeldahl nitrogen and nitrate nitrogen were determined by the method of Strickland and Parsons (1965), and ammonia nitrogen by the phenol hypochlorite method of Harwood and Kuhn (1970). Orthophosphate phosphorus was determined by the method of Strickland and Parsons (1968), and total phosphorus by the persulphate digestion according to Standard Methods (1971). Suspended solids were determined by vacuum filtration through tared 0,45 μm membrane filters dried at 105°C. Measurement of algal growth potential (AGP) and determination of growth limiting nutrients followed the methods given by Maloney (1971), with modification of the standard nutrient medium as recommended by Murray *et al* (1971).

Since there was some uncertainty regarding the chemical form and the biological availability of nutrients associated with particulate mineral material in river water entering the dam, only soluble nutrients were determined at first and samples were filtered through 0,45 μm membrane filters before freezing for storage. When the samples were thawed before analysis, coagulation of colloidal material produced turbid solutions which required further filtration through 0,45 μm membranes before analysis. The results for orthophosphate phosphorus and total dissolved phosphorus are therefore values that exclude almost all phosphorus that was not in true solution in the original samples.

Calculations of phosphorus loadings on lakes are now generally based on measurement of total phosphorus, i.e. both soluble plus suspended (Vollenweider, 1972). For this reason a conversion factor based on suspended solids concentration has been used where necessary to convert total soluble phosphorus to total phosphorus values. This factor was obtained from two sets of 7 samples taken at 4-weekly intervals at two points on the Umgeni River some 10 km apart. The results showed the phosphorus content of suspended material to be 1,25 $\mu g\ mg^{-1}$ suspended solids, with a standard error of 7,9% over the range 4 to 42 $mg\ell^{-1}$ suspended solids. Values for total phosphorus given in Tables 3 and 4 are therefore estimates based on the total soluble phosphorus plus an amount determined by the suspended solids content of each sample.

TABLE 3

MIDMAR DAM CATCHMENT. MONTHLY VARIATION IN NUTRIENT INPUT VIA CATCHMENT DRAINAGE

	INFLOW (x 10^3m^3)		PHOSPHORUS INPUT (kg P)				NITROGEN INPUT (kg N)	
Month 1973–74	Umgeni + Lions R (Station 7)	Remaining catchment (Station 8)	Umgeni + Lions R Tot sol P	Umgeni + Lions R Tot P	Remaining catchment Tot sol P	Remaining catchment Tot P	Umgeni + Lions R Tot sol N	Remaining catchment Tot sol N
March 1973	20807	6624	416	978	79	192	9883	1702
April	33923	14940	577	1289	567	852	20116	3825
May	10576	350	127	201	3	3	4516	90
June	5532	0	50	55	0	0	2301	0
July	3130	1499	28	128	18	24	861	451
August	3725	2215	37	45	18	38	823	625
September	3660	2384	22	29	14	24	1058	591
October	8200	2918	57	90	20	41	2427	481
November	9555	2870	86	134	35	54	4405	1096
December	7281	2307	58	102	25	46	2162	637
January 1974	61156	25004	1590	2324*	400	700*	27765	9001
February	73867	17915	1255	1920	179	376	31172	6414
Annual total	241412	79026	4303	7295	1358	2350	107489	24913
Nutrient concentration (g m^{-3})			0,018	0,0302	0,017	0,0297	0,445	0,315

*estimate – weir capacity exceeded

TABLE 4

MIDMAR DAM CATCHMENT. ESTIMATED MEAN ANNUAL PHOSPHORUS INPUT VIA RIVER FLOW AND HYDRAULIC RESIDENCE TIME FOR 1963–1973 AND FOR THE PERIOD MARCH 1973–FEBRUARY 1974

Year Oct.–Sept.	Annual inflow (x 10^6m^3)	Annual phosphorus input (kg P) Tot. sol. P	Annual phosphorus input (kg P) Tot. P	Hydraulic residence time (years)
1963–1964	139,21	2506	4176	1,27
1964–1965	199,86	3597	5996	0,88
1965–1966	119,24	2146	3577	1,49
1966–1967	221,26	3983	6638	0,80
1967–1968	133,98	2412	4019	1,32
1968–1969	98,36	1770	2951	1,80
1969–1970	165,61	2981	4968	1,07
1970–1971	135,55	2440	4066	1,31
1971–1972	213,76	3848	6413	0,83
1972–1973	176,70	3181	5301	1,00
Annual mean input	160,35	2886	4810	1,10
Input March 1973–February 1974	320,44	5661	9645	0,55

NOTE: Catchment mean annual rainfall = 970 mm.
Rainfall March 1973–February 1974 = 1144 mm.
Mean annual phosphorus input 1963–73 based on 0,018 g m^{-3} Tot. sol. P and 0,03 g m^{-3} Tot. P obtained from 1973–74 data (Table 3).

Nutrient input to the dam

Transport of nutrients to the Midmar dam can occur only via the rivers and streams entering the dam and by direct dry fallout and rainfall on the dam surface, since there are no habitations discharging septic tank effluent or other wastes along the shoreline.

River input

An estimate of nitrogen and phosphorus entering the dam via river flow from the catchment during 1973-74 was obtained from the product of the concentrations recorded in samples taken once each month at the Umgeni River inlet to the dam at station 7 in Figure 1, and the gross flow figures for the month provided by the Department of Water Affairs. Circumstances precluded more frequent sampling and the accuracy of the estimate is reduced by the fact that changes in concentration that may have occurred between sample collections are not taken into account.

There are a number of small streams discharging directly to the dam for which no flow records were available. There was also no record of the volume of water reaching the dam by sub-surface flow and by surface run-off during heavy rainfall. Monthly samples from two of the perennial streams entering the dam (one sample at station 8) were taken during the study period and analysis showed little difference in their nutrient concentrations. In order to estimate nutrient input from areas not drained by the Umgeni and Lions Rivers it was assumed that the results obtained for the stream sampled at station 8 (Figure 1) were representative of the nutrient concentrations in all water reaching the dam from sources other than the main Umgeni River inflow at station 7 (Figure 1).

Atmospheric input

During the 1973-74 study period no measurements of atmospheric nutrient deposition were made in the catchment area. A summary of the available data on atmospheric nutrient fallout by Uttormark *et al* (1974) drew attention to the fact that the amount of nitrogen and phosphorus reaching a lake surface from direct fallout can form a significant proportion of the total nutrient input to the lake. To obtain an indication of the significance of atmospheric deposition in the Midmar catchment the total nitrogen and phosphorus fallout reaching the land surface via rainfall and dry fallout was recorded over the period November 1975 to November 1976. Measurements were made in a grass-covered enclosure near the dam wall where contamination from road dust and other activities was minimal.

Samples were collected in two 150 mm diameter glass funnels supported 1 m above the ground and connected by polyvinyl tubing to glass bottles sunk below ground level to reduce temperature fluctuations. Each funnel was fitted with a nylon mesh disc (100 μm mesh) set 10 mm below the lip to exclude seeds and other wind-blown gross particulate matter. It was also found necessary to prevent birds perching and defaecating into the funnels, by providing a tracery of nylon monofilament fishing line above the funnel mouth stretched between external wire brackets attached to the funnel support.

Sample bottles were collected and replaced by clean bottles at intervals of 2 to 4 weeks. If no rainfall had occurred the funnels were rinsed with 200 mℓ of deionised water to collect dry fallout.

No preservatives were used to retard changes in the chemical forms of nutrients since materials such as mercury salts and acids were found to affect analytical results and the different amounts of rainfall collected caused varying dilutions of preservative. Although some loss of nitrogen may have occurred, conditions in the collection bottles were not conducive to denitrification. In this paper results for total phosphorus and total nitrogen only are presented.

Analytical results recorded were the mean of the values obtained from each bottle except, as occasionally occurred, when an abnormal value indicated contamination of the sample. In such cases the suspect result was discarded.

Results

Nutrient input via river flow

In Table 3 the flow of the combined Umgeni and Lions Rivers has been separated from the flow of the combined smaller streams of the remainder of the catchment. The monthly nutrient input from both sources has been calculated using concentrations recorded at station 7 for the combined Umgeni and Lions Rivers and those obtained from a stream draining a small undeveloped catchment (station 8 in Figure 1) to represent concentrations in the remaining contributing streams.

It is evident from the table that the Umgeni and Lions Rivers contributed about 60 per cent of the phosphorus and over 75 per cent of the nitrogen entering the dam. The annual mean concentration from both input areas was similar at near to 0,03 g m^{-3} total phosphorus, but the total soluble nitrogen concentration in the combined Umgeni and Lions Rivers of 0,44 g m^{-3} was higher than the value of 0,31 g m^{-3} for the smaller streams. Since the area drained by the smaller streams was largely forest and undeveloped grassland, the greater nitrogen loss from the Umgeni-Lions catchment may have been associated with farming activities.

From March 1973 to February 1974 the quantity of nutrients entering the dam via surface drainage from the catchment was estimated to have been 5 661 kg total soluble phosphorus and 132 402 kg total soluble nitrogen, equivalent to surface loading rates of 0,36 g phosphorus and 8,49 g nitrogen $m^{-2}a^{-1}$. The rate for total phosphorus was 0,62 g $m^{-2}a^{-1}$ (Table 3). This does not include an unmeasured but probably significant atmospheric deposition on to the dam surface during the same period.

Some evidence that these values are realistic is provided by the fact that the annual orthophosphate phosphorus input calculated from monthly samples taken at the Umgeni inflow to the dam on different dates over the same period by Furness (1974) was 3 914 kg. This is close to the value of 4 303 kg total soluble phosphorus obtained for samples taken at the same point (Table 3).

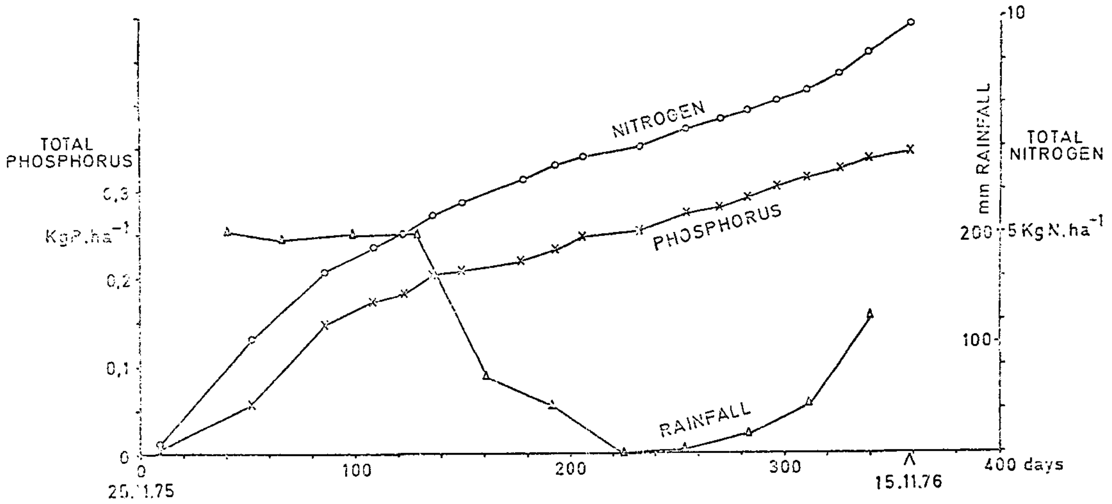

Figure 2
Rainfall and cumulative nutrient deposition in the Midmar catchment.
November 1975-November 1976

Nutrient input from the atmosphere

The cumulative results for nitrogen and phosphorus deposition in the Midmar area from November 1975 to November 1976 shown in Figure 2, indicated that deposition was continuous throughout the year, but the rate was greater during the period of summer rainfall. A complication caused by unexpected veld grass burning in the area around the collection site was encountered from mid-August to the end of September (day 268-309 in Figure 2) when a marked increase in the rate of deposition of nitrogen and a lesser increase in phosphorus deposition was recorded. The appearance of grass ash fragments in the samples at this time indicated that ash contamination was responsible for the increase. For this reason the cumulative values shown in Figure 2 have been corrected to remove the effects of grass burning by assuming the true deposition rate to have been the mean of that measured during the preceding period of the dry season, i.e. from day 150 to 268. This adjustment was considered to be justified because unpublished results from similar collectors located in rural areas in other parts of Natal did not indicate similar increases during this period. It was therefore concluded that the increase at Midmar was a local occurrence limited to the area near the collectors and that the increased fallout would have affected the adjacent shoreline only.

On this basis the total nutrient fallout during the 357 days from 25 November 1975 to 15 November 1976 was 0,348 kg total phosphorus and 9,85 kg total nitrogen ha^{-1}a^{-1}, equivalent to an input of 31,9 $\times$ 10^3 kg phosphorus and 903,2 $\times$ 10^3 kg nitrogen to the Midmar catchment and 542 kg phosphorus and 15 356 kg nitrogen directly to the dam surface.

Mean annual phosphorus input

The gross annual river flows to the dam over the ten years preceding 1973-74 shown in Table 4 make it clear that the water input during that year was approximately double the mean annual value. Since phosphorus was found to be the primary limiting nutrient in these waters (as described later), the mean annual phosphorus input is of interest. In Table 4 the annual inputs via river flow are calculated assuming a mean river water concentration of 0,03 g phosphorus m^{-3} as found during 1973-74. On this basis the mean annual total phosphorus input to the Midmar dam from catchment drainage for the period 1963-73 would have been 4 810 kg, equivalent to a dam surface loading of 0,31 g m^{-2}a^{-1}. In fact the mean value may be lower since the 1973-74 data indicated that total soluble phosphorus concentrations tend to decrease with decrease in river flow and the concentration may therefore have been less than 0,03 g m^{-3} in years with lower flows.

Catchment import and export 1973-74

During the 1973-74 study period information from agricultural fertilizer suppliers indicated an import to the catchment of approximately 1 000 $\times 10^3$ kg nitrogen and 450 $\times 10^3$ kg phosphorus, equivalent to a surface application of 10,9 kg nitrogen and 4,91 kg phosphorus ha^{-1}a^{-1} over the whole catchment. During the same period 132,4 $\times 10^3$ kg total soluble nitrogen and 9,64 $\times 10^3$ kg total phosphorus were carried from the catchment via river flow, equivalent to an export of 1,44 kg nitrogen and 0,105 kg phosphorus ha^{-1}a^{-1}. The nutrient import to the catchment via atmospheric deposition over the same period was not measured, but could have been substantial if similar to the 1975-76 value of 9,85 kg nitrogen and 0,348 kg phosphorus ha^{-1}a^{-1}. These figures illustrate the fact that the annual export of nitrogen and phosphorus from the catchment represented only a small proportion of the total entering the catchment from various sources.

Midmar Dam water

Algal growth

Although suspended solids concentrations in Midmar dam seldom exceed 10 mgℓ^{-1}, Secchi disc depths are usually less than 2 m and it cannot be classed as a clear water lake.

TABLE 5

MIDMAR DAM. MONTHLY VARIATION IN NUTRIENT AND CHLOROPHYLL *a* CONCENTRATION AND IN ALGAL GROWTH POTENTIAL (A.G.P.) MONTHLY MEANS AND RANGES FOR SAMPLES TAKEN FROM 3 DEPTHS AT 6 STATIONS.

Month	Phosphorus ($\mu g \ell^{-1}$)		Nitrogen ($\mu g \ell^{-1}$)			Chlorophyll *a*	A.G.P.**
1973–74	PO_4–P	Tot. sol. P	NO_3–N	NH_4–N	Kjeld–N	*($\mu g \ell^{-1}$)	($mg \ell^{-1}$)
March 1973 mean	4	11	55	66	297	15	
range	1–8	8–15	21–139	9–211	234–403	14–17	–
	6	15	24	88	250	14	
April	1–14	4–19	6–77	15–487	94–831	9–18	15,6
	4	7	64	115	253	12	
May	3–12	3–17	47–122	97–171	227–295	10–14	45,6
	2	8	271	16	312	3	
June	2–3	6–11	257–282	3–36	234–365	2–4	21,3
	2	10	289	27	199	4	
July	2–5	8–14	236–298	3–67	155–245	3–6	19,4
	3	8	351	8	160	3	
August	0	8–9	344–359	3–12	149–176	3–4	34,0
	2	5	380	12	231	3	
September	0	4–6	372–391	8–20	171–338	2–5	29,0
	3	8	370	10	153	4	
October	2–3	6–13	362–376	6–12	130–184	3–5	20,0
	1	7	338	18	205	5	
November	0	6–7	319–345	9–31	159–256	3–6	6,0
	2	7	282	8	168	6	
December	1–5	5–11	246–304	4–19	159–196	5–7	20,0
	8	14	247	46	282	7	
January 1974	4–19	11–22	141–323	10–116	215–399	5–9	22,0
	3	10	160	59	292	9	
February	1–5	8–14	14–205	5–332	77–606	5–13	26,0
Annual mean	3	9	225	44	240	7	24,8

*Values for samples at 1 m depth only.
**A.G.P. values for composite sample prepared from all samples.

Values for some of the parameters associated with algal growth are summarized in Table 5. Some seasonal variation in the form of soluble nitrogen present was evident but the total nitrogen concentration did not vary very much over the 1973-74 year. The concentration of total soluble phosphorus in the dam showed a small increase during the periods of high inflow but AGP measurements did not indicate any consistent relation to nitrogen or phosphorus concentrations, perhaps because the increase in chemically detectable phosphorus was not biologically available. Alternatively, the use of autoclaved unfiltered samples for algal assays may have been the cause.

Algal concentrations, estimated by chlorophyll *a* determinations, were highest during the summer and the lowest values were reached during the colder winter months. This is probably an annual pattern but at no time since the dam was commissioned have water treatment problems resulted. There is, therefore, no evidence to suggest that eutrophication of the dam has reached the stage where undesirable consequences begin to appear.

Growth limiting nutrients

The maximum cell concentration parameter of the AGP test was used to identify limiting nutrients. In Figure 3 the results for dam composite samples are expressed as a percentage of the growth obtained with the assay organism *Selenastrum capricornutum* Printz in the standard culture medium containing all the elements essential for growth. Reference to the figure shows that during most of the study period iron and trace elements were present in the dam water in excess of requirements, but at all times growth obtained without phosphorous in the added medium was almost identical to that obtained in the dam water controls. It is thus evident that phosphorus was the growth limiting nutrient in the dam water throughout the year.

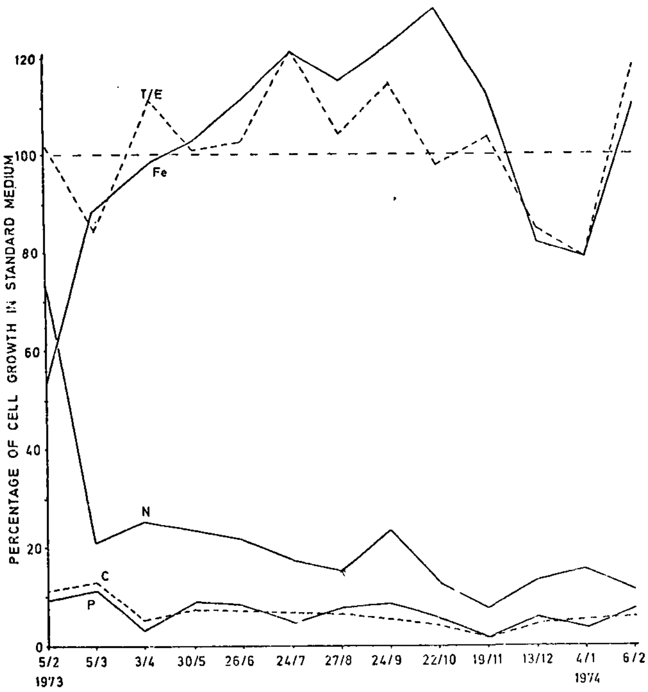

Figure 3
Growth-limiting nutrients in Midmar dam, 1973-74
T/E Dam water and nutrient mixture without trace elements
Fe Dam water and nutrient mixture without iron
N Dam water and nutrient mixture without nitrogen
P Dam water and nutrient mixture without phosphorus
C Dam water only

Discussion

In attempting to develop phosphorus criteria for lakes and impoundments, the approach has been to apply a criterion based either on concentration in the water body or on the amount of phosphorus entering. Both methods have advantages and shortcomings, but the loading concept is more easily applied once the desirable rate has been established.

A guideline for total phosphorus concentration developed from a study of over 100 lakes and impoundments in the north central and north eastern United States has been published by the National Eutrophication Survey (1974).

From the relationship between autumn total phosphorus concentrations and algal assay yield it was concluded that a median total phosphorus concentration of 25 $\mu g \ell^{-1}$ should not be exceeded if nuisance algal blooms are to be avoided. It was also concluded that in lakes classified as oligotrophic the mean chlorophyll *a* concentration was less than 7 $\mu g \ell^{-1}$ and did not exceed 12 $\mu g \ell^{-1}$ in mesotrophic lakes. Since only soluble phosphorus concentrations were determined in Midmar dam, a direct comparison cannot be made, but on the basis of mean chlorophyll *a* concentrations Midmar, with a mean value of 7 $\mu g \ell^{-1}$, would be classed as entering the mesotrophic condition.

Vollenweider (1972) modified his original relationship between total phosphorus loading and trophic state in order to allow for the effects of differences in the flushing rates of lakes. In his revised model, phosphorus load was related to the ratio of mean depth to mean hydraulic retention time and loading rates corresponding to the three classical trophic conditions were empirically determined from data on numerous phosphorus limited water bodies in the northern hemisphere.

Comparison of the estimated mean phosphorus loading rate for the period 1963-73 of 0,31 g phosphorus $m^{-2}a^{-1}$ with Vollenweider's "safe" value based on data in Table 4 of 0,33 g $m^{-2}a^{-1}$ indicate that by this loading criterion the dam is approaching the mesotrophic condition. This is in agreement with the chlorophyll *a* concentrations recorded and with general observations and experience on the dam. The fact that the load rate increased to 0,62 g phosphorus $m^{-2}a^{-1}$ during 1973-74 did not alter the trophic situation since the associated increase in river flow caused a compensatory decrease in hydraulic retention time.

Although the Vollenweider model considers the influx of total phosphorus it must be remembered that the amount that is actually available for bio-synthesis may be considerably less, depending on the chemical nature of phosphorus compounds that together comprise the total and the distribution of these compounds when they are discharged into the receiving water body.

In a tentative classification of South African impoundments based on AGP measurements Toerien *et al* (1975) have suggested that impoundments with AGP values between 25 and 50 $mg \ell^{-1}$ indicate that enrichment may be taking place but has not yet reached a level where serious problems can be expected. Midmar dam, with an annual mean AGP of 24,8 $mg \ell^{-1}$ (Table 5) appears to be approaching this situation and this conclusion is in general accord with the assessment based on chlorophyll *a* and phosphorus loading.

As remarked earlier, only a small proportion (less than 2 per cent) of the phosphorus entering the catchment from all sources during 1973-74 was exported via river flow. This is not surprising since more than half the catchment area consists of highly leached soils with high aluminium and iron content and a large capacity for phosphorus fixation (Scotney, 1970). Although there was some evidence of a small increase in nitrogen export from the partly agricultural Lions and Umgeni river catchments, compared with the undeveloped area drained by the stream at station 8, the rate was low, judging from the losses recorded for a variety of crop lands in the USA (Uttormark *et al*, 1974).

The results obtained for atmospheric nutrient deposition are of interest as similar measurements do not appear to have been recorded previously in southern Africa. The greater deposition rate during the summer rainfall period was anticipated but the magnitude of the continued deposition in this rural area during the dry season was unexpected. However, several authors have commented on the importance of dry fallout in the total atmospheric contribution. Matheson (1951) concluded that dry fallout comprises 40% of the total nitrogen contribution from the atmosphere in Canada, while Junge (1958) estimated that in arid climates 70% of the nitrogen contribution results from dry fallout. In Madison, Wisconsin, Kleusener (1972) concluded that the nitrogen contribution from dry fallout is twice that from precipitation and the phosphorus contribution is up to three times that derived from rainfall.

Uttormark *et al* (1974) have summarized the published data for atmospheric nutrient contributions. In relatively few instances has the total or "bulk" precipitation been recorded but nitrogen values have been reported ranging from 6,5 kg $ha^{-1}a^{-1}$ in Ontario, Canada, Matheson (1951) up to 30,1 kg $ha^{-1}a^{-1}$ in rural west central Wisconsin, Hoeft (1971). Equivalent data for phosphorus appear to be limited to a value of 1,02 kg $ha^{-1}a^{-1}$ for Madison, obtained by Kleusener (1972) and 0,40 and 0,27 kg $ha^{-1}a^{-1}$ based on data for 4 winter months in Ontario, Canada (Armstrong and Schindler, 1971, Barica and Armstrong, 1971). The total or "bulk" precipitation values of 9,85 kg nitrogen and 0,348 kg phosphorus $ha^{-1}a^{-1}$ recorded for the Midmar catchment area for 1975-76 thus lie in the lower part of the reported range.

Some indication of the origin of these atmospheric nutrients can be inferred from the fact that measurements in undeveloped areas up to 300 km distant from Midmar showed similar rates of deposition over the same collection period, but rates obtained in an industrial area were substantially greater. This similarity suggests that the particulate material responsible for nutrient deposition in undeveloped regions is distributed in the atmosphere over large areas. Particles with long atmospheric residence times have diameters of less than 10 μm and can be of local or very distant origin. Particles containing phosphorus have been shown to have mean diameters of a few micrometres (Lee and Patterson, 1969; Cunningham *et al,* 1974) and such particles are primarily removed by precipitation scavenging (Murphy, 1974). This would account for the higher rate of nutrient deposition observed during the summer rainfall period.

The quantity of small-diameter particulates present in the atmosphere over a region will presumably depend on climatic factors operating in both local and distant areas. Since such factors vary from year to year it would be incorrect to assume that the annual deposition recorded in 1975-76 is the same every year. However, the 1975-76 input of 9,85 kg nitrogen $ha^{-1}a^{-1}$ is of interest in that it demonstrates that the permissible nitrogen loading rate of 1,0 g nitrogen $m^{-2}a^{-1}$ (10 kg nitrogen $ha^{-1}a^{-1}$) for lakes with mean depths of less than 5 m recommended by Vollenweider (1968) may be reached through atmospheric deposition alone.

Despite the fact that for most of the year the phosphorus concentration in water entering the dam remained at a relatively constant low level, equivalent to that of water draining from undeveloped veld, it appears that the phosphorus input from all sources was sufficient to maintain the dam in a state approaching mesotrophy. Since this condition was maintained without the addition of sewage or industrial discharges there is an evident need to control development in the catchment that is likely to result in a significant increase in phosphorus influx to the dam.

It is probable that a moderate increase could be accepted without consequent excessive algal growth and water quality deterioration. At the present mean hydraulic residence time of approximately 1 year, a loading rate of about 0,5 $gm^{-2}a^{-1}$ total phosphorus could be accepted without exceeding the critical value predicted by the Vollenweider model. If the present mean rate is 0,31 $gm^{-2}a^{-1}$, an increase of about 3 000 kg total phosphorus could probably be tolerated. This estimate does not take into account the possible effects of the irregular shape of the dam. In practice it seems likely that localized algal blooms would develop in the areas where increased nutrient input occurred before the estimated critical load was reached.

Per capita contributions of phosphorus from communities are generally in the range 0,39 to 2,3 g phosphorus d^{-1} depending on various factors. At the lower value the effluent from a population of 21 000 would contain sufficient phosphorus to raise the load on the dam to Vollenweider's critical level if only conventional treatment was provided. At the higher value a community of 3 600 would achieve the same result.

Development of at least one population centre in the Midmar catchment is currently taking place and further centres and some industrial development in the Umgeni catchment as a whole is inevitable. If this essential water resource is to be protected there is clearly a need to ensure that measures to maintain phosphorus releases within acceptable limits are considered at an early stage.

Conclusions

(1) In the one year period March 1973 to February 1974 the nutrient content of rivers entering the Midmar dam was equivalent to a loading rate of 0,62 g total phosphorus and 8,49 g total soluble nitrogen $m^{-2}a^{-1}$. The mean annual phosphorus load is probably approximately half this value.

(2) During 1973-74 algal growth in the dam water was limited at all seasons by the amount of phosphorus available.

(3) The vegetation and soils of the catchment retain a very high proportion of nutrients reaching the land surface.

(4) According to the modified Vollenweider (1972) eutrophication model, the guidelines proposed by the U.S. National Eutrophication Survey and a tentative classification developed by Toerien *et al* (1975), the Midmar dam is in an oligotrophic-mesotrophic condition.

(5) At the present mean hydraulic residence time of one year an increase in total phosphorus input to 0,5 $gm^{-2}a^{-1}$ could probably be tolerated without development of problems due to algal blooms. Discharge of conventional secondary sewage effluent into the dam or its catchment from a population of more than 4 000 could exceed the critical phosphorus load indicated by the Vollenweider (1972) model.

(6) During the period November 1975 to November 1976 atmospheric deposition of nutrients in rainfall and dry fallout amounted to 9,85 kg total nitrogen and 0,348 kg total phosphorus $ha^{-1}a^{-1}$. It is probable that the atmosphere provides a small but significant contribution to the annual nutrient input to the dam.

(7) Since some urban and industrial development in the catchment appears inevitable there is an obvious need to ensure that measures to maintain phosphorus influx within acceptable limits are considered at an early stage if the present high quality of this water source is to be maintained.

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