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IMPACT OF EUTROPHICATION CONTROL MEASURES ON THE TROPHIC STATUS OF SOUTH AFRICAN IMPOUNDMENTS

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IMPACT OF EUTROPHICATION CONTROL MEASURES ON THE TROPHIC STATUS OF SOUTH AFRICAN IMPOUNDMENTS

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PREFACE

The decision to introduce a phosphate standard in sensitive catchments was based on the best available technology for phosphate removal and without an extensive quantitative evaluation of the impact such a standard may have on the trophic status of impoundments. The authorities involved requested that an evaluation of the impact of phosphate control measures should be made using existing modelling tools and data. The Water Research Commission funded a joint research project by the Institute of Environmental Sciences of the University of the Orange Free State and the Hydrological Research Institute of the Department of Environment Affairs to evaluate the impact of phosphate control measures on the trophic status of impoundments in sensitive catchments. The research project was started in January 1983 and completed in June 1984. This document presents the results of the project. It should be seen as an initial attempt to evaluate the impact of phosphate control measures. Such an evaluation was only possible by making many assumptions and sometimes extending data beyond the limits determined by cautious scientific practice. We therefore advise the potential user to carefully examine our assumptions before using our results and conclusions as a basis for decision making on any particular catchment-impoundment systems.

ABSTRACT

Eutrophication causes serious water quality problems in some South African impoundments, and the first step taken to control it was the promulgation of a 1 mg P/l standard to be implemented in so called sensitive catchments. It was necessary to evaluate the impact of that standard and other phosphate control measures, e.g. the restriction of the phosphate content of detergents, on the trophic status of impoundments.

The OECD eutrophication modelling approach, consisting of nutrient export, nutrient budget and chlorophyll-phosphate regression models was used to predict the response of nineteen impoundments to nutrient loads. We predicted the trophic response of impoundments as the % time severe nuisance conditions can be expected as a consequence of assuming various eutrophication control strategies being implemented. Severe nuisance conditions were assumed to occur if chlorophyll concentrations exceeded 30 mg/m^3. Our conclusions depended on this somewhat arbitrarily selected trophic status indicator variable and users of this report must realize that if other trophic status indicator variables or a lower chlorophyll concentrations were selected different conclusions about the response of impoundments to phosphate control measures may have been reached.

Up to the year 2000 the trophic status of the Vaal, Midmar, Albert Falls, Bronkhorst Spruit and Loskop Dams was predicted not to have reached a state that would require a phosphate standard to be introduced in their catchments. Control measures might be required in the catchments of Roodekopjes, Koppies, Bloemhof, Bridle Drift and Misverstand Dams. The phosphate standard to be implemented in August 1985, was predicted to have only a marginal impact on Roodekopjes and Bridle Drift and none on Koppies, Bloemhof and Misverstand Dams. Highly eutrophic conditions were predicted in Rietvlei, Hartbeespoort, Bon Accord, Roodeplaat, Klipvoor, Vaal Barrage, Laing, Shongweni and Inanda Dams such that control measures would have to be introduced in their catchments. Most of these impoundments were predicted to show a marked response to the phosphate standard. The exceptions are Vaal Barrage and Bon Accord Dam, which will receive such

large phosphate loads that more stringent phosphate standards would be required, and Laing Dam which receives a non-point source load so large that its response to the standard, which only controls point sources, would be marginal. Banning phosphate based detergents, as the only alternative to introducing a phosphate standard, is predicted to be unlikely to succeed in controlling eutrophication of impoundments. Nevertheless control of detergent phosphate load in the water environment may play a supporting role in a strategy to reduce phosphate at source.

Phosphate, rather than nitrogen, is predicted to limit the trophic response of impoundments after the introduction of the phosphate standard; consequently the future response of impoundments was predicted to be consistent with the OECD chlorophyll-phosphate relationship.

Runoff affects the hydraulic loads and non-point source phosphate loads on impoundments, as well as the average impoundment volumes. The large variation in annual runoff from South African catchments affects the result of phosphate control measures on the trophic response of impoundments. The OECD modelling approach assumes steady state; consequently the highly variable nature of South African hydrology is not explicitly accounted for in our predictions. We assumed annual runoff to be equal to the long term mean annual runoff for each catchment and a corresponding average impoundment volume of 80% of the full supply volume to simulate the response of impoundments. We regard the variable runoff in South Africa as the most important factor responsible for the lack of steady state in impoundment-catchments systems and recommend that procedures should be developed to take into account the effect of variable runoff in predictions of the trophic response of impoundments.

The most serious limitation on predicting the impact of eutrophication control measures on water quality is the lack of appropriate well-defined water quality variables which can be quantitatively related to eutrophication-associated water quality problems. Research to establish such relationships should receive a high priority.

The results reported and the conclusions reached in this report should be used with caution because we had to make many assumptions and had limited data for many of the systems. Decisions on eutrophication control in individual catchment-impoundment systems should only be made after careful scrutiny of our assumptions and after an effort has been made to obtain additional data on the system involved. Models should be developed to simulate the dynamic behaviour of impoundments for future assessments of the trophic response of impoundments to eutrophication control measures.

LIST OF ABBREVIATIONS

a	annum
A	area
C	concentration
[Chl]	chlorophyll concentration
L_p	surface loading rate - phosphate
L_n	surface loading rate - nitrogen
MAR	mean annual runoff
[N]	nitrogen concentration
P	mass of phosphate
[P]	phosphate concentration in impoundment
$[P]_i$	phosphate concentration in inflow to impoundment
P_{out}	mass of phosphate in outflow from impoundment
P_{sed}	mass of phosphate lost by means of sedimentation
Q	flow
q_s	surface loading rate - water
QVC	water quality variable of concern
s_p	sedimentation rate - phosphate
s_n	sedimentation rate - nitrogen
SNC	severe nuisance conditions
t	time
V	volume of impoundment
W	mass of substance in inflow

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Professor R.C. Hart of the Institute of Freshwater Studies at Rhodes University and Mr. C. Archibald of the National Institute of Water Research in Durban provided us with unpublished data. The Department of Environment Affairs through the Division of Water Pollution Control, Division of Hydrology and the Hydrological Research Institute provided the bulk of the chemical and flow data used in this report. The members of the Steering Committee for this project: Mr. E. Braune, Mr. H.J. Best, Mr. C.A. Bruwer, Mr. G.C.D. Claassens, Mrs M. Oliveira, Dr. R.D. Walmsley, Mr. P.W. Weideman and Dr. H.N.S. Wiechers provided us with guidance and general assistance in this project. We spent many hours discussing our research with Professor D.F. Toerien and acknowledge the major contributions he made.

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INTRODUCTION

The excessive enrichment of water bodies with plant nutrients, a process referred to as eutrophication, has developed rapidly in the past two decades as a serious water quality problem throughout the world (Jones and Lee, 1982a; Vollenweider, 1981). South Africa is no exception to this general pattern and eutrophication of major water storage systems is regarded as one of the most serious threats to water quality (Toerien et al., 1975; Toerien, 1977; Walmsley and Butty, 1980). The undesirable amounts of phytoplankton and/or macrophytes that occur as a consequence of eutrophication lead to many problems related to water quality e.g. increased water purification costs, interference with recreational uses of impoundments, loss of livestock and possible sublethal effects on humans using eutrophic water supplies for drinking water (Toerien, 1977; Suess and Dean, 1980; Suess, 1981; Vollenweider, 1981; Jones and Lee, 1982a).

Eutrophication should be controlled to protect the quality of South Africa's water resources. Toerien (1977) listed alternative strategies, in order of preference, that could be used to control the eutrophication of impoundments.

- Limit the fertility of the water
- Manage impoundments in such a way that eutrophication leads to valuable and harvestable crops.
- Biological control of unwanted organisms (e.g. introduction of diseases and parasites).
- Chemical control of undesirable organisms (e.g. by means of toxic chemicals and herbicides).

Limiting water fertility is generally regarded to be the most desirable strategy because it eliminates the cause of eutrophication (Toerien, 1977). However it is not always possible to limit nutrient supplies to impoundments sufficiently to achieve control (e.g. in cases of very large nutrient loads on impoundments) and additional control measures must then be considered (Benndorf et al., 1981). The first step to control eutrophication of South African impoundments was taken recently. Legislation which limits the phosphate concentration in treated domestic and industrial wastewater discharged in specified sensitive catchments to 1 mg/l dissolved ortho-phosphate expressed as P, will be in effect by August 1985 (Appendix A). Other ancillary eutrophication control measures are now being considered e.g. reducing the phosphate content of synthetic detergents and introducing stricter phosphate standards for effluents. The 1 mg P/l standard was selected after an assessment of the technical and economic feasibility of phosphate removal technology available at the time the standard was promulgated (Taylor et al., 1984). The standard was predicted to result in 80 to 90 percent reduction in the phosphate load from sewage works, which were estimated to contribute 60 to 80 percent of the total phosphate load. Considerable beneficial effects on the trophic status of impoundments in catchments where the standard is to be introduced were expected (Taylor et al., 1984).

The decision to introduce a universal standard of 1 mg P/l for all sensitive catchments was criticised on the grounds that: 1) The differences in phosphate-receiving capacity of impoundments were ignored (Pretorius, 1983; Toerien* - personal communication). 2) In some catchments the ratio between point and non-point source contributions to the total phosphate load is such that removal of phosphate contributed by point sources would have negligible effects on the trophic status of impoundments (Pretorius, 1983). In such catchments, uncertainty about the benefits that would result from introducing the standard and the high cost of compliance with it do not warrant its enforcement on small local authorities (Pretorius, 1983). Personnel of the Department of Environment Affairs, responsible for pollution control, indicated that some of these criticisms may be considered when the standard is implemented but that final decisions about the enforcement of the standard will be based on a quantitative assessment of the impact on the trophic status of impoundments (Claassens** - personal communication). To date no such estimates have been made.

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** G.C.D. Claassens, Managing Engineer, Water Quality, Department of Environment Affairs, Pretoria.

The need to assess the impact of phosphate limitation on the trophic status of South Africa's impoundments has been stated repeatedly. It was given high priority in the master plan for research on prevention and control of eutrophication considered by the Water Research Commission at its meeting in May 1981 and in a situation statement currently being prepared by Water Research Commission personnel on detergents and their impact on eutrophication. The need to evaluate the impact of the current effluent phosphate standard, as well as other means of limiting phosphate, on the water environment is recognized by personnel of the Department of Environment Affairs, who also indicated that the assessment of the impact of the standard is already receiving their attention but that the assessment could be accelerated by additional inputs from research organisations outside the Department. They requested that the Water Research Commission initiate such a study as soon as possible. The Water Research Commission then arranged a co-operative research project, which involved the Institute for Environmental Sciences of the University of the Orange Free State and the Hydrological Research Institute of the Department of Environment Affairs, to assess the impact of various phosphate control measures on the trophic status of South African impoundments.

The objectives of the research project were to provide preliminary estimates of the impact of different phosphate control measures on the trophic status of several impoundments and to point out the major deficiencies in the South African data base and in the models available for assessment of the trophic status of impoundments. In order to meet these objectives we addressed issues related to simulating water quality namely : 1) The selection of a modelling approach, 2) the selection of an appropriate water quality variable to be used for judging the effects of eutrophication control measures, and 3) the uncertainty associated with predictions.

This report deals first with the data base used for this study. Next the selection of a suitable water quality variable, criteria for judging the effects of eutrophication control measures on impoundment trophic status, and the modelling approach selected are discussed. This is followed by predictions of the effects of the eutrophication control strategies presently under consideration. Finally the conclusions are listed and research needs identified.

2. DATA BASE

The data base we used in this study consisted of river flow data provided by the Department of Environment Affairs, as well as phosphate, nitrogen and chlorophyll concentrations in rivers and impoundments provided by that Department and by various other research organisations and individuals.

The predicted impact of eutrophication control measures on the trophic status of impoundments was evaluated on 19 impoundments that were selected on the basis that sufficient data were available for the impoundment and its catchment and the impoundments were within the sensitive catchments. A list of the impoundments selected, showing the Department of Environment Affairs registered sampling stations, reservoir characteristics and main uses of the reservoirs, is provided in Table 1. The geographical locations of the impoundments are shown in Figure 1.

Table 1: List of impoundments showing registered sampling stations, and reservoir characteristics.

DAMS			REGISTERED SAMPLING STATIONS	FULL SUPPLY VOLUME (10^6 m^3)	MEAN ANNUAL INFLOW (10^6 m^3)	USAGE OF WATER
NUMBER	NAME	DE CODE				
1	Rietvlei	A2R04	A2M08 Elandsfontein A2R04A Dam Wall A2R04W	13	40	Potable Recreation
2	Hartbeespoort	A2R01	A2M12 Crocodile A2M13 Magalies A2R01C Canal A2R01W Wall A2R01X Canal	212	146	Irrigation Recreation Potable
3	Roodekopjes*		A2M19 Crocodile	52	120	Irrigation Potable
4	Bon Accord	A2R02	A2M07 Apies A2R0201 Dam	4	79	Irrigation Recreation
5	Roodeplaat	A2R09	A2M27 Pienaars A2M28 Hartbees A2M29 Edendale A2R09D Canal A2R09E Canal A2R09W Wall	42	34	Irrigation Recreation Potable
6	Klipvoor	A2R12	A2M21 Pienaars A2R1201 Dam A2R12W Wall	44	154	Irrigation
7	Vaal	C1R01	C1M11 Vaal C8M22 Wilge C8M01 Wilge C1R01W Wall	2330	2230	Potable Recreation
8	Vaal Barrage	C2R08	C2M04 Suikerbos C2M21 Klip River C2M03 Engelbrechtsdr C2R0801 Wall	57	2200	Potable Recreation
9	Koppies	C7R01		41	111	Irrigation Recreation
10	Bloemhof	C9R02	C2M22 Vaal C2M61 Vaal C4M04 Vet C4Q01 Vet C9R02W Wall	1270	2150	Irrigation Recreation
11	Laing	R2R01	R2M05 Buffalo R2M09 Ngqokweni R2M10 Buffalo R2R01A Dam	22	52	Potable Recreation
12	Bridle Drift	R2R03	R2R01A Laing Dam	75	144	Potable Recreation
13	Shongweni	U6R	U6M02 Mlazi	7	48	Potable
14	Midmar	U2R01	U2M07 Mpofana U2M13 Mgeni U2R01A Outflow U2R0101 Dam	177	137	Potable Recreation
15	Albert Falls	U2R03	U2M06 Karkloof U2M14 Mgeni U2M12 Sterk U2R03A Outflow	271	257	Potable Recreation
16	Inanda*		U2M15 Inanda	44**	394	Potable
17	Bronkhorstspruit	B2R01	B2R01A Wall	60	41	Potable Recreation
18	Loskop	B3R02	B1M02 Spookspruit B1M04 Klipspruit B3R02W Wall	363	464	Irrigation
19	Misverstand*		G1M13 Berg	200	527	

* Dams not completed
** FSV assumed during initial stages of operation

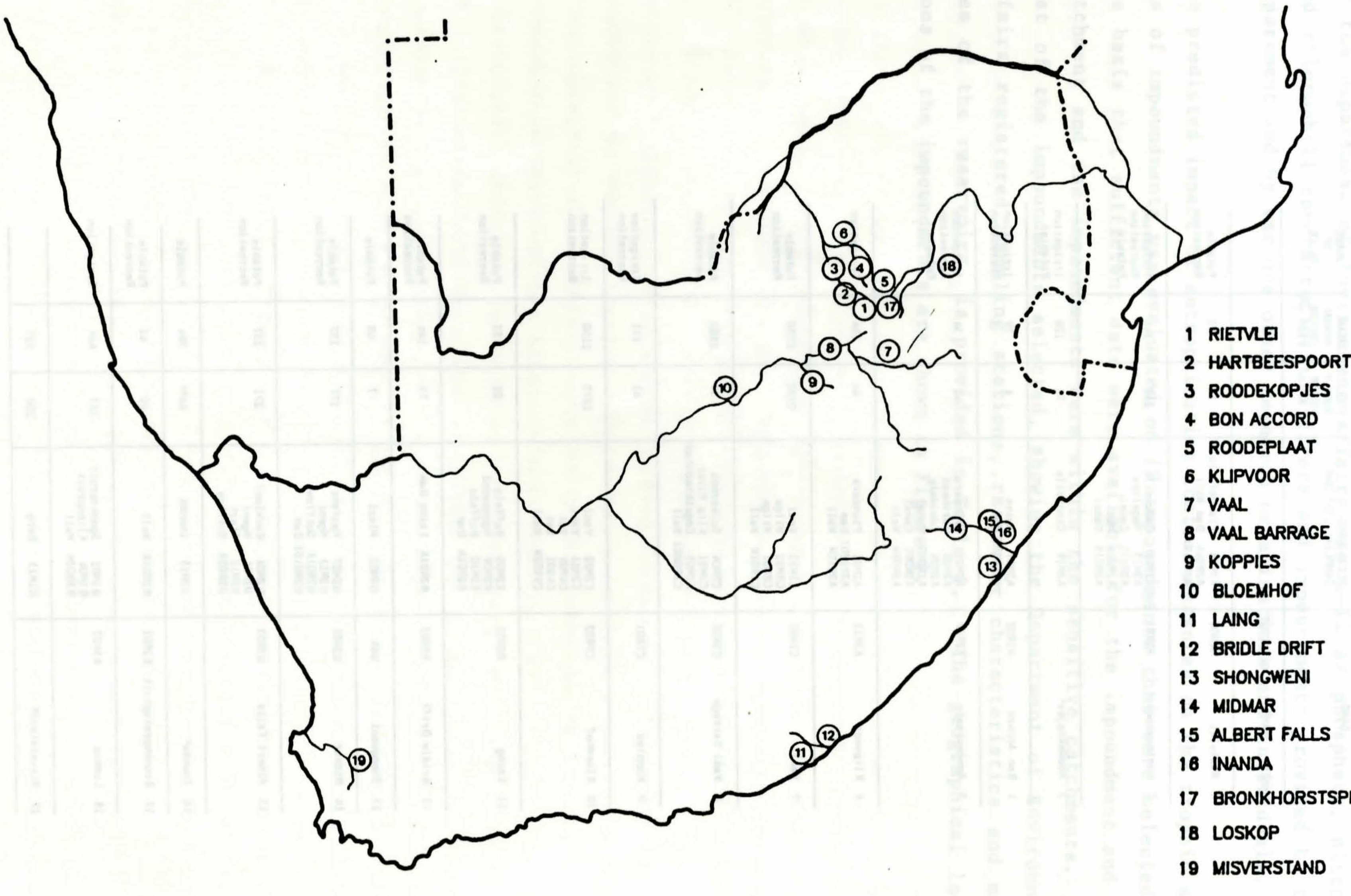

Figure 1: A map of South Africa showing the geographical location of impoundments studied

3. CRITERIA FOR EVALUATING THE CONSEQUENCES OF EUTROPHICATION CONTROL MEASURES

Three issues had to be addressed to allow a scientific evaluation of the consequences of eutrophication control measures on the trophic status of impoundments.

1. Appropriate water quality variables that relate eutrophication to water use problems had to be selected.

2. The magnitude of the differences in this variable necessary to produce perceptible effects had to be determined.

3. If water quality problems occur only when this variable exceeds or is below a certain value, such limits had to be established.

3.1 Appropriate Quality Variables

Reckhow and Chapra (1983) defined quality variables of concern (QVC's) as those variables that determine the usefulness of a water body for whatever purpose it is meant to be used. A QVC is therefore an appropriate variable to measure when considering the eutrophication response of a water body. Decision making involves the relationship between QVC's and alternative planning or management strategies. When projections of water quality are made to provide information for planning and management purposes the model output should ideally be the decision variable (or the QVC). When this is not the case the decision maker must make a mental extrapolation/interpolation (use a hidden or implied model) from the model output variable to the QVC. The model developer, who understands the assumptions and limitations of his model the best, is often in a better position to make this extrapolation explicitly by incorporating it in the mathematical model. A great advantage of making the modeller responsible for the entire modelling of the system from primary inputs to QVC is that it allows uncertainty analysis to be conducted (Reckhow and Chapra, 1983). The QVC must be clearly specified by the decision makers (Biswas, 1975; Reckhow and Chapra, 1983). In South Africa QVC's for planning or management of eutrophication-related water quality have not thus far been specified. We did not attempt to resolve this issue although we realise that as long as the choice of the best QVC's for planning and management of eutrophication-related water quality remains undecided, model development in this field is held back or could even develop in the wrong directions.

Ideally we should have started this study with a clearly defined QVC which could be used to evaluate the impact of different phosphate control strategies on the trophic status of impoundments. Because there was none we selected a chlorophyll-related variable as QVC. Most eutrophication-related water quality problems (and these potentially most serious e.g. blooms of toxic algae) result from the occurrence of undesirable quantities of phytoplankton in the water (Toerien, 1977; Jones and Lee, 1982a). We decided to base the QVC on chlorophyll-related variables because chlorophyll concentrations are the most commonly used measure of phytoplankton biomass. We could equally well have chosen total phosphate concentrations, rate of oxygen depletion in the hypolimnion, water clarity or fish yield as QVC's (e.g. see Jones and Lee, 1982a). However, total phosphate _per se_ does not adversely affect water quality, the usefulness in South African impoundments of the rate of oxygen depletion has been queried (Walmsley and Toerien, 1977) reduced water clarity in South African impoundments results from suspended clay and not eutrophication (Noble and Hemens, 1978; Walmsley and Bruwer, 1980) and quantified fish yields for South African impoundments are available in only a few cases. For these reasons, none of these characteristics were considered as suitable QVC's.

QVC's related to chlorophyll concentrations can be defined in many ways depending on the specific management and planning objectives. The most commonly used are 1) mean annual or mean summer chlorophyll concentration (Jones and Lee, 1982a; 1982b;), 2) maximum expected chlorophyll concentration (Jones _et al_., 1979; Walmsley and Butty, 1980; Walmsley, 1984; and 3) percentage of the year during which chlorophyll concentrations can be expected to exceed concentrations that are associated with severe nuisance conditions (Walmsley and Butty, 1980; Walmsley, 1984) (Figure 2).

An important difference between using the percentage time severe nuisance conditions (SNC) can be expected and mean or maximum chlorophyll concentrations as QVC is that the percentage time severe nuisance conditions can be expected reaches an upper limit (100%) at a mean annual phosphate concentration of about 800 mg/m^3. Both the maximum and mean chlorophyll

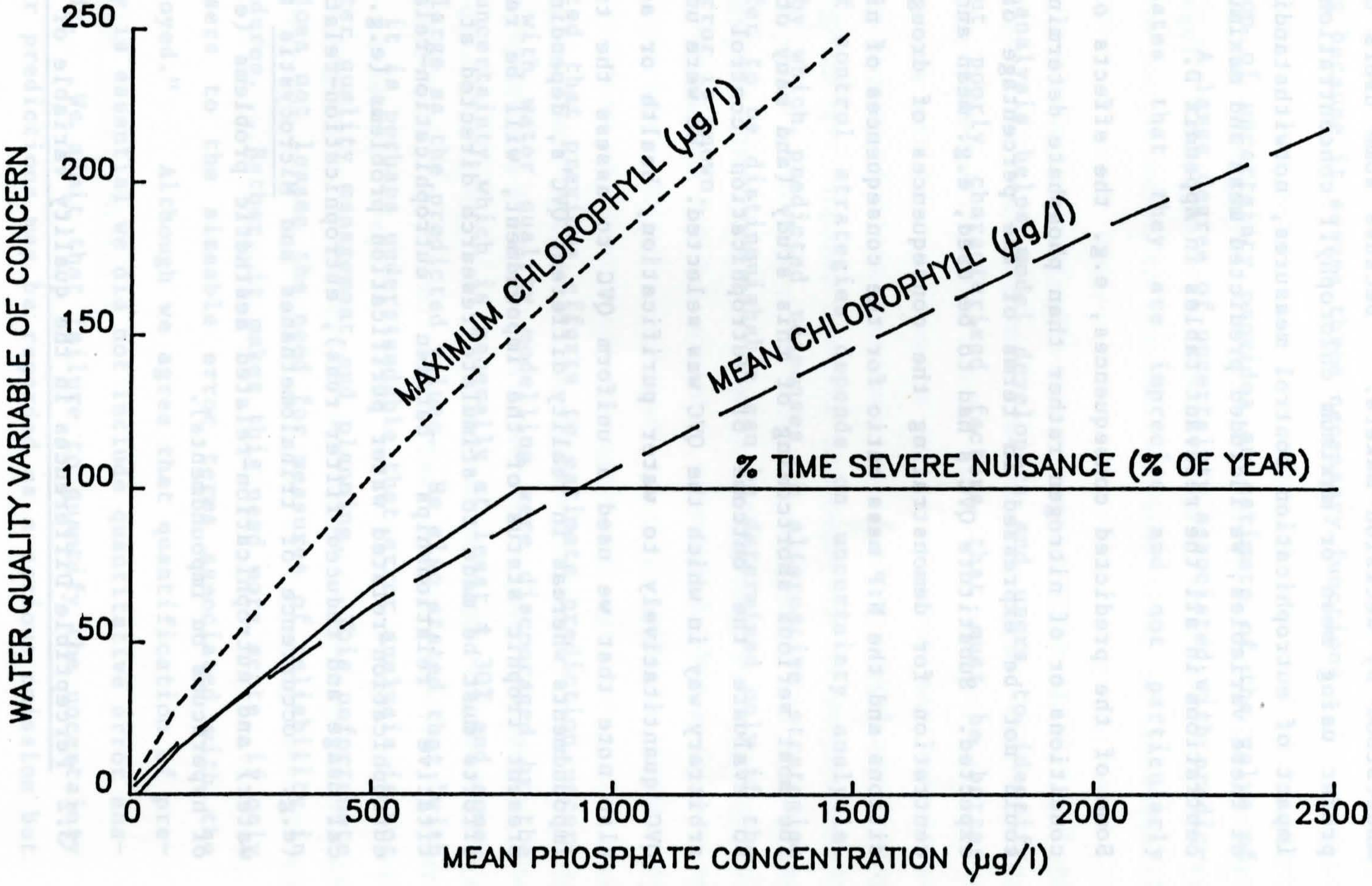

Figure 2: Plots of the response of percentage time severe nuisance conditions can be expected, mean annual chlorophyll concentration and maximum expected chlorophyll concentration (as water quality variables of concern) to changes in annual mean phosphate concentrations.

concentrations respond to changes over the entire range of mean annual phosphate concentrations (Figure 2). We selected the percentage time severe nuisance conditions can be expected because 1) It is the only QVC, to our knowledge, that relates chlorophyll concentrations to the occurrence of problem conditions (Walmsley and Butty, 1980) and 2) the concept is understood by decision makers. Because some users of this report may prefer using mean or maximum chlorophyll concentrations to evaluate the impact of eutrophication control measures, notwithstanding the limitations of these variables, we included predicted mean and maximum chlorophyll concentrations in all the relevant tables in Appendix D.

Some of the predicted consequences, e.g. the effects of drought or flood conditions or of nitrogen rather than phosphate determining trophic status could not be expressed in terms of the percentage of time SNC can be expected. Substitute QVC's had to be used, e.g. mean annual phosphate concentration for demonstrating the consequences of drought and flood conditions and the N:P mass ratio for the consequences of nitrogen limitation.

The most serious shortcoming of this study (and many others which attempt to evaluate the outcome of eutrophication control measures) is the arbitrary way in which the QVC was selected. We were unable to relate our QVC quantitatively to water purification, health or aesthetic problems. Also note that we used a uniform QVC to assess the trophic response of impoundments whereas in reality different QVC's, depending on water use and present trophic status of the impoundment, will be required. Renewed efforts must be made to stimulate research directed at establishing quantitative relationships between eutrophication-related QVC's and eutrophication-related water purification problems (e.g. increased chemical usage and reduced filter runs), eutrophication-related health problems (e.g. occurrence of trihalomethanes and Microcystis toxins in drinking water) and eutrophication-related aesthetic problems (e.g. the occurrence of hyperscums on impoundments).

3.2 Perceptible Differences in the quality variable of concern

Reckhow and Chapra (1983) defined uncertainty as "a state or condition of incomplete or unreliable knowledge". Uncertainty is always present in planning, environmental impact assessment and in projections of future conditions. The full consequences of uncertainty are not often appreciated in decision making, partly because of a reluctance on the part of modellers to admit that uncertainty is present in their work and partly because decision makers often do not know how to deal with uncertainty (Reckhow and Chapra, 1983). Reckhow (1983) stated that quantifying uncertainty (or its converse, reliability) of predictions is essential for the purpose of planning and decision making because it serves three necessary functions :

1. Quantification of uncertainty provides an estimate of the value of information. A large degree of uncertainty associated with predictions indicates that they are imprecise and not particularly valuable.

2. Uncertainty analysis helps model developers and users to identify important but poorly characterized factors that must be better defined.

3. Selection of control strategies depends on uncertainty analysis. The amount by which predicted responses to alternative strategies need to differ to be distinguishable can be determined only if the prediction error is known.

Reckhow (1983) noted that previous efforts to estimate prediction uncertainty associated with water quality modelling were discouraged by the magnitude of the uncertainty which is generally at least ± 30% and sometimes 10 times as large as the predicted values. He also stated that "with errors this large, it is perhaps understandable that error analysis is not widely used in water quality management and planning. This unfortunate state of affairs does not lessen the need for measures of reliability in our planning procedures. Rather, it makes this need more acute, if only to alert model users to the sizeable error terms associated with the methods being employed." Although we agree that quantification of prediction uncertainty is essential we did not include quantitative error analysis in this study. We admit that failure to quantify the uncertainty associated with our predictions may be regarded as a serious omission but the additional effort that would be required could not be justified considering the arbitrary manner in which our QVC was selected and that the uncertainty associated with most of the data we used was unknown.

In the absence of formal error analysis we assumed that the uncertainty associated with our QVC is such that predicted QVC's (% time SNC were expected) had to differ by at least 20 units to ensure a reasonable chance that the predicted change will be realised. The criteria we used to judge which predicted changes are likely to be perceptible were 1) changes amounting to less than 20 units in the value of QVC were regarded as imperceptible, 2) changes of 20 to 40 units were regarded as moderate differences and 3) changes greater than 40 units were regarded as large differences.

The lower limit of QVC, that would suggest that no eutrophication control measures need to be introduced, was also set in an arbitrary manner. Taking into account that many of our assumptions were conservative (they represented the worst case) we assumed that if the absence of phosphate control resulted in SNC being predicted for 20% or less of the year then eutrophication control measures are not needed. If no phosphate control resulted in SNC being expected for 20 to 40% of the time, then eutrophication control measures might be required and if SNC were predicted to occur for more than 40% of the time it warranted the introduction of eutrophication control measures.

Although Jones (personal communication) claimed that management decisions about eutrophication control is insensitive to uncertainty in predictions we are convinced that decision makers will require more sophisticated techniques which will demand that prediction uncertainty be quantified more objectively and formally. An error analysis procedure for the OECD eutrophication modelling approach as applied in South Africa should therefore be developed.

4. EUTROPHICATION MODELLING APPROACH

4.1 Introduction

The Organization for Economic Co-operation and Development (OECD) sponsored a study to quantify eutrophication-related water quality - nutrient loading relationships for water bodies. That research resulted in the development of the OECD eutrophication modelling approach (Jones and Lee 1982a; Reckhow and Chapra, 1983; Vollenweider, 1969; 1975; 1976; Vollenweider et al., 1980). The OECD modelling approach consists of the sequential application of 1) a phosphate export model to simulate nutrient loads on impoundments, 2) an impoundment nutrient budget model for simulating nutrient concentrations in impoundments and 3) a model which converts annual mean nutrient concentrations in impoundments to eutrophication-related water quality variables (Figure 3).

The OECD eutrophication modelling approach was selected to simulate the impact of eutrophication control measures on impoundment trophic status because : 1) it is in a water quality management context, the only proven and reliable approach to modelling eutrophication-related water quality (Jones and Lee, 1982a; Lee and Jones, 1982; Reckhow and Chapra, 1983), 2) the OECD modelling approach was developed using an extensive data base covering a wide variety of impoundments in many parts of the world (Jones and Lee, 1982a; Lee and Jones, 1982), and 3) the relative simplicity and limited data requirements of the OECD modelling approach enabled us to apply the model in the limited time and with the severely limited data base available for this study.

In the following sections the eutrophication control measures considered, the separate components of the OECD eutrophication modelling approach and the implementation of the eutrophication modelling approach are discussed.

4.2 Eutrophication Control Measures

We devised various scenarios combining possible hydrological regimes with the phosphate control options likely to be exercised during the two decades from 1981 to 2000. The steady-state assumption of the OECD nutrient budget model required that runoff and dam volumes be constant. We chose the mean

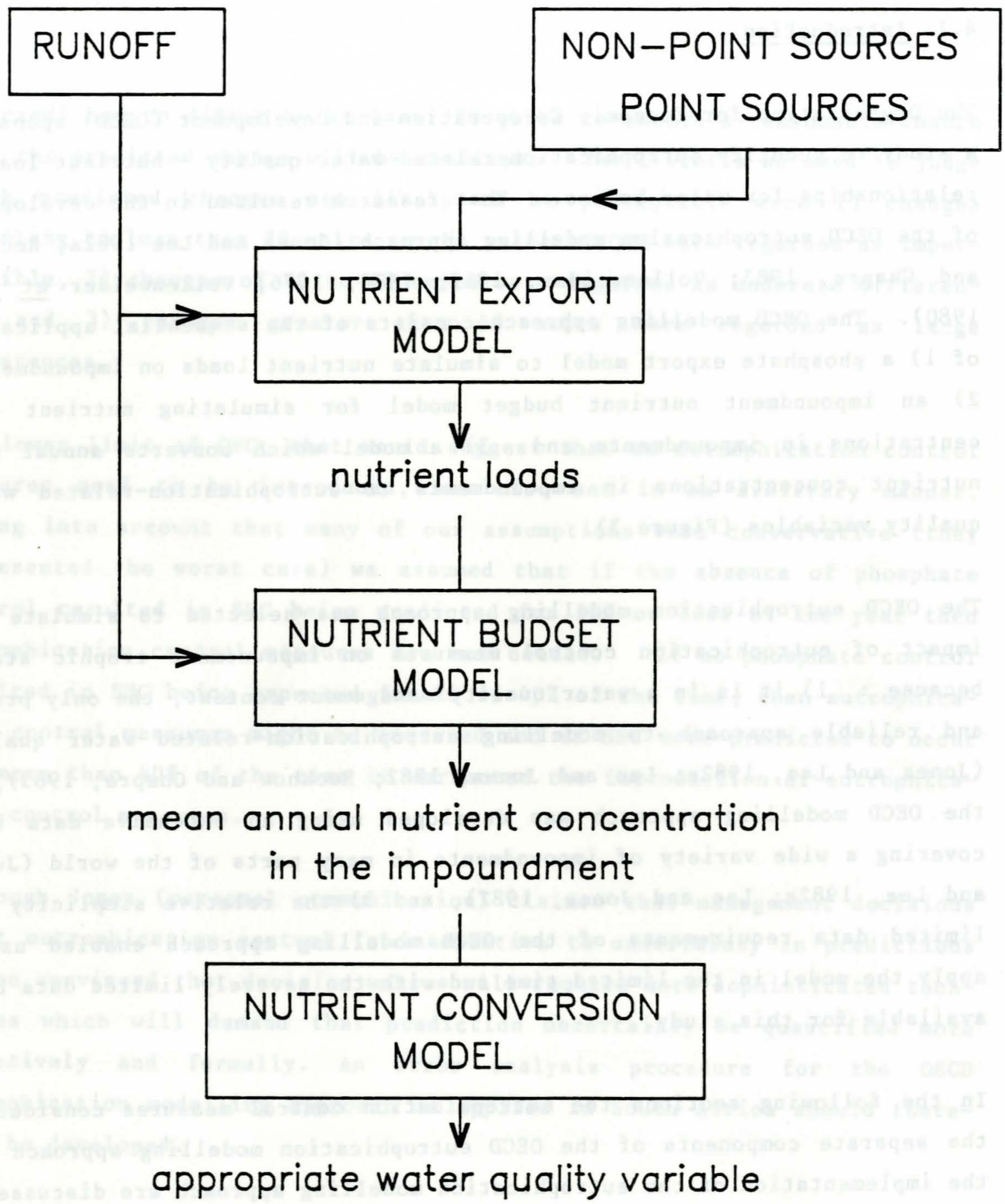

Figure 3: Schematic presentation of the components of the OECD eutrophication modelling approach

annual runoff (MAR) for the catchment in which an impoundment is situated as standard runoff and set the annual mean impoundment volumes at 80% of the full supply volume of the impoundments. We included a scenario where runoff and consequently dam volumes assumed different values from the standard ones to demonstrate the effect of runoff extremes on the trophic response of impoundments. The scenarios that we selected, and the impoundments that we simulated, are summarised in Table 2.

4.2.1 No phosphate reduction measures applied

One of the options open to the water resources manager faced with the problem of controlling the trophic status of an impoundment is not to introduce any phosphate reduction measures. There may be valid reasons for selecting this option e.g. either there may be so few sources of pollution that their combined effect is negligible or there may be so many uncontrollable sources of pollution that restrictions would be ineffective. Moreover, nitrogen or turbidity may be more important than phosphate in limiting algal growth in the particular impoundment under consideration.

4.2.2 Effluents complying with set phosphate standards

Legislation was promulgated on 1 August 1980, limiting the orthophosphate content of treated domestic and industrial wastewater discharged to seven major "sensitive catchments" to 1 mg P/l (Appendix A). The Department of Environment Affairs will phase the standard in during the latter part of 1985, making this the most important scenario for evaluation. Complying to a 1 mg P/l standard for 95 per cent of the time would require mean annual effluent concentrations to be much lower than 1 mg P/l (Water Research Commission, 1984). We decided therefore to select different effective point source effluent concentrations, e.g. 1.0, 0.5 and 0.1 mg P/l, to simulate the effects of the standard.

4.2.3 Extremes in Runoff conditions

Runoff affects both the non-point source nutrient loads and the hydraulic response of impoundments (i.e. the flushing rate and the average volume). Considering the highly variable nature of South African hydrology (Schulze and McGee, 1978; Braune and Wessels, 1980; Braune and Visser, 1981) we decided to evaluate the effect of extreme runoff on the impact of eu-

Table 2: Scenarios assumed for simulation of the trophic response of impoundments to eutrophication control measures.

Scenarios	Impoundments	Tables in Appendix D where results can be found
No eutrophication control	all impoundments	1.1 to 1.19
1 mg P/l standard	all impoundments	2.1 to 2.19
0.5 and 0.1 mg P/l standard	Hartbeespoort, Vaal Barrage, Bloemhof	3.1 to 3.6
1 mg P/l standard, runoff extremes	Hartbeespoort, Vaal Dam, Vaal Barrage	4.1 to 4.6
No standard but removing 50, 80 and 100% of detergent phosphate	Hartbeespoort, Vaal Dam, Vaal Barrage	5.1 to 5.9
Nitrogen limitation	Rietvlei, Hartbeespoort, Roodeplaat	6.1 to 6.3

trophication control measures. We demonstrated the effect of runoff by assuming that a 1 mg P/l standard is applied and annual runoff volumes in the range 10% to 200% of MAR. We assumed average impoundment volumes are a linear function of runoff for runoff volumes below 120% of MAR but for greater runoff volumes impoundment volumes were assumed to be equal to their full supply capacity.

4.2.4. Detergent phosphate restriction

Phosphate derived from detergents makes up 30 to 50 percent of the total phosphate load on sewage treatment works (Heynike and Wiechers, 1984) thus phosphate export from catchments can be controlled by limiting the amount of phosphate in detergents, rather than removing phosphate from sewage effluents (Pretorius, 1983). We investigated the effects of such a strategy by assuming that 50, 80 or 100% of the phosphate from detergents were removed and simulated the effect this had on the trophic response of selected impoundments.

4.2.5 Nitrogen limitation

The OECD chlorophyll-phosphate relationship applies to many South African impoundments. All the impoundments we studied (with the exception of Rietvlei) and for which mean chlorophyll and phosphorus data were available, plot within the 95% confidence limits about the OECD chlorophyll-phosphate line of best fit (Figure 8). Rietvlei Dam is known to be nitrogen limited (Ashton, 1981) which explains its deviation from the OECD chlorophyll-phosphate relationship. As all our predictions of the trophic response of impoundments were based on the OECD chlorophyll-phosphate relationship, which assume phosphate limitation, we wanted to investigate the possibility that nitrogen rather than phosphate might determine the trophic response of certain South African impoundments.

It is generally assumed that N:P mass ratios below about 7:1 indicate potential nitrogen limitation (Walmsley and Butty, 1980). We investigated the possibility of nitrogen controlling the trophic response of the three impoundments most likely to be nitrogen limited (Rietvlei, Roodeplaat and Hartbeespoort Dams) by simulating both nitrogen and phosphate concentrations (assuming a 1 mg P/l standard being applied). We calculated

N:P ratios and compared them to the balanced ratio of 7:1 to decide whether the impoundments were likely to be nitrogen limited or not.

4.2.5 Total dissolved solids

Salinisation is also a serious water quality problem in some South African rivers and concern was expressed about the possibility that chemical phosphate removal techniques may increase the total dissolved solids (TDS) concentrations in impoundments. Using the projected increase in TDS loads from sewage works provided by the Division of Water Pollution Control (Appendix C), we predicted the TDS concentrations in impoundments.

4.3 Components of the OECD modelling approach

4.3.1 Hydraulic loads

Hydraulic load (volume of runoff received annually by impoundments) affects the response of impoundments through its effects on both the flushing rate and the average impoundment volume and through its effect on the magnitude of non-point source phosphate loads. Hydraulic loads on South African impoundments can generally be estimated easily (Surface Water Resources of South Africa, 1981). The Department of Environment Affairs maintains a network of flow gauging stations throughout the country at which river stage is recorded continuously at a weir, bridge or some other calibrated structure. Stage height records are converted to flow figures and the results are archived in a large hydrological data base. All hydraulic loads used in this study were calculated using flow data from the Department of Environment Affairs hydrological data base. In a few cases, the flow data we required to estimate hydraulic loads were only available for a part of a catchment or only for an adjacent catchment. In those cases, we estimated the flow for the ungauged catchment as a proportion of the flow of the gauged catchment based on the ratio of the ungauged catchment area to the gauged catchment area.

4.3.2 Nutrient loads

The eutrophication control measures considered in this study were all directed at manipulating nutrient export from catchments. Because nutrient loads were so important in this study, procedures for estimating nutrient loads were examined in detail.

4.3.2.1 Direct methods for estimating nutrient loads

A detailed report on the evaluation of several direct methods which could be used to estimate pollutant loads in South African rivers is available (Grobler, 1984a) and only the more important conclusions of that report are given here.

The direct methods commonly used for estimating nutrient loads are the averaging, flow interval, and statistical methods. In the averaging methods, loads are calculated as the product of average concentration and total flow over equal time intervals. The disadvantage of averaging methods is that their accuracy decreases as the sampling frequency decreases. Averaging methods are least accurate when applied to "event response" rivers, i.e. rivers where most of the load is transported during a very small proportion of the year and should only be used to estimate loads in rivers if sampling occurs at daily (or shorter) intervals.

Flow interval methods estimate the average load in a river for each of a series of discrete flow intervals. The average load for each flow interval is calculated as the mean of the products of instantaneous flows and concentrations. Subsequently, loads for days on which concentrations were not measured can be estimated from the flow by finding the corresponding flow interval and assuming the load to be equal to the average load for that flow interval. It is technically difficult to apply flow interval methods in South Africa because the available records of both measured concentrations and flow are too short.

Statistical methods are based on regression equations of concentrations or loads against flow calculated using measured data for a river. The flow record for such a river can then be used to estimate concentrations or loads for days on which flow was gauged but no sample was taken. Two statistical methods were used to calculate phosphate loads.

1) Fit a regression equation of the log of the measured loads against the log of the measured flows and calculate loads from daily flows using this regression equation.

$$\log \text{load} = a \log \text{flow} + b$$

2) First separate the flow record into high and low flows (assuming sufficient data are available) and fit separate log-log regression equations to the high and low flow data groups.

$$\log \text{loads} = \begin{cases} a \log \text{flow} + b & \text{flows} < \text{mean flow} \\ c \log \text{flow} + d & \text{flows} \geq \text{mean flow} \end{cases}$$

It is important to note that the statistical methods we used consistently underestimated phosphate loads by about 30% when compared to estimates by an averaging method and using records consisting of daily measured concentrations.

4.3.2.2 Indirect methods

Indirect methods are models, of varying complexity, which are used to simulate nutrient export from catchments as a function of catchment properties. Indirect methods must first be calibrated against estimates by direct methods and calibration requires that enough data be available for a catchment so that loads can be estimated by at least one of the direct methods. Because of a paucity of available data we used only the export coefficient model (the simplest of the indirect methods) in this study. It was necessary to refine the use of export coefficients by taking into account catchment properties such as annual runoff and geology. (Grobler and Silberbauer, 1984).

4.3.2.3 Procedure for estimating nutrient loads

The detailed procedures which we used to estimate phosphate loads for each impoundment, listing important assumptions and shortcomings in data, are provided in Appendix B. In this section only the general procedure is discussed. We assumed that the total nutrient load exported from a catchment consists of two components, namely the point source loads and non-point source loads and used different procedures to estimate them.

a) Point Sources

Point source loads were obtained from a table of point source effluent volumes and loads provided by the Water Pollution Control Division of the Department of Environment Affairs (Appendix C). They projected a 5% per annum increase in sewage volume and the introduction of the 1 mg P/l standard late in 1985. Only soluble phosphate loads are provided in Appendix C and the Division of Water Pollution Control recommended that these loads should be multiplied by a factor of 1.25 to convert them to total phosphate loads. We made additional projections, based on the information provided in Appendix C, of the effects of no phosphate control in the sensitive catchments. We first calculated the point source loads (W_{point}) and point source discharges (Q_{point}) for each catchment before the introduction of the phosphate standard. Then we calculated the average point source effluent concentrations (C_{point}) for each catchment before introduction of the standard as

$$C_{point} = W_{point}/Q_{point}$$

The projected point source loads as a consequence of no eutrophication control measures being applied were calculated as the product of the projected point source effluent discharges obtained from Appendix C and the average point source effluent concentration before introduction of the standard

$$\text{projected } W_{point} = \text{projected } Q_{point} . C_{point}$$

The point source loads resulting as a consequence of no eutrophication control measures being applied are summarized in Appendix D, Tables 1.1 to 1.19.

We investigated two strategies for controlling point source phosphate loads on impoundments:

1. Reducing the phosphate content of detergents: We used Hartbeespoort Dam and Vaal Barrage, which receive mainly point source loads, and Vaal Dam, which receives mainly non-point source loads, as case studies for demonstrating the consequences of detergent phosphate control (Appendix D, Tables 5.1 to 5.9). We assumed that 50% of the phosphate in point source effluents originate from detergents. This assumption corresponds to the upper limit for the detergent phosphate in sewage outfall (Heynike and Wiechers, 1984) and consequently repre-

sented the scenario most likely to demonstrate the effect of restricting the phosphate content of detergents. We then assumed that the detergent phosphate load was reduced by 50%, 80% or 100% and added the residual detergent phosphate load (if any) to the faecal/other phosphate loads to yield a reduced total point source phosphate load reflecting the consequence of detergent phosphate control.

2. Reducing the phosphate concentration of point source effluents to fixed levels by implementing a phosphate standard: Present legislation allows for the introduction of a 1 mg P/l standard in sensitive catchments. In order for effluent treatment plants to comply with this standard for 95% of the time, phosphorus will have to be removed to much lower levels than 1 mg P/l for most of the time (Water Research Commission 1984). We projected point source loads assuming phosphate standards which will result in mean effluent phosphate concentrations equal to 1.0 mg P/l (for all impoundments, see Appendix D, Tables 2.1 to 2.19), 0.5 and 0.1 mg P/l (using only Hartbeespoort Dam, Bloemhof Dam and Vaal Barrage as case studies, see Appendix D, Tables 3.1 to 3.6).

Point source phosphate loads can be altered (by changes in phosphate species) and significantly reduced en route to impoundments (Sonzogni et al., 1980; Yaksich et al., 1980; Cullen and Smalls, 1981; Sonzogni et al., 1982; Rast and Lee, 1983). Although our own data (Grobler and Silberbauer, unpublished data) show that considerable reductions in point source loads occur between sewage works and impoundments we assumed, for this study, that no reductions in point source loads occur. This assumption meant that we simulated the worst case with respect to point source loads.

b) Non-point sources

A flow diagram of the general procedure we used to estimate non-point source loads is shown in Figure 4. In some catchments, non-point phosphate dominated the total phosphate load. For some of these catchments there was enough flow and phosphate concentration data to estimate non-point phosphate loads directly (see section 4.3.2.1). For these catchments we calculated phosphate export coefficients, annual runoff and linear regression equations of export versus runoff for individual catchments or groups of catchments sharing similar

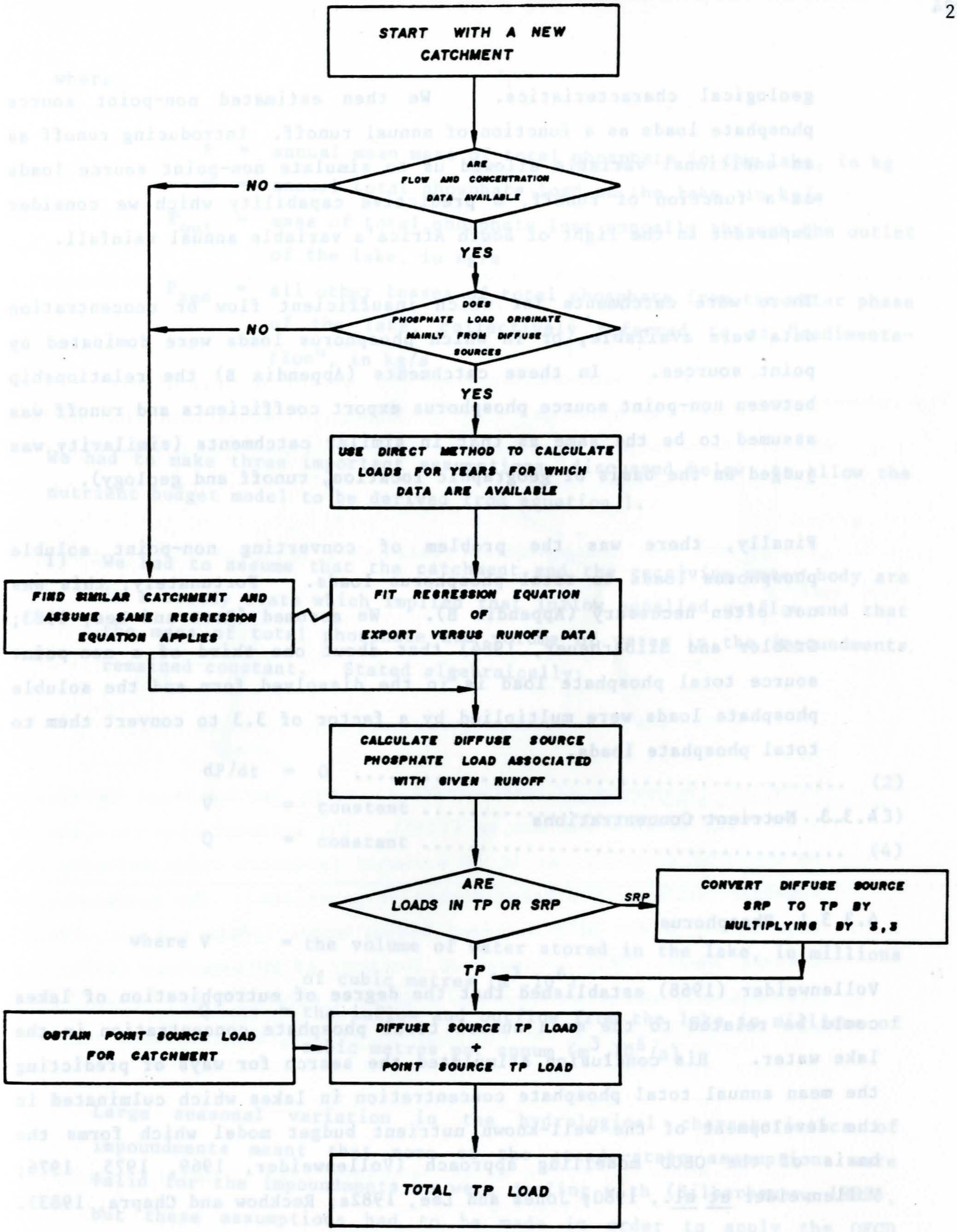

Figure 4: Schematic presentation of the procedure that was used to estimate non-point source loads.

geological characteristics. We then estimated non-point source phosphate loads as a function of annual runoff. Introducing runoff as an additional variable allowed us to simulate non-point source loads as a function of runoff, a predictive capability which we consider important in the light of South Africa's variable annual rainfall.

There were catchments for which insufficient flow or concentration data were available, or in which phosphorus loads were dominated by point sources. In these catchments (Appendix B) the relationship between non-point source phosphorus export coefficients and runoff was assumed to be the same as that in similar catchments (similarity was judged on the basis of geographic location, runoff and geology).

Finally, there was the problem of converting non-point soluble phosphorus loads to total phosphorus loads. Fortunately, this was not often necessary (Appendix B). We assumed (Rast and Lee, 1983; Grobler and Silberbauer, 1984) that about one third of a non-point source total phosphate load is in the dissolved form and the soluble phosphate loads were multiplied by a factor of 3.3 to convert them to total phosphate loads.

4.3.3 Nutrient Concentrations

4.3.3.1 Phosphorus

Vollenweider (1968) established that the degree of eutrophication of lakes could be related to the mean annual total phosphate concentration in the lake water. His conclusion stimulated the search for ways of predicting the mean annual total phosphate concentration in lakes which culminated in the development of the well-known nutrient budget model which forms the basis of the OECD modelling approach (Vollenweider, 1969, 1975, 1976; Vollenweider et al., 1980; Jones and Lee, 1982a; Reckhow and Chapra, 1983).

The OECD nutrient budget model is based on the principle of conservation of mass, and is derived from a simple mass balance equation :

$$dP/dt = W - P_{out} - P_{sed} \quad \text{.............................(1)}$$

where

P = annual mean mass of total phosphate in the lake, in kg

W = annual total phosphate load on the lake, in kg/a

P_{out} = mass of total phosphate lost annually through the outlet of the lake, in kg/a

P_{sed} = all other losses of total phosphate from the water phase of the lake, collectively referred to as "sedimentation", in kg/a

We had to make three important assumptions, discussed below, to allow the nutrient budget model to be derived from equation 1.

1) We had to assume that the catchment and the receiving water body are in a steady state which implied that inflow equalled outflow and that the mass of total phosphate and volume of water in the impoundments remained constant. Stated algebraically:

$$dP/dt = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$V = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$Q = \text{constant} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where V = the volume of water stored in the lake, in millions of cubic metres ($m^3.10^6$)

Q = the inflow and outflow from the lake in millions of cubic metres per annum ($m^3.10^6/a$)

Large seasonal variation in the hydrological characteristics of impoundments meant that none of the steady-state assumptions were valid for the impoundments we were dealing with (Silberbauer, 1983), but these assumptions had to be made in order to apply the OECD nutrient budget model.

2) We assumed that the water body is completely mixed so that total phosphate concentration in the outflow was equal to the mean total phosphate concentration in the water body and the loss of total phosphate through the outlet was therefore estimated as

$$P_{out} = (Q/V)\ P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

South African impoundments are usually not completely mixed, as demonstrated by the phosphate gradient observed in Roodeplaat Dam (Figure 5). The consequences of assuming complete mixing when in fact spatial gradients occur, can be partly corrected by using higher sedimentation coefficients (Walker, 1982) (see assumption 3). Vertical gradients in phosphate concentration may also cause complications when the outflow from stratified impoundments consists mainly of hypolimnetic water (which generally contains larger phosphate concentrations than surface water), because more phosphate is lost from the system than would be calculated from equation 5.

3) We assumed that sedimentation losses were governed by a first-order reaction

$$P_{sed} = s.P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where s = sedimentation loss rate in units of 1/a

Detailed treatments of sedimentation losses can be found in Kenney (1983) and Reckhow and Chapra (1983). The sedimentation rate cannot be measured directly, as it is a lumped parameter which reflects the combined effect of a large number of processes. The sedimentation loss rates in the OECD nutrient budget model (Jones and Lee, 1982a; Lee and Jones, 1982) is based on the work of Vollenweider (1976) who statistically analysed data for a large sample of lakes representing many different trophic and hydrological states, and concluded that

$$s = 1/\sqrt{T_w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where T_w = the water residence time in years, calculated as V/Q

Kenney (1982) doubted the validity of Vollenweider's statistical technique on the basis that it included spurious correlations. Evidence that equation 7 results in underestimates of the sedimentation loss rate for reservoirs is also building up (Walker, 1982; Grobler, 1984b). Sedimentation loss rates in reservoirs are greater because 1) reservoirs are usually plug flow systems which means that they ex-

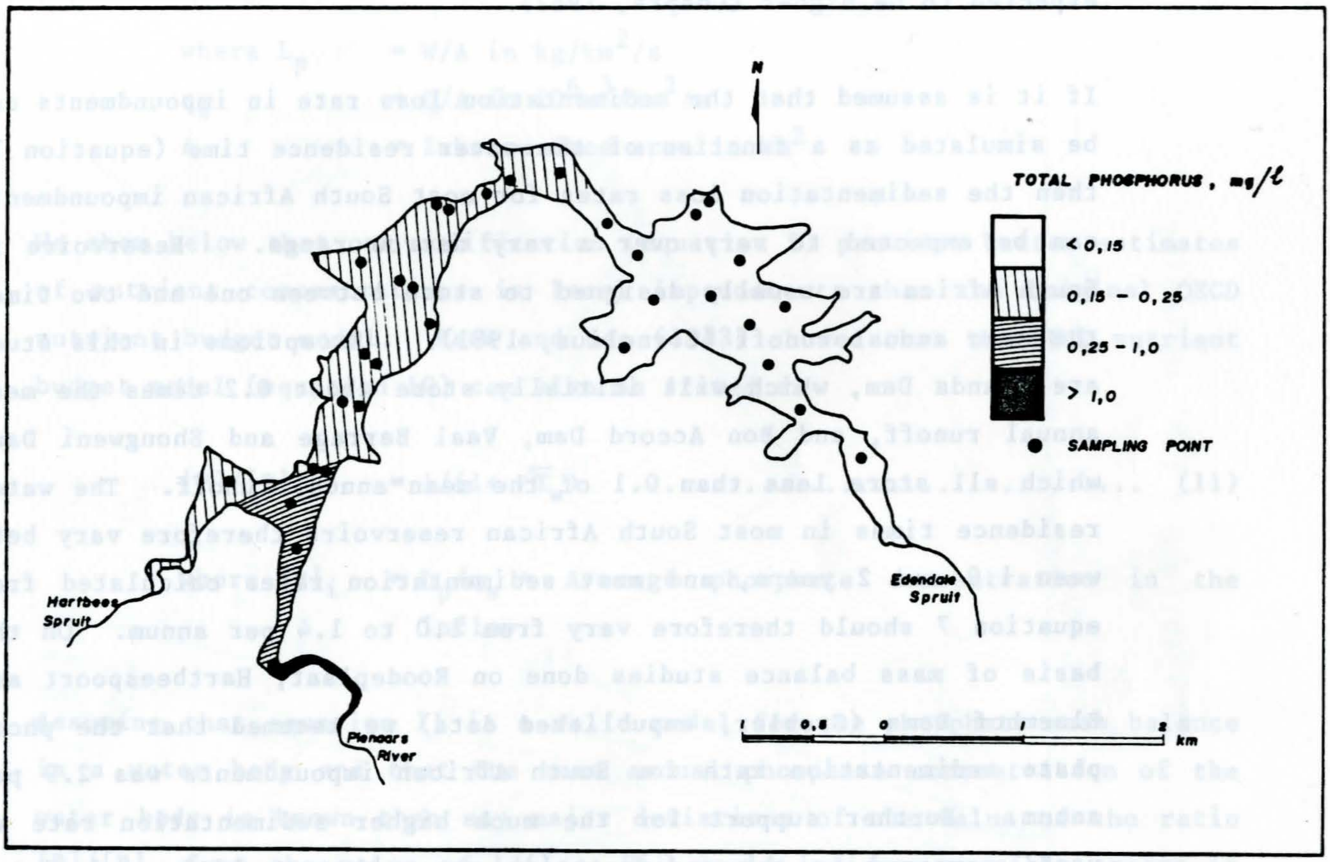

Figure 5: Total phosphate concentration gradient in the 0 to 5m layer in Roodeplaat Dam on 30/9/82. The information was supplied by A. Howman, hydrological Research Institute, Department of Environmental Affairs, Pretoria (Unpublished M.Sc. thesis).

perience greater sedimentation loss rates (Sonzogni et al., 1976; Higgens and Kim, 1981; Walker, 1982) and 2) reservoirs in general receive a higher proportion of particulate phosphorus than natural lakes and because particulate phosphorus is lost at a faster rate than dissolved phosphorus, the sedimentation loss rate in reservoirs can be expected to be higher (Chapra, 1982).

If it is assumed that the sedimentation loss rate in impoundments can be simulated as a function of the water residence time (equation 7) then the sedimentation loss rates for most South African impoundments can be expected to vary over a very narrow range. Reservoirs in South Africa are usually designed to store between one and two times the mean annual runoff (Cornelius, 1981). Exceptions in this study are Inanda Dam, which will initially store about 0.2 times the mean annual runoff, and Bon Accord Dam, Vaal Barrage and Shongweni Dam, which all store less than 0.1 of the mean annual runoff. The water residence times in most South African reservoirs therefore vary between 1.0 and 2 years, and most sedimentation rates calculated from equation 7 should therefore vary from 1.0 to 1.4 per annum. On the basis of mass balance studies done on Roodeplaat, Hartbeespoort and Bloemhof Dams (Grobler, unpublished data) we assumed that the phosphate sedimentation rate for South African impoundments was 2.9 per annum. Further support for the much higher sedimentation rate we used, compared to the sedimentation rates that would be calculated from equation 7, is that an average sedimentation rate of 3.6 per annum was found by Walker (1982) for North American Reservoirs.

The assumptions listed above allow us to substitute equations 2, 3, 4, 5 and 6 into equation 1 to obtain the nutrient budget model used to simulate annual mean total phosphate concentrations in this study

$$dP/dt = 0 = W - (Q/V)P - s.P \quad \text{.......................} \quad (8)$$

$$[P] = W/(Q + s.V) \quad \text{..............................} \quad (9)$$

where $[P]$ = the mean annual total phosphate concentration in the impoundment in mg/m^3

We used equation 9 to predict phosphate concentrations in impoundments but it can be shown that, if phosphate and hydraulic loads in equation 9 are expressed per unit area of the impoundment and s is replaced by $1/\sqrt{T_w}$ (equation 7), equation 9 is equivalent to the OECD nutrient budget model which calculates the annual mean total phosphate concentrations as

$$[P] = Lp/[q_s\ (1 + \sqrt{T_w})] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where L_p = W/A in $kg/km^2/a$

q_s = Q/A in $10^6 m^3/km^2/a$

A = lake surface area in km^2

We show below that our modification (equation 9) provides better estimates of nutrient concentrations in local impoundments than the original OECD nutrient budget model. Rast and Lee (1983) showed that the OECD nutrient budget model (equation 10) can also be stated as

$$[P]/[P]_i = 1/(1+ \sqrt{T_w}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

where $[P]_i$ = L_p/q_s = Average phosphate concentration in the inflow.

Assuming that equation 11 is a valid model for the phosphate mass balance in a water body and that the mean annual phosphate concentration of the water body is known then any major deviations of the value of the ratio $[P]/[P]_i$ from the value of $1/(1 + \sqrt{T_w})$ would indicate possible errors in load estimates. $[P]/[P]_i$ were plotted against $1/(1 + \sqrt{T_w})$ for several impoundments included in this study (Figure 6). Rast and Lee's (1983) procedure indicated that most of our load estimates were too high by a factor two to five (exceptions were Bronkhorst Spruit Dam which plotted close to the 1:1 line and Laing Dam, which indicated a 2.8 times underestimate of the phosphate load). However we underestimated non-point source loads (Grobler, 1984a) and we know that it was unlikely that the point source loads were such large overestimates as indicated by the results in Figure 6. Our modified nutrient budget model (equation 9) expressed as

$$[P]/[P]_i = 1/(1 + 2.9\ Q/V) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

can also be used to evaluate load estimates. We plotted the $[P]/[P]_i$ ratios against the values of $1/(1 + 2.9\ Q/V)$ in Figure 7 which shows that using equation 9 caused a considerable improvement in the assessment of load estimates for most impoundments. Most of the impoundments shown in

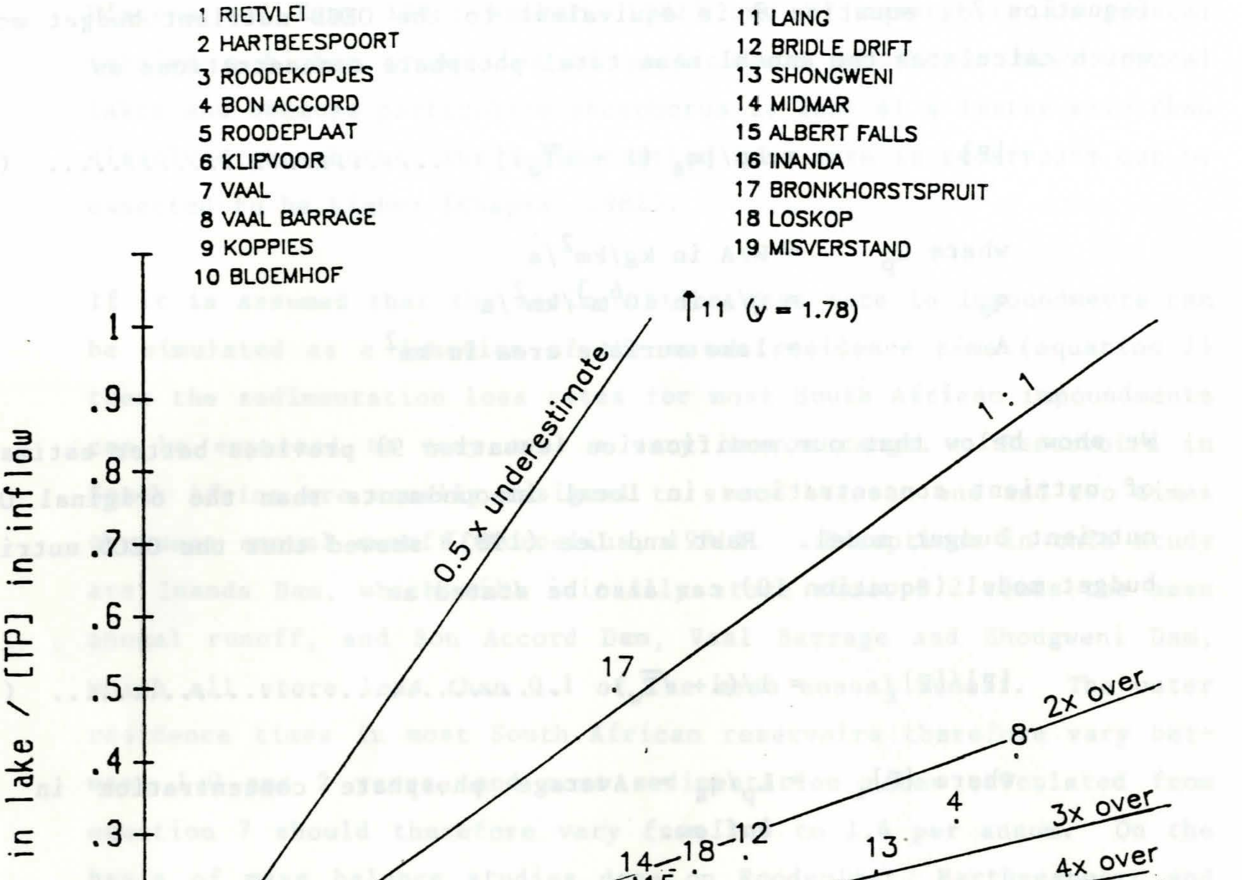

Figure 6: Assessment of phosphate load estimates assuming the OECD nutrient budget model applies to South African impoundments.

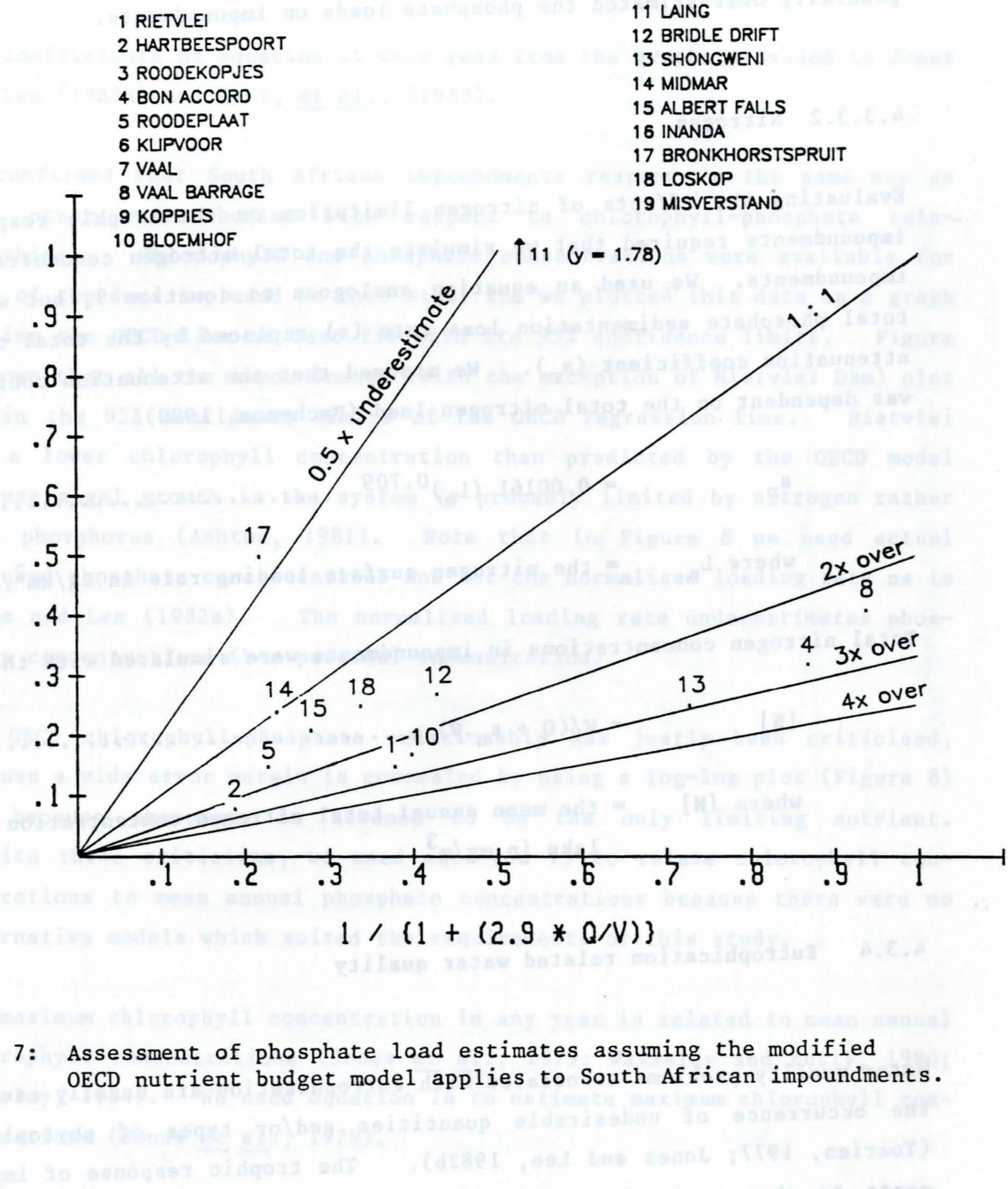

Figure 7: Assessment of phosphate load estimates assuming the modified OECD nutrient budget model applies to South African impoundments.

Figure 7 still plotted below the 1:1 line which indicated to us that either the high sedimentation rate we used might still have been an underestimate of the actual sedimentation rates for South African impoundments or that we generally overestimated the phosphate loads on impoundments.

4.3.3.2 Nitrogen

Evaluating the effects of nitrogen limitation on the trophic response of impoundments required that we simulate the total nitrogen concentration in impoundments. We used an equation analogous to equation 9, but with the total phosphate sedimentation loss rate (s) replaced by the total nitrogen attenuation coefficient (s_n). We assumed that the attenuation coefficient was dependent on the total nitrogen load (Bachmann, 1980).

$$s_n = 0.00161 \, (L_n)^{0.709} \qquad (13)$$

where L_n = the nitrogen surface loading rate in $kg/km^2/a$

Total nitrogen concentrations in impoundments were simulated with the model

$$[N] = W/(Q + s_n.V) \qquad (14)$$

where [N] = the mean annual total nitrogen concentration in the lake in mg/m^3

4.3.4 Eutrophication related water quality

Water quality problems associated with eutrophication are usually caused by the occurrence of undesirable quantities and/or types of phytoplankton (Toerien, 1977; Jones and Lee, 1982b). The trophic response of impoundments to changes in TP concentrations is therefore usually measured in terms of chlorophyll concentration, which serves as a measure of the phytoplankton standing crop. The OECD modelling approach relates mean annual chlorophyll concentrations to mean annual TP concentrations by means of a log-log regression of mean summer chlorophyll concentrations on mean annual phosphate concentrations.

$$[Chl] = 0.45\ [P]^{0.79} \qquad (15)$$

where [Chl] = mean summer chlorophyll concentration in mg/m^3

The coefficients of equation 15 were read from the graphs provided in Jones and Lee (1982a) and Rast, et al., (1983).

We confirmed that South African impoundments respond in the same way as most other water bodies with respect to chlorophyll-phosphate relationships. Chlorophyll and phosphate concentrations were available for some of the dams included in this study and we plotted this data on a graph showing the OECD line of best fit with its 95% confidence limits. Figure 8 shows that all the impoundments (with the exception of Rietvlei Dam) plot within the 95% confidence limits of the OECD regression line. Rietvlei has a lower chlorophyll concentration than predicted by the OECD model because algal growth in the system is probably limited by nitrogen rather than phosphorus (Ashton, 1981). Note that in Figure 8 we used actual measured phosphate concentrations and not the normalized loading rate as in Jones and Lee (1982a). The normalized loading rate underestimates phosphate concentrations (Lee personal communication).

The OECD chlorophyll-phosphate relationship has justly been criticised, because a wide error margin is concealed by using a log-log plot (Figure 8) and because phosphate is assumed to be the only limiting nutrient. Despite these criticisms, we used equation 15 to relate chlorophyll concentrations to mean annual phosphate concentrations because there were no alternative models which suited the requirements of this study.

The maximum chlorophyll concentration in any year is related to mean annual chlorophyll concentrations (Jones et al., 1979; Walmsley and Butty, 1980; Walmsley, 1984). We used equation 16 to estimate maximum chlorophyll concentrations (Jones et al., 1979).

$$\text{maximum summer } [Chl] = 1.7\ (\text{mean annual } [Chl]) + 0.2 \qquad (16)$$

Walmsley (1984) developed an exponential equation, based on data from 31 impoundments, to estimate maximum chlorophyll concentrations for South African impoundments

$$\text{maximum } [Chl] = 7.1 \exp\ (0.103 \text{ mean annual } [Chl]) \qquad (17)$$

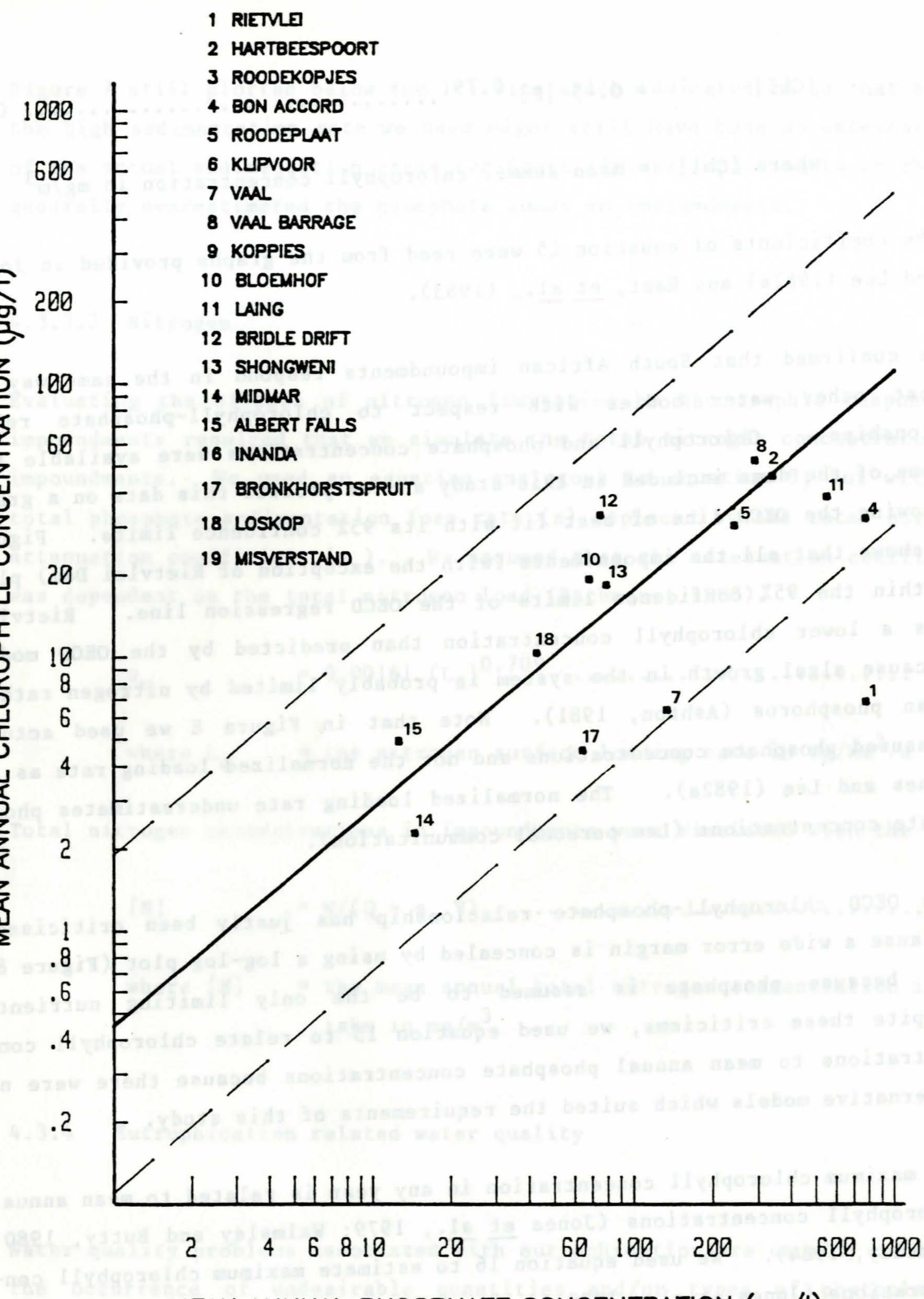

Figure 8: Chlorophyll-phosphate relationships for South African impoundments showing the OECD chlorophyll-phosphate regression line with its 95% confidence interval.

Because equation 17 has a calibration range of 0-40 mg/m^3 chlorophyll, and many of our predicted mean annual chlorophyll concentrations exceed 100 mg/m^3, unrealistically high maximum chlorophyll concentrations were predicted when we used equation 17. We therefore used equation 16 to predict the maximum chlorophyll concentrations reported in this study because 1) it had a slightly greater calibration range of 0-70 mg/m^3 for mean annual chlorophyll concentrations and 2) because equation 16 is a linear relationship with the result that unrealistic maximum chlorophyll levels were not predicted as easily with equation 16 when it is applied to data outside its calibration range. While we believe that an equation for predicting maximum chlorophyll levels for local impoundments is necessary, we feel that data for hypertrophic impoundments such as Hartbeespoort Dam should be included in the development of such an equation. The resulting equation may well have a sigmoidal form.

Walmsley and Butty (1980) and Walmsley (1984) have emphasised the importance of providing an indication of how much of the time one can expect nuisance conditions in an impoundment. Walmsley (1984) developed a set of empirical equations for estimating the percentage of time that chlorophyll concentrations would fall into each of the following four chlorophyll concentration ranges with the indicated nuisance conditions :

0-10 mg Chl/m^3 :- no problems encountered
10-20 mg Chl/m^3 :- algal scums present
20-30 mg Chl/m^3 :- nuisance conditions
>30 mg Chl/m^3 :- severe nuisance conditions

We only predicted the percentage of time that chlorophyll concentrations will exceed 30 mg/m^3 and consequently result in severe nuisance conditions being experienced, using the equation provided by Walmsley (1984)

$$F = 1.19(\text{mean chlorophyll}) - 5.36 \quad \ldots\ldots\ldots\ldots\ldots (18)$$

where F = the frequency of occurrence of severe nuisance conditions, expressed as a percentage of the year.

4.3.5 Implementation

The wide selection of electronic spreadsheet software currently available for microcomputers and main frame computers (e.g. VisiCalc) is ideally suited for implementation of the OECD modelling approach as applied in this study. We used the electronic spreadsheet software package "SUFICS", which runs on a SPERRY 1100 mainframe computer, to implement the OECD modelling approach. "SUFICS" is an exceptionally powerful and fast electronic spreadsheet but has the possible disadvantage that it only works on SPERRY computers.

5. PREDICTED TROPHIC RESPONSES

5.1 Results

The predicted trophic status of impoundments for various scenarios, reflecting different eutrophication control strategies, hydrological regimes and the likelihood of nitrogen limitation regulating impoundment trophic status, are discussed separately. The criteria used for judging the effect of nutrient control measures (see Chapter 3) were : 1) Where relevant, nuisance conditions have to be predicted to occur for at least 20% of the time before the introduction of eutrophication control measures should be considered. 2) The introduction of control measures had to result in a decrease of at least 20% in the amount of time that nuisance conditions could be expected.

5.1.1 No eutrophicaton control

Detailed results of the predicted trophic status of impoundments assuming no eutrophication control are given in Appendix D, Tables 1.1 to 1.19. Based on their predicted responses in the year 2000 as a consequence of assuming that no eutrophication control were introduced the impoundments were divided into three groups. 1) Five impoundments would experience severe nuisance conditions (SNC) for less than 21% of the year (Figure 9). Eutrophication control measures are not warranted in the catchments of Vaal, Midmar, Albert Falls, Bronkhorst Spruit and Loskop Dams. 2) Five impoundments experienced SNC for 21 to 40% of the time in the year 2000 (Figure 10). The introduction of eutrophication measures in the catchments of Roodekopjes, Koppies, Bloemhof, Bridle Drift and Misverstand Dams may therefore result in perceptible changes in trophic status but should be carefully considered in the light of the uncertainty associated with our predictions. 3) Nine impoundments were predicted to experience SNC for more than 40% of the time in the year 2000 if no measures are taken to control eutrophication (Figure 11). The impoundments with catchments in the Pretoria-Witwatersrand-Vereniging (PWV) area represented the worst cases. These highly eutrophic impoundments can be expected to respond favourably to the introduction of eutrophication control measures in their catchments granted that these measures will result in sufficiently large reductions in nutrient loads.

Figure 9: The percentage time severe nuisance conditions can be expected in Vaal , Midmar, Albert Falls, Bronkhorst Spruit and Loskop Dams if no eutrophication control measures are introduced in their catchments.

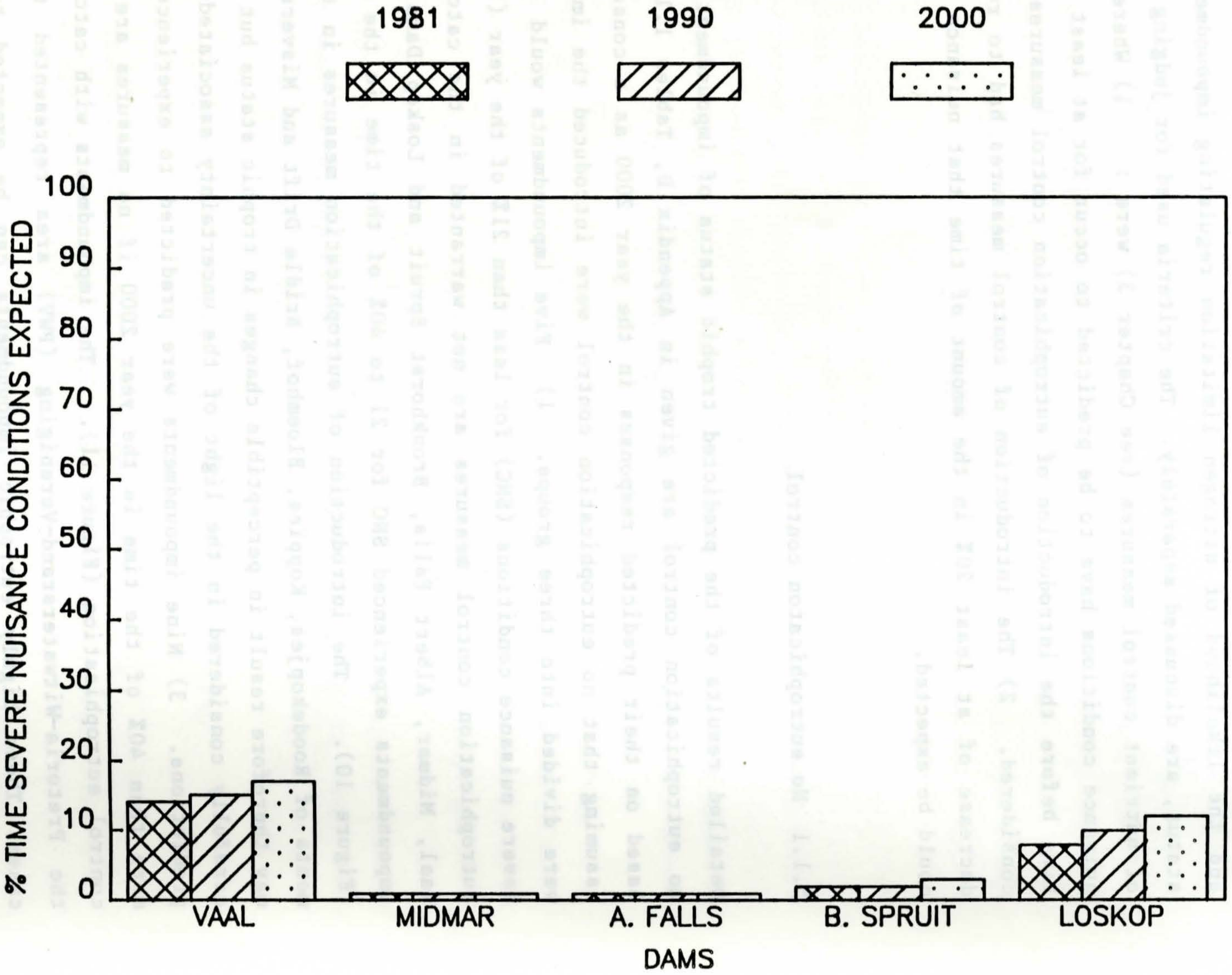

Figure 9: The percentage time severe nuisance conditions can be expected in Vaal, Midmar, Albert Falls, Bronkhorst Spruit and Loskop Dams if no eutrophication control measures are introduced in their catchments.

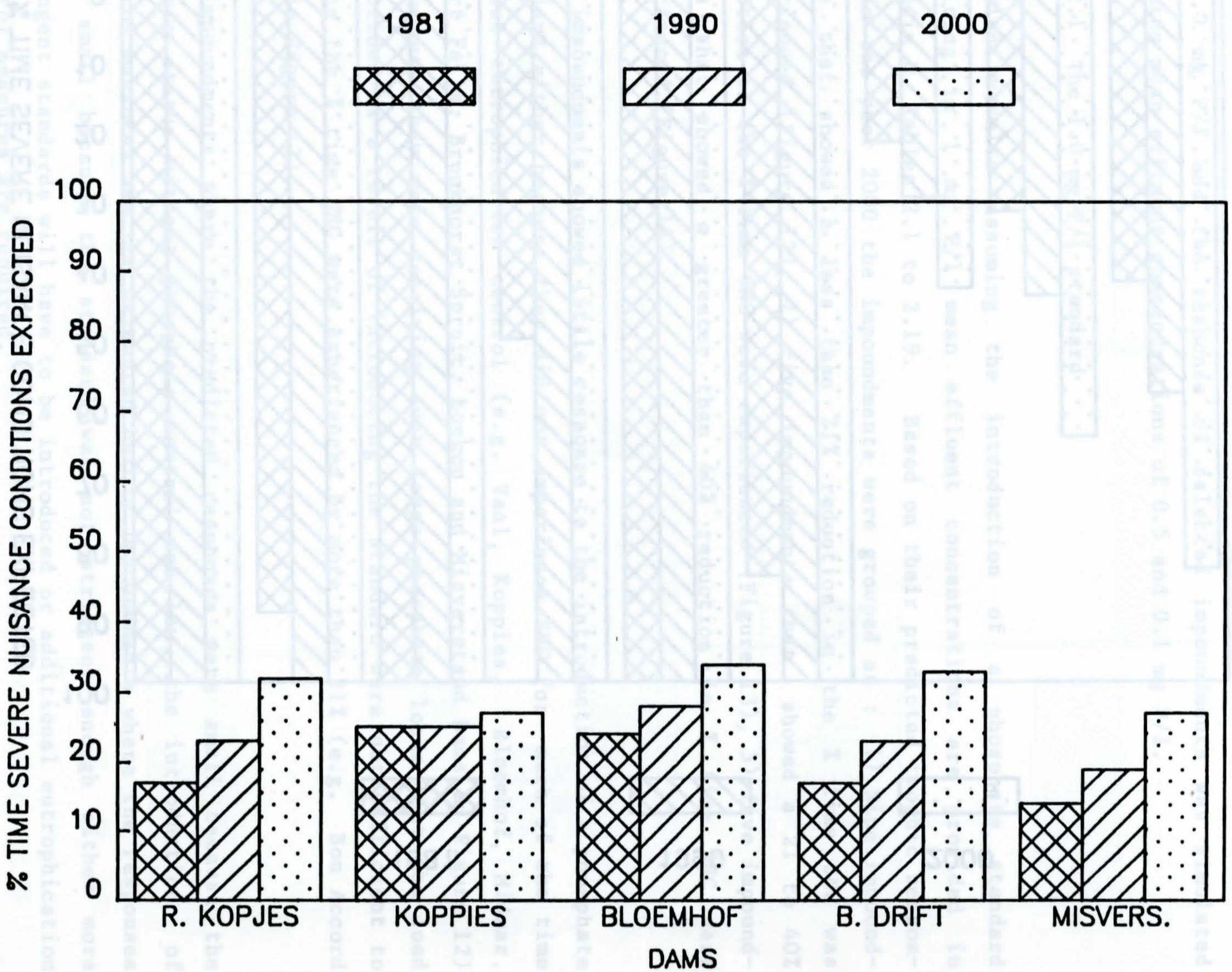

Figure 10: The percentage time severe nuisance conditions can be expected in Roodekopjes, Koppies, Bloemhof, Bridle Drift and Misverstand Dams if no eutrophication control measures are introduced in their catchments.

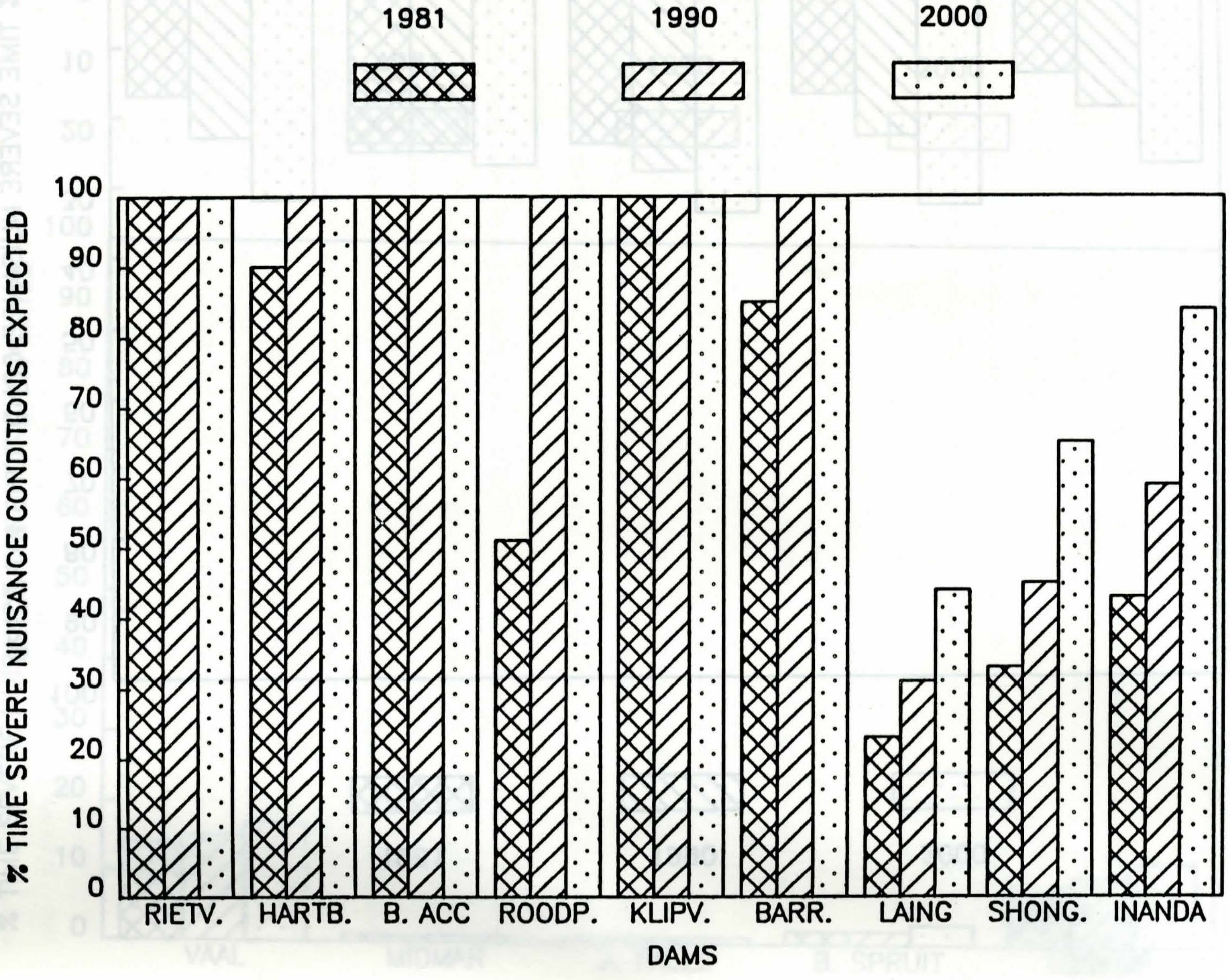

Figure 11: Comparison of the percentage time severe nuisance conditions can be expected in Rietvlei, Hartbeespoort, Bon Accord, Roodeplaat, Klipvoor, Vaal Barrage, Laing, Shongweni and Inanda Dams if no eutrophication control measures are introduced in their catchments.

5.1.2 Phosphate standards

Domestic and wastewater effluents in sensitive catchments have to comply to the 1 mg P/l standard by August 1985. Compliance to this standard for most of the time means that effluent concentrations will have to be substantially below the required limit. The trophic response of all impoundments was therefore simulated assuming mean effluent concentrations of 1.0 mg P/l and the response of selected impoundments was simulated assuming mean effluent concentrations of 0.5 and 0.1 mg P/l.

5.1.2.1 The 1.0 mg P/l standard

Detailed results assuming the introduction of a phosphate standard resulting in 1 mg P/l mean effluent concentrations are provided in Appendix D, Tables 2.1 to 2.19. Based on their predicted trophic responses in the year 2000 the impoundments were grouped as : 1) Nine impoundments that showed a less than 21% reduction in the % time SNC was experienced (Figure 12), 2) five impoundments that showed a 21 to 40% reduction in the % time SNC were experienced (Figure 13), 3) five impoundments that showed a greater than 40% reduction in % time SNC were experienced (Figure 14).

Some impoundments showed little response to the introduction of a phosphate standard either because they did not experience SNC for much of the time without eutrophication control (e.g. Vaal, Koppies, Bloemhof, Midmar, Albert Falls, Bronkhorst Spruit, Loskop and Misverstand Dams in Figure 12) or because they were receiving such large phosphate loads that the load reductions as a result of introducing the standard were not sufficient to reduce the % time SNC were experienced by more than 21% (e.g. Bon Accord Dam in Figure 12).

In impoundments where the predicted responses were small because the trophic status without phosphate control was low, the introduction of control measures are not warranted but in impoundments where the responses were small because the standard was not stringent enough either more stringent standards will have to be introduced or additional eutrophication control measures are required.

Impoundments that showed a moderate response to the introduction of the standard (Figure 13) were those in which the responses were limited either

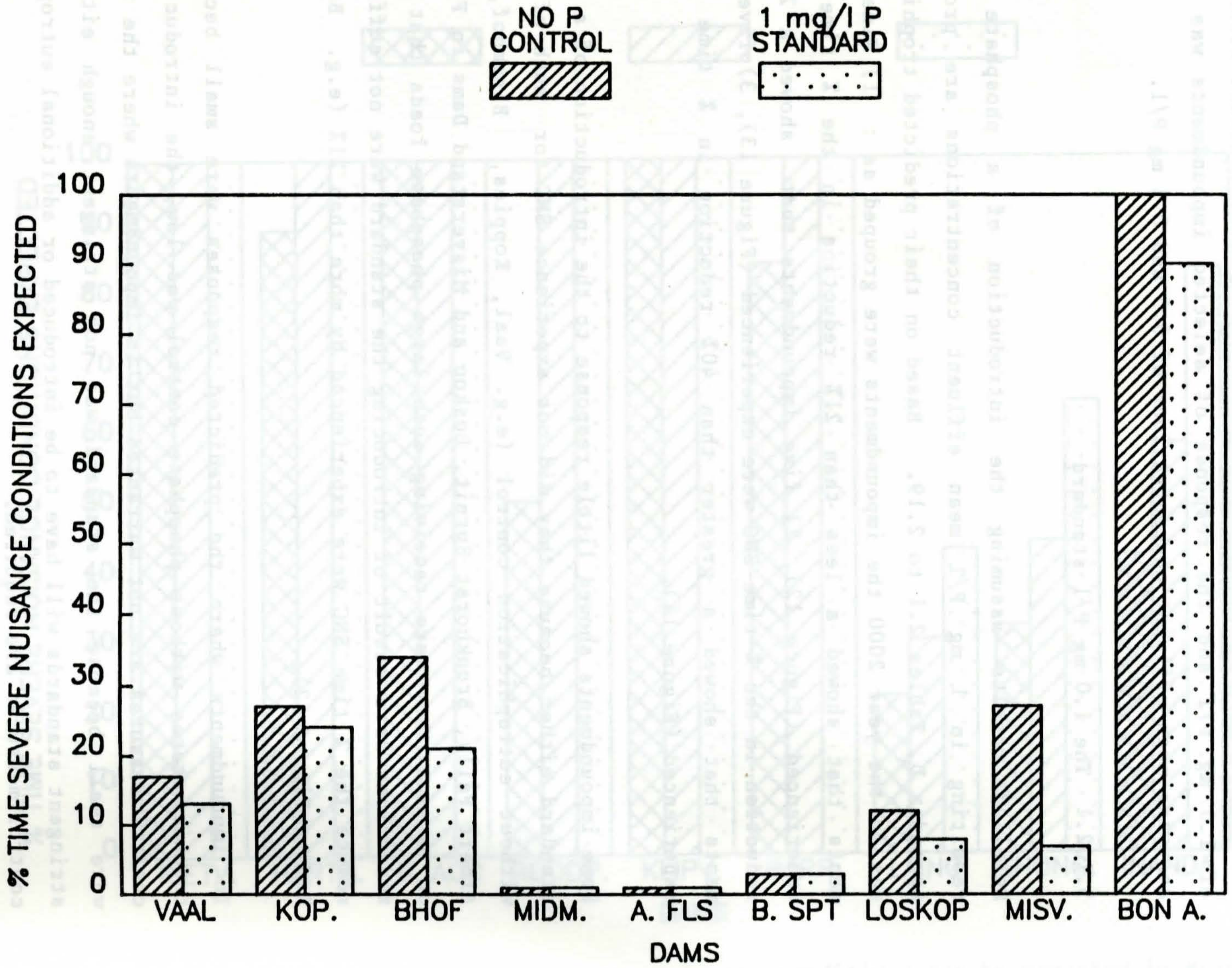

Figure 12: Comparison of the percentage time severe nuisance conditions can be expected in Vaal, Koppies, Bloemhof, Midmar, Albert Falls, Bronkhorst Spruit, Loskop, Misverstand and Bon Accord Dams by the year 2000, assuming either no phosphate control of a 1 mg P/l standard being introduced in their

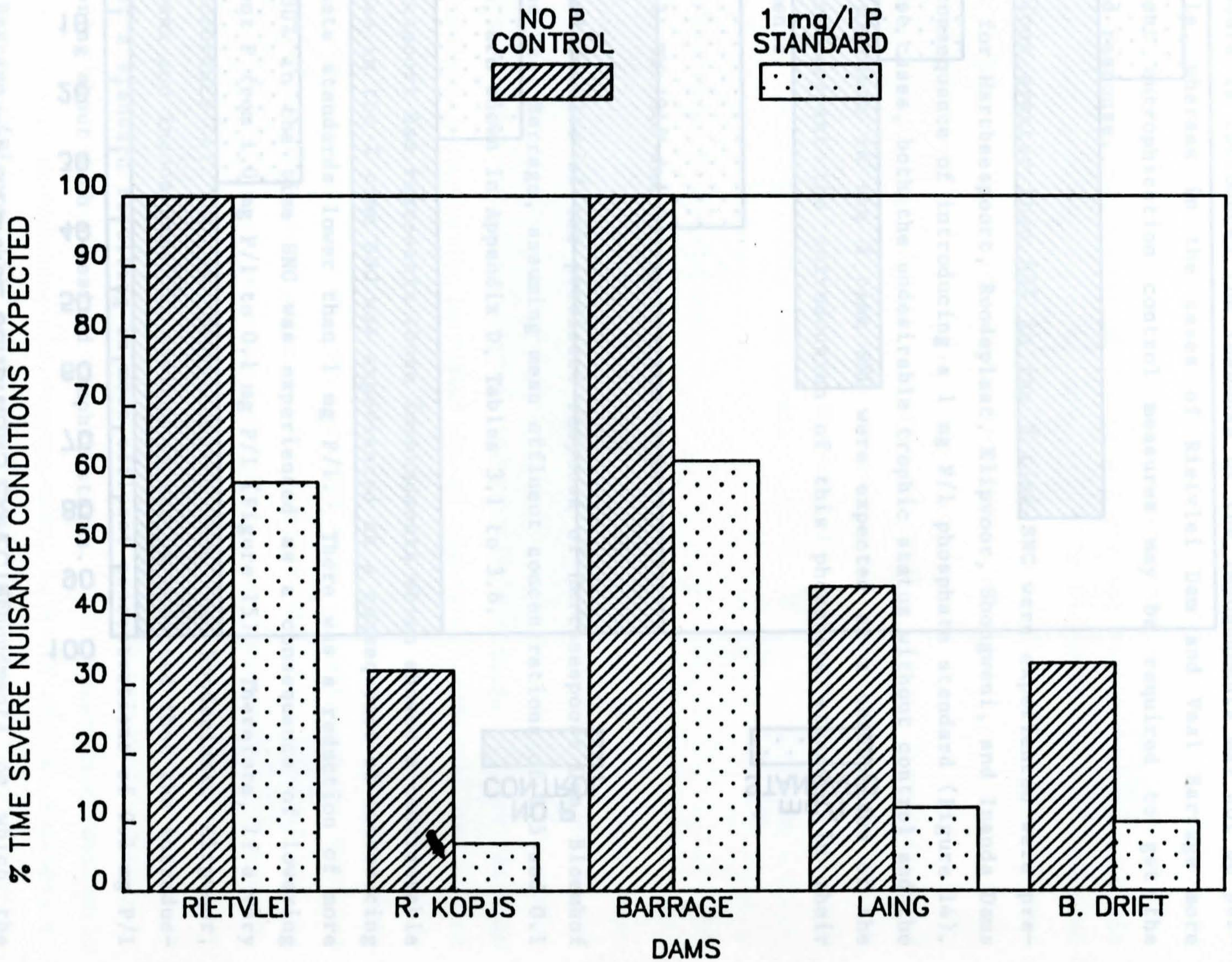

Figure 13: Comparison of the percentage time severe nuisance conditions can be expected in Rietvlei, Roodekopjes, Vaal Barrage, Laing and Bridle Drift Dams by the year 2000, assuming either no phosphate control of a 1 mg P/l standard being introduced in their catchments.

Figure 14: Comparison of the percentage time severe nuisance conditions can be expected in Hartbeespoort, Roodeplaat, Klipvoor, Shongweni and Inanda Dams by the year 2000, assuming either no phosphate control or a 1 mg P/l standard being introduced in their catchments.

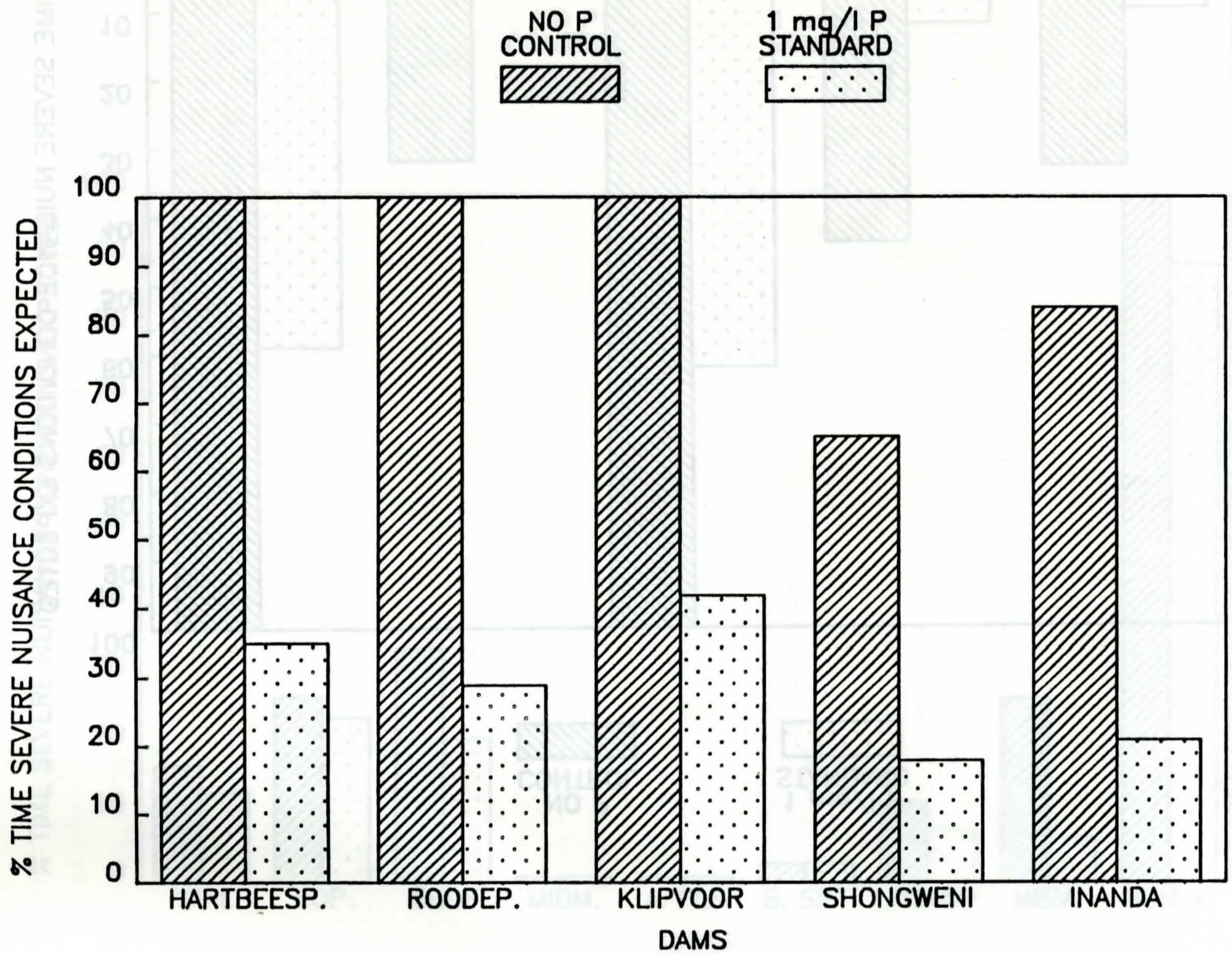

Figure 14: Comparison of the percentage time severe nuisance conditions can be expected in Hartbeespoort, Roodeplaat, Klipvoor, Shongweni and Inanda Dams by the year 2000, assuming either no phosphate control or a 1 mg P/l standard being introduced in their catchments.

because their status without phosphate control was not highly eutrophic (e.g. Roodekopjes, Laing and Bridle Drift Dams) or because they received such large nutrient loads that the standard was not stringent enough to cause a large reduction in trophic status (e.g. Rietvlei Dam and Vaal Barrage). The % time SNC were expected in the cases of Roodekopjes, Laing and Bridle Drift Dams may not warrant the introduction of a standard or if a standard is introduced the response of the impoundments may not be perceptible, whereas in the cases of Rietvlei Dam and Vaal Barrage more stringent eutrophication control measures may be required to get the desired response.

Reductions greater than 40% in the % time SNC were experienced were predicted for Hartbeespoort, Roodeplaat, Klipvoor, Shongweni, and Inanda Dams as a consequence of introducing a 1 mg P/l phosphate standard (Figure 14). In these cases, both the undesirable trophic status without control and the large decrease in the % time SNC were expected as a consequence of the standard warrant the introduction of this phosphate standard in their catchments.

5.1.2.2 The 0.5 and 0.1 mg P/l standards

Detailed results of the predicted response of Hartbeespoort Dam, Bloemhof Dam and Vaal Barrage, assuming mean effluent concentrations of 0.5 and 0.1 mg P/l, are shown in Appendix D, Tables 3.1 to 3.6.

Hartbeespoort Dam represents those impoundments which showed a considerable response in the % time SNC was experienced as a consequence of introducing phosphate standards lower than 1 mg P/l. There was a reduction of more than 30% in the time SNC was experienced as a consequence of lowering effluent P from 1.0 mg P/l to 0.1 mg P/l (Figure 15). Therefore, if a very low occurence of SNC in Hartbeespoort Dam (or Roodeplaat, Klipvoor, Shongweni and Inanda Dams) is desired it can be expected that the introduction of a standard resulting in mean effluent concentrations of 0.1 mg P/l will bring about such a desired trophic status.

Vaal Barrage (Figure 15) represents those impoundments on which the phosphate loads are so large that the introduction of very stringent phosphate standard would be required to reduce the time SNC is expected to acceptable levels. SNC were expected for more than 30% of the time

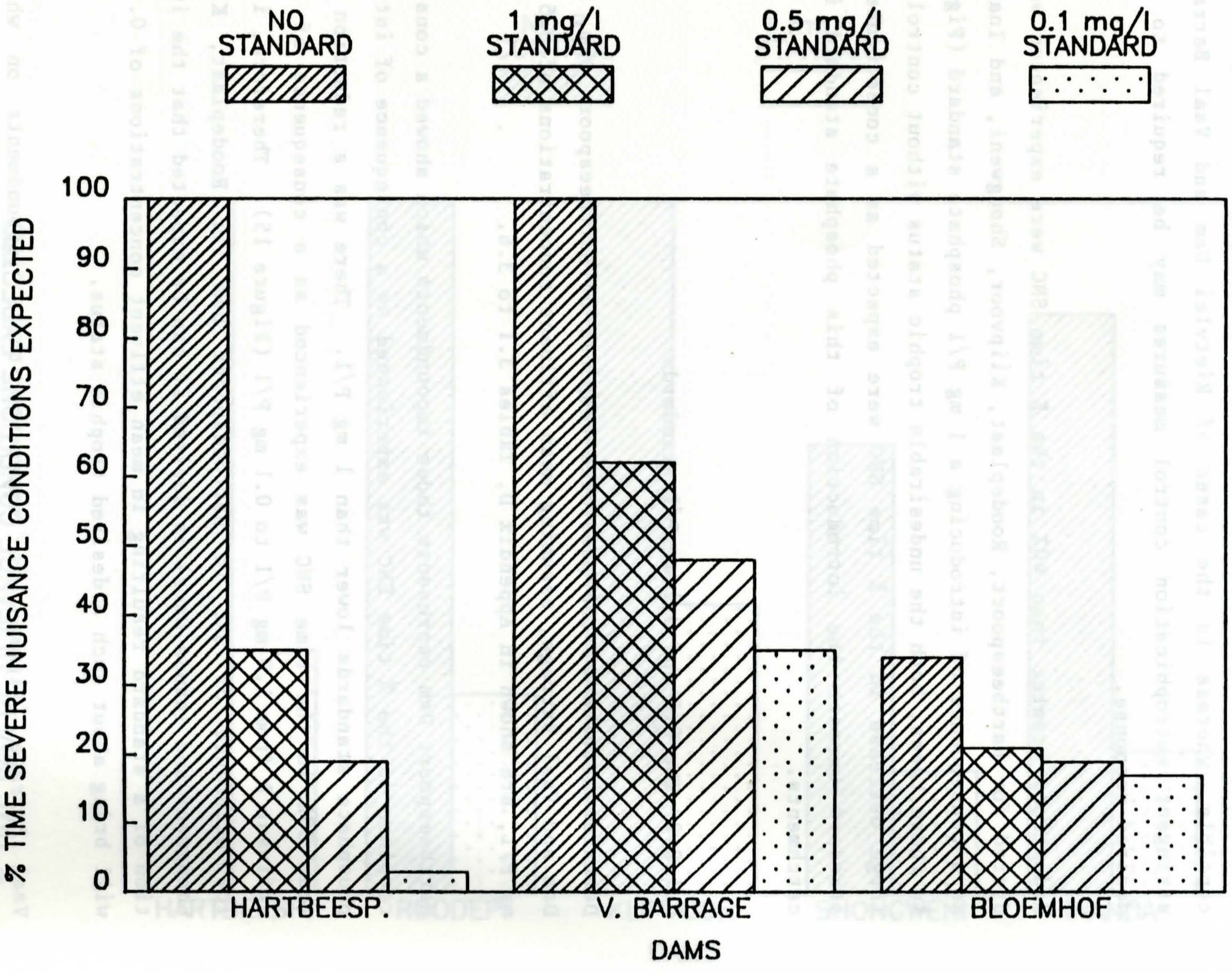

Figure 15: Comparison of the consequences by the year 2000 of no eutrophication control to the introduction of 1.0, 0.5 and 0.1 mg P/l standards in the catchments of Hartbeespoort Dam, Vaal Barrage and Bloemhof Dam.

assuming mean annual effluent concentrations as low as 0.1 mg P/l. However, taking into account that with mean effluent concentrations at 1 mg P/l SNC were expected for more than 60% of the time the introduction of more stringent standards in the catchment of Vaal Barrage is warranted. The same conclusion would apply to Rietvlei and Bon Accord Dams (see Figure 13).

Bloemhof Dam represents those impoundments that showed little response to the introduction of phosphate standards lower than 1 mg P/l (Figure 15). Mean effluent concentrations of 0.1 mg P/l did not result in a perceptible change in the % time SNC were experienced in Bloemhof Dam and the same could be expected for Vaal, Koppies, Midmar, Albert Falls, Bronkhorst Spruit, Loskop and Misverstand Dams (see Figure 12).

In Roodekopjes, Laing and Bridle Drift Dams (Figure 13) the introduction of more stringent effluent standards prior to the year 2000 would not be warranted because the 1 mg P/l standard reduced the % time SNC were experienced to sufficiently low levels.

5.1.3 Detergent Phosphate Control

The effects of a eutrophication control strategy based on detergent phosphate control, rather than a reduction of the phosphate content of effluents, were demonstrated for Hartbeespoort Dam (which showed a marked response to the introduction of phosphate standards), Vaal Barrage (intermediate response to introduction of standards) and Vaal Dam (which showed little response to introduction of standards). The effects of different levels of detergent phosphate control i.e. reducing the phosphate content of detergents by 50, 80 and 100% were investigated. Detailed results of the predicted effects of detergent phosphate removal on the trophic status of these selected impoundments are provided in Appendix D, Tables 5.1 to 5.9. When the effects of detergent phosphate removal were compared with the situation where no eutrophication control measures were taken (Figure 16) it was clear that even 100% phosphate removal had no perceptible effect on impoundment trophic status. We expect this conclusion to apply to all impoundments and suggest that, in South Africa, eutrophication could not be prevented by controlling detergent phosphate only. Nonetheless control of detergent phosphates could have an impact on the total phosphate load in the water environment and may play a supporting role in a strategy to reduce phosphate at source.

Figure 16: Comparison of the consequences by the year 2000 of no eutrophication control to the introduction of 50, 80 and 100% detergent phosphate removal in the catchments of Hartbeespoort Dam, Vaal Barrage and Vaal Dam.

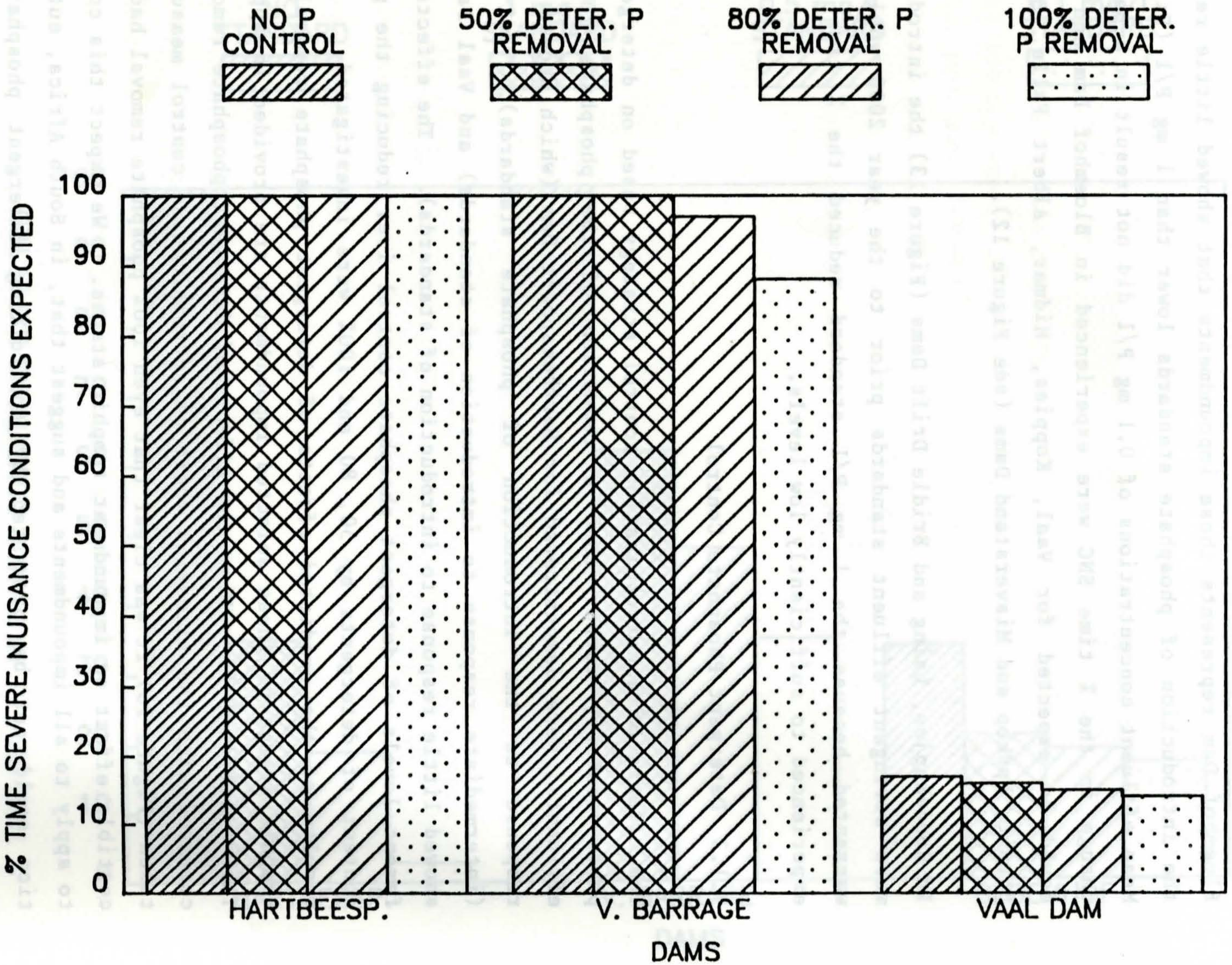

Figure 16: Comparison of the consequences by the year 2000 of no eutrophication control to the introduction of 50, 80 and 100% detergent phosphate removal in the catchments of Hartbeespoort Dam, Vaal Barrage and Vaal dam.

5.1.4 Nitrogen limitation

Nitrogen, and not phosphate, may sometimes control the trophic response of impoundments. The three impoundments most likely to be N-limited namely Rietvlei, Hartbeespoort and Roodeplaat Dams, were selected for this investigation. Detailed predictions of N:P ratios as a consequence of introducing the 1 mg P/l standard are given in Appendix D, Tables 6.1 to 6.3. N:P ratios before the introduction of phosphate control measures (1981) were considerably below the balanced ratio of 7:1 (Figure 17). After the introduction of control measures (1990, 2000) the situation in Hartbeespoort and Roodeplaat Dams was reversed and the predicted ratio exceeds 7:1, implying potential phosphate limitation. In Rietvlei Dam the N:P ratios reached only about 6:1 and 5:1 by 1990 and the year 2000 respectively.

As the volume of effluents increased from 1990 to 2000 (Appendix D, Tables 6.1 to 6.3) the N:P ratios decreased again (Figure 17). It can, however, be expected that by the time phosphate loads have increased to levels where nitrogen may again become limiting, the trophic status of impoundments would be such that additional phosphate control measures would be required to prevent excessive eutrophication.

We concluded that the introduction of phosphate control measures resulting in mean effluent concentrations equal to or lower than 1 mg P/l will result in phosphate being the limiting nutrient even in those impoundments which are at present nitrogen limited. We are therefore fairly confident that impoundments will respond according to the OECD chlorophyll-phosphate relationship (Figure 8) that was used to predict the response of impoundments for the purposes of this study.

5.1.5 Effect of runoff

Runoff affects both the hydrology of impoundments and non-point source phosphate loads (Grobler and Silberbauer, 1984). The effects of runoff on impoundment trophic status were demonstrated by calculating mean annual phosphate concentrations in Hartbeespoort Dam, Vaal Dam and Vaal Barrage. The combined effect of assuming different annual runoff volumes (expressed as a fraction of MAR) and different point source loads (along the time axes) on mean annual phosphate concentrations are displayed in Figures 18, 19 and 20. Phosphate concentrations increased slowly with time as a

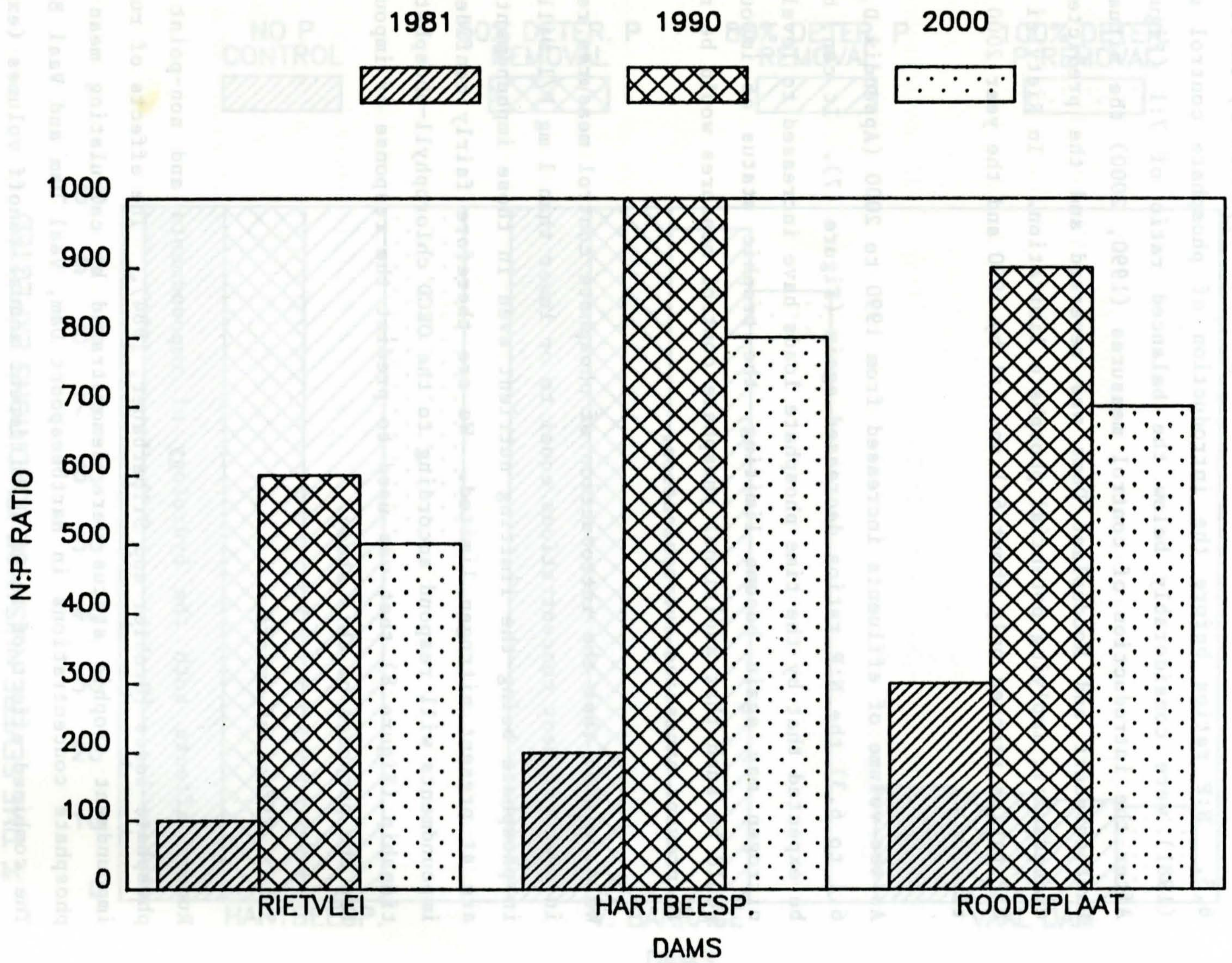

Figure 17: N:P ratios in Rietvlei, Hartbeespoort and Roodeplaat Dams now (1981) and after the introduction of the phosphate standard (1990, 2000).

result of increasing effluent volumes, but then experienced a sudden drop between 1985 and 1986 as a result of the introduction of the 1 mg P/l phosphate standard.

Hartbeespoort Dam and Vaal Barrage, both dominated by very large point source loads (Appendix D, Tables 4.1 and 4.6) responded in a similar manner to runoff. The effect of increased runoff was to dilute the phosphate concentration in the impoundment and the larger the point source load the more dramatic were the effects of dilution on phosphate concentrations in the impoundments. For example increasing runoff from 0.1 to 2 MAR under 1985 conditions (before standard was applied) resulted in 21% (Hartbeespoort Dam) and 79% (Vaal Barrage) reductions in mean annual phosphate concentrations. However, a similar increase in runoff under conditions in the year 2000 (after the standard was applied) reduced phosphate concentrations only by 8% (Hartbeespoort Dam) and 56% (Vaal Barrage). The relatively small effect of the introduction of the standard when runoff equals 2 MAR compared to the much more pronounced impact when runoff equals 0.1 MAR illustrates the effect of runoff on eutrophication control measures. This effect was especially obvious for Vaal Barrage with its high flushing rate. For example when runoff was assumed to be equal to 0.1 MAR the introduction of the phosphate standard resulted in a drop of 74% (Hartbeespoort Dam) and 65% (Vaal Barrage) in mean annual phosphate concentrations comparing 1985 to the year 2000. However assuming runoff equal to 2 MAR resulted in a 70% (Hartbeespoort Dam) and 25% (Vaal Barrage) drop in mean annual TP concentrations as a consequence of introducing a phosphate standard.

Vaal Dam (Figure 19) represents systems in which non-point source phosphate plays an important role and sometimes dominates the response of impoundments. At low runoff (0.1 MAR), point sources contributed significantly to the total load, consequently the effect of the introduction of the phosphate standard was a noticeable 43% decrease in mean annual phosphate concentration from 1985 to the year 2000. However, as runoff increased, the proportional contributions by point sources to the total load became smaller and the decrease in mean annual phosphate concentrations between 1985 and 2000 amounted to only 9% assuming runoff equal to 1 MAR and 5% at 2 MAR. An unusual feature of Vaal Dam's response to runoff was the minimum in mean annual phosphate concentrations reached when runoff was assumed equal to 1 MAR. This was the result of the combined effects of dilution of the point sources and the increase in non-point loads as a result of increased runoff.

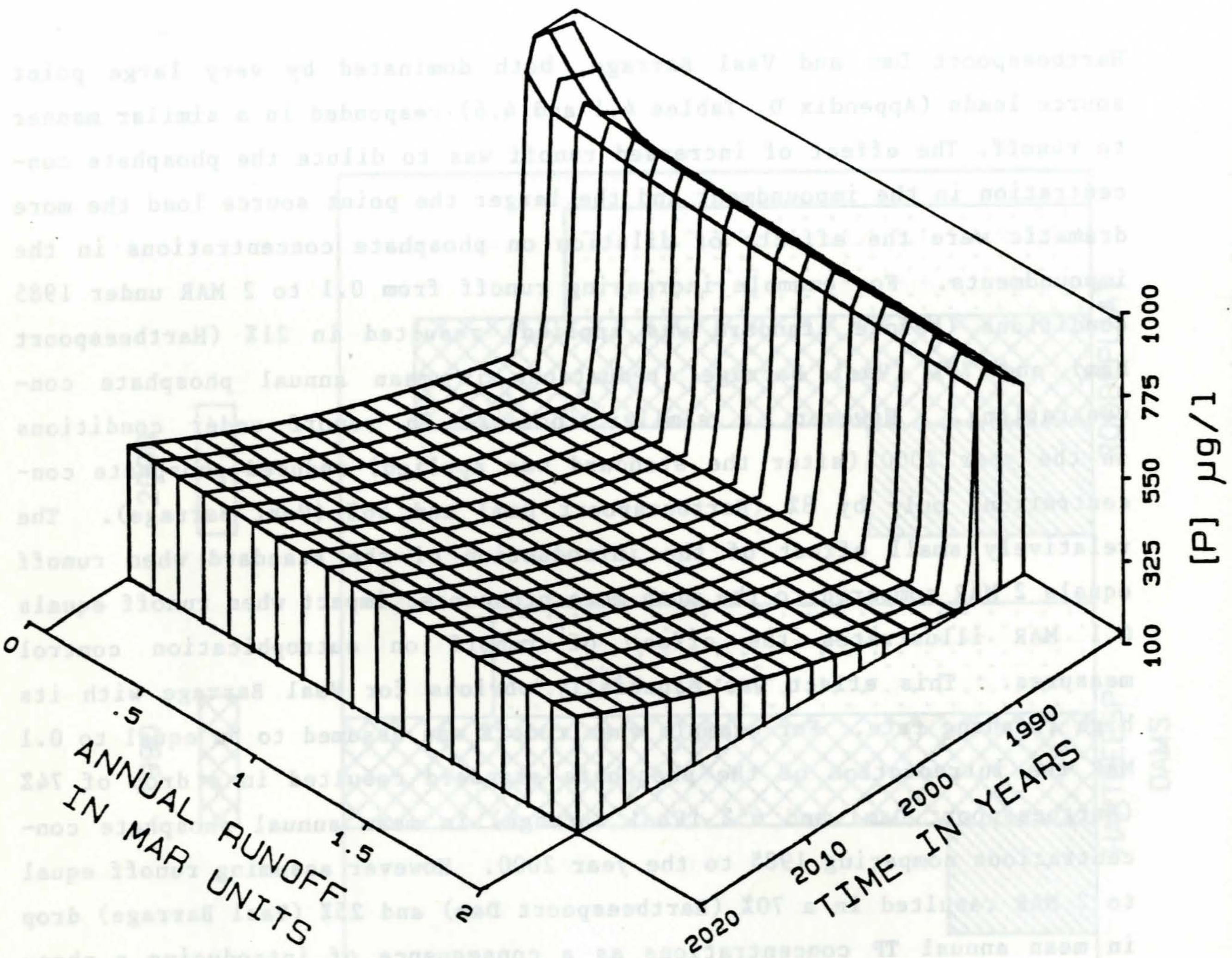

Figure 18: Response surface of mean annual local phosphate concentration in Hartbeespoort Dam as a function of time and runoff. Time indicates the changes in total phosphate loads derived from point sources caused by introduction of a standard in 1985 and a 5% per annum growth in sewage effluent volumes. Runoff indicates changes in total phosphate loads derived from non-point sources and changes in annual mean impoundment volume.

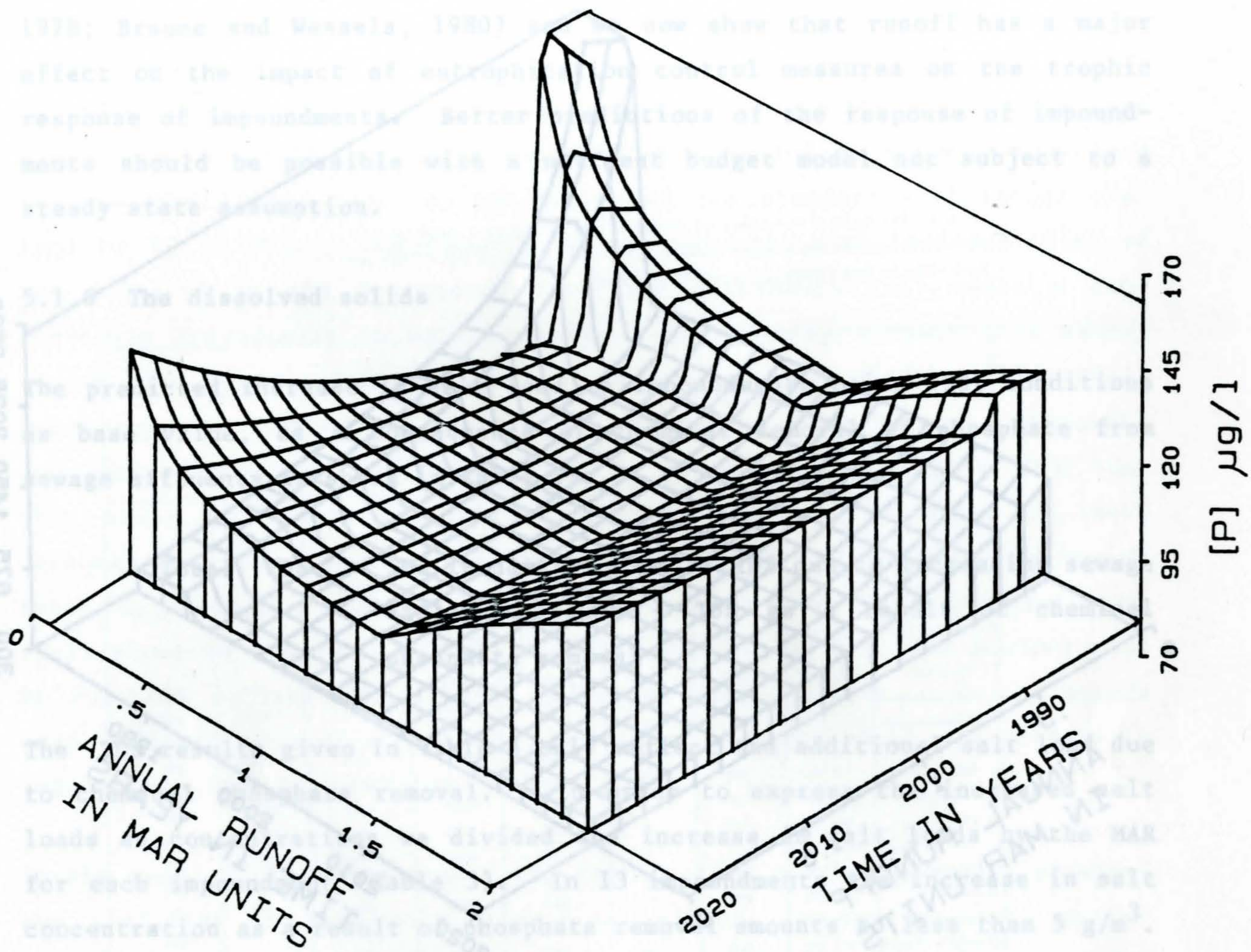

Figure 19: Response surface of mean annual local phosphate concentration in Vaal Dam as a function of time and runoff. Time indicates the changes in total phosphate loads derived from point sources caused by introduction of a standard in 1985 and a 5% per annum growth in sewage effluent volumes. Runoff indicates changes in total phosphate loads derived from non-point sources and changes in annual mean impoundment volume.

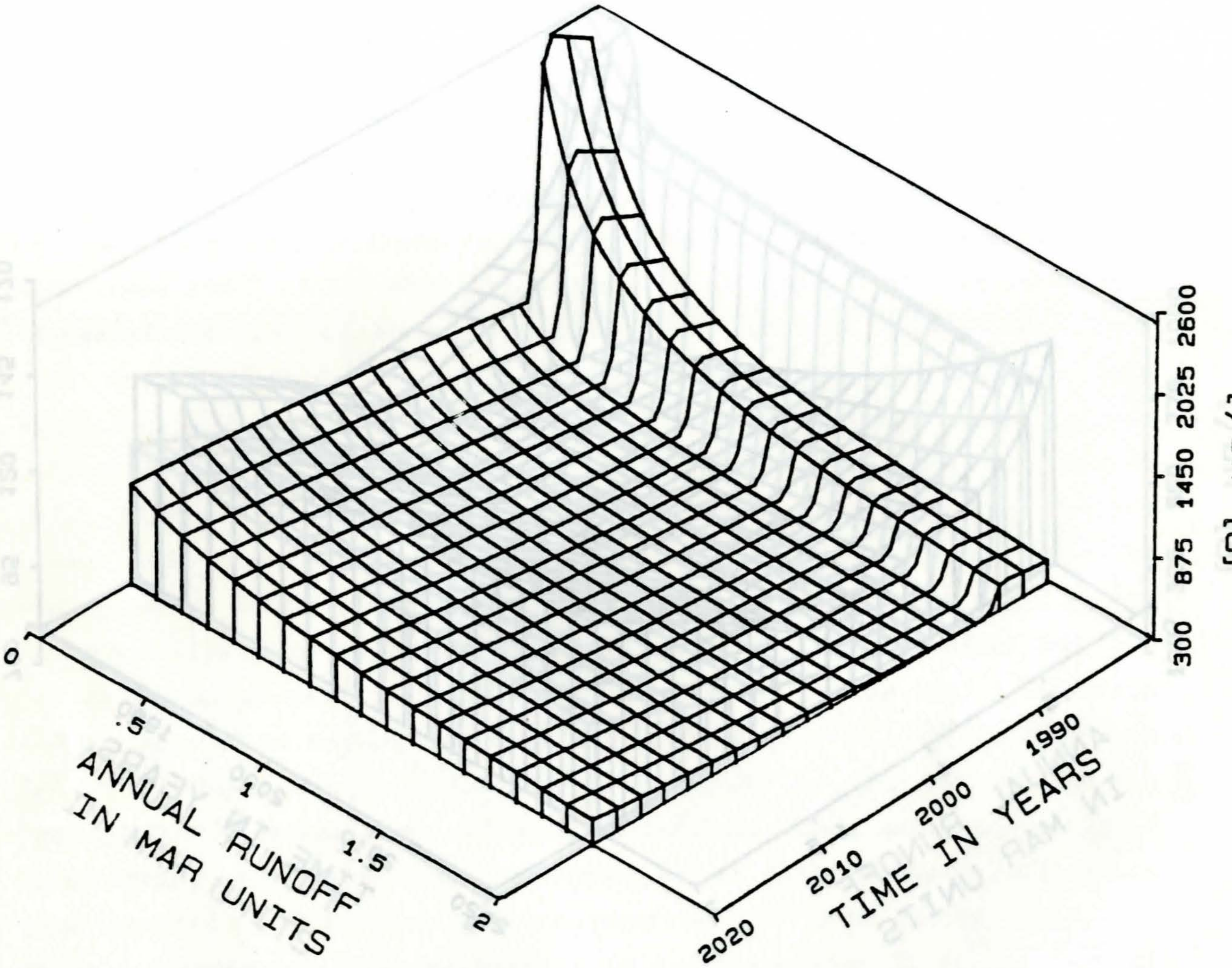

Figure 20: Response surface of mean annual local phosphate concentration in Vaal Barrage as a function of time and runoff. Time indicates the changes in total phosphate loads derived from point sources caused by introduction of a standard in 1985 and a 5% per annum growth in sewage effluent volumes. Runoff indicates changes in total phosphate loads derived from non-point sources and changes in annual mean impoundment volume.

These results demonstrate a serious limitation of the OECD modelling approach which is introduced by the steady state assumptions made. Runoff in South Africa is highly seasonal and highly variable (Schulze and McGee, 1978; Braune and Wessels, 1980) and we now show that runoff has a major effect on the impact of eutrophication control measures on the trophic response of impoundments. Better predictions of the response of impoundments should be possible with a nutrient budget model not subject to a steady state assumption.

5.1.6 The dissolved solids

The predicted increase in salt load on impoundments using 1981 conditions as base value, as a consequence of chemical removal of phosphate from sewage effluents is shown in Table 3.

Total TDS = TDS in natural flow + TDS due to increasing sewage effluent volume + TDS as a result of chemical phosphate removal

The TDS results given in Table 3 only reflect the additional salt load due to chemical phosphate removal. In order to express the increased salt loads as concentrations we divided the increase in salt loads by the MAR for each impoundment (Table 3). In 13 impoundments the increase in salt concentration as a result of phosphate removal amounts to less than 5 g/m^3. Rietvlei, Hartbeespoort, Bon Accord, Roodeplaat and Klipvoor Dams are predicted to experience increased salt concentrations of 9 to 30 g/m^3 between now and the year 2000 as a consequence of phosphate removal from effluents. These are also the impoundments which receive large and increasing sewage effluent volumes and although we do not have the data to show this, we believe that the increase in salt concentrations due to phosphate removal will be insignificant compared to increased salt concentrations resulting from increased sewage and industrial effluents.

Table 3: Estimates of the effect of increased salt loading as a consequence of removing phosphate from sewage effluents on the total dissolved salts (TDS) concentration in impoundments in sensitive catchments.

Dam name	Present state 1981		Future Projections 1985		1995		2000	
	Total TDS load (tons/a)	TDS concentration in dam (mg/l)	Sewage TDS load (tons/a)	TDS concentration in dam (mg/l)	Sewage TDS load (tons/a)	TDS concentration (mg/l)	Sewage TDS load (tons/a)	TDS concentration in dam (mg/l)
1 Rietvlei	11 400	285	625	348	556	341	1195	404
2 Hartbeespoort	58 500	401	3856	423	4114	424	4577	427
3 Roodekopjes*	-	-	0	-	0	-	0	-
4 Bon Accord	41 500	525	1073	763	667	673	735	688
5 Roodeplaat++	9 800	287	299	294	90	289	113	290
6 Klipvoor	77 000	500	2066	548	3098	571	3872	598
7 Vaal	384 000	172	710	172	722	172	893	172
8 Vaal Barrage	1386 000	630	5112	720	5994	736	7311	759
9 Koppies	24 000	219	16	219	3	219	30	220
10 Bloemhof	864 000	402	1755	404	1828	404	2023	404
11 Laing	24 000	464	77	468	77	468	77	468
12 Bridle Drift	42 000	293	127	295	38	294	48	294
13 Shongweni	9 300	194	-	-	-	-	-	-
14 Midmar	8 200	60	0	60	0	60	0	60
15 Albert Falls	15 200	59	1.5	59	0.5	59	566	64
16 Inanda*	-	-	409	-	126	-	724	-
17 Bronkhorstspruit	7 100	174	0	174	0	174	0	174
18 Loskop	70 500	152	78	152	37	152	46	152
19 Misverstand*	62 200	118	484	120	731	122	912	122

* dams not completed

\- no data available

++ planned new sewage works not included

5.2 Discussion

5.2.1 The impact of the phosphate standard

The promulgation of a 1 mg P/l standard was based on the assumptions that sewage and industrial effluents contributed 60 to 80% of the phosphate load on impoundments and that implementation of the standard will reduce that load by 80 to 90%. Consequently it was expected that implementation of the standard in the designated sensitive catchments will cause a considerable improvement in water quality. Our results support this expectation for eight of the nineteen impoundments studied. Rietvlei, Hartbeespoort, Bon Accord, Roodeplaat, Klipvoor, Vaal Barrage, Shongweni and Inanda Dams were predicted to be so eutrophic by the year 2000 that they would definitely require eutrophication control measures in their catchments to prevent a serious deterioration of water quality. In two of these impoundments phosphate standards resulting in mean effluent concentrations as low as 0.5 (Vaal Barrage) and 0.1 mg P/l (Bon Accord) will be required to have a noticeable effect on water quality. In the others mean effluent concentrations of 1 mg P/l will bring about a considerable improvement in water quality.

In the rest of the impoundments the introduction of the phosphate standard was predicted to have only a marginal effect, or none at all, on eutrophication-related water quality because one of the assumptions on which the standard was based, namely that 60 to 80% of the phosphate load originates from point sources, was not correct. Five of the impoundments studied (Vaal, Midmar, Albert Falls, Bronkhorst Spruit, and Loskop Dams) received such small loads, that they require no eutrophication control measures. In the remainder (Roodekopjes, Koppies, Bloemhof, Laing, Bridle Drift and Misverstand Dams) a certain degree of eutrophication is expected by the year 2000, but the proportion of the total phosphate load controllable at point sources is so small that in three of them (Roodekopjes, Laing and Bridle Drift) the standard is expected to have only marginal effects and in the others (Koppies, Bloemhof and Misverstand Dams) it is expected to have no effect.

5.2.2 A uniform standard for sensitive catchments

Pretorius (1983) and Toerien (personal communication) doubted the wisdom of applying a uniform phosphate standard in all sensitive catchments. They argued that differences in the capacity of impoundments to absorb phosphate loads and the small contributions made by point sources to total loads in some of the sensitive catchments were ignored. Our results support these arguments. We show that in some systems the capacity to absorb phosphate will be exceeded many times by the expected phosphate loads and that standards resulting in mean effluent concentrations of 0.5 mg P/l or less would be required to bring about a perceptible change in the trophic status of such impoundments (Bon Accord and Vaal Barrage). In other systems the carrying capacity of the impoundments is such that a mean effluent concentration of 1 mg P/l will bring about perceptible changes (e.g. Roodeplaat, Hartbeespoort, Shongweni). Systems such as Bloemhof Dam have a considerable reserve capacity to absorb phosphate without becoming eutrophic and therefore it is unlikely that the introduction of a standard will bring about a perceptible change in their trophic status.

The introduction of a uniform standard is clearly not the best strategy to control eutrophication-related water quality problems. We recommend that consideration should be given to imposing more stringent limits in some catchments and relaxing the present standard in others.

5.2.3 Detergent phosphate ban versus treatment of effluents

Different options for combining detergent phosphate removal and phosphate removal from effluents into a phosphate control strategy are available (Pretorius, 1983; Heynike and Wiechers, 1984). We compared the two ends of the scale, namely detergent phosphate removal only versus effluent treatment only. The treatment of effluents was clearly more effective because a standard of 1 mg P/l will bring about an 80 to 90% reduction in the phosphate load from sewage works. Detergents are responsible for only 50 to 60% of the phosphate reaching sewage works (Pretorius, 1983; Heynike and Wiechers, 1984), consequently a total ban on detergent phosphate can reduce the phosphate load by at most 50 to 60%, which is not enough to bring about perceptible changes in the water quality of highly eutrophic systems. Of the two options considered in this study only effluent treatment is predicted to be a satisfactory phosphate control measure.

5.2.4 Cross sectional and time series models

The concepts of cross sectional and time series models emerge from the data base used for model development and calibration. A cross sectional model compares cases, for example the OECD nutrient budget model describes the response to nutrient inputs of a cross section of lakes and reservoirs throughout the world. In contrast, time series models describe the behaviour of a single system over time. It was due to a lack of time series data (and a lack of time: it takes many years to get a time series record) that the OECD modelling approach was chosen.

The application of a cross sectional model to simulate a time series response of an individual impoundment (as was done in this study), implies that all water bodies behave essentially in an identical manner (Reckhow and Chapra, 1983). However, it is known that water bodies have both unique and common (shared by other systems) characteristics (Reckhow et al.,1980). Therefore the validity of applying a cross sectional model to simulate time series responses is questionable (Kenney, 1983; Reckhow and Chapra, 1983) and results in additional uncertainty in the predictions. Reckhow and Chapra (1983) concluded that one model can rarely be applicable to the entire population of lakes and reservoirs in the world and usually must be restricted to an appropriate subpopulation of reservoirs or lakes. The more precisely that subpopulation is specified the lower the risk of misapplication of the model (Reckhow and Chapra, 1983).

Reservoirs may be regarded as a subpopulation of the large population of freshwater bodies in the world. Generally, they have some unique features which make a cross section of reservoirs different from a cross section of natural lakes (Thornton et al., 1980; Canfield and Bachman, 1981; Higgens and Kim, 1981; Walker, 1982; Grobler, 1984b). The causes of the differences in behaviour of reservoirs from that of natural lakes are uncertain and may be due to both regional and other factors. Regional factors are recognised because most reservoirs tend to be located in areas where few natural lakes occur (Walker, 1982). Other factors are differences in hydrodynamics, sedimentation and morphometry (Thornton et al.,1980). However these differences must not be used to prejudge the likely response of a particular water body based on whether it is a lake or reservoir because lakes and reservoirs with similar morphometry, hydrology and regional influences can be expected to behave in a similar manner (Lee and Jones, 1982).

We treated South African impoundments as a subpopulation of the larger population of lakes and reservoirs in the world because they share a unique combination of regional influences and morphological characteristics. Some of the obvious regional factors are the semi-arid climate (Schulze and McGee, 1978) and highly variable rainfall resulting in highly variable runoff (Braune and Wessels, 1981). South African impoundments can all be described morphologically as river run lakes (long and narrow) because they resulted from the construction of dams in rivers. Most reservoirs are also relatively shallow as indicated by mean depths for 260 impoundments, which range from 1 to 40 m (median = 5 m) (Bruwer unpublished data). The hydraulic loads on South African reservoirs are remarkably similar because most are designed to hold between one and two times the mean annual runoff of the rivers they were built in. Therefore, the average water residence time varies little (1.0 to 1.4 year). We assumed that the subpopulation of South African impoundments is sufficiently different from the world population of lakes and reservoirs to warrant the modifications we made to the OECD nutrient budget model to make it more applicable to local conditions. We believe that these modifications resulted in more realistic simulations (reduced uncertainty) of the time series response of South African reservoirs.

5.2.5 Application of the results

This study is a first attempt at quantifying the impact of phosphate control measures on impoundments in sensitive catchments. As such it may serve as a guide to water resources managers for decision making concerning eutrophication control. However the potential user of this report is cautioned to carefully scrutinise the assumptions we made and to make sure that all these assumptions (see Chapters 3 and 4) are in fact valid for his specific application.

In our predictions we did not use all the data that may be available for any particular catchment impoundment system because we had to come up with predictions for many impoundments in a limited time. We therefore recommend that for actual application of the standard in catchment-impoundment systems fresh attempts should be made to obtain all the relevant data. Any new data which may become available should be used to verify assumptions and to update predictions of the response of impoundments to proposed eutrophication control measures. Nutrient budget models not subject to the steady state assumption and which also use a more realistic sedimentation submodels are being developed (Grobler, 1984b). From preliminary studies it is recommended that these models should be used in future for predicting the response of impoundments to eutrophication control measures as they allow the effect of variable runoff to be taken into account.

6. RESEARCH AND MONITORING REQUIREMENTS

This summary is not intended to be a complete list of research and monitoring requirements in the field of modelling eutrophication related water quality. It is rather a list of what we found in our particular application of the OECD modelling approach to be the most serious limitations to making reliable predictions which are at the same time useful in the context of water resources management.

6.1 Research requirements

6.1.1 Appropriate water quality variable

The most serious limitation to the development and application of eutrophication models is the poor definition of appropriate water quality variables and lack of quantitative relationships between eutrophication-related water quality variables and eutrophication-related water quality problems. A high priority should be given to research directed at addressing these problems.

6.1.2 Uncertainty analysis

A serious shortcoming of this study is that it did not quantify the uncertainty associated with predictions. It may be argued that management requirements in South Africa are presently not sophisticated enough to warrant uncertainty analysis. However, we are convinced that decision makers will soon require uncertainty statements to accompany predictions. Research directed at developing such an error analysis procedure for the OECD modelling approach or any future modifications of it should be undertaken and the sensitivity of management decisions to uncertainty in the predictions should be investigated.

6.1.3 OECD Modelling approach

Several shortcomings of the OECD modelling approach emerged during its application in this study. Critical shortcomings in each of the components of the OECD eutrophication modelling approach are listed seperately below:

6.1.3.1 Nutrient loads

South African rivers were shown to be event-response rivers for which event-oriented monitoring programmes would be required to estimate nutrient loads accurately. At the same time we realise that event-oriented monitoring will probably only be made possible by automated sampling with all its accompanying problems. We therefore recommend that research is undertaken to quantify the gains in accuracy of load estimates that could be achieved by event-orientated monitoring compared to fixed interval monitoring in order to indicate whether event-orientated monitoring programmes are justified.

We used the concept that nutrient export is a function of both runoff and geology rather than land-use. This concept needs further exploration and if found valid in general, an effort should be made to obtain the data required to delineate regions in South Africa with equal nutrient export per unit area per unit runoff.

The whole question of bio-availability of phosphate remains to a large degree unanswered. The bio-availability of particulate phosphate can be determined fairly easily by means of bio-assay techniques and has been done locally (Grobler and Davies, 1979; 1981) and elsewhere (DePinto et al., 1980; Rast and Lee 1983). The problem is to determine how much and which fraction of the particulate load reaching an impoundment actually stays suspended long enough in the euphotic zone to act as a source of bio-available phosphate. This question is specially important in South Africa where many impoundments receive relatively large particulate phosphate loads. Another problem is the conversion in rivers of soluble phosphate originating from point sources to particulate phosphate. Research programmes to resolve these problems should be initiated.

6.1.3.2 Nutrient budgets for impoundments

There are clear indications that most South African impoundments are river-run systems, typically with strong gradients in nutrient and chlorophyll concentrations from inlet to outlet. They also have fairly uniform but short water residence times and vary considerably in volume because inflow exceeds the draft during wet periods and draft exceeds inflows during the dry season. These characteristics of South African reservoirs render invalid the steady state and complete mixing assumptions, central in the development of the OECD nutrient budget model. Research directed at investigating ways to accomodate the lack of complete mixing and dynamic state of local impoundments, without doing away with the essential simplicity of the OECD nutrient budget model, should be encouraged.

Research done concurrently with this project (Grobler, 1984b) indicated that the rates of sedimentation loss of phosphate in some impoundments were a function of phosphate concentration in the impoundment rather than constant (as assumed in this study) or a function of the water residence time as assumed in the OECD nutrient budget model. This conclusion has important implications for the processing of phosphate in impoundments and consequently the response of impoundments to phosphate control measures. Further research to validate the concept of a concentration dependent sedimentation rate should be undertaken.

6.1.3.3 Trophic status - nutrient concentration relationships

Assuming that chlorophyll concentrations are the best way in which to express eutrophication-related water quality the research needs in this section will refer to chlorophyll-related parameters only. However it must be realized that chlorophyll may not be the best representation of appropriate water quality variables (see section 6.1.1). When selecting a chlorophyll-related variable we were faced with three types of possible responses, namely maximum chlorophyll which could be either a power function or linear function of mean annual chlorophyll, and the percentage time severe nuisance conditions can be expected, which is initially a linear function of mean annual chlorophyll but reaches a saturation level (see Figure 2). Conclusions about the effectiveness of phosphate control measures depend on which of these responses is considered. Every application of the OECD modelling approach has to assume one of the above responses, therefore research to identify which of these responses is most appropriate has to be undertaken.

If nutrient budget models that can simulate the seasonal distribution of phosphate concentrations in impoundments are developed, a logical extension of the OECD nutrient - chlorophyll model would be the development of relationships between seasonal nutrient concentrations and seasonal chlorophyll concentrations. Water transparency may influence chlorophyll-nutrient relationships and water transparency shows seasonal changes, so the effect of transparency is just one variable that might be incorporated into such chlorophyll-nutrient relationships.

6.2 Monitoring

A fair proportion of potentially useful data could not be used in this study because contemporaneous flow and concentration data were not available for many river and dam stations. This problem should be fairly easy to correct as flow data in many cases may become available in future.

A more serious problem is the monitoring of total phosphate concentrations for which the dissolved and particulate fractions may have to be determined separately. Total phosphate determinations are tedious and difficult, consequently only limited numbers of samples will as a rule be analysed for total phosphate. Important catchments and impoundments should be identified and monitored regularly as well as on an event basis. Chemical monitoring and working up of flow records should be co-ordinated to ensure contemporaneous availability of flow and phosphate data.

A possible reason for poorly defined appropriate eutrophication-related water quality variables is the lack of measured chlorophyll data in water purification intakes and at heavily used recreational sites. An effort should be made to persuade all those operating water purification plants and responsible for recreational use of water to monitor chlorophyll concentrations and the occurrence of other problem conditions. Development of such a data base could make a large contribution towards resolving our present problems with relating eutrophication-related problems to eutrophication-related water quality.

The most useful contribution to the predicting of eutrophication-related water quality that can be made by monitoring is a better co-ordination of existing monitoring efforts rather than monitoring additional sites.

7. SUMMARY

1. The impact of the 1985 phosphate standard for sensitive catchments on the trophic status of impoundments was predicted to be large in eight, marginal in three and imperceptible in eight of the nineteen impoundments studied.
2. There is no justification for a uniform phosphate standard for all sensitive catchments. In some cases (e.g. Bon Accord and Vaal Barrage) more stringent standards are required whereas in other cases no eutrophication control measures are required.
3. A phosphate control strategy based on treatment of effluents to comply with a specified standard is expected to control eutrophication effectively whereas a strategy based only on banning phosphate based detergents is not.
4. It is predicted unlikely that, after the introduction of phosphate control measures, the trophic status of impoundments will be limited by nitrogen rather than phosphate. Consequently impoundments are expected to respond to phosphate control measures.
5. The hydrological regime (above or below average runoff, varying impoundment volume) had a marked effect on the predicted response of impoundments. This suggests that the steady state assumption of the OECD nutrient budget model may seriously limit its applicability to South African impoundments.
6. Future developments in and present applications of eutrophication-related water quality modelling is limited by the lack of appropriate quantitatively-defined water quality variables which are directly linked to the water purification, health and aesthetic problems associated with eutrophic impoundments.

REFERENCES

ASHTON, P.J. 1981 Nitrogen fixation and the nitrogen budget of a eutrophic impoundment. Wat. Res., 15: 823-833

BACHMANN, R.W. 1980 Prediction of total nitrogen in lakes and reservoirs. In: Restoration of Lakes and Inland waters International Symposium on inland waters and lake restoration, Sept. 8-12 1980, Portland, Maine, EPA 440/5-81-010, NTIS, Washington D.C.

BENNDORF, J., UHLMANN, D. AND PÜTZ, K. 1981 Strategies for water quality management in reservoirs in the German Democratic Republic. Water Quality Bulletin, 6: 68

BISWAS, A.K. 1975 Mathematical modelling and environmental decision making. Ecol. Modell., 1: 31-48

BRAUNE, E. AND VISSER, A.A. 1981 Flow Characteristics of South African rivers. Unpublished report of the Division of Hydrology, Department of Environment Affairs, Pretoria

BRAUNE, E. AND WESSELS, H.P.P. 1980 Effects of land-use on runoff from catchments and yield of present and future storage. Unpublished Report of the Department of Environment Affairs, Pretoria.

CANFIELD, D.E. AND BACHMANN, R.W. 1981 Prediction of total phosphorus concentrations, Chlorophyll a, and Secchi depths in natural and artificial lakes. Can. J. Fish. Aquat. Sci., 38: 414-423

CHAPRA, S.C. 1982 A budget model accounting for the positional availability of phosphorus in lakes. Wat. Res., 16: 205-209

CORNELIUS, F.P. 1981 Die bedryf van 'n aantal departementele besproeiingsdamme. Unpublished report of the Division of Hydrology, Department of Environment Affairs, Pretoria

CULLEN, P. AND SMALLS, I. 1981 Eutrophication in semi-arid areas: The Australian experience. Water Qual. Bull., 6: 79

DEPINTO, J.V., YOUNG, T.C. AND MARTIN, S.C. 1980 Algal-available phosphorus in suspended sediments from lower Great Lakes tributaries. J. Great Lakes Res., 7: 311-325

GROBLER, D.C. 1984a Estimating nutrient loads in rivers. Unpublished report, Institute for Environmental Sciences, University of the Orange Free State, Bloemfontein

GROBLER, D.C. 1984b Assessment of the impact of eutrophication control measures on South African impoundments. Paper presented at the 4th International Conference of the International Society for Ecological Modelling in Tsukuba, Japan, August 20-25, 1984

GROBLER, D.C. AND DAVIES, E. 1979 The availability of sediment phosphate to algae. Water SA, 5: 114-122

GROBLER, D.C. and DAVIES, E. 1981 Sediments as a source of phosphate: A study of 38 impoundments. Water S.A., 7: 54-60

GROBLER, D.C. AND SILBERBAUER, M.J. 1984 The combined effect of geology, phosphate sources and runoff on phosphate export from drainage basins. Submitted for publication

HEYNIKE, J.J.C AND WIECHERS, H.N.S. 1984 Situation statement on detergent phosphates and their impact on eutrophication in South Africa. Internal Report of the Water Research Commission, Pretoria.

HIGGINS, J.M. AND KIM, B.R. 1981 Phosphorus retention models for Tennessee Valley Authority reservoirs. Wat. Resour. Res., 17: 571-576.

JONES, R.A. AND LEE, G.F. 1982a Recent advances in assessing impact of phosphorus loads on eutrohication-related water quality. Wat. Res., 16: 503-515

JONES, R.A. AND LEE, G.F. 1982b Chlorophyll - a raw water quality para meter. J. Am. Wat. Wks Ass., 74: 490-494

JONES, R.A., RAST, W. AND LEE, G.F. 1979 Relationship between summer mean and maximum chlorophyll a concentrations in lakes. Environ. Sci. & Technol., 13: 869-870

KENNEY, B.C. 1982 Beware of spurious self-correlations! Wat. Resour. Res., 18: 1041-1048

KENNEY, B.C. 1983 On predicting eutrophication. Unpublished Report. Freshwater Institute, Winnipeg, Manitoba

LEE, G.F., AND JONES, R.A. 1982 Comments on Corps of Engineers EWQOS Program. North American Lake Management Society, Lake Line, 2: 3, 14

NOBLE, R.G. AND HEMENS, J. 1978 Inland water ecosystems in South Africa - a review of research needs. South African National Scientific Programmes Report No. 34 CSIR, Pretoria, South Africa

PRETORIUS, W.A. 1983 Should the phosphate concentration in sewage effluents be restricted? IMIESA, 8: 23-29

RAST, W., JONES, R.A. AND LEE, G.F. 1983 Predictive capability of U.S. OECD phosphorus loading-eutrophication response models. J. Wat. Pollut. Control Fed., 55: 990-1003

RAST, W. AND LEE, G.F. 1983 Nutrient loading estimated for lakes. J. environ. Engng Div. Am. Soc. civ. Engrs, 109: 502-517

RECKHOW, K.H. 1983 A method for the reduction of lake model prediction error. Wat. Res., 17: 911-916

RECKHOW, K.H., BEAULAC, M.N. AND SIMPSON, J.T. 1980 Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. EPA 440/5-80-011, NTIS, Washington D.C.

RECKHOW, K.H. AND CHAPRA, S.C. 1983 Engineering approaches for lake management. Volume I: Data analysis and empirical modeling. Butterworth Publishers, Durban

SCHULZE, R.E. AND McGEE, O.S. 1978 Climatic indices and classifications in relation to the biogeography of southern Africa. In: Biogeography and ecology of Southern Africa. Edited by M.J.A. Werger. Junk Publishers, The Hague

SILBERBAUER, M.J. 1983 Variability of hydrological and morphometric characteristics of 19 South African impoundments. Internal report B-N3/0613, Hydrological Research Institute, Dept. Environment. Affairs, Pretoria

SONZOGNI, W.C., CHAPRA, S.C., ARMSTRONG, D.E. AND LOGAN, T.J. 1982 Bioavailability of phosphorus inputs to lakes. J. environ. Qual., 11: 555-563

SONZOGNI, W.C., CHESTERS, G., COOTE, D.R., JEFFS, D.N., KONRAD, J.C., OSTRY, R.C. AND ROBINSON, J.B. 1980 Pollution from land runoff. Environ. Sci. and Technol., 14: 148-153

SONZOGNI, W.C., UTTORMARK, P.C. AND LEE, G.F. 1976 A phosphorus residence time model: Theory and application. Wat. Res., 10: 429-435

SUESS, M.J. 1981 Health aspects of eutrophication. Water Qual. Bull., 6: 63

SUESS, M.J. AND DEAN, R.B. 1980 Health aspects of eutrophication. In: Restoration of lakes and inland waters. EPA 440/5 - 81-010. NTIS, Washington D.C.

SURFACE WATER RESOURCES OF SOUTH AFRICA 1981 Volumes 1 to 6. Prepared for the Water Research Commission by the Hydrological Research Unit, University of the Witwatersrand, Johannesburg

TAYLOR, R., BEST, H.J. AND WIECHERS, H.N.S. 1984 The effluent phosphate standard in perspective. Submitted for publication to IMIESA

THORNTON, K.W., KENNEDY, R.H., CARROLL, J.H., WALKER, W.W., GUNKEL, R.C. AND ASHBY, S. 1980 Reservoir sedimentation and water quality - a heuristic model. Presented at ASCE Symposium on Surface Water Impoundments, June 2-5, 1980 Minneapolis, MN

TOERIEN, D.F. 1977 A review of eutrophication and guidelines for its control in South Africa. Special Report WAT. 48. National Institute for Water Research, CSIR, Pretoria, RSA

TOERIEN, D.F., HAYMAN, C.L. AND BRUWER, M.J. 1975 A preliminary trophic status classification of some South African impoundments. Water S.A., 1: 15-23

VOLLENWEIDER, R.A. 1968 Scientific fundamentals of eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD Paris Tech. Report DAS/DSI/68

VOLLENWEIDER, R.A. 1969 Möglichkeiten und grenzen elementarar modelle der stoffbilanz von seen. Arch. Hydrobiol., 66: 1-36

VOLLENWEIDER, R.A. 1975 Input/output models. Schweiz. Z. Hydrol., 37: 53-84

VOLLENWEIDER, R.A. 1976 Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol., 33: 53-83

VOLLENWEIDER, R.A. 1981 Eutrophication: A global problem. Water Qual. Bull., 6: 59

VOLLENWEIDER, R.A., RAST, W. AND KEREKES, J. 1980 The phosphorus loading concept and Great Lakes eutrophication. In: Proc. 11th Annual Cornell University Conference. Phosphorus Management Strategies for the Great Lakes, April 1979, Rochester, NY Ann Arbor Science Publishers, Ann Arbor, Michigan.

WALKER, W.W. 1982 Empirical methods for predicting eutrophication in impoundments. Phase 2: Model testing. Technical Report E-81-9, prepared for the U.S. Army Waterwys Experiment Station, Vicksburg, Miss.

WALMSLEY, R.D. 1984 A chlorophyll a trophic status classification system for South African impoundments. J. Environ. Qual., 13: 97-104

WALMSLEY, R.D. AND BRUWER, C.A. 1980 Water transparancy characteristics of South African impoundments. J. Limnol. Soc. Sth. Afr., 6: 69-76

WALMSLEY, R.D. AND BUTTY, M. 1980 Guidelines for the control of eutrophication in South Africa. Report. Water Research Commission, Pretoria, South Africa

WALMSLEY, R.D. AND TOERIEN, D.F. 1977 The summer conditions of three eastern Transvaal reservoirs and some considerations regarding the assessment of trophic status. J. Limnol. Soc. sth. Afr., 3: 37-41

WATER RESEARCH COMMISSION 1984 Theory, design and operation of nutrient removal activated sludge processes. A collaborative information document prepared for the Water Research Commission by the University of Cape Town, City Council of Johannesburg and the National Institute for Water Research of the CSIR

YAKSICH, S.M., MELFI, D.A. AND ADAMS, J.R. 1980 Sediment and phosphorus transport. Lake Erie Wastewater Management Study, U.S. Army Corps of Engineers, Buffalow District, New York

GOVERNMENT GAZETTE, 18 MAY 1984 No. 9225 17

No. 991 18 May 1984

REQUIREMENTS FOR THE PURIFICATION OF WASTE WATER OR EFFLUENT

By virtue of the powers vested in me by section 21 (1) (a) of the Water Act, 1956 (Act 54 of 1956) I, Sarel Antoine Strydom Hayward in my capacity as Minister of Environment Affairs and Fisheries, hereby prescribe the following requirements for the purification of waste water or effluent produced by or resulting from the use of water for industrial purposes.

2. SPECIAL STANDARD FOR PHOSPHATE

Waste water or effluent arising in the catchment area within which water is drained to any river specified in Schedule II or a tributary thereof at any place between the source thereof and the point mentioned in the schedule, in so far as such catchment area is situated within the territory of the Republic of South Africa shall not contain soluble ortho phosphate (as P) in a higher concentration than 1,0 milligram per litre.

SCHEDULE II

CATCHMENT AREAS WITHIN THE TERRITORY OF THE REPUBLIC OF SOUTH AFRICA IN WHICH WASTE WATER OR EFFLUENT MUST BE PURIFIED TO CONTAIN NO SOLUBLE ORTHO PHOSPHATE (AS P) IN A HIGHER CONCENTRATION THAN 1,0 MILLIGRAM PER LITRE

(i) Vaal River upstream and inclusive of the Bloemhof Dam;
(ii) Pienaars and Crocodile Rivers upstream of their confluence;
(iii) Great Olifants River upstream and inclusive of the Loskop Dam;
(iv) Umgeni River upstream of the influence of tidal water;
(v) Umlaas River upstream of its point of discharge into the sea;
(vi) Buffels River upstream and inclusive of the Bridle Drift Dam;
(vii) Berg River upstream of the inlfuence of tidal water.

APPENDIX B

LOADING ESTIMATES FOR INDIVIDUAL DAMS

This Appendix discusses, in greater detail, the application of the methods described in Chapter 4.3.2.3 to each of the dams which we studied. Limitations in the data and assumptions made are highlighted.

1. Rietvlei Dam

a) Point source loads

The phosphate load to Rietvlei is dominated by the effluent from the Kempton Park sewage works. The total point source P load was calculated as the sum of the loads for the four sewage works listed in Table 1 (data from Appendix F).

Table 1 : Sewage works in the Rietvlei Dam catchment

Kempton Park (Rietfontein) biofilter plant
Kempton Part (Rietfontein) activated sludge plant
Hartbeesfontein (Ester Park) activated sludge plant with nutreint removal
Hartbeesfontein (Ester Park) activated sludge plant
Total sewage effluent volume in 1981 = 11.5 106 m^3
Total sewage effluent soluble phosphate load in 1981 = 80.2 tons

b) Non-point source loads

No flow and TP concentration data were available for the Rietvlei Dam inflow, therefore the non-point source phosphorus load estimate was based on the

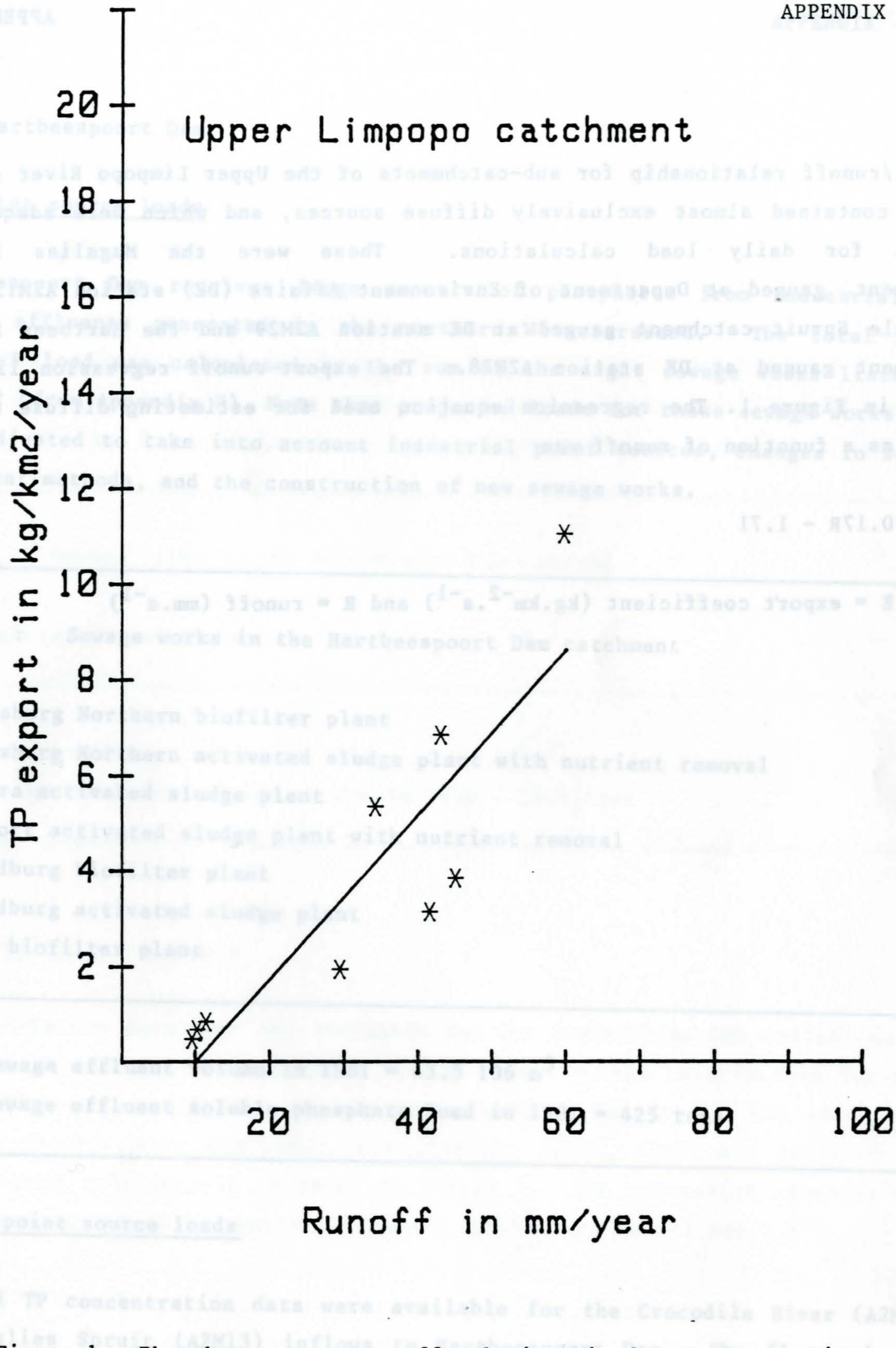

Figure 1: Phosphate export-runoff relationship for the upper Limpopo River catchments.

export/runoff relationship for sub-catchments of the Upper Limpopo River system which contained almost exclusively diffuse sources, and which were adequately gauged for daily load calculations. These were the Magalies Spruit catchment, gauged at Department of Environment Affairs (DE) station A2M13, the Edendale Spruit catchment gauged at DE station A2M29 and the Hartbees Spruit catchment gauged at DE station A2M28. The export-runoff regression line is shown in Figure 1. The regression equation used for estimating diffuse source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

2. Hartbeespoort Dam

a) Point source loads

Hartbeespoort Dam receives large amounts of phosphorus from industrial and sewage effluents generated in the northern Witwatersrand. The total point source P load was calculated as the sum of the eight sewage works listed in Table 2 (from Appendix F). Note that projected loads for these sewage works have been adjusted to take into account industrial point sources, changes in sewage treatment methods, and the construction of new sewage works.

Table 2 : Sewage works in the Hartbeespoort Dam catchment

Johannesburg Northern biofilter plant
Johannesburg Northern activated sludge plant with nutrient removal
Alexandra activated sludge plant
Roodepoort activated sludge plant with nutrient removal
Verwoerdburg biofilter plant
Verwoerdburg activated sludge plant
Tembisa biofilter plant

Total sewage effluent volume in 1981 = 63.5 106 m^3
Total sewage effluent soluble phosphate load in 1981 = 425 tons

b) Non-point source loads

Flow and TP concentration data were available for the Crocodile River (A2M12) and Magalies Spruit (A2M13) inflows to Hartbeespoort Dam. The flow and concentration data for the Magalies Spruit were used to generate annual non-point sewage loads. These were used in combination with the data for Edendale Spruit (A2M29) and Hartbees Spruit (A2M28) to generate an export/runoff relationship

(Figure 1). The regression equation used for estimating non-point source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

3 Roodekopjes Dam

a) Point source loads

The only point source in the Roodekopjes catchment is a small activated sludge plant on the Crocodile River (Table 3, Appendix F). Point sources upstream of Hartbeespoort Dam were not included in the point source to Roodekopjes, because of the "trapping" effect which upstream dams have on nutrients.

Table 3: Sewage works in the Roodekopjes Dam catchment

Brits activated sludge plant

Total sewage effluent volume in 1981 = 1.46 $10^6 m^3$

Total sewage effluent soluble phosphate load = 14.6 tons

b) Non-point source loads

TP concentration data were not available for the Roodekopjes Dam inflow, so the non-point phosphorus load was based on the export/runoff relationship for non-point source sub-catchments of the Upper Limpopo catchment, for which more detailed records were available. (DE stations A2M13, A2M28 and A2M29). The export/runoff relationship is shown in Figure 1. The regression equation used for estimating non-point source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

The total catchment area of Roodekopjes Dam was used in the non-point source load calculation (i.e. including the Hartbeespoort Dam catchment). This was done in order to make some allowance for the phosphorus load discharged from Hartbeespoort Dam.

4. Bon Accord Dam

a) Point source loads

Bon Accord Dam lies a few kilometres downstream of Pretoria's central sewage works. The total point source P load was calculated as the sum for the two plants indicated in Table 4 (from Appendix F).

Table 4: Sewage works in the Bon Accord Dam catchment

Pretoria (Daspoort) biofilter plant
Pretoria (Daspoort) activated sludge plant

Total sewage effluent volume in 1981 = 27.4 $10^6 m^3$

Total sewage effluent soluble phosphate load = 148 tons

b) Non-point source loads

Flow and TP concentration data were not available for the Bon Accord Dam inflow, so the non-point source phosphorus load was based on the export/runoff relationship for nearby sub-catchments of the Upper Limpopo River system which contained mainly non-point sources (DE stations A2M13, A2M29 and A2M28). The export/runoff regression line is shown in Figure 1. The regression equations used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

5 Roodeplaat Dam

a) Point source loads

Until about 1985, the main phosphate load to Roodeplaat Dam will be from the Baviaanspoort sewage works on the Pienaars River (Table 5(a) and Appendix F). An additional sewage works is planned for this catchment, and flow data for the new works was supplied by the City Engineer, Pretoria (Table 5(b)).

Table 5(a): Sewage works in the Roodeplaat Dam catchment

Pretoria (Baviaanspoort) activated sludge plant with nutrient removal
Pretoria (New Roodeplaat) activated sludge plant with nutrient removal

Total sewage effluent volume in 1981 = 4.02 $10^6 m^3$
Total sewage effluent soluble phosphate load in 1981 = 40.2 tons

Table 1.4.5(b): Future discharges from the New Roodeplaat works (supplied by the Pretoria City Engineer).

Year	Minimum discharge ($x10^6 m^3.a^{-1}$)	Maximum discharge ($x10^6 m^3.a^{-1}$)
1981	0	0
1985	0	0
1990	6.6	23.7
1995	10.6	27.0
2000	14.2	29.6
2005	17.9	32.1
2010	21.9	35.0
2015	25.9	38.3
2020	30.3	41.6

b) <u>Diffuse source load</u>

Two of the sub-catchments in the Roodeplaat catchment, namely the catchments of Hartbees/Moreletta Spruit (A2M28) and Edendale Spruit (A2M29), were not influenced by point source loads and had daily concentration and flow records. Their data were combined with that of the Magalies Spruit at A2M13 in the Hartbeespoort Dam catchment to generate the export/runoff relationship shown in Figure 1. The regression equation used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) R = runoff ($mm.a^{-1}$)

6 Klipvoor Dam

a) Point source loads

Klipvoor Dam is located downstream of three sewage works (Table 6, Appendix F) The total point source P load was taken as the sum of the effluents from these sewage works.

Table 6: Sewage works in the Klipvoor Dam catchment

Rooiwal East biofilter plant
Rooiwal West biofilter plant
Babalegi Huisman plant

Total sewage effluent volume in 1981 = 26.2 $10^6 m^3$

Total sewage effluent soluble phosphate load = 199 tons

b) Non-point source loads

Flow and TP concentration data were not available for the Klipvoor Dam inflows (Apies and Pienaars Rivers) so the export/runoff relationship developed for two Roodeplaat Dam sub-catchments and one Hartbeespoort Dam sub-catchment DE stations A2M28, A2M29 and A2M13) was used (Figure 1). The regression equation used for estimating non-point source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

Although Klipvoor Dam catchment contains two other dams, Roodeplaat and Bon Accord, the whole catchment area was used in calculating non-point TP export.

This was done to make allowance for discharge from the upstream dams. This simplification may lead to an under-estimate of non-point source loads in dry years.

7. **Vaal Dam**

a) Point source loads

Vaal Dam has a large, sparsely populated catchment and non-point sources dominate the total phosphorus loads. Nevertheless, there are several sewage works which discharge effluent into the catchment (Table 7 and Appendix F).

Table 7: Sewage works in the Vaal Dam catchment

Ermelo (old) biofilter plant
Ermelo (new) activated sludge plant
Secunda (unit 53) activated sludge plant with nutrient removal
Secunda (unit 253) activated sludge plant with nutrient removal
Evander biofilter plant
Bethal biofilter plant
Harrismith (old) biofilter plant
Harrismith (new) activated sludge plant with nutrient removal
Bethlehem activated sludge plant with nutrient removal
Standerton activated sludge plant with nutrient removal
Standerton Pasveer plant

Total sewage effluent volume in 1981 = 15.4 $10^6 m^3$
Total sewage effluent soluble phosphate load = 76.8 tons

b) Non-point source loads

Flow and TP concentration data were not available for the Vaal and Wilge inflows to the Vaal Dam, so the diffuse phosphorus load was based on the export/runoff relationship developed for the Vet River (DE station C4M04). Note that this relationship could only be developed for the 0-8 mm/a runoff range (Figure 2). The regression used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.304R - 0.283$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

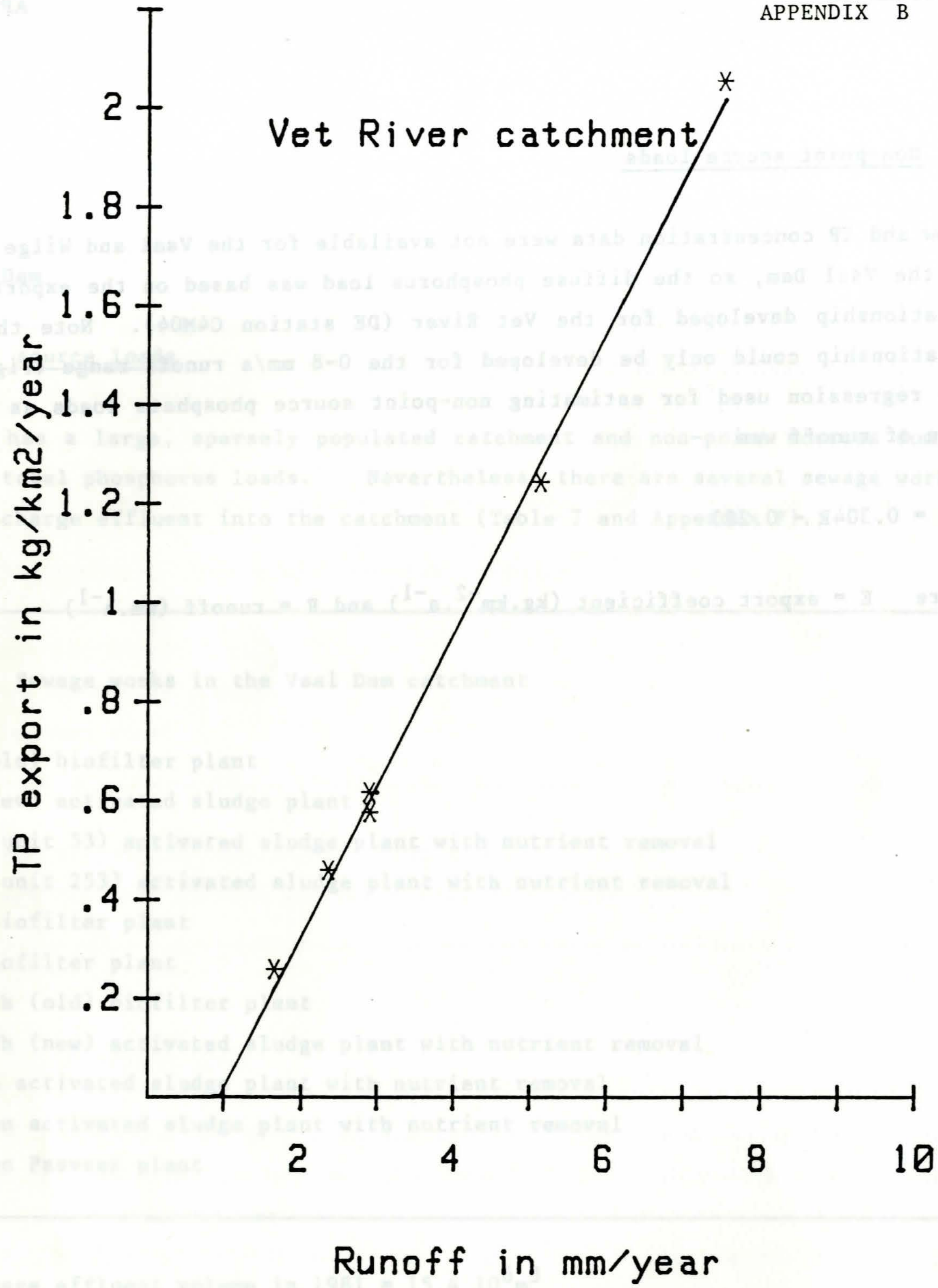

Figure 2: Phosphate export-runoff relationship for the Vet River catchment.

8 Vaal Barrage

a) Point source loads

Of all the dams in South Africa, the Vaal Barrage probably has the densest concentration of sewage works in its catchment (Appendix F, Table 8). The point-source phosphorus load for the catchment was obtained by summing the loads for all these works. Future loads were projected by using the present mean P concentration for all the sewage works in the catchment and the projected future discharge rate based on an annual increase of 5%. Where a standard was applied, it was considered to apply to all sewage works equally. This is not strictly true, since some works in the region have to comply with a 0.3 mg P/l standard, and others are not expected to expand. However, the results projected by our model were considered acceptable as they were within 5% of the figures provided by the Division of Pollution Control (Appendix F).

Table 8: Sewage works in the Vaal Barrage catchment

Nigel (Bickley) biofilter plant
Nigel (Grundling) Pasveer plant
Nigel (Marievale) biofilter plant
Springs (Ancor) biofilter plant
Springs (McComb) biofilter plant
Brakpan biofilter plant
Benoni (old) biofilter plant
Benoni (Rhynfield) biofilter plant
Benoni (Rhynfield extension) activated sludge plant with nutrient removal
Heidelberg activated sludge plant
Boksburg biofilter plant
Germiston (Rondebult) biofilter plant
Germiston (Dekema) biofilter plant
Germiston (Waterval) activted sludge plant with nutrient removal
Johannesburg (Klipspruit) biofilter plant
Johannesburg (Olifantsvlei) biofilter plant
Johannesburg (Goudkoppies) activated sludge plant with nutrient removal
Johannesburg (Olifantsvlei) activated sludge plant with nutrient removal
Meyerton activated sludge plant with nutrient removal
Daveyton biofilter plant
Vereeniging (old) biofilter plant with irrigation
Vereeniging (new) activated sludge plant with nutrient removal (to 0.3 mg P/1)

Total sewage effluent volume in 1981 = 201 $10^6 m^3$

Total sewage effluent soluble phosphate load = 773 tons

b) Non-point source loads

Because of the large number of point sources in this catchment, it was not possible to calculate an export/runoff relationship for non-point sources in the

Barrage catchment itself. For this reason, the non-point phosphorus load was based on the export/runoff relationship developed for the Vet River (DE station C4M04). It must be pointed out that the regression line was only fitted over a limited range of runoff values 0-8 mm/a (Figure 2). The regression used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.304R - 0.283$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

Although the Barrage catchment contains the Vaal Dam upstream, it was decided to use the full catchment area in calculating the non-point source loads. This was done in order to allow for phosphate loads exported from Vaal Dam.

9 Koppies Dam

a) Point source loads

Koppies Dam catchment contains only one point source (Table 9 ,Appendix F).

Table 9: Sewage works in the Koppies Dam catchment.

Heilbron Huisman plant
Total sewage effluent volume in 1981 = 0.30 $10^6 m^3$
Total sewage effluent soluble phosphate load = 1.50 tons

b) Non-point source loads

No flow or TP concentration data were available for the Koppies Dam catchment, so the export/runoff equation for the Vet River catchment was used (Figure 2). Note that the regression was only done over the range 0-8 mm. The regression equation used to estimnate non-point source phosphate loads as a function of runoff was

$$E = 0.304R - 0.283$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

10 Bloemhof Dam

a) Point Source loads

The point sources in the Bloemhof Dam catchment are summarized in Table 10 from the information provided in Appendix F.

Table 10: Sewage works in the Bloemhof Dam catchment

Klerksdorp (old) biofilter plant
Klerksdorp (new) activated sludge plant with nutrient reduction
Kroonstad biofilter plant
Krugersdorp (old) biofilter plant
Krugersdorp (new) activated sludge plant with nutrient removal
Parys biofilter plant
Potchefstroom (old) biofilter plant
Potchefstroom (new) activated sludge plant with nutrient removal
Sasol 1 biofilter plant
Stilfontein (old) biofilter plant
Stilfontein (new) activated sludge plant with nutrient removal
Orkney biofilter plant
Virginia biofilter plant
Winburg Huisman plant
Wolmaransstad biofilter plant
Bothaville activated sludge plant
Carletonville biofilter plant
Fochville activated sludge plant

Total sewage effluent volume in 1981 = 52.5 $10^6 m^3$

Total sewage effluent soluble phosphate load in 1981 = 210 tons

b) Non-point source loads

The Vaal River is the main inflow to Bloemhof Dam but contains most of the point sources in the dam catchment. For this reason, the flow and TP concentration data available for the Vet River (Figure 2) were used to calculate an export/runoff regression equation. The regression equation used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.304R - 0.283$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

The equation could only be fitted over a runoff range of 0-8 mm/a because of the low flow in the Vet River, and should be used with caution. Despite the presence of the Vaal Barrage, Vaal Dam, Erfenis Dam, Koppies Dam and Allemanskraal Dam upstream of Bloemhof Dam, it was decided to use the full Bloemhof Dam catchment for non-point phosphorus export calculations. This decision was aimed at making some allowance for the outflow from the upstream dams.

11 Laing Dam

a) Point Source Loads

Laing Dam lies downstream of King William's Town and all point sources (including tannery and textile effluent) in the catchment are grouped under the two sewage works in Table 11. The full table of effluent phosphorus data for these sewage works is provided in Appendix F.

Table 11: Sewage works in the Laing Dam catchment

Zwelitsha (old) biofilter works
Zwelitsha (new) activated sludge works
Total sewage effluent volume in 1981 = 1.31 $10^6 m^3$
Total sewage effluent soluble phosphate load = 9.17 tons

b) Non-point source loads

The DE station R2M05 on the Buffalo River upstream of King William's Town was assumed to be representative of the non-point source loading in this catchment. Only dissolved phosphorus data were available for this station, so the phosphorus concentration was multiplied by a factor of 3.3 to give an estimate of total phosphorus load. The export/runoff relationships is shown in Figure 3. The regression equation used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.089R - 0.789$$

where E = TP export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

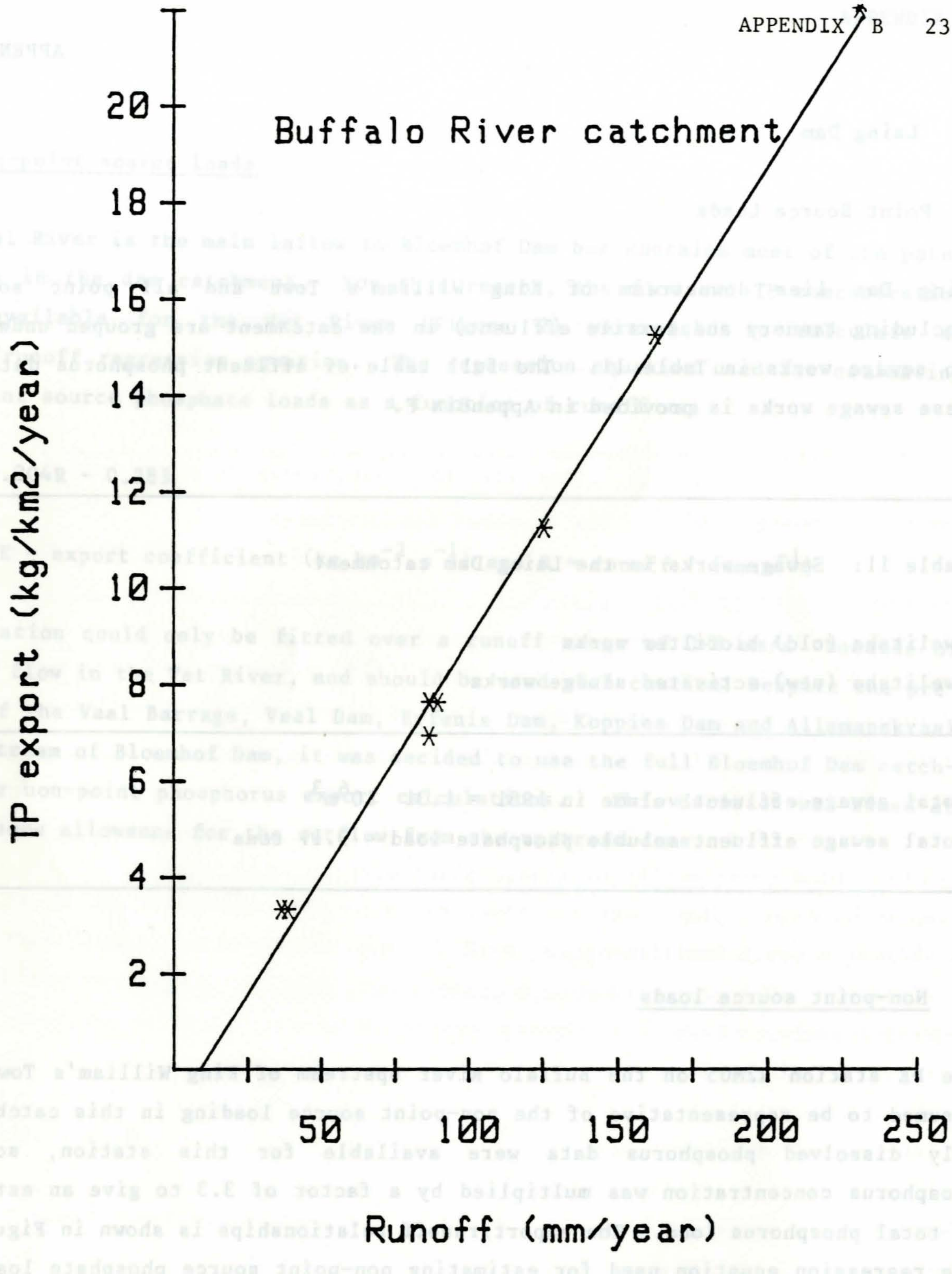

Figure 3: Phosphate export-runoff relationship for the Buffalo River catchment.

12 Bridle Drift Dam

a) Point source loads

Only one sewage works is located in the Bridle Drift Dam catchment (Table 12, Appendix F).

Table 12: Sewage works in the Bridle Drift catchment

Potsdam activated sludge plant
Total sewage effluent volume in 1981 = 3.37 $10^6 m^3$
Total sewage effluent soluble phosphate load = 20.2 tons

b) Non-point source loads

Undoubtedly the large town of Mdantsane situated in the catchment must contribute to the non-point source load to Bridle Drift Dam. However, with no sure way of estimating such a load, within the brief of this project, we decided to use the export/runoff relationship for DE station R2M05 in the upper Buffalo catchment (Figure 3) to estimate the diffuse load. The regression equation used to estimate non-point source phosphate loads as a function of runoff was

$$E = 0.089R - 0.789$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

13 Shongweni

a) Point source loads

There are two sewage works in this catchment, at Mpumalanga and Hammarsdale (Kröger, 1983). No data were available for Hammarsdale and Mpumalanga (located in Kwa Zulu, so the data of Kröger (1983) for this catchment were examined and the following estimate of the 1981 point source loads was made :

sewage volume = 2 $10^6 m^3/a$

sewage P concentration = 5 mg/l

sewage P load = 10 tons

sewage TP load = 12.5 tons

For future projections, the point source load was assumed to increase by 5% per annum.

b) Non-point source loads

Because of the lack of TP concentration and flow data for the Shongweni Dam catchment, the export/runoff relationship established for the Mgeni catchment was used (Figure 4). The regression equation used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.066R - 1.088$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

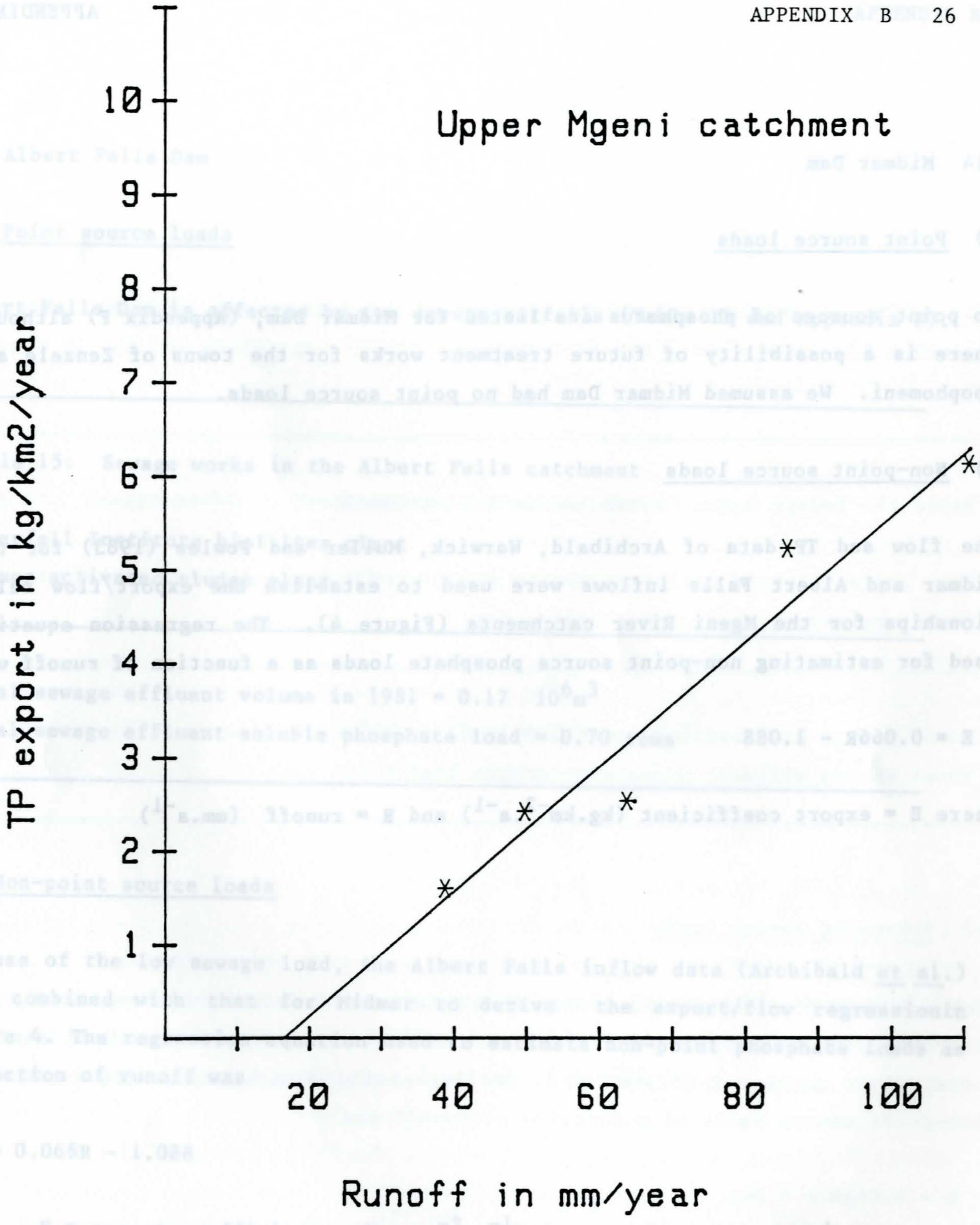

Figure 4: Phosphate export-runoff relationship for the Upper Mgeni River catchment.

14 Midmar Dam

a) Point source loads

No point sources of phosphorus are listed for Midmar Dam, (Appendix F) although there is a possibility of future treatment works for the towns of Zenzele and Mpophomeni. We assumed Midmar Dam had no point source loads.

b) Non-point source loads

The flow and TP data of Archibald, Warwick, Muller and Fowles (1983) for the Midmar and Albert Falls inflows were used to establish the export/flow relationships for the Mgeni River catchments (Figure 4). The regression equation used for estimating non-point source phosphate loads as a function of runoff was

$$E = 0.066R - 1.088$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

15 Albert Falls Dam

a) Point source loads

Albert Falls Dam is affected by two sewage outfalls (Table 15 and Appendix F).

Table 15: Sewage works in the Albert Falls catchment
Waterfall Institute biofilter plant
Midmar activated sludge plant
Total sewage effluent volume in 1981 = 0.17 $10^6 m^3$
Total sewage effluent soluble phosphate load = 0.70 tons

b) Non-point source loads

Because of the low sewage load, the Albert Falls inflow data (Archibald et al.) were combined with that for Midmar to derive the export/flow regressionin Figure 4. The regression equation used to estimate non-point phosphate loads as a function of runoff was

$$E = 0.066R - 1.088$$

where E = export coefficient $(kg.km^{-2}.a^{-1})$ and R = runoff $(mm.a^{-1})$

16 Inanda Dam

a) Point source loads

The catchment of the proposed Inanda Dam contains two point sources (Table 16, Appendix F).

Table 16: Sewage works in the Inanda Dam catchment.

Cato Ridge Abbatoir activated sludge plant with nutrient removal
Pietermaritzburg activated sludge plant

Total sewage effluent volume in 1981 = 17.6 $10^6 m^3$

Total sewage effluent soluble phosphate load = 106 tons

b) Non-point source loads

Insufficient TP concentration and flow data were available for the Inanda Dam catchment, therefore we used the export/runoff relationship developed for the upper Mgeni catchment (Figure 4). The regression equation used for estimating non-point source loads as a function of runoff was

$$E = 0.066R - 1.088$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

Although several dams occur in the catchment, the total catchment area was used ~~the total catchment area was~~ when calculating non-point source phosphorus export, to make some allowance for discharges from upstream dams.

17 Bronkhorstspruit Dam

a) Point source loads

There is one point source in the Bronkhorst Spruit Dam catchment (Table 7, Appendix F) and the discharge already complies with the 1 mg/l standard.

Table 17: Sewage works in the Bronkhorstspruit catchment

Delmas activated sludge plant with nutrient removal

Total sewage effluent volume in 1981 = 0.44 $10^6 m^3$
Total sewage effluent soluble phosphate load = 0.44 tons

b) Non-point source loads

No flow or TP concentration data were available for this catchment, so non-point source loads were estimated using the export/runoff relationship developed for the upper Limpopo River catchment (Figure 1). The regression equation used to estimate non-point source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E= export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

18 Loskop Dam

a) Point source loads

There are six point sources in the Loskop Dam catchment area (Table 18, Appendix F).

Table 18: Sewage works in the Loskop Dam catchment

Witbank (Ferrobank) biofilter plant
Witbank (Riverview) biofilter plant
Witbank (Riverview) activated sludge plant
Middelburg Activated sludge plant
Bronkhorstspruit activated sludge plant

Total sewage effluent volume in 1981 = 9.49 $10^6 m^3$

Total sewage effluent soluble phosphate load = 19.9 tons

b) Non-point source loads

No flow or TP concentration data were available for this catchment, so non-point source loads were estimated using the export/runoff relationship developed for the upper Limpopo River catchment (Figure 1). The regression equation used for estimating non-point source loads as a function of runoff was

$$E = 0.17R - 1.71$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) and R = runoff ($mm.a^{-1}$)

19 Misverstand Dam

a) Point sources

There are two sewage works in the catchment of this proposed dam (Table 19). The complete flow and phosphorus load data set is contained in Appendix F.

Table 19: Sewage works in the Misverstand Dam catchment

Paarl biofilter plant
Wellington biofilter plant

Total sewage effluent volume in 1981 = 7.43 $10^6 m^3$
Total sewage effluent soluble phosphate load = 48.3 tons

b) Diffuse sources

Flow and dissolved phosphorus data were available for DE station G1M13 upstream of the proposed dam site. Because of the low point source load, we decided to establish the export/runoff relationship for this catchment on data obtained from this station. The regression line is shown in Figure 5 and the regression equation used for estimating non-point source soluble phosphate loads as a function runoff was

$$E = 0.086R - 2.814$$

where E = export coefficient ($kg.km^{-2}.a^{-1}$) R = runoff ($mm.a^{-1}$)

Total non-point source phosphate loads were obtained by multiplying soluble phosphate loads with a factor 3.3

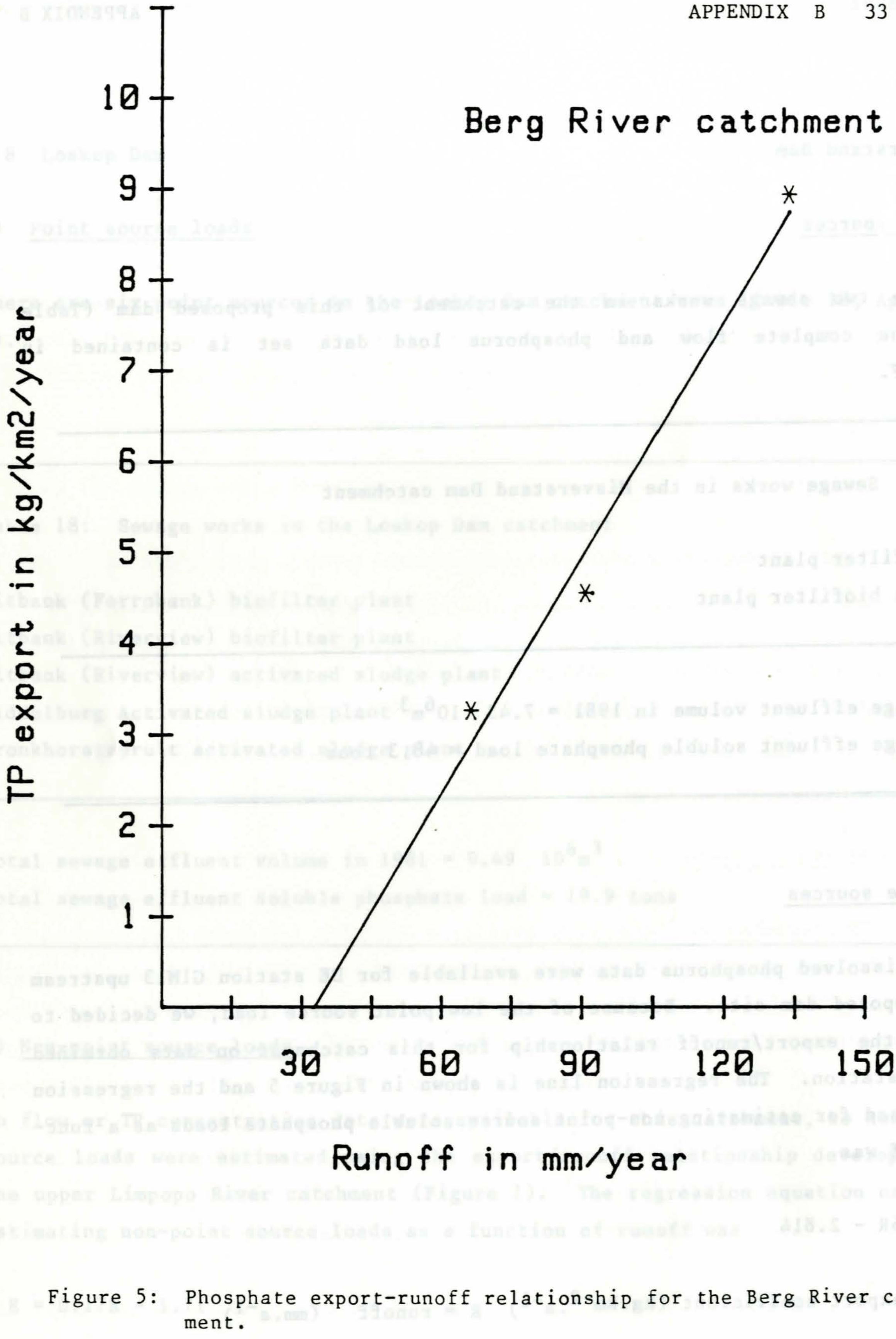

Figure 5: Phosphate export-runoff relationship for the Berg River catchment.

IMPLICATION OF APPLYING
THE
PHOSPHATE STANDARD TO
SENSITIVE CATCHMENTS

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POLLUTION CONTROL DIVISION

APRIL 1983

IMPLICATION OF APPLYING THE PHOSPHATE

STANDARD TO SENSITIVE CATCHMENTS

This survey is an extension to the previous one carried out in the Division by Mr Zunckel and Mrs Oliveira.

In the previous report, it was assumed that all activated sludge plants are capable of removing phosphates to the extent that the Special Standard of 1 mg/ℓ as P will be achieved by the year 1985, and thereafter, without the use of chemicals. In practice, this is not the case, and it was considered a reasonably simple process to modify the figures to account for the limited use of chemicals for pbosphate removal by the activated sludge plants. The following plan of action was conceived:

(a) Untill 1990:

(i) During the "winter months" (June, July, August), chemica will be used 100 % of the time. This amounts to 92 days of the year.

(ii) During the "summer months" (the remainder of the year), chemicals will be used 50 % of the time, i.e. 136,5 days per year.

(b) After 1990:

(i) During the winter months, chemicals will be used 50 % of the time, i.e. 46 days per year.

(ii) During the summer months, no chemicals will be used.

As before, it was assumed that 10 mg/ℓ of chemicals will be required to remove 1 mg/ℓ of phosphates, all the time for biological filter plants, and when required by activated sludge plants (as detailed above).

/2...

Other assumptions made during the previous report are made, namely:

(i) 5 % population growth per annum in each municipality.

(ii) No future extensions to biological filter plants, only to activated sludge plants.

On assemption that all biological filter plants will be phased out by the year 2000, the value of TDS will become more steady, and subsequent to the year 2000, it will increase by 5 % per annum. (The previous report predicted that TDS will be zero when all biofilter plants are phased out).

In addition to the information on phosphate loads and TDS increases in the various sensitive catchments, the nitrate (as N) and ammonia (as N) concentrations are given for 1981. These are used to calculate the nitrogen loads for 1981, and predicts future values for 1985, 1995 and 2000, assuming the concentrations are repeatable from year to year. The nitrogen loads are hence dependant on the flows, and thus increase by 5 % per annum.

PLANT LOCATION	TYPE	1981 Flow m^3/d	1981 Summer NO_3 mg/ℓ	1981 Summer NH_3 mg/ℓ	1981 Winter NO_3 mg/ℓ	1981 Winter NH_3 mg/ℓ	1981 Total N tonnes /year	1981 Total P tonnes /year	1981 TDS tonnes /year	1985 Flow m^3/d	1985 Total N tonnes /year	1985 Total P tonnes /year	1985 TDS tonnes /year	1995 Flow m^3/d	1995 Total N tonnes /year	1995 Total P tonnes /year	1995 TDS tonnes /year	2000 Flow m^3/d	2000 Total N tonnes /year	2000 Total P tonnes /year	2000 TDS tonnes /year
Ermelo																					
Old	BF	2 000	3,0	23,0	3,0	23,0	19,0	7,3	0,0	2 000	19,0	0,7	65,7	2 000	19,0	0,7	65,7	2 000	19,0	0,7	65,7
New	AS	1 500	3,0	10,0	3,0	10,0	7,1	5,5	0,0	2 200	10,4	0,8	45,2	4 300	20,4	1,6	17,8	5 900	27,9	2,2	24,4
Secunda (Unit 53)	AS(NR)	6 700	5,0	1,2	2,4	0,6	13,2	3,2	0,0	8 040	15,8	2,9	5,5	12 060	23,8	4,4	1,7	15 075	29,7	5,5	2,1
(Unit 253)	AS(NR)	4 700	2,8	0,8	9,1	0,0	8,5	10,8	0,0	5 640	10,2	2,1	68,3	8 460	15,3	3,1	20,6	10 575	19,1	3,9	36,8
Evander	BF	9 200	2,8	6,4	4,4	9,9	35,2	21,8	0,0	11 040	42,2	4,0	221,6	16 600	63,5	6,1	333,2	20 750	79,3	7,5	416,6
Bethal	BF	2 300	4,4	5,0	3,3	5,5	7,7	7,2	0,0	2 760	9,2	1,0	76,6	4 140	13,7	1,5	114,8	5 175	17,3	1,9	143,6
Harrismith																					
Old	BF	1 700	16	6	8,5	11	13,3	4,5	0,0	1 200	9,4	10,4	27,2	1 200	9,4	0,4	27,2	1 200	9,4	0,4	27,2
New	AS(NR)	0	-	-	-	-	-	-	0,0	800	4,8	0,3	-	1 800	10,8	0,7	-	2 600	15,6	0,9	-
Bethlehem	AS(NR)	9 000	0,9	14,5	1,3	22,7	57,7	24	0,0	10 800	69,2	3,9	130	16 200	104	5,9	46,9	20 250	130	7,4	58,7
Standerton																					
White	AS(NR)	3 000	7,0	5,5	4,2	7,6	13,4	2,2	0,0	3 600	16,2	1,3	8,2	5 400	24,3	2,0	2,5	6 750	30,4	2,3	3,1
Black	PASVEER	2 000	14,0	11,0	8,4	15,2	18	5,8	0,0	2 400	21,6	0,9	61,3	3 600	32,4	1,3	92,0	4 500	40,5	1,6	115
Nigel																					
Bickley	BF	2 000	14,3	8	9	12,1	16,0	6,9	0,0	2 400	19,3	0,9	74,5	3 600	28,9	1,3	111,7	4 500	36,1	1,6	139,6
Grundling	PASVEER	3 800	13,2	12,1	8,1	16,3	34,8	8,3	0,0	4 560	41,7	1,7	83,2	6 840	62,6	2,5	124,8	8 550	82,6	3,1	156,0
Marievale	BF	1 000	12,5	8,5	8	1,5	6,6	2,6	0,0	1 200	7,9	0,4	26,3	1 800	11,9	0,7	39,4	2 250	14,9	0,9	49,3
Springs																					
Ancor	BF	11 000	14,3	5,5	15,8	6,8	82,3	16,1	0,0	16 800	126	6,1	184	34 200	255	12,5	375	47 250	354	17,2	517,4
	Note: Ancor current flow 29 000 m^3/d of which 18 000 goes to SAPPI.																				
McComb	BF	8 700	14,6	4,9	15,3	6,3	63,9	9,2	0,0	10 440	76,3	3,8	72,4	15 660	115	5,7	109	19 575	143	7	135,7
Brakpan	BF	8 000	13,3	2,8	13,8	4,0	48,3	21,9	0,0	9 600	57,9	3,5	228	14 400	86,9	5,3	342	18 000	109	6,6	427
Benoni (Old)	BF	16 000	20,5	36,2	46,3	37,7	371	46,6	0,0	19 200	445	7	491	28 800	668	10,5	736	36 000	835	13,1	920
Rhynfield	BF	3 000	1,6	11,7	2,3	9,4	14,1	10,4	0,0	4 400	20,7	1,6	137	5 000	23,3	1,8	155	5 000	23,3	1,8	155,1
Rhynfield Ext.	AS(NR)	4 000	5,3	1,6	8,2	6,5	12,9	13,9	0,0	4 000	12,9	1,5	159	7 600	24,5	2,8	29,7	10 750	37,9	3,9	42,0
Heidelberg	AS	3 200	0,6	5	0,8	22,6	11,7	8,2	0,0	3 840	14,1	1,4	107,7	5 760	21,1	2,1	15,9	7 200	26,4	26	19,9
Boksburg	BF	44 000	5,7	5,1	3,2	9,2	179	104	0,0	52 800	215	19,3	1 060	79 200	324	28,9	1 590	99 000	405	36,1	1 987
Germiston																					
Rondebult	BF	37 400	5,2	6,1	1,7	11,0	159	20,5	0,0	37 400	159	13,7	68,3	37 400	159	13,7	68,3	37 400	159	13,7	68,3
Dekema	BF	35 800	6,1	4,0	5,3	8,5	144	58,8	0,0	35 800	144	13,1	457	35 800	144	13,1	457	35 800	144	13,1	457,3
Waterval	AS(NR)	16 500	10,3	0,7	10,7	0,3	66,2	15,1	0,0	34 400	138	12,6	241	88 260	354	32,2	60,9	128 625	516	46,9	88,8
Johannesburg																					
Klipspruit	BF	25 000	6,3	5,0	4,6	3,3	95,3	18,3	0,0	25 000	95,3	9,1	91,3	25 000	95,3	9,1	91,3	25 000	95,3	9,1	91,3
	Note: Total Klipspruit effluent 55 000 m^3/d of which 30 000 m^3/d goes to power station.																				
Olifantsvlei	BF	50 000	5,8	7,1	5,7	9,5	246	69,4	0,0	50 000	246	18,3	511	50 000	246	18,3	511	50 000	246	18,3	511
	Note: Total Olifantsvlei BF = 80 000 m^3/d of which 30 000 m^3/d is irrigated.																				
Goudkoppies	AS(NR)	100 000	6,3	5,0	4,6	3,3	381	73	0,0	120 000	458	43,8	274	150 000	572	54,8	69,0	150 000	572	54,8	69,0

PLANT LOCATION	TYPE	1981 Flow m^3/d	1981 Summer NO_3 mg/ℓ	1981 Summer NH_3 mg/ℓ	1981 Winter NO_3 mg/ℓ	1981 Winter NH_3 mg/ℓ	1981 Total N tonnes /year	1981 Total P tonnes /year	1981 TDS tonnes /year	1985 Flow m^3/d	1985 Total N tonnes /year	1985 Total P tonnes /year	1985 TDS tonnes /year	1995 Flow m^3/d	1995 Total N tonnes /year	1995 Total P tonnes /year	1995 TDS tonnes /year	2000 Flow m^3/d	2000 Total N tonnes /year	2000 Total P tonnes /year	2000 TDS tonnes /year
Olifantsvlei	AS(NR)	170 000	5,8	7,1	5,7	9,5	836	235	0,0	231 000	1 136	84,3	1 478	444 000	2 184	162	572	626 000	3 078	228	806
Meyerton	AS(NR)	3 300	1,0	13,3	0,8	2,7	13,9	3	0,0	3 960	16,7	1,4	13,6	5 940	25,1	2,2	4,1	7 425	31,4	2,7	5,1
Daveton	BF	9 000	2	38,1	1,5	7,0	105	33	0,0	10 800	127	3,9	355	16 200	190,4	5,9	532	20 250	238	7,4	665
Vereeniging																					
Old	BF	0	-	-	-	-	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
	Note:	25 000 m^3/d irrigated will drop to 16 000 m^3/d in 1985																			
New	AS(NR)	0	-	-	-	-	-	-	-	14 000	56,7	1,5	-	29 000	116	3,2	-	40 750	161	4,4	-
	Note:	P will be 0,3 mg/ℓ as required by RWB																			
Bothaville	AS	142	3,0	14,5	2,5	13,5	1,0	0,3	0,0	170	1,1	0,1	1,9	255	1,6	0,1	0,6	320	2,0	0,1	0,7
Carletonville	BF	3 200	6,0	7,2	4,5	6,9	14,9	11,7	0,0	3 840	17,9	1,4	126	5 760	26,8	2,1	189	7 200	33,5	2,6	237
Fochville	AS	2 000	0,4	3,4	0,6	20,6	5,9	8,7	0,0	2 400	7,1	0,9	60,3	3 600	10,7	1,3	18,2	4 500	13,4	1,6	22,8
Heilbron	HUISMAN	731	8,5	0,5	20	0,3	3,1	1,6	0,0	876	3,8	0,3	16,0	1 320	5,7	0,5	3,0	1 650	7,1	0,6	30,1
Klerksdorp (Old)	BF	4 500	0	17,8	2,0	10,5	27	9,9	0,0	4 500	27	1,6	82,1	4 500	27	1,6	82,1	4 500	27	1,6	82,1
New	AS(NR)	11 500	1,5	11,3	2,1	14,0	57,2	4,2	0,0	14 700	73,1	5,4	0,0	24 300	121	8,9	0,0	31 500	156	11,5	0,0
Kroonstad	BF	7 000	6,3	6,8	7,9	13,4	38,7	28,6	0,0	8 400	46,5	3,1	313	12 600	69,7	4,6	469	15 750	87	5,7	161
Krugersdorp																					
Old	BF	15 000	12,5	5,5	15,8	6,8	104	47,6	0,0	8 000	55,9	2,9	225	8 000	55,9	2,9	225	8 000	55,9	2,9	225
New	AS(NR)	0	13	4	9,6	4,2	-	-	-	10 000	59,1	3,7	-	17 000	101	6,2	-	25 250	149	9,4	-
Parys	BF	1 770	17,3	5,2	9,3	10,5	14,1	3,9	0,0	2 100	16,7	0,8	38,3	3 200	25,5	1,1	58,4	4 000	31,9	1,4	73,0
Potchefstroom																					
Old	BF	9 400	12,5	5,5	15,8	6,8	65,7	20,6	0,0	9 400	65,7	3,4	172	9 400	65,7	3,4	172	9 400	65,7	3,4	172
New	AS(NR)	6 400	13,0	4,0	9,6	4,2	37,8	14	0,0	9 560	56,5	3,5	22,0	19 000	112	6,9	43,7	26 150	154	9,5	60,1
Sasol I	BF	60 000	4,4	7,1	1,6	1,1	203	22,3	-	60 000	203	22,3	-	60 000	203	22,3	-	60 000	203	22,3	-
Stilfontein																					
Old	BF	2 500	6	6,6	4,2	7,6	11,3	6,4	0,0	2 500	11,3	0,9	54,8	2 500	11,3	0,9	54,8	2 500	11,3	0,9	54,8
New	AS(NR)	4 800	6	6,6	4,2	7,6	21,7	3,5	0,0	6 260	28,3	2,3	14,3	10 640	48,2	3,9	4,9	13 925	63	5,1	6,4
Orkney	BF	5 000	2,5	10,8	2,7	6,7	22,5	12,8	0,0	6 000	27	2,2	131,4	9 000	40,5	3,3	197	11 250	50,6	4,1	246
Virginia	BF	6 700	4,9	5,1	5,0	4,9	24,4	10,3	0,0	9 760	35,5	3,5	114	18 940	68,9	6,9	221	25 830	94	9,4	302
	Note:	Virginia total effluent 15 300 m^3/d of which 8,600 is re-used.																			
Welkom	BF	0	2,4	17,0	8,2	14,9	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
	Note:	Welkom all effluent re-used with capacity for more re-use in future.																			
Westonaria	BF	4 800	2,7	10,6	2,9	6,5	21,6	16,5	0,0	5 760	25,9	2,1	177	8 640	38,9	3,2	53,6	10 800	48,6	3,9	331
Winburg	HUISMAN	280	9	0,2	20	0,1	1,2	1,2	0,0	336	1,5	0,1	13,5	504	2,2	0,2	20,2	630	2,7	0,2	25,3
Wolmaranstad	BF	580	14,5	7,5	9	0,5	4	1,3	0,0	700	4,8	0,3	12,7	1 040	7,2	0,4	19,0	1 300	8,9	0,5	23,7
Total Vaal River		740 100					3 758	1 093	0,0	945 940	4 740	331	8 395,7	1 380 460	7 347	504	8 547,6	1 738 500	8 852	634,6	9 657,6

CROCODILE RIVER CATCHMENT

PLANT LOCATION	TYPE	1981 Flow m³/d	1981 Summer NO3 mg/ℓ	1981 Summer NH3 mg/ℓ	1981 Winter NO3 mg/ℓ	1981 Winter NH3 mg/ℓ	1981 Total N tonnes /year	1981 Total P tonnes /year	1981 TDS tonnes /year	1985 Flow m³/d	1985 Total N tonnes /year	1985 Total P tonnes /year	1985 TDS tonnes /year	1995 Flow m³/d	1995 Total N tonnes /year	1995 Total P tonnes /year	1995 TDS tonnes /year	2000 Flow m³/d	2000 Total N tonnes /year	2000 Total P tonnes /year	2000 TDS tonnes /year
JHB. Northern	BF	100 000	16,3	7,4	16,8	5,0	848	219,8	0,0	120 000	1 018	43,8	2 190	120 000	1 018	43,8	2 190	120 000	1 018	43,8	2 190
	AS	20 000	6,0	0,0	10,8	0,2	53,0	43,8	0,0	28 000	74,2	10,2	320	112 000	297	40,9	258	175 000	464	63,9	403
	Johannesburg Northern Works treats a total of 140,000 m³/d of which 45,000 m³/d is re-used in Kelvin Power Station, 20,000 m³/d is irrigated, and 30,000 m³/d will be pumped to UCOR in the near future. Effluent to Kelvin is returned to the catchment. The biofilter capacity is 120,000 m³/d.																				
Johannesburg Alexandra	AS	27 000	17,8	2,3	9,9	1,6	176	54,2	0,0	32 400	212	11,8	333	48 600	318	17,7	101	60 750	398	22,2	126
Randfontein -	Works being considered, but load projections covered under Johannesburg.																				
Roodepoort	AS(NR)	3 500	6,3	6,4	5,0	7,3	16,1	10,6	0,0	4 200	19,3	1,5	70,1	6 300	29,0	2,3	21,2	7 880	36,2	2,9	26,5
Krugersdorp (Northern WKS)	BF	-	13,0	3,0	16,5	4,0	-	8,2	0,0	-	-	-	-	12 600	78,8	4,6	331	15 750	98,5	5,7	414
Kempton Park Rietfontein	BF	10 000	5,4	3,7	4,9	4,3	33,3	29,2	0,0	12 000	40,0	4,4	307	18 000	60,0	6,6	460	22 500	74,9	8,3	574
	AS	10 000	5,4	3,7	4,9	4,3	33,3	29,2	0,0	12 000	40,0	4,4	192	18 000	60,0	6,6	58,0	22 500	74,9	8,3	574
Hartebeesfontein	AS(NR)	11 300	1,9	6,6	3,0	6,8	36,4	20,6	0,0	13 560	43,7	4,9	124	20 340	65,5	7,4	37,4	25 430	81,9	9,3	46,8
Ester Park	AS	100	2,6	15,1	1,1	14,8	0,6	0,3	0,0	120	0,8	-	1,7	180	1,1	0,1	0,5	230	1,4	0,1	0,6
Verwoerdburg																					
New	BF	10 870	8,4	10,7	14,9	9,6	81,2	47,6	0,0	10 000	74,7	3,7	402	10 000	74,7	3,7	402	10 000	74,7	3,7	402
Old	AS	-	0,6	13,5	2,0	3,2	-	-		3 000	13,0	1,1	-	9 570	41,4	3,5	-	14 460	62,6	5,3	-
Tembisa	BF	13 000	28,3	3,4	32,3	6,8	159	49,8	0,0	15 600	191	5,7	541	23 400	287	8,5	811	29 250	358	10,7	1 015
Brits	AS	4 000	0,1	12,4	1,0	6,1	16,3	1,5	0,0	4 800	19,5	1,8	-	7 200	29,3	2,6	-	9 000	36,6	3,3	-
Rustenburg	BF	6 000	24,4	0,3	26	2,2	56,0	24,5	0,0	7 200	67,2	2,6	268	10 800	101	3,9	402	13 500	126	4,9	503
Babalegi	Huisman	1 900	7,1	2,0	15	3,0	7,9	4,2	0,0	2 280	9,4	0,8	41,6	3 420	14,2	1,2	62,4	4 280	17,7	1,6	78,1
Pretoria Daspoort	BF	28 000	6,2	5,1	4,5	3,4	107	55,2	0,0	28 000	107	10,2	450	28 000	107	10,2	450	28 000	107	10,2	450
	AS	47 000	6,2	5,1	4,5	3,4	179	92,6	0,0	62 000	236	22,6	623	107 000	408	39,1	217	140 800	537	51,4	285
Baviaanspoort	AS(NR)	11 000	9,3	0,8	1,8	12,5	44,8	43,8	0,0	13 200	53,8	4,8	299	19 800	80,6	7,2	90,2	24 750	101	9,0	112,7
Rooiwal E	BF	35 000	9,4	7,0	8,3	8,0	209	97,1	0,0	42 000	251	15,3	1 012	63 000	377	23,0	1 518	78 750	471	28,7	1 897
Rooiwal W	BF	35 000	9,4	7,0	8,3	8,0	209	97,1	0,0	42 000	251	15,3	1 012	63 000	377	23,0	1 518	78 750	471	28,7	1 897
Total (Crocodile River)		373 670					2 266	929,3	0,0	452 350	2 722	164,9	8 186	701 200	3 825	254,9	8 597	861 580	4 610	322	10 994

OTHER CATCHMENTS (PART 1)

PLANT LOCATION	TYPE	1981								1985				1995				2000			
		Flow m^3/d	Summer NO_3 mg/ℓ	Summer NH_3 mg/ℓ	Winter NO_3 mg/ℓ	Winter NH_3 mg/ℓ	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year
UMGENI RIVER CATCHMENT																					
Clermont	BF	4 320	2,9	10,5	3,0	10,0	21,0	9,5	0,0	5 180	25,1	1,9	94,5	7 780	37,8	2,8	142	9 720	47,2	3,6	177
Kwa-Mashu																					
Old	BF	12 000	13,5	6,0	15,0	7,2	88,4	74,5	0,0	12 000	88,4	4,4	701	12 000	88,4	4,4	701	12 000	88,4	4,4	701
New	AS	13 700	13,5	6,0	15,0	7,2	100,9	85,0	0,0	18 840	139	6,9	689	34 260	252	12,5	252	45 830	338	16,7	337
W/Fall Inst.	BF	300	13,0	8,0	10,5	10,0	2,3	0,1	0,0	360	2,7	0,1	0,0	540	4,1	0,2	0,0	680	5,2	17,0	0,0
N. Germany	AS	2 250	21,6	4,6	26,3	1,2	21,8	6,6	0,0	2 700	26,1	1,0	43,2	4 050	39,2	1,5	13,0	5 060	49,0	1,8	18,6
Durban	AS	24 500	3,3	4,3	9,0	3,7	79,5	80,5	0,0	29 400	95,4	10,7	538	44 100	143	16,1	162	55 130	179	20,1	203
P'M'Burg	AS	43 500	8,8	7,8	6,5	5,5	245	47,6	0,0	52 200	294	19,1	239	78 300	441	28,6	72,0	97 880	311	35,7	90,0
Midmar	AS	180	3,2	13,5	2,0	13,8	1,1			220	1,3	0,1	1,5	325	2,0	0,1	0,5	410	2,5	0,2	566
Cato Ridge Abattoir	AS(NR)																				
	COMPLEX	4 860	1,0	17,5	2,5	10,0	30,1	0,3	0,0	5 830	36,1	2,1	180	8 750	54,3	3,2	54,3	10 950	67,9	4,0	634
Pinetown	AS	5 000	6,4	6,6	4,1	7,7	20,4	25,7	0,0	6 000	24,5	2,2	68,6	9 000	36,8	3,3	20,7	11 250	44,9	4,1	25,9
Total (Umgeni Catchment)		110 610					618,6	329,8	0,0	132 730	732,6	48,5	2 603	199 100	1 099	72,7	1 276	248 910	1 053	107,6	2 753
OLIFANTS RIVER CATCHMENT																					
Witbank	BF	14 000	16,0	3,5	15,0	4,5	99,6	5,1	0,0	16 800	119,6	6,1	-	25 200	179,4	9,2	-	31 500	224	11,5	-
Riverview	BF	1 000	0,5	2,5	10,0	4,0	2,1	0,7	0,0	1 200	2,6	0,4	4,4	1 800	3,8	0,7	6,6	2 250	5,1	0,8	8,2
	AS	1 000	0,3	1,0	12,0	5,0	2,0	0,7	0,0	1 200	2,3	0,4	2,7	1 800	3,5	0,7	0,8	2 250	4,3	0,8	1,0
Naauwpoort	AS	2 500	4,5	1,0	5,0	2,0	5,4	1,8	0,0	3 000	6,5	1,1	6,9	4 500	9,7	1,6	2,1	5 630	12,2	2,1	2,6
Middelburg	AS	7 000	4,2	3,3	1,9	20,3	28,6	10,2	0,0	8 400	34,7	3,1	57,6	12 600	52,1	4,6	17,4	15 750	65,1	5,7	21,7
Delmas	AS(NR)	1 200	0,1	1,1	12,2	5,0	2,3	0,4	0,0	1 400	2,7	0,5	-	2 100	4,1	0,8	-	2 600	5,1	0,9	-
Bronkhorstspruit	AS	500	19,0	6,5	22,5	3,5	4,7	1,1	0,0	600	5,6	0,2	6,9	900	8,5	0,3	10,3	1 100	10,3	0,4	12,6
Total (Olifants River)		27 200					144,7	20,0	0,0	32 600	174	21,7	78,5	4 890	261,1	17,9	37,2	61 080	326,1	22,2	46,1

OTHER CATCHMENTS (PART 2)

PLANT LOCATION	TYPE	1981								1985				1995				2000			
		Flow m^3/d	Summer		Winter		Total — N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year	Flow m^3/d	Total N tonnes /year	Total P tonnes /year	TDS tonnes /year
			NO_3 mg/ℓ	NH_3 mg/ℓ	NO_3 mg/ℓ	NH_3 mg/ℓ															
BUFFALO RIVER CATCHMENT																					
ZWELITSHA																					
Old	BF	3 600	2	11,3	2,6	9,2	17,0	9,2	0,0	3 500	16,5	1,3	76,7	3 500	16,5	1,3	76,7	3 500	16,5	1,3	76,7
New	AS	0	-	-	-	-	-	-	-	800	-	0,3	-	2 980	-	1,1	-	4 600	-	1,7	-
Potsdam	AS	9 240	1,1	14,2	1,5	19	56,4	20,2	0,0	11 090	67,7	4,0	127	16 630	102	6,1	38,2	20 790	127	7,6	47,8
Total (Buffalo River)		12 840					73,4	29,4	0,0	15 410	84,2	5,6	203,7	23 110	118,5	8,5	114,9	28 890	143,5	10,6	124,5
BERG RIVER CATCHMENT																					
Paarl	BF	18 650	12,5	8,0	14,0	8,5	143,8	44,2	0,0	22 380	172,6	8,2	449	33 570	258,9	12,3	674	41 960	323,6	15,3	842
Wellington	BF	1 700	10,4	6,0	14,0	7,5	11,0	3,7	0,0	2 000	13,0	0,7	35	3 100	20,1	1,1	56,6	3 830	24,9	1,4	70
Total (Berg River)		20 350					154,8	47,9	0,0	24 380	185,6	8,9	484	36 670	279,0	13,4	730,6	45 790	348,5	16,7	912

Table 1.1: Projection of the future trophic status of Rietvlei Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	100	122	156	199	253
Non-point TP tons/annum	4	4	4	4	4
Total TP load t/a	104	126	159	202	257
Predicted [TP] mg/m3	1374	1607	1942	2327	2759
Mean [chlorophyll] mg/m3	136	153	178	206	235
% change over initial [chl]	0	13	31	52	73
Max. [chlorophyll] mg/m3	231	261	303	349	400
% of year with severe nuisance conditions	100	100	100	100	100

Table 1.2: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	825	1053	1344
Non-point TP tons/annum	7	7	7	7	7
Total TP load t/a	539	654	832	1060	1351
Predicted [TP] mg/m3	708	843	1045	1287	1574
Mean [chlorophyll] mg/m3	80	92	109	129	151
% change over initial [chl]	0	15	36	60	88
Max. [chlorophyll] mg/m3	137	157	186	219	257
% of year with severe nuisance conditions	90	100	100	100	100

Table 1.3: Projection of the future trophic status of Roodekopjes Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	18	22	28	36	46
Non-point TP tons/annum	10	10	10	10	10
Total TP load t/a	28	32	38	46	56
Predicted [TP] mg/m3	113	128	152	183	221
Mean [chlorophyll] mg/m3	19	21	24	28	32
% change over initial [chl]	0	11	27	46	70
Max. [chlorophyll] mg/m3	32	35	41	47	54
% of year with severe nuisance conditions	17	19	23	27	32

Table 1.4: Projection of the future trophic status of Bon Accord Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	185	225	287	366	467
Non-point TP tons/annum	8	8	8	8	8
Total TP load t/a	193	233	295	374	475
Predicted [TP] mg/m3	2119	2400	2777	3172	3575
Mean [chlorophyll] mg/m3	191	211	236	263	289
% change over initial [chl]	0	10	24	38	51
Max. [chlorophyll] mg/m3	325	358	402	446	491
% of year with severe nuisance conditions	100	100	100	100	100

Table 1.5: Projection of the future trophic status of Roodeplaat Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	50	63	200	250	300
Non-point TP tons/annum	4	4	4	4	4
Total TP load t/a	54	67	204	254	304
Predicted [TP] mg/m3	363	435	1219	1482	1733
Mean [chlorophyll] mg/m3	47	55	123	144	163
% change over initial [chl]	0	15	160	204	244
Max. [chlorophyll] mg/m3	81	93	210	245	277
% of year with severe nuisance conditions	51	59	100	100	100

Table 1.6: Projection of the future trophic status of Klipvoor Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	249	303	387	494	630
Non-point TP tons/annum	11	11	11	11	11
Total TP load t/a	261	314	398	505	641
Predicted [TP] mg/m3	927	1096	1346	1645	1996
Mean [chlorophyll] mg/m3	99	113	133	156	182
% change over initial [chl]	0	14	34	57	83
Max. [chlorophyll] mg/m3	169	193	227	266	310
% of year with severe nuisance conditions	100	100	100	100	100

Table 1.7: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	149	190	243
Non-point TP tons/annum	662	662	662	662	662
Total TP load t/a	758	779	811	852	905
Predicted [TP] mg/m3	95	98	102	107	113
Mean [chlorophyll] mg/m3	16	17	17	18	19
% change over initial [chl]	0	2	5	9	14
Max. [chlorophyll] mg/m3	28	29	30	31	32
% of year with severe nuisance conditions	14	14	15	16	17

Table 1.8: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	967	1175	1500	1914	2443
Non-point TP tons/annum	595	595	595	595	595
Total TP load t/a	1562	1770	2095	2509	3038
Predicted [TP] mg/m3	664	738	848	979	1136
Mean [chlorophyll] mg/m3	76	83	93	104	117
% change over initial [chl]	0	9	21	36	53
Max. [chlorophyll] mg/m3	130	141	157	176	198
% of year with severe nuisance conditions	85	93	100	100	100

Table 1.9: Projection of the future trophic status of Koppies Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	2	2	3	4	5
Non-point TP tons/annum	33	33	33	33	33
Total TP load t/a	35	35	36	37	38
Predicted [TP] mg/m3	166	167	170	174	178
Mean [chlorophyll] mg/m3	25	26	26	26	27
% change over initial [chl]	0	1	2	4	6
Max. [chlorophyll] mg/m3	43	44	44	45	46
% of year with severe nuisance conditions	25	25	25	26	27

Table 1.10: Projection of the future trophic status of Bloemhof Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	263	319	408	520	664
Non-point TP tons/annum	608	608	608	608	608
Total TP load t/a	871	928	1016	1129	1273
Predicted [TP] mg/m3	163	173	188	207	230
Mean [chlorophyll] mg/m3	25	26	28	30	33
% change over initial [chl]	0	5	12	20	31
Max. [chlorophyll] mg/m3	43	45	48	52	56
% of year with severe nuisance conditions	24	26	28	31	34

Table 1.11: Projection of the future trophic status of Laing Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	11	14	18	23	29
Non-point TP tons/annum	5	5	5	5	5
Total TP load t/a	17	19	23	28	34
Predicted [TP] mg/m3	155	178	211	254	307
Mean [chlorophyll] mg/m3	24	27	31	36	41
% change over initial [chl]	0	11	27	47	71
Max. [chlorophyll] mg/m3	41	46	53	61	71
% of year with severe nuisance conditions	23	26	31	37	44

Table 1.12: Projection of the future trophic status of Bridle Drift Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	25	31	39	50	64
Non-point TP tons/annum	13	13	13	13	13
Total TP load t/a	39	44	53	64	77
Predicted [TP] mg/m3	117	132	157	187	225
Mean [chlorophyll] mg/m3	19	21	24	28	32
% change over initial [chl]	0	11	26	45	68
Max. [chlorophyll] mg/m3	33	36	41	48	55
% of year with severe nuisance conditions	17	20	23	28	33

Table 1.13: Projection of the future trophic status of Shongweni Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	13	15	19	25	32
Non-point TP tons/annum	2	2	2	2	2
Total TP load t/a	15	17	22	27	34
Predicted [TP] mg/m3	222	260	319	391	480
Mean [chlorophyll] mg/m3	32	36	43	50	59
% change over initial [chl]	0	13	33	57	84
Max. [chlorophyll] mg/m3	55	62	73	85	100
% of year with severe nuisance conditions	33	38	45	54	65

Table 1.14: Projection of the future trophic status of Midmar Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	0	0	0	0	0
Non-point TP tons/annum	8	8	8	8	8
Total TP load t/a	8	8	8	8	8
Predicted [TP] mg/m3	14	14	14	14	14
Mean [chlorophyll] mg/m3	4	4	4	4	4
% change over initial [chl]	0	0	0	0	0
Max. [chlorophyll] mg/m3	6	6	6	6	6
% of year with severe nuisance conditions	0	0	0	0	0

Table 1.15: Projection of the future trophic status of Albert Falls Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	1	1	1	2	2
Non-point TP tons/annum	15	15	15	15	15
Total TP load t/a	16	16	17	17	17
Predicted [TP] mg/m3	17	18	18	18	19
Mean [chlorophyll] mg/m3	4	4	4	4	5
% change over initial [chl]	0	1	2	4	6
Max. [chlorophyll] mg/m3	7	7	8	8	8
% of year with severe nuisance conditions	0	0	0	0	0

Table 1.16: Projection of the future trophic status of Inanda Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	132	160	205	261	334
Non-point TP tons/annum	21	21	21	21	21
Total TP load t/a	153	181	225	282	354
Predicted [TP] mg/m3	302	355	435	534	656
Mean [chlorophyll] mg/m3	41	47	55	64	76
% change over initial [chl]	0	14	34	57	85
Max. [chlorophyll] mg/m3	70	79	93	109	129
% of year with severe nuisance conditions	43	50	59	71	84

Table 1.17: Projection of the future trophic status of Bronkhorstspruit Dar using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	1	1	1	1	1
Non-point TP tons/annum	5	5	5	5	5
Total TP load t/a	5	5	6	6	6
Predicted [TP] mg/m3	28	29	29	31	32
Mean [chlorophyll] mg/m3	6	6	7	7	7
% change over initial [chl]	0	2	4	7	11
Max. [chlorophyll] mg/m3	11	11	11	11	12
% of year with severe nuisance conditions	2	2	2	2	3

Table 1.18: Projection of the future trophic status of Loskop Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	25	30	39	49	63
Non-point TP tons/annum	56	56	56	56	56
Total TP load t/a	81	86	95	106	119
Predicted [TP] mg/m3	59	63	69	76	85
Mean [chlorophyll] mg/m3	11	12	13	14	15
% change over initial [chl]	0	5	12	21	32
Max. [chlorophyll] mg/m3	19	20	22	23	26
% of year with severe nuisance conditions	8	9	10	11	12

Table 1.19: Projection of the future trophic status of Misverstand Dam using the OECD eutrophication modelling approach and assuming no phosphorus standard applied and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	60	73	94	120	153
Non-point TP tons/annum	35	35	35	35	35
Total TP load t/a	95	108	129	154	187
Predicted [TP] mg/m3	93	106	125	149	180
Mean [chlorophyll] mg/m3	16	18	20	23	27
% change over initial [chl]	0	10	26	45	68
Max. [chlorophyll] mg/m3	28	30	35	40	46
% of year with severe nuisance conditions	14	16	19	22	27

Table 2.1: Projection of the future trophic status of Rietvlei Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	100	122	22	28	36
Non-point TP tons/annum	4	4	4	4	4
Total TP load t/a	104	126	26	32	40
Predicted [TP] mg/m3	1374	1607	316	369	428
Mean [chlorophyll] mg/m3	136	153	43	48	54
% change over initial [chl]	0	13	-69	-65	-60
Max. [chlorophyll] mg/m3	231	261	72	82	92
% of year with severe nuisance conditions	100	100	45	52	59

Table 2.2: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	123	157	201
Non-point TP tons/annum	7	7	7	7	7
Total TP load t/a	539	654	130	164	208
Predicted [TP] mg/m3	708	843	164	199	242
Mean [chlorophyll] mg/m3	80	92	25	30	34
% change over initial [chl]	0	15	-69	-63	-57
Max. [chlorophyll] mg/m3	137	157	43	50	58
% of year with severe nuisance conditions	90	100	24	29	35

Table 2.3: Projection of the future trophic status of Roodekopjes Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff

	1981	1985	1990	1995	2000
Sewage TP tons/annum	18	22	3	4	5
Non-point TP tons/annum	10	10	10	10	10
Total TP load t/a	28	32	13	13	14
Predicted [TP] mg/m3	113	128	51	53	57
Mean [chlorophyll] mg/m3	19	21	10	10	11
% change over initial [chl]	0	11	-47	-45	-42
Max. [chlorophyll] mg/m3	32	35	17	18	19
% of year with severe nuisance conditions	17	19	6	7	7

Table 2.4: Projection of the future trophic status of Bon Accord Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff

	1981	1985	1990	1995	2000
Sewage TP tons/annum	185	225	53	68	86
Non-point TP tons/annum	8	8	8	8	8
Total TP load t/a	193	233	61	76	95
Predicted [TP] mg/m3	2119	2400	577	644	713
Mean [chlorophyll] mg/m3	191	211	68	75	81
% change over initial [chl]	0	10	-64	-61	-58
Max. [chlorophyll] mg/m3	325	358	116	127	137
% of year with severe nuisance conditions	100	100	76	83	90

Table 2.5: Projection of the future trophic status of Roodeplaat Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	50	63	20	25	30
Non-point TP tons/annum	4	4	4	4	4
Total TP load t/a	54	67	24	29	34
Predicted [TP] mg/m3	363	435	143	169	193
Mean [chlorophyll] mg/m3	47	55	23	26	29
% change over initial [chl]	0	15	-52	-45	-39
Max. [chlorophyll] mg/m3	81	93	39	44	49
% of year with severe nuisance conditions	51	59	21	25	29

Table 2.6: Projection of the future trophic status of Klipvoor Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	249	303	51	65	83
Non-point TP tons/annum	11	11	11	11	11
Total TP load t/a	261	314	62	76	94
Predicted [TP] mg/m3	927	1096	210	248	293
Mean [chlorophyll] mg/m3	99	113	31	35	40
% change over initial [chl]	0	14	-69	-65	-60
Max. [chlorophyll] mg/m3	169	193	52	60	68
% of year with severe nuisance conditions	100	100	31	36	42

Table 2.7: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	30	38	49
Non-point TP tons/annum	662	662	662	662	662
Total TP load t/a	758	779	692	700	711
Predicted [TP] mg/m3	95	98	87	88	89
Mean [chlorophyll] mg/m3	16	17	15	15	16
% change over initial [chl]	0	2	-7	-7	-6
Max. [chlorophyll] mg/m3	28	29	26	26	26
% of year with severe nuisance conditions	14	14	13	13	13

Table 2.8: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	967	1175	391	498	636
Non-point TP tons/annum	595	595	595	595	595
Total TP load t/a	1562	1770	985	1093	1231
Predicted [TP] mg/m3	664	738	399	427	460
Mean [chlorophyll] mg/m3	76	83	51	54	57
% change over initial [chl]	0	9	-33	-29	-25
Max. [chlorophyll] mg/m3	130	141	87	92	97
% of year with severe nuisance conditions	85	93	55	58	62

Table 2.9: Projection of the future trophic status of Koppies Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	2	2	1	1	1
Non-point TP tons/annum	33	33	33	33	33
Total TP load t/a	35	35	34	34	34
Predicted [TP] mg/m3	166	167	159	160	161
Mean [chlorophyll] mg/m3	25	26	25	25	25
% change over initial [chl]	0	1	-3	-3	-2
Max. [chlorophyll] mg/m3	43	44	42	42	42
% of year with severe nuisance conditions	25	25	24	24	24

Table 2.10: Projection of the future trophic status of Bloemhof Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	263	319	102	130	166
Non-point TP tons/annum	608	608	608	608	608
Total TP load t/a	871	928	710	739	774
Predicted [TP] mg/m3	163	173	132	135	140
Mean [chlorophyll] mg/m3	25	26	21	22	22
% change over initial [chl]	0	5	-16	-14	-11
Max. [chlorophyll] mg/m3	43	45	36	37	38
% of year with severe nuisance conditions	24	26	20	20	21

Table 2.11: Projection of the future trophic status of Laing Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runof

	1981	1985	1990	1995	2000
Sewage TP tons/annum	11	14	3	3	4
Non-point TP tons/annum	5	5	5	5	5
Total TP load t/a	17	19	8	9	9
Predicted [TP] mg/m3	155	178	72	77	84
Mean [chlorophyll] mg/m3	24	27	13	14	15
% change over initial [chl]	0	11	-46	-42	-38
Max. [chlorophyll] mg/m3	41	46	22	24	25
% of year with severe nuisance conditions	23	26	10	11	12

Table 2.12: Projection of the future trophic status of Bridle Drift Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runof

	1981	1985	1990	1995	2000
Sewage TP tons/annum	25	31	7	8	11
Non-point TP tons/annum	13	13	13	13	13
Total TP load t/a	39	44	20	22	24
Predicted [TP] mg/m3	117	132	59	64	70
Mean [chlorophyll] mg/m3	19	21	11	12	13
% change over initial [chl]	0	11	-41	-38	-33
Max. [chlorophyll] mg/m3	33	36	19	21	22
% of year with severe nuisance conditions	17	20	8	9	10

Table 2.13: Projection of the future trophic status of Shongweni Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	13	15	4	5	6
Non-point TP tons/annum	2	2	2	2	2
Total TP load t/a	15	17	6	7	8
Predicted [TP] mg/m3	222	260	89	103	121
Mean [chlorophyll] mg/m3	32	36	16	18	20
% change over initial [chl]	0	13	-51	-45	-38
Max. [chlorophyll] mg/m3	55	62	27	30	34
% of year with severe nuisance conditions	33	38	13	15	18

Table 2.14: Projection of the future trophic status of Midmar Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	0	0	0	0	0
Non-point TP tons/annum	8	8	8	8	8
Total TP load t/a	8	8	8	8	8
Predicted [TP] mg/m3	14	14	14	14	14
Mean [chlorophyll] mg/m3	4	4	4	4	4
% change over initial [chl]	0	0	0	0	0
Max. [chlorophyll] mg/m3	6	6	6	6	6
% of year with severe nuisance conditions	0	0	0	0	0

Table 2.15: Projection of the future trophic status of Albert Falls Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	1	1	0	0	1
Non-point TP tons/annum	15	15	15	15	15
Total TP load t/a	16	16	16	16	16
Predicted [TP] mg/m3	17	18	17	17	17
Mean [chlorophyll] mg/m3	4	4	4	4	4
% change over initial [chl]	0	1	-3	-2	-2
Max. [chlorophyll] mg/m3	7	7	7	7	7
% of year with severe nuisance conditions	0	0	0	0	0

Table 2.16: Projection of the future trophic status of Inanda Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	132	160	34	44	56
Non-point TP tons/annum	21	21	21	21	21
Total TP load t/a	153	181	55	64	76
Predicted [TP] mg/m3	302	355	106	122	141
Mean [chlorophyll] mg/m3	41	47	18	20	22
% change over initial [chl]	0	14	-56	-51	-45
Max. [chlorophyll] mg/m3	70	79	30	34	38
% of year with severe nuisance conditions	43	50	16	18	21

Table 2.17: Projection of the future trophic status of Bronkhorstspruit Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	1	1	1	1	1
Non-point TP tons/annum	5	5	5	5	5
Total TP load t/a	5	5	6	6	6
Predicted [TP] mg/m3	28	29	29	31	32
Mean [chlorophyll] mg/m3	6	6	7	7	7
% change over initial [chl]	0	2	4	7	11
Max. [chlorophyll] mg/m3	11	11	11	11	12
% of year with severe nuisance conditions	2	2	2	2	3

Table 2.18: Projection of the future trophic status of Loskop Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	25	30	18	23	30
Non-point TP tons/annum	56	56	56	56	56
Total TP load t/a	81	86	75	80	86
Predicted [TP] mg/m3	59	63	54	57	61
Mean [chlorophyll] mg/m3	11	12	11	11	12
% change over initial [chl]	0	5	-7	-3	2
Max. [chlorophyll] mg/m3	19	20	18	19	20
% of year with severe nuisance conditions	8	9	7	7	8

Table 2.19: Projection of the future trophic status of Misverstand Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	60	73	14	18	23
Non-point TP tons/annum	35	35	35	35	35
Total TP load t/a	95	108	49	53	58
Predicted [TP] mg/m3	93	106	48	51	56
Mean [chlorophyll] mg/m3	16	18	10	10	11
% change over initial [chl]	0	10	-41	-37	-33
Max. [chlorophyll] mg/m3	28	30	16	17	18
% of year with severe nuisance conditions	14	16	6	6	7

Table 3.1: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.5 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	62	79	100
Non-point TP tons/annum	7	7	7	7	7
Total TP load t/a	539	654	69	86	107
Predicted [TP] mg/m3	708	843	86	104	125
Mean [chlorophyll] mg/m3	80	92	15	18	20
% change over initial [chl]	0	15	-81	-78	-75
Max. [chlorophyll] mg/m3	137	157	26	30	35
% of year with severe nuisance conditions	90	100	12	15	19

Table 3.2: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.5 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	15	19	24
Non-point TP tons/annum	662	662	662	662	662
Total TP load t/a	758	779	677	681	686
Predicted [TP] mg/m3	95	98	85	85	86
Mean [chlorophyll] mg/m3	16	17	15	15	15
% change over initial [chl]	0	2	-9	-9	-8
Max. [chlorophyll] mg/m3	28	29	26	26	26
% of year with severe nuisance conditions	14	14	12	12	12

Table 3.3: Projection of the future trophic status of Bloemhof Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.5 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	263	319	51	65	83
Non-point TP tons/annum	608	608	608	608	608
Total TP load t/a	871	928	659	674	691
Predicted [TP] mg/m3	163	173	122	124	125
Mean [chlorophyll] mg/m3	25	26	20	20	20
% change over initial [chl]	0	5	-21	-20	-19
Max. [chlorophyll] mg/m3	43	45	34	34	35
% of year with severe nuisance conditions	24	26	18	18	19

Table 3.4: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.1 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	12	16	20
Non-point TP tons/annum	7	7	7	7	7
Total TP load t/a	539	654	19	23	27
Predicted [TP] mg/m3	708	843	24	28	32
Mean [chlorophyll] mg/m3	80	92	6	6	7
% change over initial [chl]	0	15	-93	-92	-91
Max. [chlorophyll] mg/m3	137	157	10	11	12
% of year with severe nuisance conditions	90	100	1	2	3

Table 3.5: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.1 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	3	4	5
Non-point TP tons/annum	662	662	662	662	662
Total TP load t/a	758	779	665	666	667
Predicted [TP] mg/m3	95	98	83	83	83
Mean [chlorophyll] mg/m3	16	17	15	15	15
% change over initial [chl]	0	2	-10	-10	-10
Max. [chlorophyll] mg/m3	28	29	25	25	25
% of year with severe nuisance conditions	14	14	12	12	12

Table 3.6: Projection of the future trophic status of Bloemhof Dam using the OECD eutrophication modelling approach and assuming [P] limit = 0.1 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	263	319	10	13	17
Non-point TP tons/annum	608	608	608	608	608
Total TP load t/a	871	928	619	621	625
Predicted [TP] mg/m3	163	173	115	114	113
Mean [chlorophyll] mg/m3	25	26	19	19	19
% change over initial [chl]	0	5	-24	-25	-25
Max. [chlorophyll] mg/m3	43	45	32	32	32
% of year with severe nuisance conditions	24	26	17	17	17

Table 4.1: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	123	157	201
Non-point TP tons/annum	0	0	0	0	0
Total TP load t/a	532	647	123	157	201
Predicted [TP] mg/m3	1019	1048	171	210	256
Mean [chlorophyll] mg/m3	107	109	26	31	36
% change over initial [chl]	0	2	-76	-71	-66
Max. [chlorophyll] mg/m3	182	186	44	52	61
% of year with severe nuisance conditions	100	100	25	31	37

Table 4.2: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	30	38	49
Non-point TP tons/annum	56	56	56	56	56
Total TP load t/a	152	173	86	94	105
Predicted [TP] mg/m3	141	158	77	83	90
Mean [chlorophyll] mg/m3	22	25	14	15	16
% change over initial [chl]	0	10	-38	-34	-30
Max. [chlorophyll] mg/m3	38	42	24	25	27
% of year with severe nuisance conditions	21	24	11	12	13

Table 4.3: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	967	1175	391	498	636
Non-point TP tons/annum	48	48	48	48	48
Total TP load t/a	1014	1223	438	546	684
Predicted [TP] mg/m3	2335	2544	793	847	897
Mean [chlorophyll] mg/m3	206	221	88	93	97
% change over initial [chl]	0	7	-57	-55	-53
Max. [chlorophyll] mg/m3	350	375	149	157	165
% of year with severe nuisance conditions	100	100	99	100	100

Table 4.4: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	123	157	201
Non-point TP tons/annum	21	21	21	21	21
Total TP load t/a	553	668	144	178	222
Predicted [TP] mg/m3	655	778	164	197	236
Mean [chlorophyll] mg/m3	76	87	25	29	34
% change over initial [chl]	0	15	-66	-61	-55
Max. [chlorophyll] mg/m3	128	147	43	50	57
% of year with severe nuisance conditions	84	97	24	29	34

Table 4.5: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	96	117	30	38	49
Non-point TP tons/annum	1335	1335	1335	1335	1335
Total TP load t/a	1431	1452	1365	1373	1384
Predicted [TP] mg/m3	128	130	122	122	123
Mean [chlorophyll] mg/m3	21	21	20	20	20
% change over initial [chl]	0	1	-4	-3	-3
Max. [chlorophyll] mg/m3	35	36	34	34	34
% of year with severe nuisance conditions	19	19	18	18	18

Table 4.6: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming [P] limit = 1.0 mg/l after 1985 and runoff = 1 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	967	1175	391	498	636
Non-point TP tons/annum	1203	1203	1203	1203	1203
Total TP load t/a	2170	2378	1593	1701	1839
Predicted [TP] mg/m3	497	539	356	373	394
Mean [chlorophyll] mg/m3	61	65	47	48	50
% change over initial [chl]	0	7	-23	-20	-17
Max. [chlorophyll] mg/m3	103	110	79	82	86
% of year with severe nuisance conditions	67	71	50	52	54

Table 5.1: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	532	647	825	1053	1344
Detergent TP tons/annum	261	317	404	516	659
% of detergent TP removed	0	0	50	50	50
Residual detergent TP, tons	261	317	202	258	329
Faecal sewage TP tons/annum	271	330	421	537	685
Diffuse TP tons/annum	7	7	7	7	7
TP total load t/a	539	654	630	802	1022
Predicted [TP] in mg/m3	708	843	791	974	1191
Mean [chlorophyll] mg/m3	80	92	88	103	121
% change over initial chl	0	15	9	29	51
Max. [chlorophyll] mg/m3	137	157	149	176	206
% of year with severe nuisance conditions	90	100	99	100	100

Table 5.2: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	96	117	149	190	243
Detergent TP tons/annum	47	57	73	93	119
% of detergent TP removed	0	0	50	50	50
Residual detergent TP, tons	47	57	37	47	59
Faecal sewage TP tons/annum	49	60	76	97	124
Diffuse TP tons/annum	662	662	662	662	662
TP total load t/a	758	779	775	806	845
Predicted [TP] in mg/m3	95	98	97	101	105
Mean [chlorophyll] mg/m3	16	17	17	17	18
% change over initial chl	0	2	1	4	8
Max. [chlorophyll] mg/m3	28	29	28	29	30
% of year with severe nuisance conditions	14	14	14	15	16

Table 5.3: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.

Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	967	1175	1500	1914	2443
Detergent TP tons/annum	474	576	735	938	1197
% of detergent TP removed	0	0	50	50	50
Residual detergent TP, tons	474	576	367	469	598
Faecal sewage TP tons/annum	493	599	765	976	1246
Diffuse TP tons/annum	595	595	595	595	595
TP total load t/a	1562	1770	1727	2040	2439
Predicted [TP] in mg/m3	664	738	699	796	912
Mean [chlorophyll] mg/m3	76	83	79	88	98
% change over initial chl	0	9	4	15	29
Max. [chlorophyll] mg/m3	130	141	135	150	167
% of year with severe nuisance conditions	85	93	89	99	100

Table 5.4: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.

Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	532	647	825	1053	1344
Detergent TP tons/annum	261	317	404	516	659
% of detergent TP removed	0	0	80	80	80
Residual detergent TP, tons	261	317	81	103	132
Faecal sewage TP tons/annum	271	330	421	537	685
Diffuse TP tons/annum	7	7	7	7	7
TP total load t/a	539	654	509	647	824
Predicted [TP] in mg/m3	708	843	639	786	960
Mean [chlorophyll] mg/m3	80	92	74	87	102
% change over initial chl	0	15	-8	9	27
Max. [chlorophyll] mg/m3	137	157	126	148	174
% of year with severe nuisance conditions	90	100	82	98	100

Table 5.5: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	96	117	149	190	243
Detergent TP tons/annum	47	57	73	93	119
% of detergent TP removed	0	0	80	80	80
Residual detergent TP, tons	47	57	15	19	24
Faecal sewage TP tons/annum	49	60	76	97	124
Diffuse TP tons/annum	662	662	662	662	662
TP total load t/a	758	779	753	778	810
Predicted [TP] in mg/m3	95	98	94	97	101
Mean [chlorophyll] mg/m3	16	17	16	17	17
% change over initial chl	0	2	-1	2	4
Max. [chlorophyll] mg/m3	28	29	28	28	29
% of year with severe nuisance conditions	14	14	14	14	15

Table 5.6: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	967	1175	1500	1914	2443
Detergent TP tons/annum	474	576	735	938	1197
% of detergent TP removed	0	0	80	80	80
Residual detergent TP, tons	474	576	147	188	239
Faecal sewage TP tons/annum	493	599	765	976	1246
Diffuse TP tons/annum	595	595	595	595	595
TP total load t/a	1562	1770	1507	1759	2080
Predicted [TP] in mg/m3	664	738	610	686	778
Mean [chlorophyll] mg/m3	76	83	71	78	87
% change over initial chl	0	9	-6	3	13
Max. [chlorophyll] mg/m3	130	141	121	133	147
% of year with severe nuisance conditions	85	93	79	88	97

Table 5.7: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	532	647	825	1053	1344
Detergent TP tons/annum	261	317	404	516	659
% of detergent TP removed	0	0	100	100	100
Residual detergent TP, tons	261	317	0	0	0
Faecal sewage TP tons/annum	271	330	421	537	685
Diffuse TP tons/annum	7	7	7	7	7
TP total load t/a	539	654	428	544	693
Predicted [TP] in mg/m3	708	843	537	661	807
Mean [chlorophyll] mg/m3	80	92	65	76	89
% change over initial chl	0	15	-20	-5	11
Max. [chlorophyll] mg/m3	137	157	110	129	151
% of year with severe nuisance conditions	90	100	71	85	100

Table 5.8: Projection of the future trophic status of Vaal Dam using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	96	117	149	190	243
Detergent TP tons/annum	47	57	73	93	119
% of detergent TP removed	0	0	100	100	100
Residual detergent TP, tons	47	57	0	0	0
Faecal sewage TP tons/annum	49	60	76	97	124
Diffuse TP tons/annum	662	662	662	662	662
TP total load t/a	758	779	738	759	786
Predicted [TP] in mg/m3	95	98	93	95	98
Mean [chlorophyll] mg/m3	16	17	16	16	17
% change over initial chl	0	2	-2	-0	2
Max. [chlorophyll] mg/m3	28	29	27	28	29
% of year with severe nuisance conditions	14	14	14	14	14

Table 5.9: Projection of the future trophic status of Vaal Barrage using the OECD eutrophication modelling approach and assuming no [P] limit introduced, but some detergent P removed.
Runoff = 1.0 * Mean annual runoff

	1981	1985	1990	1995	2000
Uncontrolled sewage TP load	967	1175	1500	1914	2443
Detergent TP tons/annum	474	576	735	938	1197
% of detergent TP removed	0	0	100	100	100
Residual detergent TP, tons	474	576	0	0	0
Faecal sewage TP tons/annum	493	599	765	976	1246
Diffuse TP tons/annum	595	595	595	595	595
TP total load t/a	1562	1770	1360	1571	1841
Predicted [TP] in mg/m3	664	738	550	613	689
Mean [chlorophyll] mg/m3	76	83	66	72	79
% change over initial chl	0	9	-14	-6	3
Max. [chlorophyll] mg/m3	130	141	112	122	134
% of year with severe nuisance conditions	85	93	73	80	88

Table 6.1: Projection of the future trophic status of Rietvlei Dam using the OECD eutrophication modelling approach and assuming [P] limit of 1.0 mg/l after 1985, no nitrogen limitation and runoff = 1.0 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	100	122	22	28	36
Non-point TP tons/annum	4	4	4	4	4
TP total load t/a	104	126	26	32	40
Sewage N tons/annum	115	139	178	227	290
Non-point N tons/annum	74	74	74	74	74
N total load t/a	189	213	252	301	364
Predicted [TP] mg/m3	1356	1587	314	367	425
Predicted [TN] mg/m3	2	2	2	2	2
N:P ratio *	1:1	1:1	6:1	6:1	5:1

* as a rule of thumb, when N:P < 7, nitrogen is the limiting nutrient.

Table 6.2: Projection of the future trophic status of Hartbeespoort Dam using the OECD eutrophication modelling approach and assuming [P] limit of 1.0 mg/l after 1985, no nitrogen limitation and runoff = 1.0 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	532	647	123	157	201
Non-point TP tons/annum	6	6	6	6	6
TP total load t/a	538	653	129	163	207
Sewage N tons/annum	2423	2718	3176	3761	4508
Non-point N tons/annum	111	111	111	111	111
N total load t/a	2535	2829	3287	3873	4620
Predicted [TP] mg/m3	712	849	163	200	242
Predicted [TN] mg/m3	2	2	2	2	2
N:P ratio *	2:1	2:1	10:1	9:1	8:1

* as a rule of thumb, when N:P < 7, nitrogen is the limiting nutrient.

Table 6.3: Projection of the future trophic status of Roodeplaat Dam using the OECD eutrophication modelling approach and assuming [P] limit of 1.0 mg/l after 1985, no nitrogen limitation and runoff = 1.0 * mean annual runoff.

	1981	1985	1990	1995	2000
Sewage TP tons/annum	50	63	20	25	30
Non-point TP tons/annum	4	4	4	4	4
TP total load t/a	54	67	24	29	34
Sewage N tons/annum	48	60	192	240	288
Non-point N tons/annum	74	74	74	74	74
N total load t/a	122	134	266	314	362
Predicted [TP] mg/m3	363	435	143	169	193
Predicted [TN] mg/m3	1	1	1	1	1
N:P ratio *	3:1	2:1	9:1	8:1	7:1

* as a rule of thumb, when N:P < 7, nitrogen is the limiting nutrient