TROPHIC STATUS ASSESSMENT

Executive Summary

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INTRODUCTION

1.1 Purpose of the Trophic Status Project Assessment

The purpose of this report is to:

- Assess the current scope and operational effectiveness of the Trophic Status Project (hereafter called the TSP) for South African impoundments.
- Analyse the data generated by the Trophic Status Project,
  - To determine time-related project changes during the monitoring programme.
  - To investigate trends in nutrient concentrations and eutrophication symptoms in selected South African impoundments.
  - To determine the trophic status of impoundments in the catchments described as being sensitive.
  - To evaluate the effect of the 1mg/ℓ P effluent discharge standard (P-Standard) on the trophic status of selected impoundments.
- Provide Water Resource Managers (National and Regional) with information that can be used in the development of future eutrophication monitoring programmes and management strategies.

1.2 Eutrophication

Eutrophication refers to the enrichment of water bodies with plant nutrients, particularly phosphorus and nitrogen compounds. It is a natural phenomenon that normally occurs during the life of an impoundment or a lake and can take thousands of years to occur. This phenomenon is also known as the ageing of a lake. The natural succession of lakes is from oligotrophic (low in productivity and species abundance) through mesotrophic (moderate productivity and high species diversity) to eutrophic (high productivity and high species abundance, but low species diversity). The extreme eutrophic condition is often referred to as being hyper-eutrophic. Cultural eutrophication, on the other hand, is an unnatural process caused by increased nutrient loading from the surrounding catchment areas as a direct result of man's activities. Agricultural and urban run-off, municipal and industrial wastewater effluents, and septic tank leach fields all contribute plant nutrients, as well as other pollutants, to catchment areas. This greatly accelerates the eutrophication of lakes and thus reduces the time scale for the ageing of lakes to take place (VOLLENWEIDER 1981, SKICKO, 1983).

Nutrient-enriched (eutrophic to hyper-eutrophic) systems result in significant water quality problems, for example nuisance growth of aquatic material such as algae and macrophytes. This in turn leads to water quality deterioration, algal toxin production, taste and odour problems, oxygen depletion, decline of more desirable fish species, the clogging of waterways, disruption of flocculation and chlorination processes in water treatment plants, and in some cases, excessive loss of water through evapotranspiration. Nutrient enrichment, therefore, continues to be one of the leading causes of water quality impairment in the world.

1.3 Eutrophication Management in South Africa

South Africa's most limiting natural resource is fresh water. Therefore, the then Department of Water Affairs promulgated the 1 mg/ℓ -P effluent discharge standard in 1980 (WATER, 1988). The Hydrological Research Institute (now the Institute for Water Quality Studies - IWQS) initiated a monitoring programme in 1985 in the seven sensitive catchments mentioned in the Government Gazette Notice No. 1567. The aim of the monitoring programme was to gauge the effect of the 1 mg/ℓ P effluent discharge standard on the water quality of the specified impoundments.

1.3.1 *The 1 mg/ℓ P-Standard*

Phosphorus is strongly implicated in the growth of undesirable algae. It is also the most controllable of the nutrients from a management perspective.

The wording of the 1 mg/ℓ P-Standard announcement made on 1 August 1980 (in terms of Section 21(1)(a) of the Water Act, 1956 announced in Government Notice No.1567) is as follows:

"Waste water or effluent produced by or resulting from the use of water for industrial purposes and which drains to any portions of a river mentioned in Schedule 2 or any tributary of such a river within the catchment areas or portions thereof described in the Schedule, shall not contain soluble ortho phosphate (as P) in a higher concentration than 1.0 milligram per litre"

"Schedule 2

(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) Buffalo River upstream and inclusive of Bridle Drift Dam;
(vii) Berg River upstream of the influence of tidal water."

It should be noted that the 1 mg/ℓ P-Standard is an Effluent Discharge Standard, not an in-stream standard. The ameliorating effect of the in-stream processes are required to act on the discharged effluent to lower the in-stream nutrient concentrations to within acceptable levels when the trophic status is considered.

Due to requests made by local authorities that capacity and resources were not available to meet the deadline, an extension of 5 years was given. After this time all local authorities and industries discharging in the sensitive catchments were to comply with the P-Standard (TAYLOR, *et al.* 1984, DWA 1988 & VAN DER MERWE 1988)).

A preliminary assessment of the P-Standard on the water quality was undertaken during 1985. On the basis of this study and because of the poor state of the economy in 1985, the Department decided to:

(i) Only implement the P-Standard in the Vaal River catchment up to the Barrage and in the Crocodile River catchment up to the confluence of the Crocodile and Pienaars Rivers
(ii) Grant a further three years exemption, until August 1988, from complying with the P-Standard in the remaining catchments.

In this three-year period from 1985 to 1988 the Department of Water Affairs and the CSIR (Council for Scientific and industrial Research) completed an investigation, using the Reservoir Eutrophication Model (REM), to predict the impact of the P-Standard on water quality in the sensitive catchments. On the basis of these findings further exemptions from the implementation of the phosphate standard were granted (see Table 1). The target water quality aimed for to control eutrophication was set "*to maintain mean chlorophyll concentrations in the receiving water bodies at such levels that severe nuisance conditions would not occur for more than 20 % of the time. This translated into a phosphorus management objective (PMO) or endpoint of maintaining mean total phosphorus concentrations in reservoirs at 130 µg/ℓ P or lower."* (DWA 1988, ANON 1988a, ANON 1988b)

Table 1. Summary of decisions made concerning the implementation of 1 mg/ℓ P-Standard (DWA, 1988).

Catchment	Impoundment/River	No Standard	1 mg/ℓ P-Standard	Additional measures
Crocodile (North West)	Rietvlei		X	X
	Harbeespoort		X	X
	Roodeplaat		X	
	Apies/Klipvoor		X	
Olifants (Mpumalanga)	Bronkhorstspruit	X		
	Loskop	X		
Vaal (Gauteng/Free State)	Grootdraai	X		
	Vaal Barrage	X	X	X
	Middle Vaal River	X		
	Bloemhof	X		
Mgeni (KwaZulu Natal)	Midmar	X		
	Albert Falls	X		
	Nagle	X		
	Inanda		X	
Mlaas (KwaZulu Natal)	Shongweni		X	
Buffalo (Eatern Cape)	Laing		X	
	Bridle Drift	X		
Berg (Western Cape)		X		

- No Standard = In these catchments implementation of the 1 mg/ℓ P-Standard was postponed for a specific period or until further notice;
- 1 mg/ℓ P-Standard = In these catchments the 1 mg/ℓ P-Standard will strictly be enforced (This was, however, not implemented strictly (VAN VLIET Pers. Comm. 2001; HOHLS *et al.* 1998) – the phosphorus concentration inputs from discharges did, however, decreased apparently in an attempt to adhere to the 1 mg/ℓ P-Standard)
- Additional measures = In these catchments the receiving water bodies are so overloaded with phosphorus that implementation of the 1 mg/ℓ P-Standard will be insufficient to improve water quality. These additional measures refer to the implementation of either stricter standards or other management strategies.

DWA (1988) stressed the fact that results from the eutrophication monitoring (TSP) might result in a review of decisions concerning the implementation of the P-Standard. This project was initially intended to ascertain the effect of the 1 mg/ℓ P-Standard. However, the emphasis of the Trophic Status Project shifted to determine the trophic status of impoundments in 1990, due to a lack of information from the institutions that should have been complying with the 1 mg/ℓ P-Standard. The report is, therefore, addressing questions relating to the trophic status trends in the impoundments to determine if there were any changes in the relevant impoundments' water quality.

1.4 Assessment of Trophic Status

The eutrophication classification method adopted in this report is based on the following variables:

- **Mean annual chlorophyll-*a* concentration** since it is a symptom of eutrophication.
- **Per cent of time that the actual chlorophyll-*a* concentrations are greater than 30 µg/ℓ**.
- **Mean annual total phosphorus (TP) concentrations.**
- **Presence of cyanobacteria** (mean annual percentage cyanobacteria in the phytoplankton population).
- **Mean annual transparency** (as determined as Secchi disc depth).

The variables used and their respective ranges are presented in Table 2.

Table 2. Trophic status indicators and the appropriate ranges used to classify the impoundments.

Variable	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hyper-eutrophic**
Mean Chl *a* (µg/ℓ)	0 –10	10 – 20	20 – 30	> 30
% of time Chl *a* > 30 µg/ℓ	0	< 8	8 – 50	>50
Total Phosphorus (mg/ℓ)	< 0.015	0.015 – 0.047	0.047 – 0.130	> 0.130
Mean annual % cyanobacteria in phytoplankton population	0 - 1	1 – 10	10 - 50	> 50

Mean annual transparency	**Highly turbid**	**Turbid**	**Clear**
Secchi disc depth (m)	< 0.2	0.2 – 0.8	> 0.8

- *Even where the first four variables may be indicative of a specific trophic status, the fifth variable may play a significant role in the establishment or retardation of eutrophication symptoms.*

In the classification of the impoundments, the mean annual TP concentration was used as the most important indicator since the development of the chlorophyll-*a* concentration might be limited by light penetration.

The TN:TP ratio was used to indicate the limiting nutrient in an impoundment. A TN:TP ratio of greater than 10:1 signifies phosphorus limitation. From an eutrophication management perspective this is desirable, as P is easier to manage and favours green algae, which may be less problematic to manage than cyanobacteria. From a eutrophication viewpoint a TN:TP ratio less than 10:1 (nitrogen limitation) is a less desirable situation since some of the cyanobacteria are able to fix atmospheric nitrogen, and favours cyanobacterial development and dominance in a system.

Table 3 lists the catchments and impoundments that were included in the TSP, together with an indication of whether the 1 mg/ℓ P-Standard was applicable to the individual impoundments.

Table 3. The catchments and impoundments included in the Trophic Status Project from 1985 to 1999, indicating the catchment areas that were subject to the P-Standard.

Catchment	Impoundment	P-Standard
Berg River (Western Cape)	Misverstand	
	Voëlvlei	
	Wemmershoek	
Buffalo River (Eastern Cape)	Bridle Drift	
	Laing	X
Crocodile & Pienaars Rivers (North West & North Gauteng)	Bon Accord	X
	Buffelspoort	
	Hartbeespoort	X
	Klipvoor	X
	Kosterrivier	
	Lindleyspoort	
	Rietvlei	X
	Roodeplaat	X
	Roodekopjes	
	Vaalkop	
Knysna Lakes (Western Cape)	Bo-Langvlei	
	Groenvlei	
	Onder-langvlei	
	Rondevlei	
	Sedgefield lagoon	
	Swartvlei	
	Wilderness lagoon	
Letaba River (Northern Province)	Ebenezer	
	Magoebaskloof	
	Tzaneen (Fanie Botha)	
Mgeni River (KwaZulu Natal)	Albert Falls	
	Henley	
	Inanda	X
	Midmar	
	Nagle	
Mlaas River (KwaZulu Natal)	Shongweni	X
Molopo River (North West)	Cooks Lake	
	Disaneng	
	Lotlamoreng	
	Modimola	
Olifants River (Mpumalanga)	Loskop	
	Middelburg	
	Witbank (Nuwe Doringpoort)	
Orange River (Free State)	Gariep (Verwoerd)	
Vaal River (South Gauteng & Free State)	Allemanskraal	
	Bloemhof	
	Boskop	
	Erfenis	
	Grootdraai	
	Koppies	
	Sterkfontein	
	Vaal	
White Mfolozi (KwaZulu Natal)	Klipfontein	

2. EFFECTIVENESS OF THE TROPHIC STATUS PROJECT

A programme's operational effectiveness is essential to the continued success of such a programme. It is, therefore, essential to evaluate the effectiveness of the TSP in terms of its need for trained personnel, data collection, the provision of sampling equipment and the procedures for sampling. The analysis of the samples and the completeness of the data record for all the selected sites and for all the required variables is also essential to the success of such a project.

The operational effectiveness of the TSP was determined by auditing the amount of available data for the TSP for the duration of the project. This information is summarised in Table 4 and it is shown that at nineteen of the 48 impoundment's (40 %) the sampling programmes were highly successful in terms of providing data for the determination of trends and the trophic status of the impoundments. All of the other impoundments (60 %) have numerous periods of missing data, especially in the case of biological information.

Table 3 and Figure 1 show that impoundments throughout the country were included in the monitoring programme. The only Province that is not represented is the Northern Cape. The impoundments reflect a spread from highly eutrophic impoundments (e.g. the Hartbeespoort and the Roodeplaat Dams) to impoundments that do not experience serious eutrophication problems (e.g. the Magoebaskloof and the Sterkfontein Dams).

3. TROPHIC STATUS OF SOUTH AFRICAN IMPOUNDMENTS

In the main report, the section on the Trophic Status of South African Impoundments includes an overview of each catchment followed by separate discussions of each impoundment, showing the mean annual trends for eutrophication related variables. The results are discussed under four headings: 1) nutrients, 2) biological characteristics, 3) physical characteristics, and 4) trophic status of the impoundment.

The nutrient discussion includes annual trends in phosphorus species, nitrogen species and mean annual TN:TP ratios. The TN:TP ratio indicates the potential limiting nutrient within a system and is, therefore, an indication as to which variable needs to be managed in a system's catchment. The TN:TP ratio also indicates the potential for cyanobacterial dominance.

The biological characteristic discussions include the annual trends in chlorophyll *a* concentration and changes in algal species composition.

Under the physical characteristics, the transparency and suspended solids results are discussed, as well as the temperature and oxygen profiles of the systems.

The sections on the trophic status of the impoundments classify the impoundments into a specific trophic class on an annual basis.

The results of the trophic status classification of the impoundments that have been included in the TSP are summarised in Figure 1. The overall classification for the ten years of data have been summarised to indicate whether a system is classified as oligotrophic (blue), mesotrophic (green), eutrophic (yellow) or hyper-eutrophic (red).

4. EVALUATION OF THE EFFECT OF THE 1 mg/ℓ P STANDARD IN SELECTED IMPOUNDMENTS

The report did not attempt to report on the compliance of institutions to the 1 mg/ℓ P-Standard. The TSP report rather surveyed noticeable effects in the impoundments that led to decreases or increases in eutrophication related variables since the time that the 1 mg/ℓ P-Standard was supposed to be strictly adhered to.

The 1 mg/ℓ P Standard was only implemented in the catchments of eight impoundments, of which five are situated in the Crocodile and Pienaars River catchments (See Table 3).

The implementation of the 1 mg/ℓ P Standard had an effect (although it was not strictly implemented) in the catchments of the Bon Accord Dam, the Hartbeespoort Dam and the Rietvlei Dam. Although the trophic status did not change significantly, a significant decrease in phosphorus concentrations was apparent in these three impoundments.

No significant reduction in phosphorus concentration was noticed in the Laing Dam, the Klipvoor Dam, the Inanda Dam and the Shongweni Dam, and the supposed implementation of the 1 mg/ℓ P Standard in these catchments, therefore, had no effect.

The nutrient concentrations in the Roodeplaat Dam are a major concern. Stricter eutrophication management strategies are needed since the 1 mg/ℓ P Standard (not strictly implemented) has had no effect. A constant increase in nutrients within the impoundment was apparent and symptoms of hyper-eutrophication are on-going.

A number of the impoundments, where the 1 mg/ℓ P Standard was not implemented, are in need of urgent eutrophication management strategies, e.g. the Allemanskraal Dam, the Bloemhof Dam, the Erfenis Dam, the Koppies Dam, the Misverstand Weir, the Bridledrift Dam and most of the impoundments in the Molopo River catchment.

The supposed implementation of the 1 mg/ℓ P Standard had, therefore, an effect to different degrees. It is important to note that the 1 mg/ℓ P-Standard will remain for all permitted discharges where it was an original requirement. With the new licensing of lawful water uses the consideration of even stricter phosphorus concentrations should be considered in order to combat eutrophication.

5. PRIORITISATION OF THE IMPOUNDMENTS FOR MANAGEMENT PURPOSES

This section of the report demonstrates the potential use of the information generated from the data collected during the TSP. Even though some of the data sets are not complete, they might be used in the determination of priority management needs on a national, regional and/or local level.

The "SMART" prioritisation method of GOODWIN and WRIGHT (1991) was used to determine the importance, or the extent, of eutrophication in the impoundments. This gives an indication of the severity of eutrophication within all of the impoundments in relation to the other impoundments.

The prioritised rankings of the TSP impoundments are tabulated in the main report. The ten impoundments that were allocated the highest priority are situated within only four catchments, namely, the Crocodile/Pienaars River (the Rietvlei, Klipvoor, Roodeplaat, Bon Accord and Hartbeespoort Dams), the upper Vaal River (the Erfenis and Bloemhof Dams), the Molopo River (the Cook's Lake and Lotlamoreng Weir) and the Mlaas River (the Shongweni Dam) catchments. The Laing Dam might have come higher up in the priority list if data were available on the extent of the eutrophication symptoms. In spite of the lack of data, the Laing Dam is ranked at number 13 on the priority list.

The lowest ten impoundments based on the priority ranking fall within the B1, B2 and B3 (the Loskop Dam), the B8 (the Tzaneen and the Ebenezer Dams), the C (the Boskop Dam), the G2 (the Voëlvlei and Wemmershoek Dams) and the K3 and K4 (the Swartvlei Lake, Sedgefield Lagoon, Groenvlei Lake and Wilderness Lagoon) catchments. The Wemmershoek Dam and the Wilderness Lake were given the lowest priority ranking. This indicates that the water quality, when eutrophication is considered, of these systems is highly acceptable and needs to be maintained in such pristine conditions to have examples in which the biotic diversity and water quality reflects the un-impacted state most closely and to ensure sustainable water supplies in these areas.

The list of prioritised impoundments and associated data will enable national, regional and local managers to decide on the management approaches required within each impoundment or catchment. The impoundments that fall within the first 10 on the ranking list should be considered serious eutrophication and health hazards. These impoundments might be further prioritised by the water usage. However, this was not considered to be within the scope of this study.

The prioritisation exercise has now proved that the TSP information that has been collected over many years and by the effort of numerous people has not been a futile exercise. The information can be used in decision making.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The TSP was comprehensive and effective in certain impoundments due to the dedication of samplers and the project leaders. Even the sparse availability of data enables the manager to have actual information, where an educated guess would have been the only other option upon which to base decisions.

6.1.2 The available data enabled the presentation of time-series of fluctuations in concentrations of variables within the impoundments. The changes of emphasis in the TSP and the relatively limited extent of this study led to the omission of the load determinations of nutrients being discharged into each impoundment. However, this should be done in future to determine trends in loads entering the impoundments.

6.1.3 The trophic status of the impoundments studied in the TSP project covered the entire trophic spectrum from the oligotrophic to hyper-eutrophic state.

6.1.4 The 1 mg/ℓ P-Standard showed an effect in the Bon Accord, the Hartbeespoort and the Rietvlei dams, where significant reductions in phosphorus concentrations were apparent. The decreases in phosphorus concentrations did, however, not make significant changes to the trophic status classification of these impoundments.

6.1.5 The 1 mg/ℓ P Standard had no effect or was totally ineffective in all the other catchments where the standard was implemented (if it was implemented strictly).

6.1.6 The Crocodile/Pienaars River catchment experienced the highest level of eutrophication due to the extensive human activities within the upper reaches of the catchment. The Pienaars River impoundments are all in the hyper-eutrophic class. As these impoundments are used extensively for human consumption and recreation, this catchment is in dire need of fast and effective management strategies.

The Crocodile catchment also contains impoundments that are classified as hyper-eutrophic. In the upper reaches of the Crocodile River both the Rietvlei and the Hartbeespoort Dams have histories of major eutrophication symptoms. Although there seems to have been a decrease in eutrophic indicator concentrations and incidents, the Hartbeespoort Dam is still highly nutrient enriched.

6.1.7 The Natal impoundments showed a marked difference in temperature ranges throughout the winter period that might explain the persistence of cyanobacteria as a dominant group within the phytoplankton population. Overall, the Natal impoundments did not develop extreme eutrophication conditions, possibly due to the different climatic conditions (higher rainfalls and regular flushing of nutrients) that these impoundments are exposed to.

6.1.8 The eutrophication management priority rating of the impoundments on a catchment basis was shown. The impoundments in highest need of management strategies were indicated, with the top 10 catchments on the priority list being:

- A2 Catchment — Rietvlei Dam, Klipvoor Dam, Roodeplaat Dam, Bon Accord Dam, Hartbeespoort Dam
- C Catchment — Erfenis Dam, Bloemhof Dam
- D Catchment — Cook's Lake, Lotlamoreng Weir
- U6 Catchment — Shongweni Dam

It is interesting to note that at least six of these impoundments (namely the Rietvlei, Klipvoor, Roodeplaat, Hartbeespoort, Erfenis and Bloemhof Dams) also have histories of toxic algal incidents. Of these upper ten impoundments, only the Klipvoor and the Shongweni Dams are not used for domestic water supplies. One could argue that these impoundments should, therefore, not be as high on the priority list. However, they might pose a serious problem for recreational users.

6.1.9 The occurrence of toxic algal incidents in the above-mentioned impoundments, and the associated lethal effects they often have on the livestock agricultural sector, as well as the potential of toxic effects on human health, highlights the need for public awareness.

6.1.10 There is a need for the development of a more extensive Eutrophication Monitoring Programme in order to include the impoundments of the entire country for future monitoring and management purposes. This will enable water resource managers to know the true extent of eutrophication within their management areas. Such a monitoring programme should include biological measurements (chlorophyll *a* and algal identification) for the determination of potential cyanobacterial toxicity in impoundments.

6.2 Recommendations

6.1.1 The changes of emphasis to the TSP and the limited extent of this report led to the omission of nutrient load determinations for each impoundment. Nutrient load determinations should, however, be conducted in future.

6.1.2 The Crocodile and Pienaars River impoundments are all in the hyper-eutrophic class. As the water in these impoundments is used extensively for human consumption, this catchment is in dire need of fast and effective management strategies.

6.1.3 The development of an extensive, National Eutrophication Monitoring Programme for the rest of the country is needed (a current WRC project) and should include the biological determinands (chlorophyll *a* and algal identifications).

6.1.4 Bi-weekly monitoring is preferable.

6.1.5 Impoundments that are not prone to nutrient enrichment should be included in such a monitoring programme since eutrophication problems and algal blooms might in future develop in such catchments. If an impoundment is excluded, no baseline information will be available to determine historical trends, or to predict emerging problems.

6.1.6 The field determination of temperature and dissolved oxygen levels would add value to the information, even if it were only a surface determination. Depth profile data is, however, preferable. Depth profile data is preferable because it provides essential information for the understanding of the limnology of an impoundment and, therefore, of the functioning and reactions of such a system.

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- MAGALIES WATER for the monitoring of the Vaalkop Dam.
- Cape Parks Board for monitoring the Wilderness Lakes.
- North West Regional Office (situated at Mmabatho) for monitoring the Molopo impoundments.

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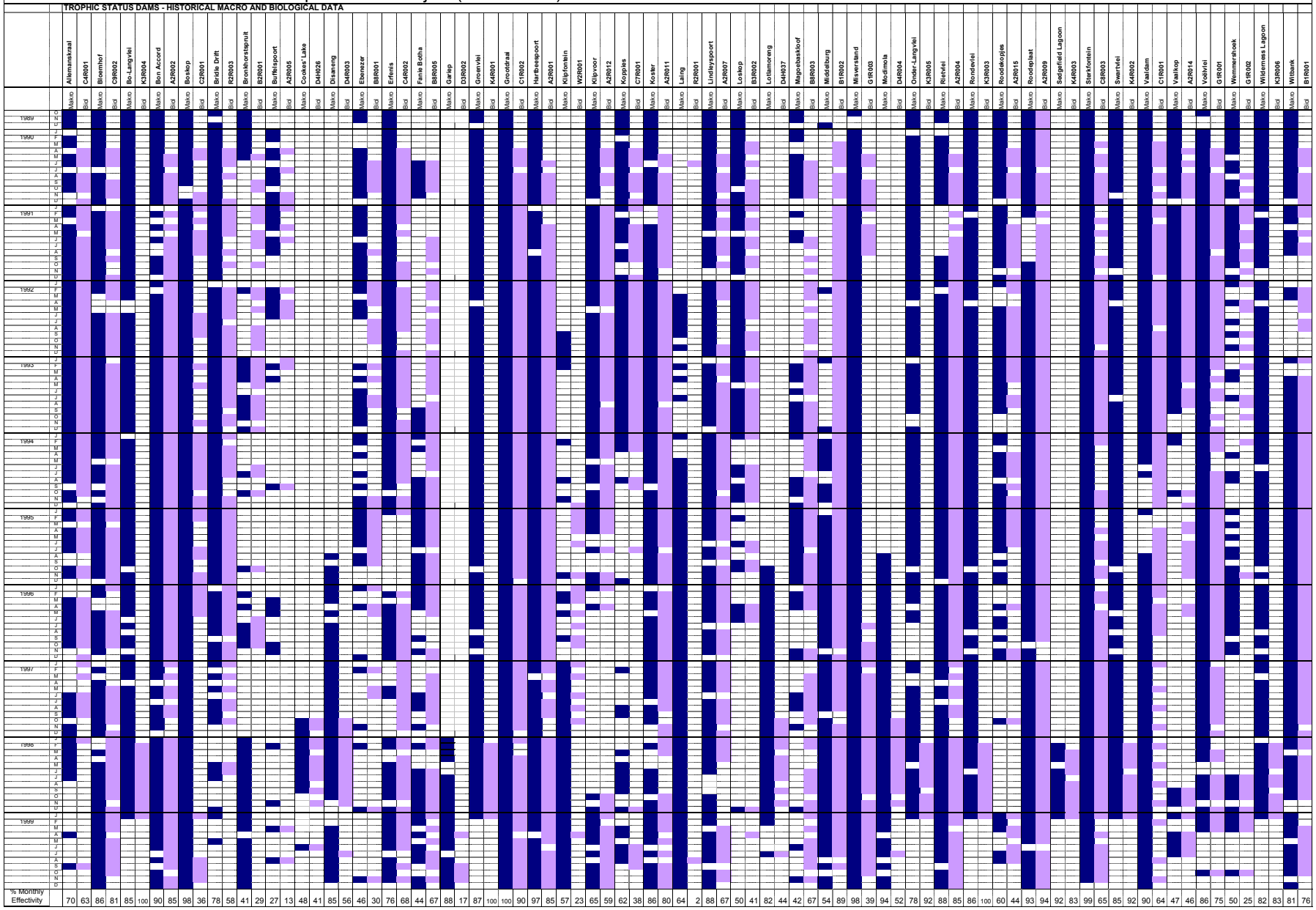
Table 4. The available data for the Trophic Status Project (1989 - 1999)



The trophic status of selected South African Impoundments (1990 to 2000)