Pre-impoundment as a eutrophication management option: a simulation study at Hartbeespoort Dam

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Abstract

This study simulates the role of small pre-impoundments in reducing phosphorus loading to a hypertrophic water body, Hartbeespoort Dam. The simulations were undertaken using three models which employed different methods of estimating in-lake phosphorus losses. Under the existing phosphorus loading regime on Hartbeespoort Dam, all of the models predict substantial load reduction (24-55%) in a pre-impoundment of 12,8 million m^3. However, depending on a projected doubling of river flow as a result of further sewage augmentation in the drainage basin, and on a reduction in phosphorus concentrations in the river water due to the implementation of the 1 mg ℓ^{-1} effluent phosphate standard, the retention efficiency of a pre-impoundment up to 30 million m^3 in volume could be negligible by the year 2000. The applicability of pre-impoundments as supplementary eutrophication management options at more suitable sites is discussed.

Introduction

Increased phosphorus inputs have been shown to be a major cause of eutrophication in fresh waters (Mackenthun, 1973) and most successful management strategies have been aimed at reducing phosphorus loading by point-source nutrient removal or effluent diversion (Welch, 1984). These methods are costly and, in drainage basins characterised by high levels of diffuse source pollution or containing large numbers of point sources at which limited nutrient reduction is possible, are not suited to achieving the desired level of load reduction. When diffuse sources provide a substantial proportion of the load, options for nutrient load reduction are limited. Phosphate elimination plants on polluted tributaries can be used to reduce diffuse loading on important water bodies (Bernhardt and Schnell, 1982) but, because of the large volume of water that has to be treated, this is an extremely costly option and probably not feasible in most instances. Other options include appropriate control of land use practices in drainage basins (e.g. Logan, 1982) and the optimization of the natural ability of drainage basins to retain phosphorus by appropriate catchment management strategies (e.g. Stepanek, 1980).

Aquatic and wetland ecosystems have the ability to remove some soluble and particulate components from through flowing water and can thus act as effective traps for silt and some soluble nutrients (Toerien and Walmsley, 1979; Reckhow and Chapra, 1983; Nichols, 1983; State Pollution Control Commission, 1983; Twinch, 1984), particularly in disturbed or polluted drainage basins, resulting in improved downstream water quality. Phosphorus does not behave conservatively in drainage basins and its transport in surface waters has been shown to be subject to biotic and abiotic influences (Logan, 1982). Generally aquatic and wetland ecosystems retain a high proportion of the incoming phosphorus (Toerien and Walmsley, 1979; Stepanek, 1980; Hill, 1982; Reddy, 1983; Nichols, 1983). The 'self-purification' ability of these systems can be optimised by management strategies such as conservation or construction of wetlands (marshes and vleis) and construction of pre-impoundments in drainage basins. Phosphorus load reductions of up to 97%, resulting from small reservoirs constructed upstream of important water supply lakes and impoundments, have been reported (Nichols, 1983; Stepanek, 1980; Benndorf *et al.*, 1981; Fiala and Vasata, 1982; OECD, 1982).

This paper describes the use of simple simulation models to assess the potential role of various sized pre-impoundments, upstream of an important water supply reservoir, in reducing phosphorus loading from a highly polluted drainage basin. It also considers the implication of projected hydrological changes in the drainage basin in the use of pre-impoundment as a supplementary eutrophication management option.

The study area

Hartbeespoort Dam (Fig. 1) is a hypertrophic reservoir receiving most of its water from a heavily developed urban/industrial/agricultural drainage basin in the greater Johannesburg area. Phosphorus loading to the reservoir is extremely high (>15 g m^{-2} a^{-1}) and the water body is hypertrophic (Scott *et al.*, 1980, Robarts *et al.*, 1983). The phosphorus load to the water body is carried almost exclusively by the Crocodile River and is predominantly ($>80\%$) in the form of soluble reactive phosphorus (SRP), which is used as an index of soluble phosphate.

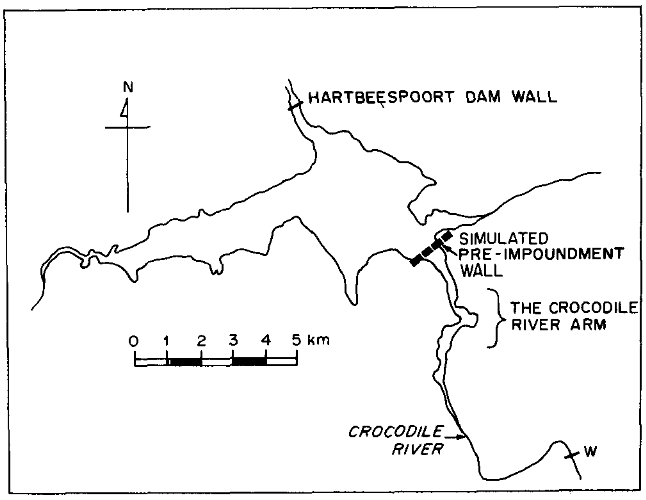

Figure 1
Hartbeespoort Dam showing the simulation site in the Crocodile River Arm and the gauging weir at which phosphate loads were calculated (W).

The Crocodile River flows into an elongated 'river-like' arm of the reservoir (Fig. 1) and the inflowing water passes along this 7 km stretch before entering the main basin of Hartbeespoort

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Dam. By virtue of its morphometric characteristics, the Crocodile River Arm (CRA) of the reservoir provides a suitable site at which to assess the impact of various pre-impoundments on phosphorus loads entering the main basin of Hartbeespoort Dam. To simulate pre-impoundment in the CRA, dam walls of varying height were assumed to be constructed at the junction of the CRA and the main basin of the reservoir (Fig. 1). An existing model (Twinch, 1984) was used to estimate volumes and surface areas of the hypothetical pre-impoundments based on existing morphometric features in the CRA. The feasibility of the chosen simulation site, from an engineering viewpoint, is not considered since the concepts being addressed would be equally applicable at alternative sites on the Crocodile River and the main objective of this simulation study is to demonstrate principles.

Five pre-impoundment sizes were used in the simulations. The smallest assumed a water level 5 m below that of the existing full supply level in the CRA and the largest a water level 5 m above the existing full supply level. Intermediate sizes of pre-impoundment were simulated by setting water levels at 2,5 m intervals between the upper and lower extremes.

Simulations of phosphate retention

The data used in simulating phosphorus retention in the pre-impoundments were drawn from the data base compiled during the first phase of the Hartbeespoort Dam Ecosystem Study (NIWR, 1985). For the period October 1980 to October 1983 mean monthly values for Crocodile River flow, total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations were calculated from daily values and monthly loads of both forms of phosphorus were calculated as the product of flow and concentration (Fig. 2).

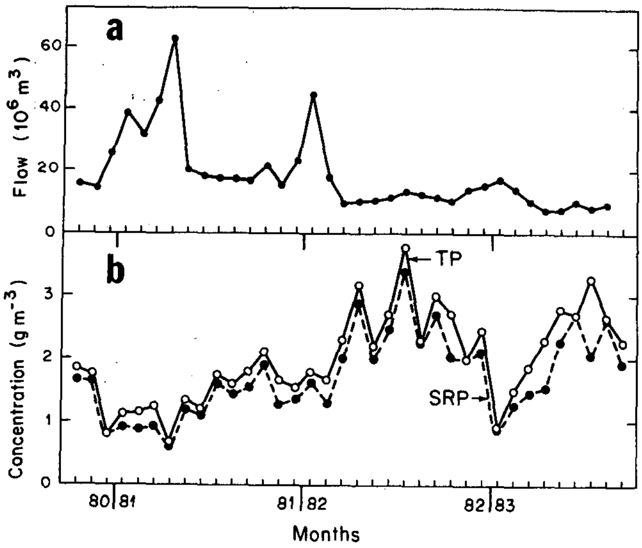

Figure 2
(a) Monthly flow in the Crocodile River. (b) Mean monthly total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations in the inflowing water.

Two approaches were used to estimate monthly phosphate retention in the simulated pre-impoundments. The first approach employed a simulation model (RIVMOD) which predicts phosphate losses due to direct uptake by bottom sediments. Details of this model are given by Twinch (1984). Essentially the model uses laboratory determined sediment/water phosphate exchange characteristics to quantify the loss of phosphate from overlying water at varying phosphate concentrations. Both the rate and direction of phosphate flux across the sediment/water interface in Hartbeespoort Dam and Crocodile River have been shown to be related to the phosphate concentration in the overlying water (Twinch and Ashton, 1984). These relationships provide the basis for RIVMOD and variable hydrological conditions in the river and water depths in the reservoir, which interact to determine water residence time in the pre-impoundments, are taken into account in the model.

The second approach was to estimate phosphorus retention with the OECD type phosphorus models (Vollenweider, 1976; Reckhow and Chapra, 1983) which simulate phosphorus concentrations in reservoirs as:

$$P = W/(Q + sV) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where:

P = mean phosphorus concentration in the reservoir (g m^{-3})
Q = inflow (10^6 m^3 per time)
s = sedimentation rate (per time)
V = volume of reservoir (10^6 m^3)
W = phosphorus load (kg per time)

The two phosphorus budget models used in this study were calibrated for South African reservoirs and differed only with respect to the sedimentation sub-model employed. The model FIXS (Grobler and Silberbauer, 1984) uses a constant sedimentation rate which was estimated to be 3,5 a^{-1} for Hartbeespoort Dam (Grobler, 1985). The model VARS (Grobler, 1985) uses a variable sedimentation rate which is proportional to the in-lake phosphorus concentration:

$$s = kP^2$$

where k is a parameter calibrated for Hartbeespoort Dam as $2,3 \times 10^{-5}$ (P is the phosphorus concentration in mg m^{-3}).

Assuming that inflow and outflow rates were equal, and water levels in the simulated pre-impoundments remained constant, the phosphorus load leaving the pre-impoundments was calculated as the product of predicted in-lake phosphorus concentration and flow rate. The proportion retained in the pre-impoundments was calculated as the difference between the phosphorus loads entering and leaving the pre-impoundments.

It must be stressed that the models used to predict phosphate retention in the simulated pre-impoundments have not been validated in lakes with low water residence times. In such lakes (including the simulated pre-impoundments) many of the assumptions of the models could be seriously violated, particularly under the typically variable hydrological conditions in South Africa, resulting in inaccurate predictions. In the absence of suitably validated models for use in systems such as the simulated pre-impoundments these three models were selected to provide rough estimates only. Further development and validation of the models are required before they can be generally applied to problems such as those outlined in this paper.

Results

Monthly water flow in the Crocodile River during the simulation period peaked at 62 million m^3 during March 1981 and, thereafter, with the exception of a single increase to 44 million m³ in January 1982, remained below 20 million m³ (Fig. 2). The total annual inflows into Hartbeespoort Dam, via the Crocodile River, during the three year study period were 234, 149 and 101 million m³ respectively. Based on a mean annual runoff (MAR) of 159,4 million m³ (Department of Water Affairs) in the Crocodile River drainage basin and sewage inputs of 63 million m³ a^{-1} (Grobler and Silberbauber, 1984), annual inflow to Hartbeespoort Dam during 1980/81 was 5% above average, while inflows during the subsequent two years were 33% and 55% below average reflecting the onset of a dry period. The mean monthly total phosphorus concentrations in the inflow varied from 3,3 to 0,7 g m^{-3}, of which more than 85% occurred as soluble reactive phosphorus (soluble phosphate) (Fig. 2). Monthly total phosphorus loads varied from 10 to 56 t, and soluble phosphate loads from 10 to 43 t. These variations were due to the combined effects of fluctuating flow and phosphorus concentrations in the Crocodile River (Fig. 2).

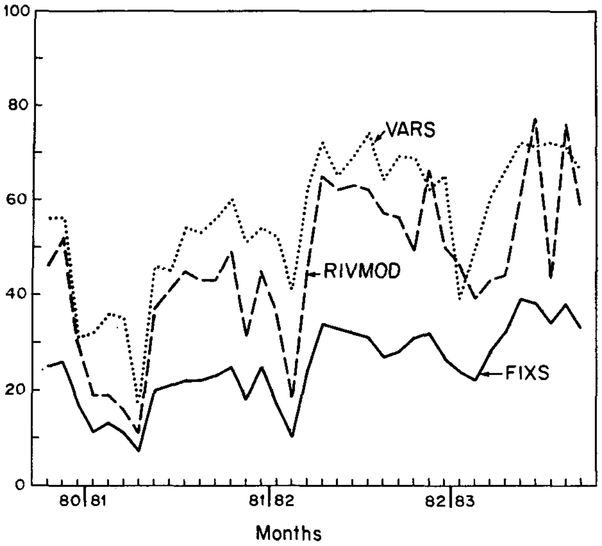

Figure 3
Monthly phosphorus retention efficiency in a pre-impoundment of 12,8 million m³ estimated using FIXS (——), VARS (.....) and RIVMOD (– – –).

Morphometric details of the pre-impoundments used in the simulations are given in Table 1. Volumes ranged from 0,9 to 12,8 million m³, surface areas from 36 to 220 ha and mean depths from 2,4 to 5,8 m. The largest pre-impoundment simulated represented 6,6%, 10,8% and 60% of the volume, surface area and mean depth of Hartbeespoort Dam at full supply level.

Some of the predicted monthly phosphorus retention efficiencies are shown in Fig. 3, using the largest pre-impoundment as an example. The model employing a fixed sedimentation rate (FIXS) predicted the lowest retention, while the two concentration dependent models (RIVMOD and VARS) predicted far higher phosphorus retention. Generally RIVMOD gave lower predictions than VARS, and, as shown in Table 2, this discrepancy became larger in the smaller pre-impoundments. The lower retention predicted using RIVMOD can be partially attributed to the fact that this model only predicts losses of soluble phosphate while VARS predicts losses of total phosphorus. Thus the differences between predictions using RIVMOD and VARS were

TABLE 1
MORPHOMETRIC FEATURES OF THE PRE-IMPOUNDMENTS USED IN THE SIMULATIONS DURING 1980/83. PERCENTAGES INDICATE THE RELATIVE SIZES OF THE PRE-IMPOUNDMENTS IN COMPARISON WITH HARTBEESPOORT DAM AT FULL SUPPLY LEVEL.

Volume $m^3 \times 10^6$	%	Area ha	%	$\bar{x}$ Depth m	%
0,9	0,5	36	1,8	2,4	2,5
2,1	1,1	66	3,2	3,1	32
4,4	2,3	117	5,6	3,8	40
7,9	4,1	169	8,3	4,7	49
12,8	6,6	220	10,8	5,8	60

TABLE 2
THE PHOSPHORUS RETENTION EFFICIENCIES IN PRE-IMPOUNDMENTS OF VARYING VOLUME PREDICTED USING FIXS, RIVMOD AND VARS DURING THE THREE HYDROLOGICAL YEARS BETWEEN 1980 AND 1983. ANNUAL INFLOWS, AVERAGE WATER RETENTION TIMES (TW) AND PHOSPHORUS LOADS DURING THE RESPECTIVE YEARS ARE SHOWN

Volume 10^6 m^3	Year	Inflow 10^6 m^3	Tw days	P Load tonnes	FIXS %	RIVMOD %	VARS %
0,9	1	234	1,4	186	1	4	12
	2	149	2,2	329	2	7	28
	3	101	3,3	219	4	10	33
	$\bar{x}$	161	2,3	278	2	7	24
2,1	1	234	3,3	286	3	8	20
	2	149	5,2	329	5	14	38
	3	101	7,6	219	7	18	44
	$\bar{x}$	161	5,4	278	5	13	34
4,4	1	234	6,7	286	7	17	28
	2	149	10,8	329	10	27	47
	3	101	15,9	219	14	34	53
	$\bar{x}$	161	11,1	278	10	26	43
7,9	1	234	12,3	286	12	25	36
	2	149	19,4	329	6	38	54
	3	101	28,5	219	22	46	60
	$\bar{x}$	161	20,1	278	17	36	50
12,8	1	234	20,0	286	17	31	41
	2	149	31,4	329	24	46	59
	3	101	46,3	219	32	54	65
	$\bar{x}$	161	32,6	278	24	44	55

greatest at times when the particulate fraction of the phosphorus load is highest (Figs. 2 and 3).

The phosphorus retention data (such as that for a single pre-impoundment size shown in Fig. 3) for all of the simulated pre-impoundments is summarised in Table 2. The predicted phosphorus retention efficiencies varied depending on the model used, the annual hydrological conditions and the volume of the simulated pre-impoundment. Predicted mean annual retention efficiencies were always lowest using FIXS, highest using VARS and intermediate using RIVMOD, however, all models showed the same general trends. The range of mean annual predicted phosphorus retention efficiencies increased progressively from 2-24% in the smallest pre-impoundment to 24-55% in the 12,8 million m³ pre-impoundment, coinciding with an increase in mean water residence time from 2,3 to 32,5 days (Table 2). The importance of water residence time in phosphorus retention efficiency in the pre-impoundments is also evident in the progressive increase in retention efficiency, in all simulated pre-impoundments, during the three years of the study when annual inflows decreased from 234 million m³ in 1980/81 to 101 million m³ in 1982/83.

Based on these simulations it is concluded that phosphorus loads on Hartbeespoort Dam during the period 1980/83 could have been reduced by between 24% and 55% (depending on the model used to estimate phosphorus losses) in a pre-impoundment of 12,8 million m³. Such phosphorus load reduction potential represents a useful supplementary eutrophication control option. However, projected alterations to the phosphorus loading patterns in this drainage basin will influence the phosphorus retention efficiency of pre-impoundments, and these changes must be considered in making future predictions regarding the use of pre-impoundments in eutrophication management.

With the exception of FIXS, which assumes a constant sedimentation rate, the sedimentation losses in the models used in these simulations are dependent on in-lake phosphorus concentrations (which are a function of inflow concentration) and on water residence time in the pre-impoundments. The interacting influence of these two factors on phosphorus retention efficiency, is shown in Fig. 4. Similar patterns resulted when RIVMOD was used to predict retention efficiency, but since this model ignores the particulate phosphorus fraction, which may become increasingly more important as soluble loads are reduced in future, VARS is regarded as more appropriate for future predictions. Fig. 4 shows that maximum phosphorus retention occurs at the highest inflow phosphorus concentrations and longest water residence times, and that retention efficiency is most susceptible to rapid change at residence times of less than 10 days.

Projected changes in the Hartbeespoort Dam drainage basin include a reduction in phosphate concentrations in treated sewage effluents and increased sewage volumes, both of which, on the basis of Fig. 4, would tend to reduce retention efficiency. The influence of these changes was simulated on the phosphorus retention efficiency in a pre-impoundment with a water residence time of 30 days, and on phosphorus concentrations in Hartbeespoort Dam with and without pre-impoundment, using the models FIXS and VARS. These two models were selected because they consistently gave the lowest and highest predictions of phosphorus retention in the simulations shown in Table 2.

To comply with the 1 g m^{-3} (1 mg ℓ^{-1}) phosphate standard for 95% of the time the phosphorus concentration in effluents will have to be reduced to about 0,5 g m^{-3} (Water Research Commission, 1984). Further losses of phosphorus may occur in the river so that there is considerable uncertainty regarding the concentration that will enter Hartbeespoort Dam (or the simulated pre-impoundment). Effluent concentrations were selected varying from 100 to 1 000 mg m^{-3}, and the mean phosphorus concentration of the natural runoff was assumed to be 114 mg m^{-3} (derived from historical data for the Magalies River which drains a relatively unpolluted area of the drainage basin).

Based on an annual 6% increase in the volume of sewage entering the drainage basin (Grobler and Silberbauer, 1984) the volume of sewage entering the Hartbeespoort Dam will increase from 63,5 million m³ in 1980 to 204 million m³ in the year 2000, while the mean annual natural runoff will remain constant at 159 million m³, resulting in a total annual inflow to Hartbeespoort Dam of 363 million m³, by the year 2000 (more than double the mean inflow during 1980/83). At this flow a pre-impoundment of 30 million m³ is required to attain a water residence time of 30 days. Mixing of effluents with phosphorus concentrations ranging from 100 to 1 000 mg m^{-3}, with natural runoff with a fixed phosphorus concentration (114 mg m^{-3}) results in simulated phosphorus concentrations in the Crocodile River ranging from 117 to 626 mg m^{-3} (Fig. 5).

It is assumed that a phosphorus concentration of 130 mg m^{-3} must be attained in Hartbeespoort Dam if the frequency of occurrence of nuisance algal blooms is to be reduced to tolerable levels i.e. severe nuisance conditions for less than 20% of time (Grobler and Silberbauer, 1984). FIXS predicts that, even without a pre-impoundment, the 1 g m^{-3} effluent standard, if it achieves an effluent concentration of about 500 mg m^{-3}, will result in a reduction in phosphorus concentration in the dam to 110 mg m^{-3} (Fig. 5). A pre-impoundment could further reduce this to 96 mg m^{-3}, thereby reducing the frequency of nuisance algal blooms from 17% to 13% (calculated as in Grobler and Silberbauer, 1984). In this case the pre-impoundment could be regarded as an effective supplementary eutrophication management option.

In contrast, VARS predicts that, with or without a pre-impoundment, effluent phosphorus concentrations of below 250 mg m^{-3} will be required to achieve in-lake concentrations of 130 mg m^{-3}. At these low concentrations VARS predicts that the pre-impoundment would have a negligible effect i.e. reducing in-lake concentrations by 2%. Based on these predictions the construction of a pre-impoundment could not be justified under the hydrological conditions projected for the year 2000.

Discussion

The eutrophication problem in South Africa is being addressed by the authorities and the first major step in eutrophication control will be the introduction of a 1 g m^{-3} effluent phosphate standard in selected watersheds, including that of Hartbeespoort Dam, from August 1985 (Republic of South Africa, 1984). The impact of this legislation on a number of eutrophication related water quality parameters in Hartbeespoort Dam has been assessed (Grobler and Silberbauer, 1984; NIWR, 1985), but the possible use of pre-impoundment, as an alternative or supplementary eutrophication control option, has not been seriously considered thus far. This simulation study has shown that pre-impoundment should be given more general consideration as a eutrophication control measure since, in many instances where diffuse source loading dominates or where point source loading is excessive, there is considerable doubt concerning the efficacy of the 1 g m^{-3} effluent phosphate standard as the only management strategy (Grobler, 1985).

In all of the simulations undertaken during this study the responses varied considerably according to the model used. This

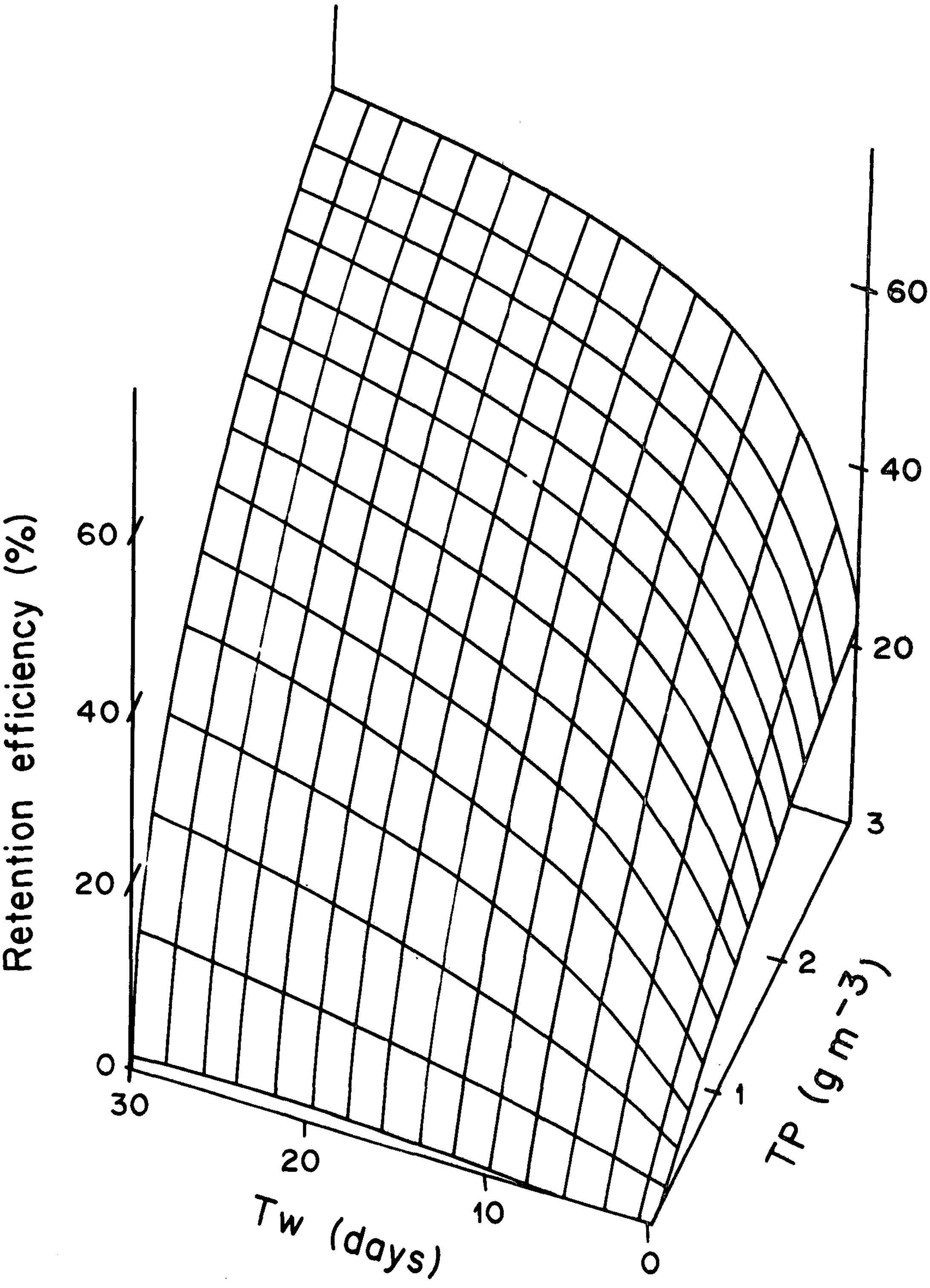

Figure 4
A three dimensional plot relating predicted phosphorus retention efficiency in pre-impoundments (using VARS) to water residence time and phosphorus concentration in the water.

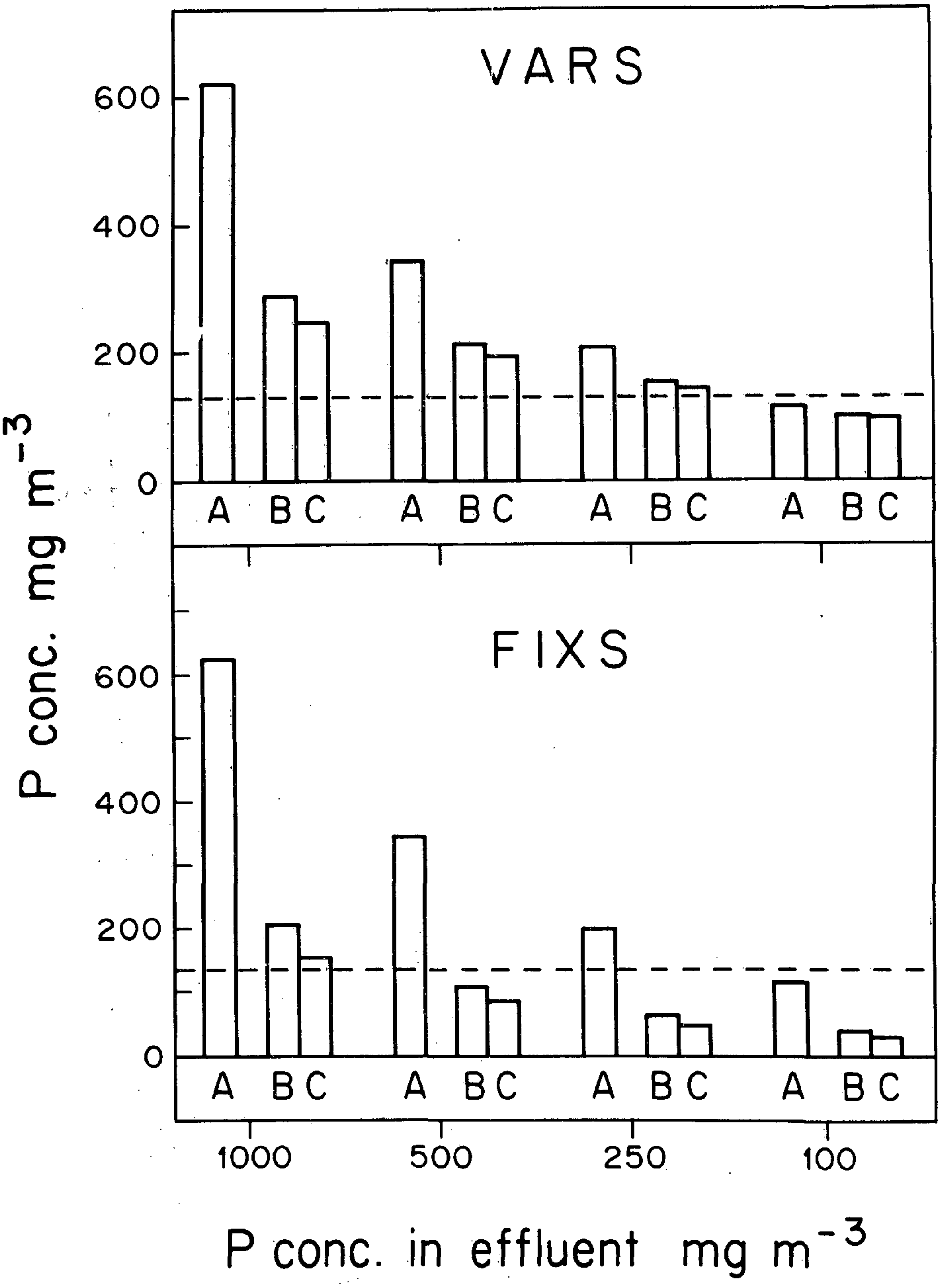

Figure 5

The predicted influence of a pre-impoundment, with a water residence time of 30 days (volume approximately 30 million m^3) on phosphorus concentrations in Hartbeespoort Dam under projected hydrological conditions in the year 2000. A range of effluent phosphorus concentrations is used to simulate various levels of phosphorus removal. Predictions were made with the models VARS and FIXS. Phosphorus concentrations shown for: (a) Inflow into pre-impoundment; (b) Hartbeespoort Dam with no pre-impoundment; (c) Hartbeespoort Dam with pre-impoundment. Broken lines indicate the in-lake phosphorus concentration above which severe water quality problems in the reservoir can be expected.

variation is largely attributable to differences in the method of calculating sedimentation losses. In the model FIXS sedimentation losses are independent of phosphorus concentration in the water and consequently, at a fixed water residence time, this model predicts a constant phosphorus retention efficiency despite wide variations in the phosphorus concentrations in the pre-impoundment. In contrast, the other two models used (VARS and RIVMOD) predict sedimentation losses on the basis of phosphorus concentration in the water, with maximum phosphorus retention at higher phosphorus concentrations and retention efficiencies approaching zero as the phosphorus concentration declines. There is accumulating evidence, based on process research (Canfield *et al.*, 1982; Twinch, 1984) and on modelling studies (Clasen, 1981; Frisk, 1981; Walker, 1982; Grobler, 1985), that phosphorus retention in reservoirs is more efficient at higher phosphorus concentrations. The authors therefore believe that responses predicted using the sedimentation losses dependent on concentration are more realistic. There is considerable uncertainty associated with predictions made in this study, but the need to make a preliminary assessment of pre-impoundment as potential eutrophication management tool necessitated the use of the best available models. There is an urgent need for more detailed mass balance studies in small impoundments with short residence times so that available load/response models for use in eutrophication management can be verified or modified as required.

Under the existing loading regime on Hartbeespoort Dam the simulations suggest that pre-impoundment could be an effective means of reducing phosphorus inputs. A pre-impoundment of 12,8 million m^3 could have retained between 24% and 55% of the phosphorus load during 1980/83. By increasing the pre-impoundment volume these efficiencies could be increased further and retention efficiencies of above 60% appear to be quite feasible. The findings of the simulations on 1980/83 data support observations elsewhere that pre-impoundments, or 'cascade reservoirs', can play a useful role in eutrophication management by improving down-stream water quality. (Wrobel and Bombona, 1976; Stepanek, 1980; Fiala and Vasata, 1982).

The projected changes in the phosphorus loading patterns in the Hartbeespoort Dam drainage basin have an important bearing on the long-term use of pre-impoundment as a eutrophication control strategy. Due to increased sewage inputs and to decreased phosphorus concentrations resulting from the implementation of the $1\ g\ m^{-3}$ effluent phosphate standard, by the year 2000 inflow into Hartbeespoort Dam will have nearly doubled while the phosphorus concentration in the inflow will have dropped by about 75% in comparison with the 1980/83 levels. Under these conditions FIXS predicts a consistent 23% retention in a pre-impoundment with a water retention time of 30 days, resulting in a significant improvement in Hartbeespoort Dam in comparison to conditions with no pre-impoundments. The authors regard the constant sedimentation losses in FIXS as inappropriate for such predictions and feel that the responses shown by VARS are more likely. These show that the pre-impoundment, at the site selected for the simulations, will have negligible influence on phosphorus loading under projected conditions in the year 2000. However, the projected changes in drainage basin depend on long-term water resource planning in the region. If, for example, indirect or direct reuse of treated sewage in the drainage basin were introduced, runoff may decrease and the implications of pre-impoundment for water quality management should be re-assessed.

This study has highlighted the fact that, under the appropriate circumstances, pre-impoundment can be highly effective in reducing phosphorus loads. Since phosphorus retention in pre-impoundments will be greatest when inflow phosphorus concentrations are highest and when water residence times are longest, a general principle when selecting sites for their construction should be to move as close as possible to the source of pollution. In the case of the Hartbeespoort Dam drainage basin, sites on any of the smaller tributaries closer to the sewage treatment plant would be more appropriate than the site adjoining Hartbeespoort Dam.

This assessment of the potential of pre-impoundment as a eutrophication management option has not considered many practical problems that are likely to arise. Rapid siltation of small impoundments is a common problem in South Africa and the resultant loss in storage volume, and decrease in water residence time, could be important factors to consider in relation to the contruction of pre-impoundments for eutrophication control. Siltation would progressively decrease the efficiency of phosphorus retention in pre-impoundments and careful assessments of this aspect would be necessary before embarking on a programme of pre-impoundment construction. In many watersheds in South Africa the short life expectancy of small pre-impoundments due to siltation may render them economically not feasible, although small scale dredging operations may solve this problem. Furthermore, accumulated silt, together with its associated phosphorus, could be transported out of pre-impoundments into downstream waterbodies during severe floods. Some of the silt associated phosphorus is bioavailable (Grobler and Davies, 1981) and could contribute to eutrophication problems in the receiving waters. To what extent this sporadic increase in phosphorus load from pre-impoundments would counteract their general ability to reduce phosphorus loading is not clear.

Since pre-impoundments will require reasonably constant water levels to function as reliable nutrient traps, they will provide suitable sites for activities such as fish production and other aquacultural practices, and recreational angling and boating. However, since efficient phosphorus retention in pre-impoundments is partially due to uptake by algae (Fiala and Vasata, 1982; OECD, 1982), they can be expected to exhibit severe symptoms of eutrophication, with the attendant aesthetic problems.

This paper is not intended to fulfil the role of a comprehensive feasibility study. It simply sets out to make a preliminary assessment of the potential use of pre-impoundments in eutrophication management in the Hartbeespoort Dam catchment area, and other catchment areas, and to stress the need for combined management strategies in heavily polluted drainage basins, or drainage basins dominated by diffuse source loads, where point source nutrient removal alone may be inappropriate. This study has highlighted two important areas for future research, the validation of existing load/response models for use in systems with short residence times and the validation of the concentration dependency of sedimentation losses in impoundments.

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