THE LIMNOLOGY OF SOME SELECTED SOUTH AFRICAN IMPOUNDMENTS

A collaborative report by

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THE LIMNOLOGY OF SOME SELECTED SOUTH AFRICAN IMPOUNDMENTS

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SAMEVATTING

'n Deeglike limnologiese kennis van Suid-Afrikaanse damme is noodsaaklik vir die doeltreffende beheer en benutting van water. Hierdie dokument beskryf kortliks die limnologie van 21 Suid-Afrikaanse damme. Hierdie damme is ondersoek as deel van 'n opname om die verwantskap tussen trofiese stand en voedingstowwe toe te lig. Die verhouding tussen die hidrologiese, chemiese, fisiese en biologiese eienskappe van elke dam, sy toevloeiende water en die ontwikkeling binne die opvanggebied word kortliks bespreek. Dit blyk uit die globale opname dat Suid-Afrikaanse damme dikwels troebel is en dat die meeste limnologiese eienskappe aansienlik varieer as gevolg van groot jaarlikse verskille in watertoevloei. Wanneer fosfaat die beperkende voedingstof is hou die trofiese stand verband met die ortofosfaatbelading. Verder is gevind dat troebelheid 'n belangrike rol speel om die invloed van voedingstofbelading op die trofiese stand van 'n dam te bepaal.

SYNOPSIS

A sound limnological background on South African impoundments is a prerequisite for the efficient management and usage of water. This document presents brief limnological descriptions of 21 South African impoundments which were investigated during a survey to elucidate the relationships between trophic status and nutrient characteristics. Hydrological, chemical, physical and biological characteristics of each impoundment and its inflowing waters are considered in relation to the development within the catchment. From the overall survey it can be stated that most South African impoundments have a low water transparency and that limnological characteristics vary considerably as a consequence of the unstable seasonal hydrology. It was established that when phosphate was the limiting nutrient, trophic status was related to the orthophosphate loading rate. Furthermore, water transparency is a variable which plays a major role in dictating the impact of a nutrient load on the trophic status of any impoundment.

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FOREWORD

In the Republic of South Africa the total number of dams, including farm dams, is more than 500 000, of which 306 are classed as being large in terms of the International Commission on Large Dams. It has also been estimated that approximately 20 018 x 10^6 m^3 of water is held within state-owned impoundments and that the country's water demand will exceed supply within the foreseeable future. It is therefore imperative that optimum utilisation of these limited water resources be ensured. One of the major threats in this regard is the pollution of the environment which accompanies urban and industrial development.

In order to understand the effects of increasing urban and industrial development on the water quality of an impoundment, it is essential that the physical, chemical and biological characteristics of the latter are well established, so that any subsequent changes can be quickly identified and remedial action taken. For this purpose, however, the limnological data must be framed in clear statements of the ecological interrelations in rivers and impoundments, so that the effect of proposed developments or changes in the water regime, may be predicted. Limnology thus has a vital role to play in safeguarding our water resources but an equally important responsibility rests upon the relevant researchers to ensure correct interpretation of their findings and predictions.

The present report contains valuable limnological information on impoundments throughout South Africa, some of which have been investigated before whilst others are now better understood. The entire effort has been a co-operative one since it has involved water research administrators and researchers from numerous organizations. It is hoped that their efforts will be of use to water authorities and planners in management of our water resources for optimum utilisation.

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INTRODUCTION

In 1972 the Department of Water Affairs and the Bureau of Standards expressed concern at eutrophication as a water quality problem and requested the Water Research Commission (WRC) to initiate research on its causes, consequences and control. In 1973 the National Institute for Water Research (NIWR) entered into a contract with the WRC to carry out this research. The research programme aimed at obtaining information on the prevention of eutrophication of systems which were not enriched and the rehabilitation of systems where eutrophication problems were being experienced. A document *Guidelines for the control of eutrophication in South Africa* (Walmsley and Butty, 1980) resulted from this work.

In developing guidelines for eutrophication control, it is of considerable value to planners to have a method of predicting the amount of algal growth which will occur in a water body. Empirical relationships which predict the quantity of algal growth from certain nutrient characteristics have been established for lakes situated in the temperate zone of the Northern Hemisphere (Sawyer, 1947; Sakamoto, 1966; Vollenweider, 1968; 1976; Dillon and Rigler, 1974; Jones and Bachmann, 1976; Collingwood, 1977). It was decided that part of the NIWR/WRC eutrophication project should be aimed at developing similar predictive capabilities for South African impoundments. Consequently, in co-operation with other institutions and organizations a data collection programme was initiated in which 21 impoundments were investigated. Certain of these impoundments were studied more intensively than others, but each one was investigated in sufficient detail to comply with a set of specified minimum requirements. This report presents the basic limnological characteristics of each impoundment.

The results for each impoundment are presented separately. Raw data for the impoundments are contained in appendices whose distribution has been restricted because of their bulk. Copies can be obvtained from the WRC, the Committee for Inland Water Ecosystems and the NIWR.

MATERIALS AND METHODS

STUDY IMPOUNDMENTS

Twenty-one impoundments were selected for inclusion in the data collection programme. These impoundments are listed in Table 1 along with the researchers involved and the period of investigation. The siting of each impoundment within the Republic of South Africa is indicated in Figure 1. Twelve of the impoundments are in the Transvaal, six in Natal and three in the Cape Province.

SAMPLING

Sampling frequency

A list of minimum requirements for data collection was drawn up in consultation with a technical subcommittee. It was decided that with the available manpower, fortnightly sampling would be the most convenient sampling interval. However, certain deviations from this schedule became necessary as shown by the frequency of sampling for each of the 21 study impoundments (Table 1).

TABLE 1: A list of the study impoundments, the researchers involved, the study period and frequency

Impoundment	Researchers	Study period
TRANSVAAL		
1. Bospoort	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
2. Bronkhorstspruit	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
3. Buffelspoort	Walmsley & Alexander	May 1975/May 76 (W)
4. Lindleyspoort	Walmsley	May 1975/May 76 (W)
5. Loskop	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
6. Olifantsnek	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
7. Rust der Winter	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
8. Tonteldoos	Walmsley	Jan. 1976/Jan. 77 (W—F)
9. New Doringpoort	Butty, Walmsley & Alexander	Aug. 1977/July 78 (F)
10. Bloemhof	Bruwer	Sept. 1977(Oct. 78 (M)
11. Rietvlei	Ashton	Jan. 1976/Jan. 77 (W)
12. Roodeplaat	Pieterse & Bruwer	Dec. 1977/Dec. 78 (F)

TABLE 1 (Continued): A list of the study impoundments, the researchers involved, the study period and frequency

Impoundment	Researchers	Study period
NATAL		
13. Albert Falls	Archibald *et al*	Nov. 1977/Nov. 78 (F)
14. Hazelmere	Archibald *et al*	Nov. 1977/Nov. 78 (F)
15. Henley	Archibald *et al*	Nov. 1977/Nov. 78 (F)
16. Midmar	Archibald *et al*	Nov. 1977/Nov. 78 (F)
17. Nagle	Archibald *et al*	Nov. 1977/Nov. 78 (F)
18. Vernon Hooper	Archibald *et al*	Jan. 1976/Jan. 77 (F)
EASTERN CAPE		
19. Bridle Drift	Tow	Aug. 1977/Aug. 78 (F)
20. Laing	Tow	Nov. 1977/Nov. 78 (F)
21. Nahoon	Tow	Aug. 1976/Aug. 77 (W—F)

(W) = weekly sampling; (F) = fortnightly sampling; (M) = monthly sampling; (W—F) = weekly and fortnightly sampling.

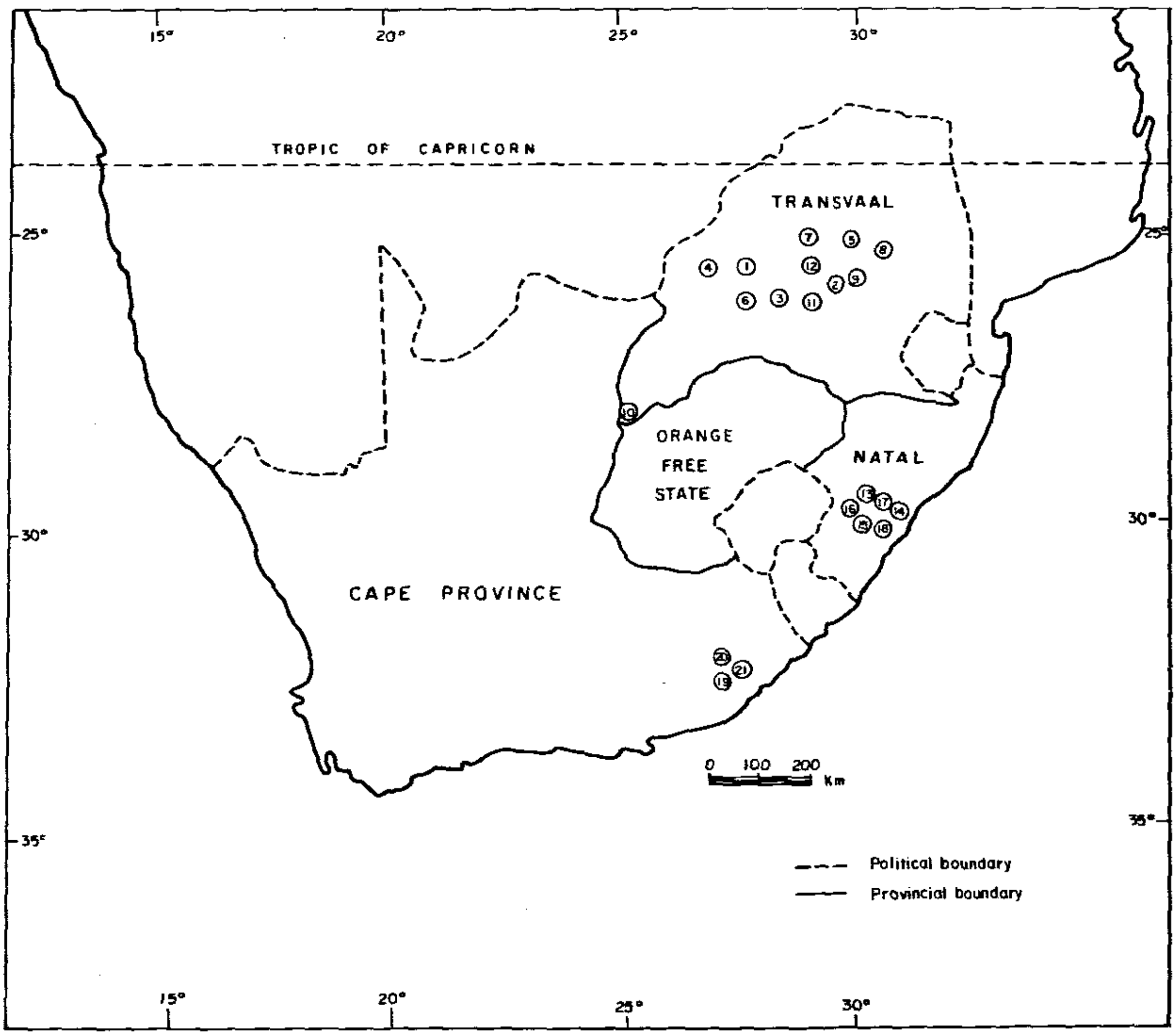

FIGURE 1. Map of South Africa showing the position of the 21 study impoundments.

Field observations

Field data were collected to elucidate whether there was a relationship between algal growth within an impoundment and the nutrient characteristics of the impounded water and inflowing streams. Essentially a "black box" approach had to be followed in which little attempt was made to account for processes within the impoundment. The minimal requirement therefore stipulated that only data from one impoundment station near the dam wall should be used in describing the water body within the dam. In addition, inflowing rivers were to be sampled and if possible, also the impoundment's outflow.

At the impoundment station, temperature and oxygen profiles were recorded by means of meters which were calibrated according to the manufacturer's specification. Water transparency was recorded using a standard 20 cm black and white quadranted Secchi disc. Water for chemical analysis was collected 1 m below the surface and 1 m above the bottom. In order to ensure that no changes in nutrient content occurred during transportation, field filtration and preservation were advocated wherever applicable (Standard Methods, 1974). An integrated sample of the top five meters in each impoundment was collected by means of a plastic hosepipe. This sample was used for the estimation of the average chlorophyll a concentration within this surface layer. pH of the waters was determined in the field by means of meters calibrated by standard buffer solutions.

LABORATORY ANALYSES

The minimal requirements specified that as far as possible the nitrogen and phosphorus content of each water sample should be determined. Thus, analyses for nitrate, nitrite, ammonia, Kjeldahl nitrogen, orthophosphate and total phosphate of filtered samples plus Kjeldahl nitrogen and total phosphate of unfiltered samples were advocated. For some impoundments, additional analyses were made of other chemical constituents, viz. sodium, potassium, calcium, magnesium, chloride, sulphate, conductivity, alkalinity, iron, manganese and silicate. Methods employed for these analyses varied in technique, but generally followed procedures recommended by Standard Methods (1974). The symbols and units for parameters presented in the individual contributions are given in Table 2.

TABLE 2. Symbols and units for parameters presented in the individual contributions

Symbol	Parameter	Unit
Na	Sodium	mg/dm^3
K	Potassium	mg/dm^3
Ca	Calcium	mg/dm^3
Mg	Magnesium	mg/dm^3
SO_4	Sulphate	mg/dm^3
Cl	Chloride	mg/dm^3
Si	Reactive silicate	mg/dm^3
Cond	Conductivity	mS/m at 20 °C
Alk	Alkalinity	mg/dm^3 as $CaCO_3$
Tot. Kj-N	Total Kjeldahl nitrogen	mg/dm^3
Dis Kj-N	Kjeldahl nitrogen of filtered sample	mg/dm^3
NH_4-N	Ammonia	mg/dm^3
NO_3-N	Nitrate	mg/dm^3
NO_2-N	Nitrite	mg/dm^3
Tot P	Total phosphate phosphorus	mg/dm^3
Tot dis P	Total phosphate phosphorus of filtered sample	mg/dm^3
PO_4-P	Orthophosphate phosphorus	mg/dm^3
Fe	Iron	mg/dm^3
Mn	Manganese	mg/dm^3
Temp	Temperature	°C
DO	Dissolved oxygen	mg/dm^3
Tu	Turbidity	JTU
pH	Hydrogen ion concentration	Bronstēd
SS	Suspended solids	mg/dm^3

The chlorophyll a content of hosepipe samples was determined by different techniques. Essentially, these involved the filtration of an aliquot of water through a filter followed by extraction of the pigment from the filter with solutions of acetone or methanol. These extracts were analysed for optical density at prescribed wavelengths and the chlorophyll a content computed according to the relevant formulae (viz. Talling and Driver, 1963; Marker, 1972).

DATA MANAGEMENT AND COMPUTING

Most computations were performed using a Control Data Corporation CDC-CYBER-174 at the Centre for Computing Services of the Council for Scientific and Industrial Research. The data collected in Natal were processed on a UNIVAC-1108 mainframe. Data management and simple computations were performed using programs written in COBOL.

Statistical analysis of the data was generally performed using the 1977 updated version of the SPSS package (Nie, Hull, Jenkins, Steinbrenner and Bent, 1975). The subprograms "Condescriptive" and "Frequencies" were utilized to obtain descriptive statistics (means, maximums, minimums, frequency histograms and coefficients of variation) of limnological characteristics.

HYDROLOGY

Monthly records of inflow and outflow volumes as well as rainfall and evaporation of most dams were obtained from the Department of Water Affairs. These data were calculated from the daily water levels, records of releases, weir gaugings and observations of rainfall and evaporation submitted by the water bailiffs in charge of the individual impoundments. From these data, the following information was extracted (symbols and units given in Table 3) –

Volume of dam by the time t	V_t
Volume of dam by the time $t+\triangle t$	V_{tdt}
Outflow from t to $t+\triangle t$	O_{dt}
Rainfall from t to $t+\triangle t$	R_{dt}
Evaporation from t to $t+\triangle t$	E_{dt}

It follows that the average volume of the dam from t to $t+\triangle t$ can be defined as:

$$V_{dt} = (V_t + V_{tdt})/2 \qquad [1]$$

And the change in volume from t to $t + \triangle t$ as:

$$DV - DT = (V_{tdt} - V_t) \qquad [2$$

The total inflow (I_{dt}) from t to $t + \triangle t$ was calculated as folows:

$$I_{dt} = (O_{dt} + DV_{dt} + E_{dt})\, R_{dt} \qquad [3]$$

Where applicable values were calculated for $\triangle t = 1$ week or 1 month.

When assessing the hydrological trends, the annual period, where applicable, was fixed as that which coincided with the study year. Thus, if samplings were done from August until July the following year, then this 12-monthly period was used in the calculations.

The following expressions, serving partly as definitions, were used:

Mean volume
$$\bar{V} = \left(\sum_{t=1}^{n} V_t \;/n\right) \qquad [4]$$

Total outflow
$$O_a = \left(\sum_{t=1}^{n} O_{dt}\right) \qquad [5]$$

Mean depth
$$\bar{Z} = \bar{V}/\bar{A} \qquad [6]$$

Mean retention time
$$\bar{T} = \bar{V}/O_a \qquad [7]$$

Partial retention time $T_{dt} = V_{dt}(D_{dt} \times 12)$ [8]

where O_{dt} is measured over 1 month

Mean hydraulic load $\overline{Q} = \overline{Z}/\overline{T}$ [9]

CALCULATION OF LOADS

All mean concentrations of the constituents were calculated as

$$\overline{X} = \left(\sum_{i=1}^{n} X_i \right) / n \qquad [10]$$

where n is the number of samplings and X_i is the associated concentration of the constituent.

In the calculation of loads it was necessary to distinguish between impoundments with one inflow and those with multiple inflows. In both cases there might have been a number of minor tributaries with intermittent flows, which were not sampled. The contributions from such streams could only be accounted for in the sense that the total inflow was calculated using equation (3), which includes water from all sources.

In the case of impoundments with one inflow, the total incoming volume of water, as calculated from (3), was arbitrarily assigned to this source. The mass of a constituent entering the impoundments over a period of time (e.g. $\triangle t$ = 1 month) was then calculated as:

$$MX_i = I_{dt} (\overline{X}_i) \qquad [11]$$

where $\overline{X}_i$ is the average concentration of the constituent over the period $\triangle t$.

The total annual incoming mass of the constituent was calculated as:

$$MX_a = \sum_{i=1}^{n} MX_i \qquad [12]$$

where n is the number of periods within the year for which MX_i was calculated, e.g. n = 12 in case of monthly intervals.

The annual average surface loading rate of the constituent was calculated by the expression:

$$\overline{L}_x = MX_a / \overline{A} \qquad [13]$$

where the subscript x denotes the particular constituent, e.g. Lp for the total phosphate loading rate.

In the case of an impoundment having more than one inflow, the total inflow was proportionally divided between the ones observed, unless otherwise specified in the individual accounts. Where observations were available from weir gauging stations on the inflows, it was possible to calculate the proportional contribution for each river (P_{pdt}) during $\triangle t$. The inflowing volume from river # p was then judged to be:

$$I_{pdt} = (I_{dt})(P_{pdt}) \qquad [14]$$

and the mass contribution of the constituent:

$$M_p X_i = (I_{pdt})(X_{ip}) \qquad [15]$$

where $\overline{X}_{ip}$ is the mean concentration of the constituent during $\triangle t$ in river # p.

Where there were no weir gauging stations on the inflows, the proportionate flow (P_p) was estimated on basis of the catchment areas ratios. Thus, if river # p had a catchment area of size A and the sum of the catchment areas of the inflow was B, then P = A/B. Subsequently P_p was substituted for P_{pdt} in expressions (14) and (15).

In either case, the total mass of the constituent entering the impoundment during $\triangle t$ was calculated as:

$$MX_i = \sum_{i=1}^{n} M_p X_i \qquad [16]$$

where n is the number of inflows.

Thereafter, MX_a and L_x were calculated using equations (12) and (13).

TABLE 3. The meanings and dimensions of symbols used in hydrological calculations

Symbol	Meaning	Units
A	Surface area of dam	10^4 x m^2
$\overline{A}$	Mean surface area of dam	10^4 x m^2
dt	Time interval from t to t + $\triangle t$	weeks or months
dV_{dt}	Change in volume during $\triangle t$	10^6 x m^3
E_{dt}	Evaporation from dam during $\triangle t$	10^6 x m^3
I_{dt}	Inflow to dam during $\triangle t$	10^6 x m^3
I_{pdt}	Inflow to dam from river # p during $\triangle t$	10^6 x m^3
L_x	Surface loading rate	$g/m^2\ a^{-1}$
MX_a	Total annual mass of a constituent	tons
MX_i	Mass of a constituent entering during $\triangle t$	tons
$7\ _pX_i$	Mass of a constituent entering from river # p during $\triangle t$	tons
O_a	Total annual outflow	10^6 x m^3
O_{dt}	Outflow during $\triangle t$	10^6 x m^3
P_p	Estimated proportion of I_{dt} from river # p	—
P_{pdt}	Calculated proportion of I_{dt} from river * p during $\triangle t$	—
$\overline{Q}$	Mean hydraulic load	m/a
R_{dt}	Rainfall on to dam during $\triangle t$	10^6 x m^3*
$\overline{T}$	Mean retention time	years
T_{dt}	Retention time (partial) during $\triangle t$	years
V	Volume of dam	10^6 x m^3
$\overline{V}$	Mean volume of dam	10^6 x m^3
V_t	Volume of dam at the time t	10^6 x m^3
V_{tdt}	Volume of dam at the time t + $\triangle t$	10^6 x m^3
$\overline{X}_i$	Mean concentration of a constituent at t = i	mg/dm³ or µg/dm³
$\overline{X}_{ip}$	Mean concentration of a constituent in river # p at t = i	mg/dm³ or µg/dm³
$\overline{Z}$	Mean depth	m

*Alternative units: mm

CONCLUSIONS

The primary objective behind the preparation of the records on the 21 impoundments was to create a data base which would lead to the establishment of empirical relationships between the chlorophyll and nutrient characteristics of groups of impoundments. A detailed description of the methodology behind the derivation of suitable empirical relationships is given by Walmsley and Butty (1979).

From the data set available, it was established that the frequency of occurrence of certain chlorophyll ranges could be described by the following equations —

$$\text{Chl } 10 = -\overline{CHL}/0{,}269 + 108{,}5 \qquad r^2 = 0{,}92 \qquad [17]$$

$$\text{Chl } 20 = \overline{CHL}/0{,}399 - 7{,}2 \qquad r^2 = 0{,}75 \qquad [18]$$

$$Chl\ 30 = \overline{Chl}/1,436 - 2,0 \qquad r^2 = 0,82 \qquad [19]$$

$$Chl\ gt = \overline{Chl}/0,726 - 5,1 \qquad r^2 = 0,71 \qquad [20]$$

where $\overline{Chl}$ = mean annual chlorophyll a concentration of a 5 m hosepipe sample in $\mu g/dm^3$

Chl 10 = per cent of the year during which the chlorophyll a concentration of 5 m hosepipe sample was less than 10 $\mu g/dm^3$.

Chl 20 = same for a chlorophyll a range between 10 and 20 $\mu g/dm^3$.

Chl 30 = same for a chlorophyll a range between 20 and 30 $\mu g/dm3^3$.

Chl gt = same for a chlorophyll a range greater than 30 $\mu g/dm^3$.

It was also established that the maximum chlorophyll a value during an annual cycle could be related to the mean chlorophyll a value by the equation

$$Max\ Chl = 4,33\ Chl - 1,1 \qquad r^2 = 0,89 \qquad [21]$$

where Mx Chl = maximum chlorophyll a value expected in the 5 m hosepipe samples.

Analysis of the data also revealed several empirical equations which could be used to describe the variation in mean chlorophyll a for certain groups of impoundments. These equations take into account the fact that water transparency and nitrogen limitation play a significant role in determining the impact of a particular phosphate load on algal growth.

For impoundments where the inorganic nitrogen:inorganic phosphate phosphorus loading rate ratio (N:P) exceeded 5:1 (mass:mass) the following equations were established:

(i) Chlorophyll-nutrient concentration relationships

For impoundments where N:P >5:1 and Secchi depth >0,4 m

$$\overline{Chl} = 203(PO_4\text{-}D) + 4,13 \qquad r^2 = 0,77 \quad n = 13 \qquad [22]$$
$$\overline{Chl} = 188(TP\text{-}D) + 0,10 \qquad r^2 = 0,82 \quad n = 10 \qquad [23]$$

where Secchi depth $\leq 0,8$ m

$$\overline{Chl}\ 243,7(PO_4\text{-}D)(Se) - 1,10(PO_4\text{-}D + 1/Se) + 5,57 \qquad r^2 = 0,75 \quad n = 10 \qquad [24]$$

(ii) Chlorophyll-nutrient loading relationships

For impoundments where N:P >5:1 and Secchi depth >0,2 m

$$\overline{Chl} = 1,62\ L_{op} + 3,80 \qquad r^2 = 0,70 \quad n = 17 \qquad [25]$$

$$\overline{Chl} = 0,83\ L_{tp} + 2,97 \qquad r^2 = 0,52 \quad n = 13 \qquad [26]$$

where Secchi depth $\leq 0,8$ m

$$\overline{Chl} = 3,8(L_{op})(Se) - 0,706(L_{op} + 1/Se) + 5,80 \qquad r^2 = 0,83 \quad n = 10 \qquad [27]$$

where PO_4-D = mean annual orthophosphate phosphorus concentration of the impoundment surface waters in mg/dm^3

TP-D = mean annual total phosphate phosphorus concentration of surface waters in mg/dm^3

L_{op} = orthophosphate phosphorus surface loading rate in $g/m^2.a^{-1}$

Se = mean annual Secchi depth in m.

It is hoped that these equations will be found useful in providing guidelines for eutrophication control since for a particular phosphate loading, a probable mean chlorophyll a value can be computed (equations 22 to 27). The use of these equations and their limitations are discussed more fully by Walmsley and Butty (1979).

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BOSPOORT DAM

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INTRODUCTION

No records exist of any previous limnological work done on Bospoort Dam. Consequently it is not possible to discuss the condition of this impoundment prior to 1977. It is situated on a river which drains the mining and urban areas of Rustenburg and can be considered to be susceptible to the effects of industrial and domestic pollution. This report presents the results of a limnological study conducted between 1977 and 1978.

DESCRIPTION OF THE AREA

Bospoort Dam is situated in the Western Transvaal approximately 25 km north-east of Rustenburg. Characteristics of the impoundment and its catchment are given in Table 1 and Figure 1. The impoundment is situated downstream of Rustenburg and the single inflow, the Hex River, after receiving sewage and mining effluents from this area, passes through a large township within the Republic of Bophuthatswana before entering the impoundment. Most of the land surrounding the impoundment belongs to Bophuthatswana whereas the impoundment itself lies within South African boundaries.

At present the impoundment is used as a source of potable water by the Rustenburg Municipality. Some angling takes place along the banks, but boating is not permitted. The shallow upper reaches of the impoundment which extend into a township are utilized by the residents for drinking, watering cattle and washing clothes. As the township lacks modern sanitation, these upper reaches probably receive a certain amount of untreated domestic effluents.

Average values for the basic hydrological characteristics between 1974 and 1978 are presented in Table 2. Although based on a limited data set, it can be seen that the volume, area and mean depth show a small variation whereas inflow is highly variable. The mean water retention time of the impoundment (0,22 years) is extremely low and indicates that on the average, the system is flushed 4 to 5 times per annum.

RESULTS AND DISCUSSION

Hydrological characteristics for the study year indicate that inflow was over 50 % higher than average (Table 3). The retention time for the annual period was 0,16 years indicating that the system was flushed more than 6 times.

Chemical characteristics of the inflowing, outflowing and impounded waters are presented in Table 4. The concentrations of dissolved minerals were high and typical of a system which is polluted with sewage and/or industrial effluents. The degree of pollution can be judged by comparing the chemical composition of the outflow from the Olifantsnek Dam (an impoundment situated on the Hex River above Rustenburg) with that of the inflow to Bospoort Dam (Butty *et al.*, 1979). Clearly, considerable quantities of nutrients are derived from the Rustenburg area and on the basis of the concentrations of nitrogen and phosphorus compounds encountered in the waters of the impoundment, the system can be regarded as highly eutrophic. Figures 3 to 5 present frequency histograms for selected limnological lparameters and give an indication of the period of time during which a particular range of values was encountered. Concentrations of ammonia, nitrate and orthophosphate in the surface waters were always high and indicated that sufficient nitrogen and phosphorus were always present for algal growth.

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During the 1977/78 study period the nutrient surface loading rates for the impoundment were 5 28 7,7 53,7 and 70,5 $g.m^{-2}.a^{-1}$ for orthophosphate phosphorus, total phosphate phosphorus, inorganic nitrogen and total nitrogen respectively (Table 5). These figures indicate that approximately 70 % of the incoming phosphate load was in the form of orthophosphate. This high percentage can be ascribed to the fact that a large proportion of the phosphate loading from the catchment area is derived from point sources. In the case of impoundments where no point sources exist in the catchment it has been found that orthophosphate usually contributed only 10 to 20 % of the total phosphate loading. Nevertheless, nutrient loading rates for Bospoort are extremely high and the system can be classified as eutrophic.

Algal growth in the impoundment was found to be high and blooms of the blue-green alga *Microcystis* were observed. The maximum chlorophyll *a* value recorded in the impoundment in November 1977 was 45 $\mu g/dm^3$. In December 1977 flood waters flushed out this high algal population. The nitrogen:phosphate content (mass:mass) of the inflowing waters (10:7) indicate that the algae in the system are limited by phosphate since waters with a ratio greater than 7:1 can be considered phosphate-limited (Vollenweider, 1968).

Bospoort Dam, with a maximum depth of 14 m is too shallow to exhibit stable thermal stratification during summer. However, under calm conditions there were indications that weak temperature stratification could lead to the development of anaerobiasis in the bottom waters (Figs. 6 and 7). When large populations of algae were present in the surface waters (Dec. 1977) there were indications of oxygen supersaturation. The impoundment, with a water temperature range of 10,8 to 28 °C can be considered to be warm monomictic. Flood waters played a major role in disrupting stratification during summer and also had a beneficial effect in reoxygenating the bottom waters, particularly in January 1978.

The most surprising aspect of Bospoort Dam is that in spite of a very high nutrient loading there was not a higher degree of nuisance conditions in terms of algal growth. The most likely explanation is the flushing effect which summer flooding has on the system. Summer flooding not only introduces a better quality water into the system, but also disrupts stratification, reoxygenates the anaerobic bottom waters and flushes out the high resident algal populations. Nevertheless, the impoundment can be considered to be highly eutrophic.

ACKNOWLEDGEMENTS

The Department of Water Affairs is gratefully acknowledged for providing the basic hydrological data. We also thank Mrs A. Engelbrecht, Mr P.A. Joubert, Miss M. Pistorius and Mrs K. van Niekerk, who helped with sampling, and the Analytical Division of the National Institute for Water Research who did most of the chemical analyses.

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VOLLENWEIDER, R.A. 1968 *Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication.* Organization for Economic Co-operation and Development, Paris.

TABLE 1. *Characteristics of Bospoort Dam and its catchment*

Geographical location	25° 33,75'S; 27° 21'E
Magisterial district	Rustenburg
Catchment type	Urban, mines
Usage of dam	Potable water supply, fishing
Catchment area	1 080 km^2
Inflowing river	Hex
Dam wall completed	1936, raised in 1974
F.S.L. volume	19,4 x 10^6 m^3
F.S.L. area	3,63 km^2
F.S.L. maximum depth	14,35 m
F.S.L. mean depth	5,3 m

F.S.L. = full supply level

TABLE 2. *Average hydrological characteristics of Bospoort Dam*

	*Average mean	*C.V.
Volume x 10^6 m^3	18,73	17,4
Area km^2	3,63	12,2
Mean depth m	5,1	6,6
Annual inflow x 10^6 m^3	89,11	157,0
Annual outflow x 10^6 m^3	85,98	163,4
Retention time a	0,22	—

*Average mean is based on monthly values and an annual cycle
Period: August to July (1974 – 1978);
C.V. = Coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Bospoort Dam (Aug. 1977 – Jul. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	21,62	17,83	19,75	5,8	1
Area km^2	4,02	2,48	3,77	4,2	1
Mean depth m	5,3	5,0	5,2	1,9	1
Monthly inflow x 10^6 m^3	49,43	0,16	11,54	154,5	55
Monthly outflow x 10^6 m^3	48,51	0,42	11,34	155,3	60

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers, the outflow and dam station. Values are based on fortnightly samples collected between August 1977 and July 1978.

PARAMETER	DAM STATION								HEX RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	10,0	44,0	27,0	38	10,0	43,0	27,4	39	8,0	145,0	46,6	78	15,0	97,0	41,3	55
K	1,7	12,0	3,5	51	1,8	12,0	3,5	53	1,8	18,0	5,3	72	1,7	12,0	4,5	53
Ca	16,0	36,0	26,8	20	11,0	37,0	28,7	27	16,0	74,0	39,5	45	11,0	57,0	31,4	32
Mg	10,0	31,0	21,1	28	9,0	31,0	21,3	32	12,0	56,0	31,46	43	9,0	50,0	25,0	41
SO_4	35,0	120,0	73,7	37	38,0	113,0	75,5	37	31,0	182,0	92,6	37	39,0	190,0	96,6	35
Cl	7,0	34,0	19,5	45	8,0	39,0	21,5	39	7,0	114,0	39,4	75	8,0	98,0	32,4	69
Cond	26,0	58,0	39,4	28	20,8	55,0	36,1	29	17,5	100,0	59,8	47	35,0	52,0	43,0	13
Alk	56,0	140,0	108,4	16	68,0	156,0	110,5	25	67,0	236,0	129,8	30	52,0	230,0	127,5	32
Tot Kj-N	0,240	1,450	0,569	44	0,260	1,340	0,719	41	0,200	1,520	0,719	54	0,400	1,690	0,922	40
Dis Kj-N	0,220	1,460	0,518	49	0,200	1,300	0,673	50	0,200	1,700	0,666	59	0,300	1,720	0,846	47
NH_4-N	0,028	0,200	0,089	58	0,026	1,100	0,273	105	0,024	0,90	0,150	116	0,05	1,30	0,409	107
NO_3-N	0,002	4,6	1,169	82	0,004	4,3	1,376	79	0,540	8,6	3,845	69	0,003	9,1	1,446	148
NO_2-N	0,002	0,071	0,027	71	0,002	0,082	0,037	70	0,012	0,150	0,063	71	0,002	0,069	0,034	126
Tot P	0,013	0,140	0,072	51	0,031	0,246	0,127	48	0,027	4,212	0,718	125	0,036	1,600	0,239	148
Tot dis P	0,014	0,140	0,063	53	0,013	0,256	0,123	46	0,010	2,000	0,524	99	0,062	1,600	0,228	155
PO_4-P	0,002	0,083	0,039	63	0,013	0,226	0,095	57	0,010	1,600	0,454	88	0,047	0,250	0,111	58
Fe	0,025	0,780	0,201	105	0,025	1,090	0,280	104	0,025	0,730	0,236	91	0,025	1,070	0,239	146
Mn	0,025	0,050	0,026	19	0,025	0,815	0,171	146	0,025	0,400	0,048	155	0,025	1,100	0,240	154
Temp	11,9	28,0	21,0	25	11,5	23,0	18,0	25	9,9	28,5	21,2	26	12,0	22,0	16,8	25
DO	3,9	14,9	8,5	35	0,10	12,2	3,9	79								
Tu	4,0	78,0	22,0	93	5,7	225,0	48,4	106								
pH	7,5	9,3	8,4	7	7,5	8,5	7,9	5	7,0	9,4	8,3	6	7,8	8,3	8,0	5

*C.V. = *coefficient of variation*

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Bospoort Dam (Aug. 1977 – Jul. 1978)

Mean depth m	5,2
Retention time a	0,16
Hydraulic load m/a	32,5
Surface loading rates g/m^2.a^{-1}	
PO_4-P	5,285
Total P	7,710
Inorganic nitrogen	53,726
Total nitrogen	70,566

	Maximum	Minimum	Mean
Chlorophyll *a* µg/dm^3	45,0	1,0	12,0
Secchi depth m	2,00	0,120	0,75

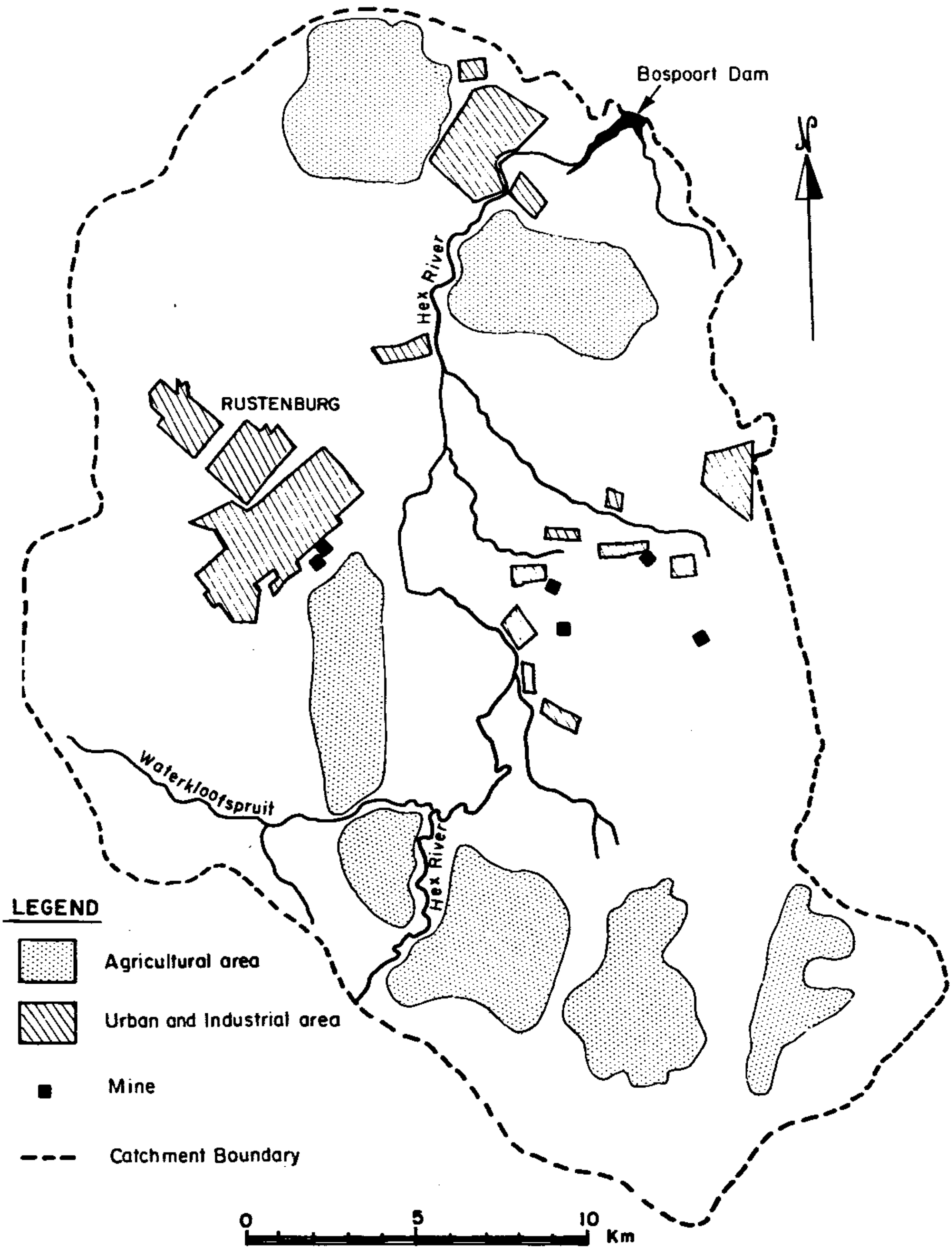

FIGURE 1. Bospoort Dam catchment.

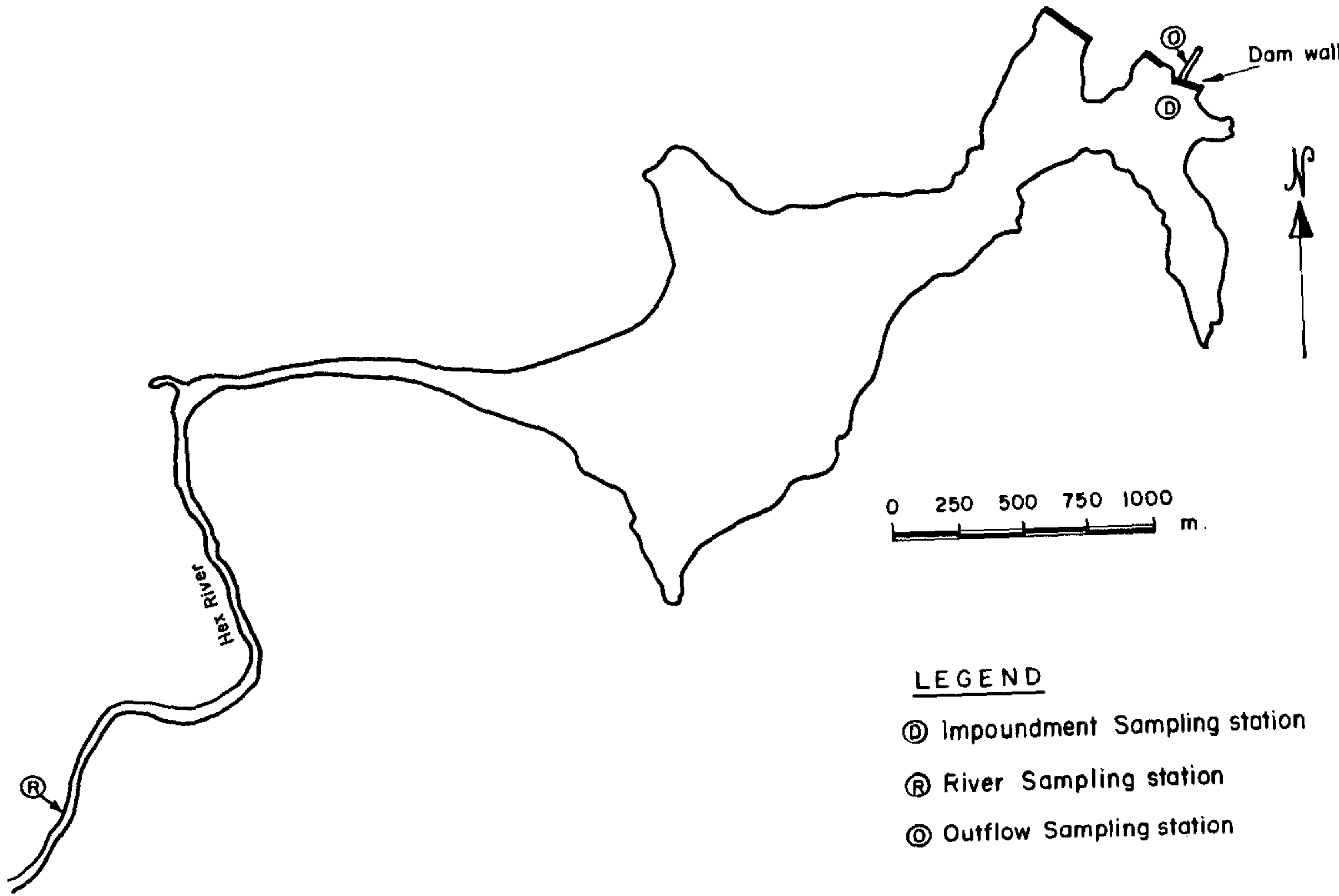

FIGURE 2. Map of Bospoort Dam showing sampling station.

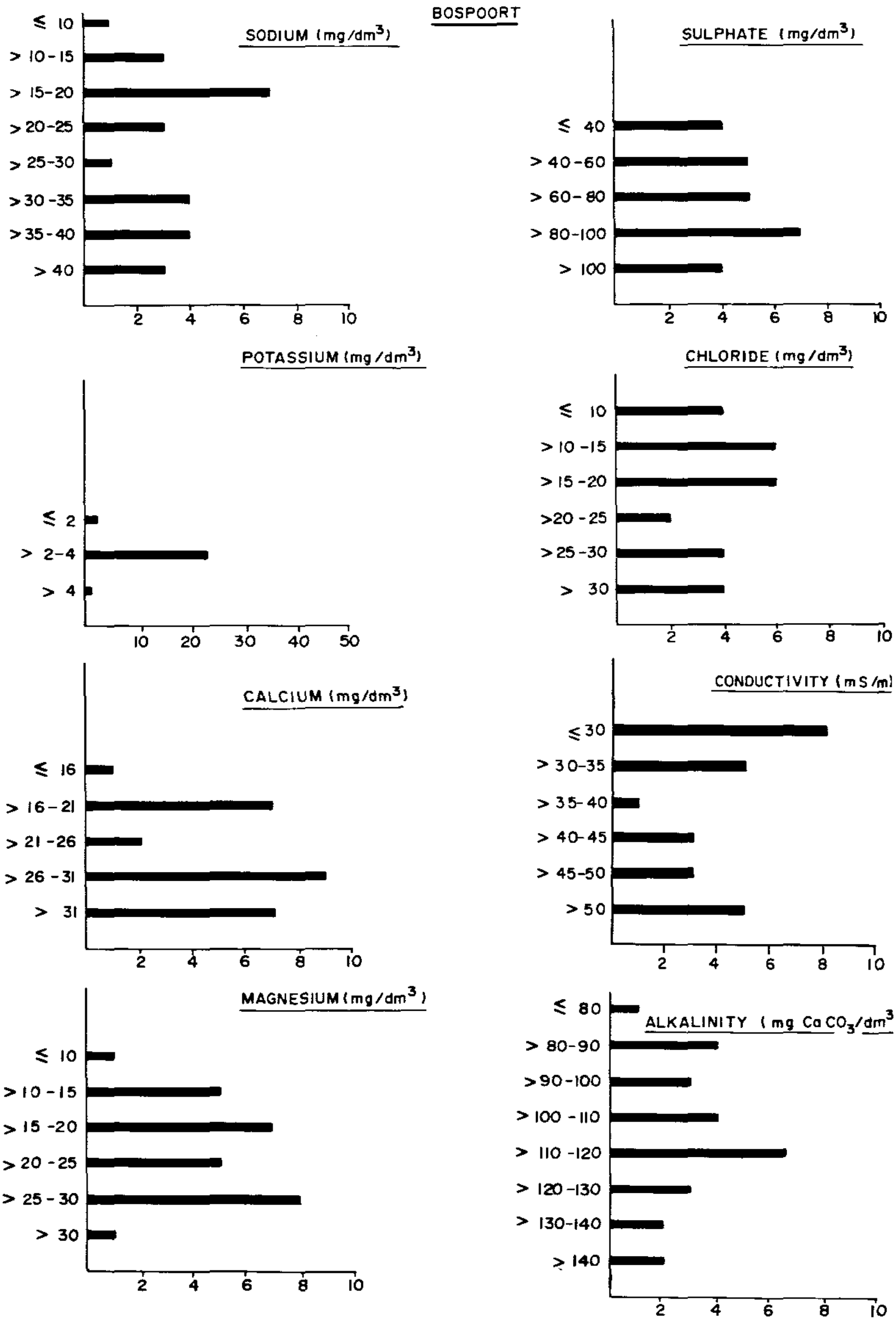

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Bospoort Dam.

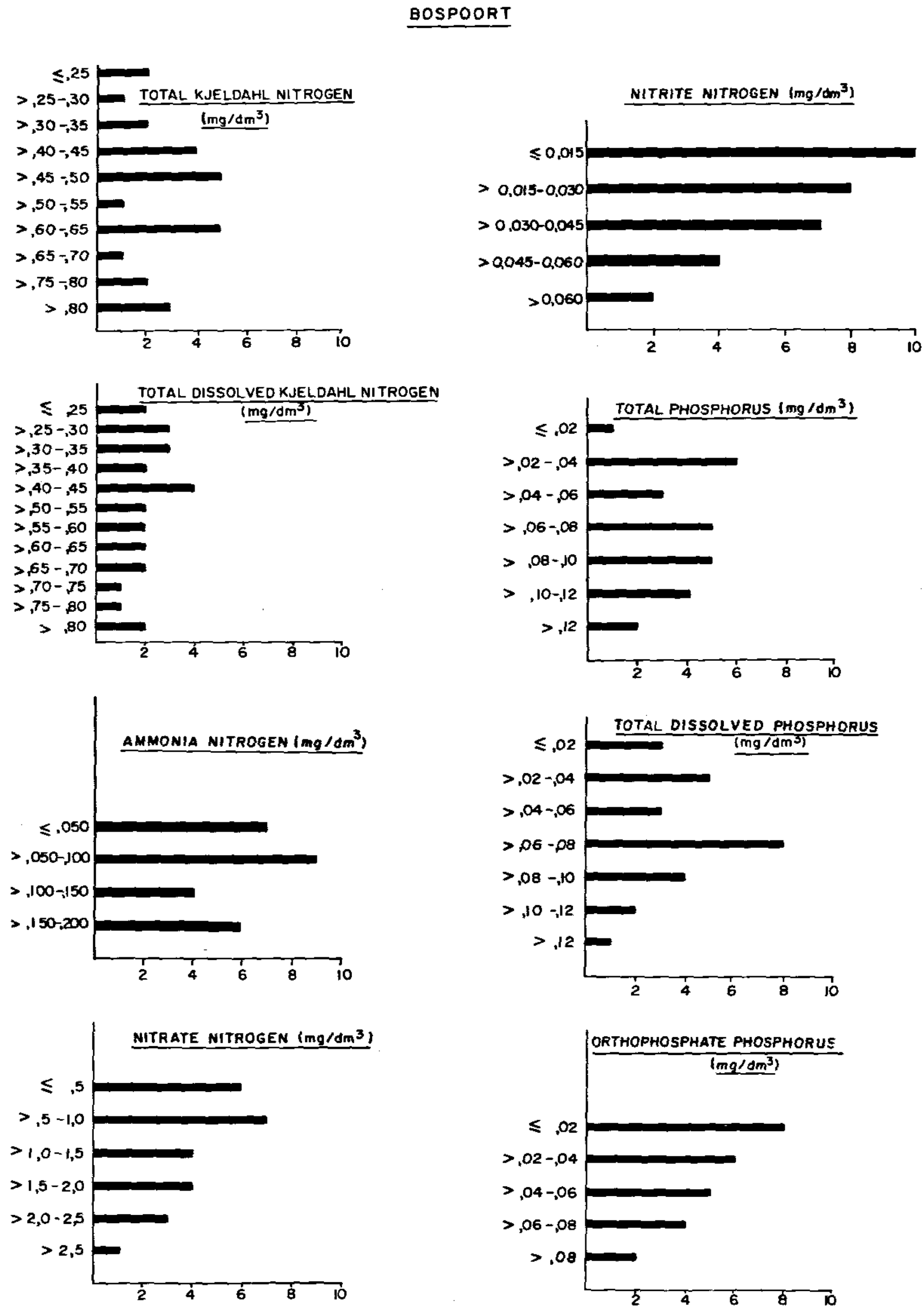

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Bospoort Dam.

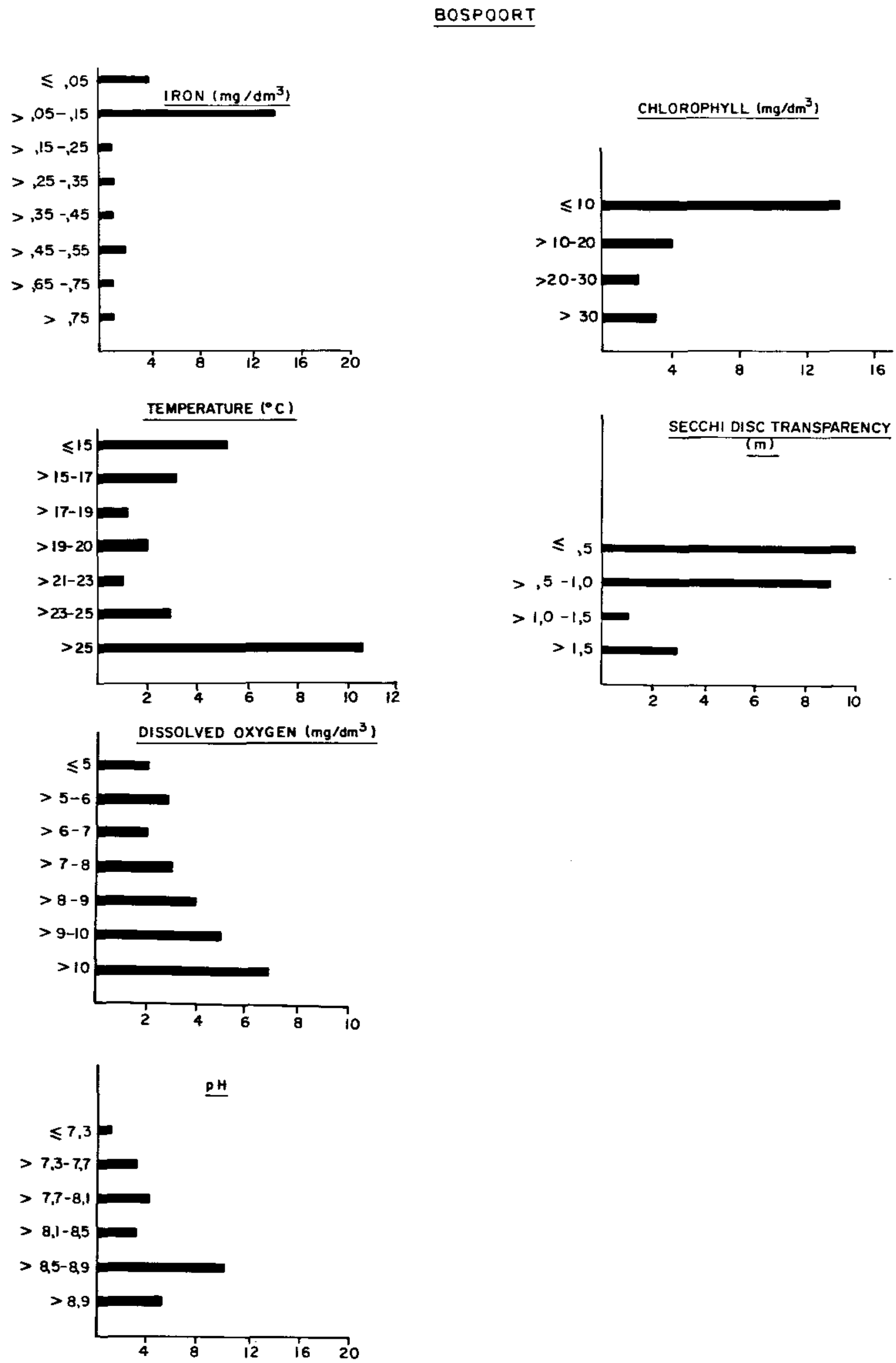

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Bospoort Dam.

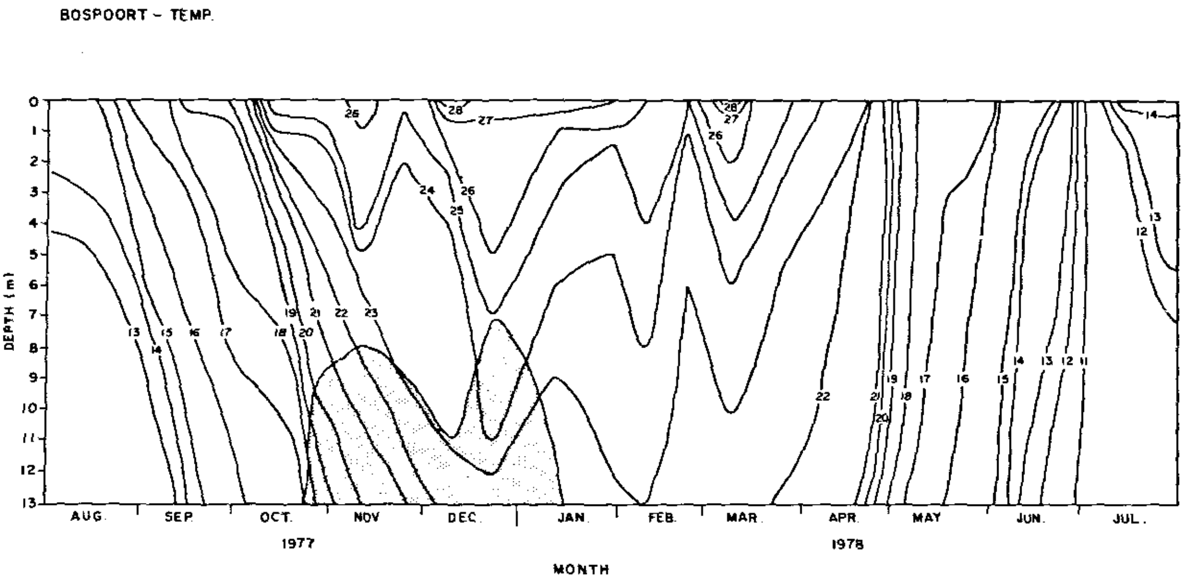

FIGURE 6. Temperature distribution in Bospoort Dam (shaded area indicates anaerobic zone).

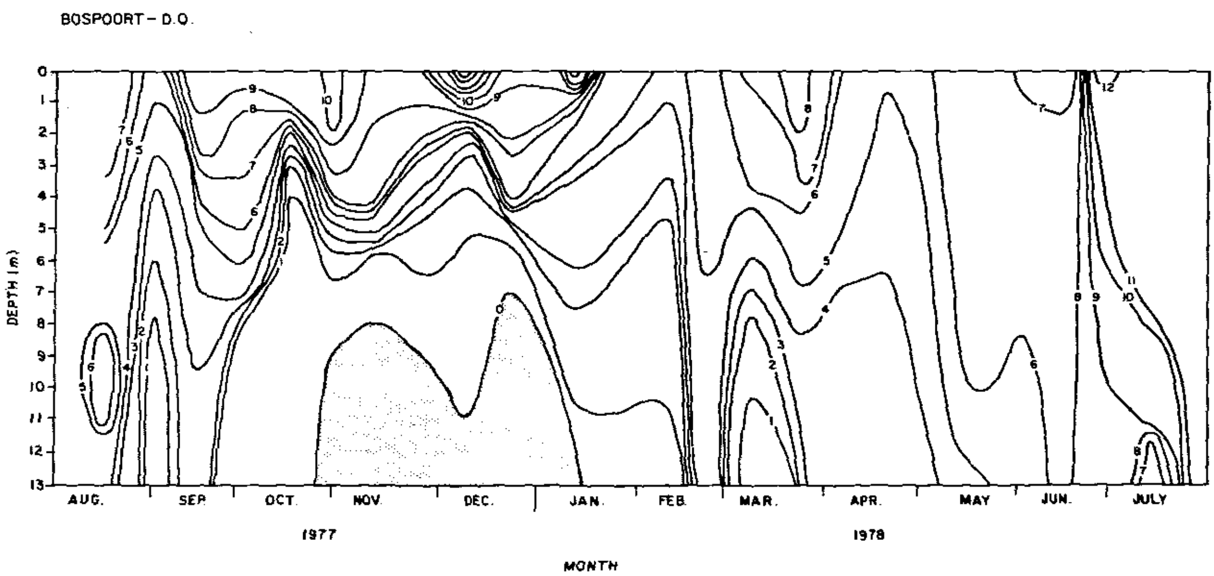

FIGURE 7. Dissolved oxygen distribution in Bospoort Dam (shaded area indicates anaerobic zone).

BRONKHORSTSPRUIT DAM

by

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INTRODUCTION

Limited limnological information is available on Bronkhorstspruit Dam. Apart from being included in an algal assay survey of 98 South African impoundments (Toerien *et al.*, 1975) and a physico-chemical limnological survey by Schutte and Bosman (1973), no detailed limnological studies have been made of the impoundment. In the abovementioned survey the impoundment was ranked 59th highest (AGP of 34,5 mg/dm^3) and placed in the mesotrophic category. This report presents limnological information on the impoundment covering an annual period between August 1977 and July 1978.

DESCRIPTION OF THE AREA

Bronkhorstspruit Dam is situated in the highveld climatic region approximately 70 km east of Pretoria. Characteristics of the impoundment and its catchment are given in Table 1 and Figures 1 and 2. The impoundment has two inflows, the larger Bronkhorstspruit and the smaller Osspruit which flow in a northerly and easterly direction respectively. Both these rivers drain a region which has extensive maize land but only limited urban and industrial areas. A small sewage works at Delmas discharges treated effluents into the feeder stream of the Bronkhorstspruit.

The impoundment was originally constructed as an irrigation supply, but this potential is not at present fully utilized. In recent years holiday resorts have proliferated and the impoundment has become an important recreational site. The annual number of visitors is estimated at about 60 000, mainly from the Pretoria-Witbank area (Cook, personal communication).

Average values for the basic hydrological characteristics between 1968 and 1978 are presented in Table 2. Volume, area and mean depth of the impoundment have shown little annual variation over the past decade (coefficient of variation c.a. 4 %) indicating that water usage is minimal. Annual inflow is normally higher than the maximum volume and the impoundment has a mean water retention time less than 1 year.

RESULTS AND DISCUSSION

Hydrological characteristics for the study year show that the inflow was almost 90 % higher than average (Table 3). Consequently, the system had a low water retention time (0,37 years) and was flushed approximately three times during the study period.

Chemical characteristics of the inflowing, outflowing and impounded waters are presented in Table 4. The concentrations of dissolved minerals in the impounded water were not high and indicate that at present the impoundment is not affected by the discharges of treated effluent in the catchment. Nevertheless, the maximum concentrations of certain constituents which were encountered in the Bronkhorstspruit inflow (e.g. chloride, sulphate, nitrogen compounds) indicate that at times levels can become extremely high, presumably as a result of these discharges. The highest concentrations were recorded at the beginning of a flood event in January 1978. Figures 3 to 5 present frequency histograms for selected limnological parameters recorded for the surface waters, and give an indication of the length of time during which a particular range of values was encountered. With respect to the nutrients nitrogen and phosphorus, it can be seen that orthophosphate concentrations were at times low whereas nitrogen compounds were

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usually present in higher proportional concentrations. This suggests that the impoundment is phosphate-limited whi h is contrary to the results of Toerien *et al.* (1975) who reported that the waters were nitrogen-limiting. Nevertheless, the frequently high values for orthophosphate and nitrogen compounds indicate that both nitrogen and phosphate were available in sufficient quantities for algal growth during most of the study period.

During the 1977/78 study period the nutrient surface loading rates for the impoundment were 0,33 1,14 6,42 and 26,04 for orthophosphate phosphorus, total phosphate phosphorus, inorganic nitrogen and total nitrogen respectively (Table 5). Algal growth in the impoundment showed a wide variation (mean of 5 $\mu g/dm^3$ and maximum of 19 $\mu g/dm^3$ chlorophyll) and the maximum value was recorded during a *Microcystis* bloom. It was subsequently found that this particular bloom contained the toxic variety of this species (Hauman, personal communication).

Bronkhorstspruit Dam can be classified as a turbid impoundment on the basis of the low Secchi depth (mean 0,3 m) and high turbidity of the surface waters (38,0 JTU). The high turbidity and low water retention time during the study period were possibly the two main factors which contributed to the low algal standing crop in the impoundment.

Bronkhorstspruit Dam, with a maximum depth of 19,5 m and a mean depth of 6,8 m is not deep enough to exhibit stable thermal stratification during summer. Periods of fluctuating calm and rough weather produce a system which is obviously polymictic. In addition, flood events play a significant role in mixing of the water column. This is evident from the temperature and oxygen distribution in the water column at the impoundment station (Figs. 6 and 7).

On the basis of the results gained from this present investigation it can be confirmed that Bronkhorstspruit is indeed a mesotrophic system. Algal growth within the impoundment is affected to a large extent by the high turbidity and summer floods which flush out resident algal populations. Caution should be exercised in the regulations governing nutrient inputs, particularly as the impoundment's usage as a recreational centre might become jeopardised.

ACKNOWLEDGEMENTS

The help of Mrs A. Engelbrecht, Mr P.A. Joubert, Miss M. Pistorius and Mrs K. van Niekerk with the data collection and processing is gratefully acknowledged. Hydrological data were compiled from records of the Department of Water Affairs and the chemical analyses were done by the Chemical Division of the National Institute for Water Research.

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TOERIEN, D.F., HYMAN, K.L. and BRUWER, M.J. 1975 A preliminary trophic status classification of some South African impoundments. *Water SA* 1(1), 15–23.

TABLE 1. Characteristics of Bronkhorstspruit Dam and its catchment.

Geographical location	25° 53,25'S; 28° 43,5'E
Magisterial district	Bronkhorstspruit
Catchment type	Rural, Highveld
Usage of dam	Irrigation and potable water supply
Catchment area	1 263 km^2
Inflowing rivers	Bronkhorstspruit, Osspruit
Dam wall completed	1949
*F.S.L. volume	58,5 x 10^6 m^3
F.S.L. area	8,5 km^2
F.S.L. maximum depth	19,5 m
F.S.L. mean depth	6,8 m

*F.S.L. = full supply level

TABLE 2. Hydrological characteristics of Bronkhorstspruit Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	58,5	4,0
Area km^2	8,5	3,5
Mean depth m	6,7	0,4
Annual inflow x 10^6 m^3	86,6	170,4
Annual outflow x 10^6 m^3	82,1	181,0
Retention time a	0,71	–

*Average mean is based on monthly values and an annual cycle
Period: August to July (1968 – 1978);
C.V. = Coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Bronkhorstspruit Dam (Aug. 1977 – Jul. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	60,0	57,4	58,4	1,3	0
Area km^2	8,9	8,5	8,6	1,2	0
Mean depth m	6,7	6,7	6,7	0	0
Monthly inflow x 10^6 m^3	64,8	1,1	13,6	139,2	88
Monthly outflow x 10^6 m^3	65,1	0,2	13,3	144,9	94

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers and dam station. Values are based on fortnightly samples collected between August 1977 and July 1978.

PARAMETER	DAM STATION								BRONKHORSTSPRUIT				OSSPRUIT			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	6,0	16,0	9,7	28	5,0	13,0	8,8	33	6,0	20,0	10,7	37	6,0	20,0	10,4	38
K	2,8	9,0	3,4	35	2,8	4,0	3,1	12	1,0	21,0	3,2	118	1,0	11,1	2,2	91
Ca	10,0	18,0	14,3	15	7,0	18,0	13,2	21	7,0	35,0	19,8	30	10,0	34,0	19,0	25
Mg	7,0	14,0	10,2	17	5,0	13,0	9,9	27	4,0	27,0	14,0	35	1,0	24,0	14,0	35
SO_4	5,0	18,0	10,8	29	5,0	17,0	10,6	27	5,0	67,0	12,2	110	5,0	100,0	12,4	152
Cl	5,0	15,0	7,4	36	5,0	13,0	6,7	34	5,0	76,0	11,8	116	5,0	45,0	9,2	90
Cond	13,5	24,0	17,5	18	10,0	21,0	15,4	20	14,5	40,0	21,7	30	9,8	59,5	20,7	44
Alk	14,0	106,0	77,3	19	36,0	110,0	74,4	25	5,0	176,0	100,0	38	5,0	167,0	100,6	33
Tot Kj-N	0,080	1,550	0,523	54	0,140	1,660	0,653	57	0,200	5,500	0,860	119	0,061	1,350	0,555	52
Dis Kj-N	0,160	1,320	0,516	46	0,180	1,620	0,662	55	0,105	6,500	0,993	148	0,125	1,4	0,547	57
NH_4-N	0,018	0,267	0,099	66	0,008	0,900	0,226	116	0,004	4,3	0,434	240	0,010	0,590	0,121	120
NO_3-N	0,02	0,76	0,354	53	0,036	0,990	0,410	52	0,115	1,8	0,453	69	0,001	0,600	0,368	45
NO_2-N	0,003	0,026	0,009	56	0,004	0,025	0,010	60	0,004	0,400	0,033	254	0,004	0,027	0,012	83
Tot P	0,002	0,180	0.066	64	0,005	0,300	0,098	82	0,010	0,210	0,064	88	0,080	1,8	0,660	65
Tot dis P	0,002	0,248	0,054	93	0,012	0,400	0,089	94	0,006	0,260	0,064	104	0,008	0,28	0,065	92
PO_4-P	0,006	0,058	0,021	57	0,007	0,400	0,041	183	0,002	0,208	0,025	156	0,002	0,279	0,034	177
Fe	0,230	2,470	0,713	86	0,054	1,600	0,609	72	0,025	2,210	0,468	100	0,009	1,345	0,420	77
Mn	0,025	0,061	0,027	28	0,025	0,355	0,082	115	0,025	0,110	0,032	56	0,025	0,067	0,029	32
Temp	10,5	27,0	18,9	26	9,5	21,0	16,1	23	8,0	28,0	18,4	32	7,5	28,0	18,2	33
DO	3,8	13,0	7,0	28	0,0	8,3	4,11	77								
Tu	11,0	88,0	38,0	46	22,0	98,0	74,9	60								
pH	7,14	8,73	7,92	5	7,17	8,42	7,8	4	7,54	8,87	8,02	5	7,65	8,8	7,9	7

*C.V. = Coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Bronkhorstspruit Dam (Aug. 1977 – Jul. 1978)

Mean depth m	6,7
Retention time a	0,37
Hydraulic load m/a	18,2
Surface loading rates $g/m^2.a^{-1}$	
PO_4 – P	0,33
Total P	1,14
Inorganic nitrogen	6,42
Total nitrogen	26,04

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	19	1	5
Secchi depth m	0,8	0,1	0,3

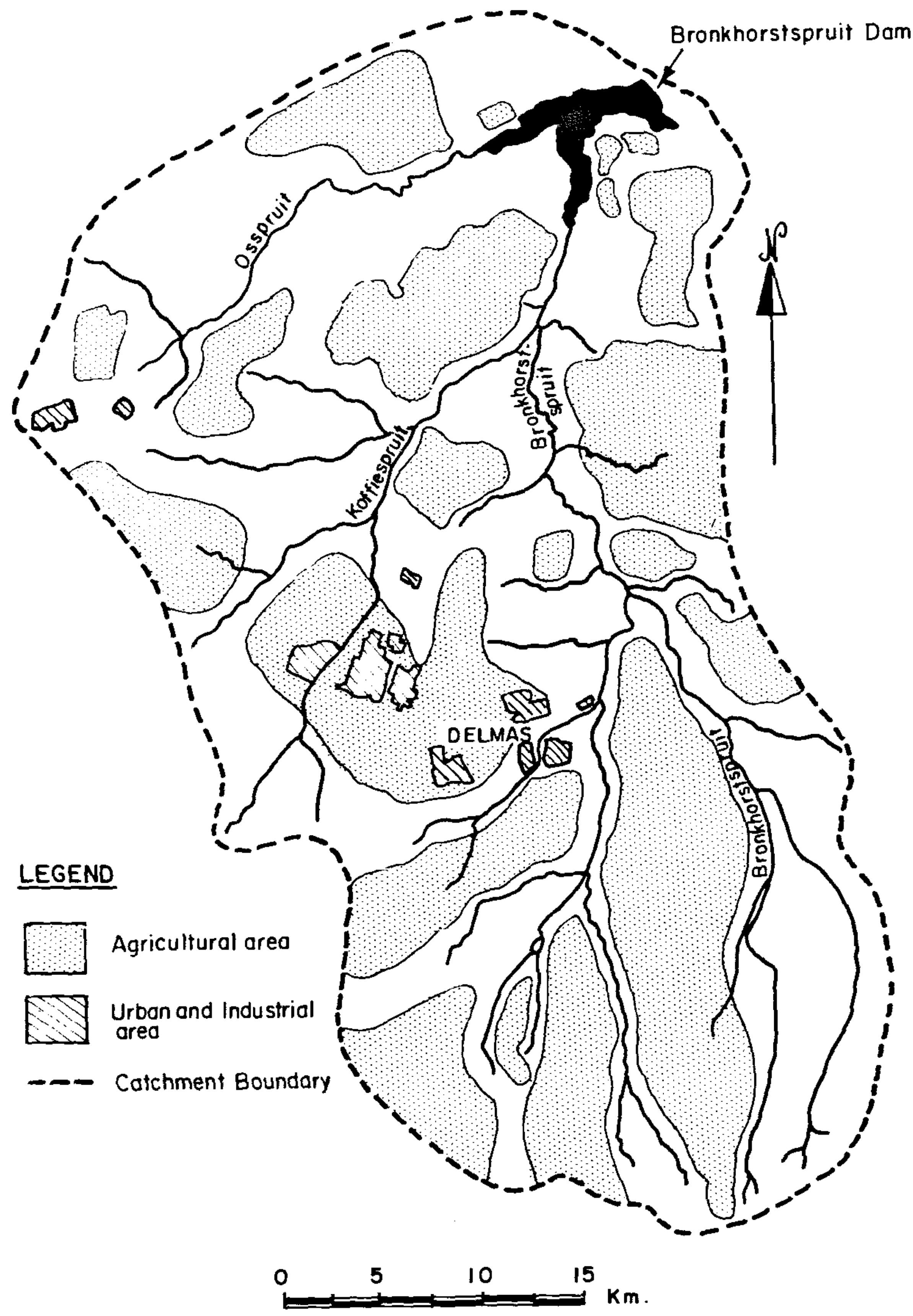

FIGURE 1. Bronkhorstspruit Dam catchment

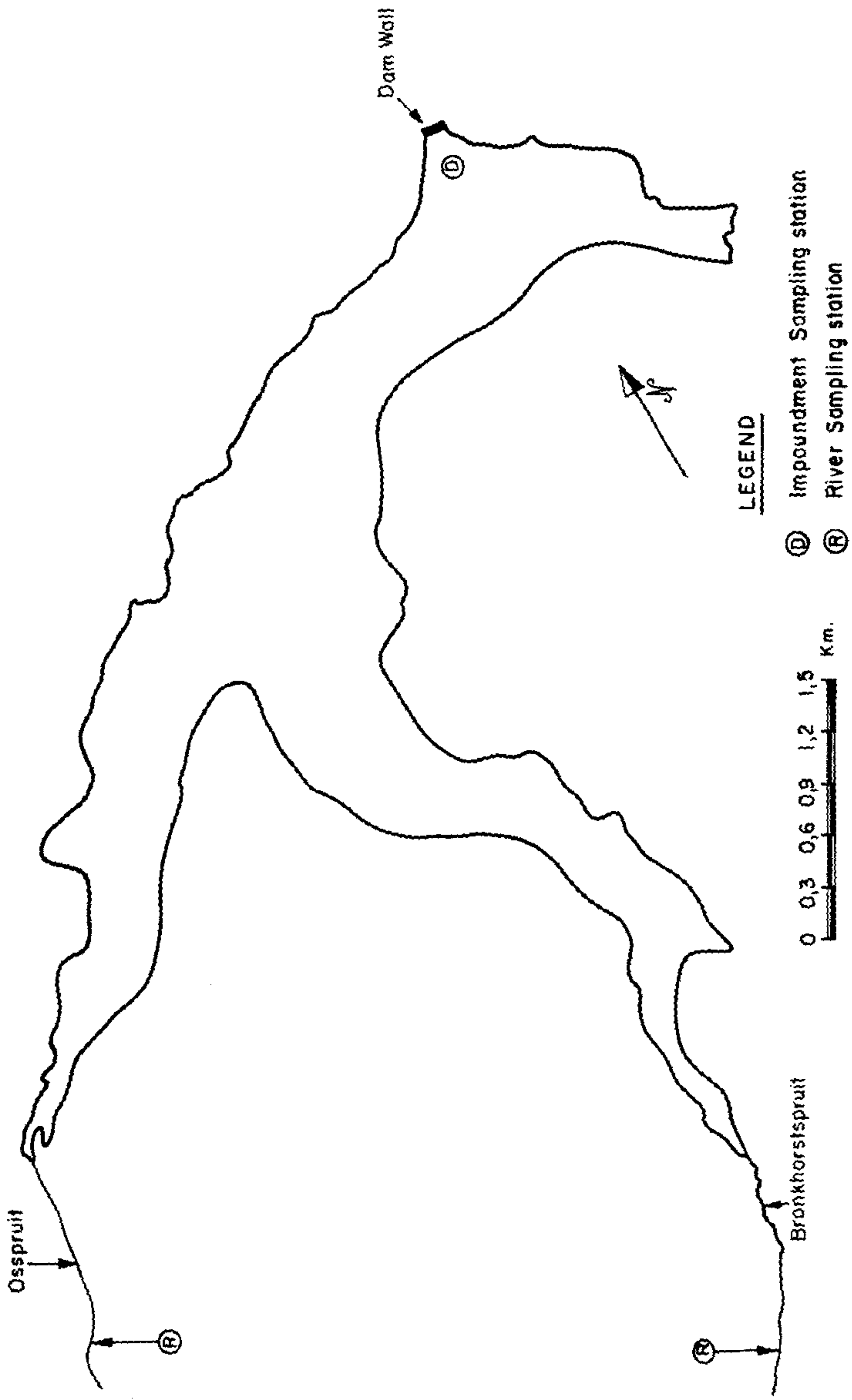

FIGURE 2. Map of Bronkhorstspruit Dam showing sampling stations.

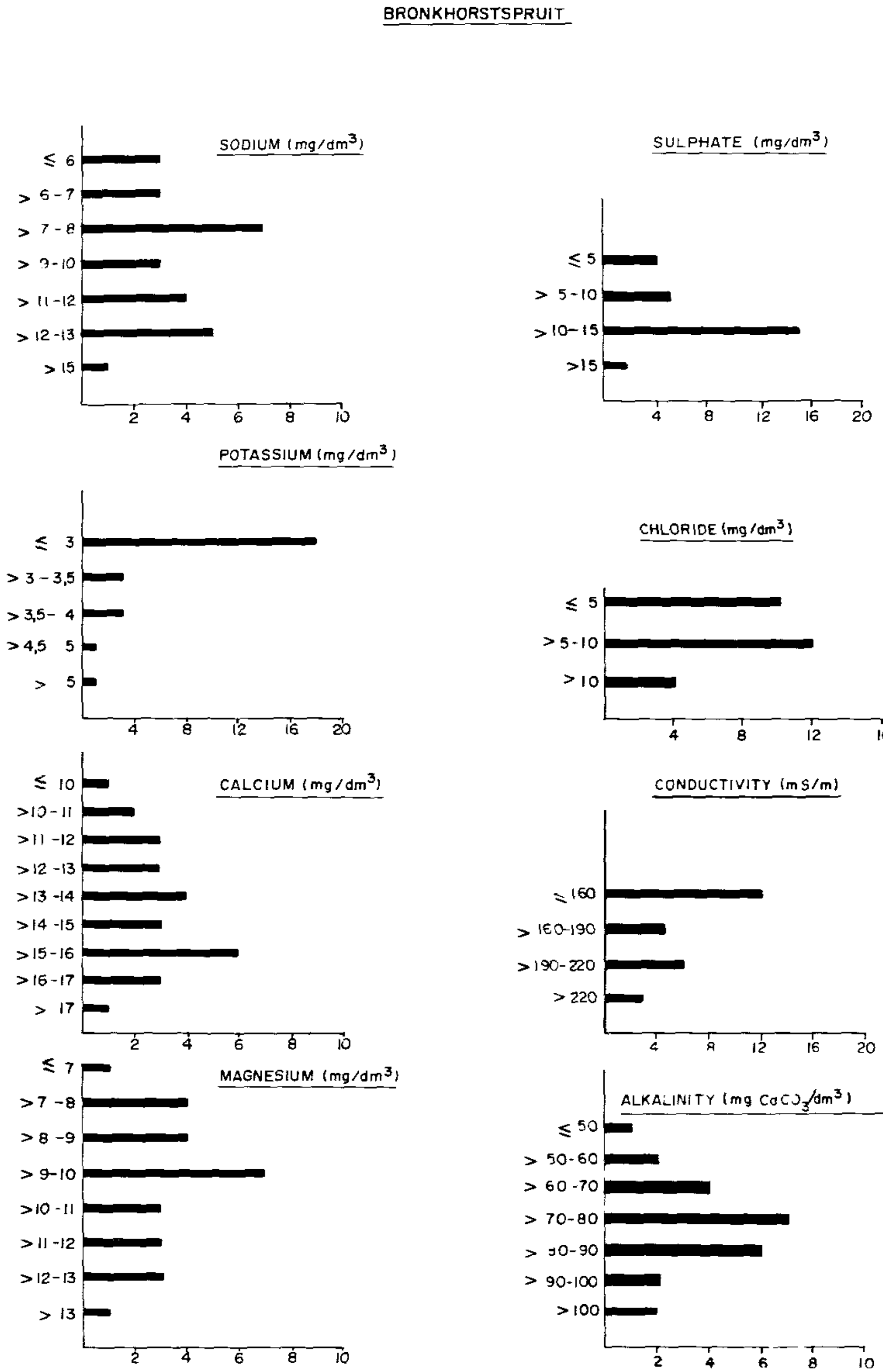

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Bronkhorstspruit Dam.

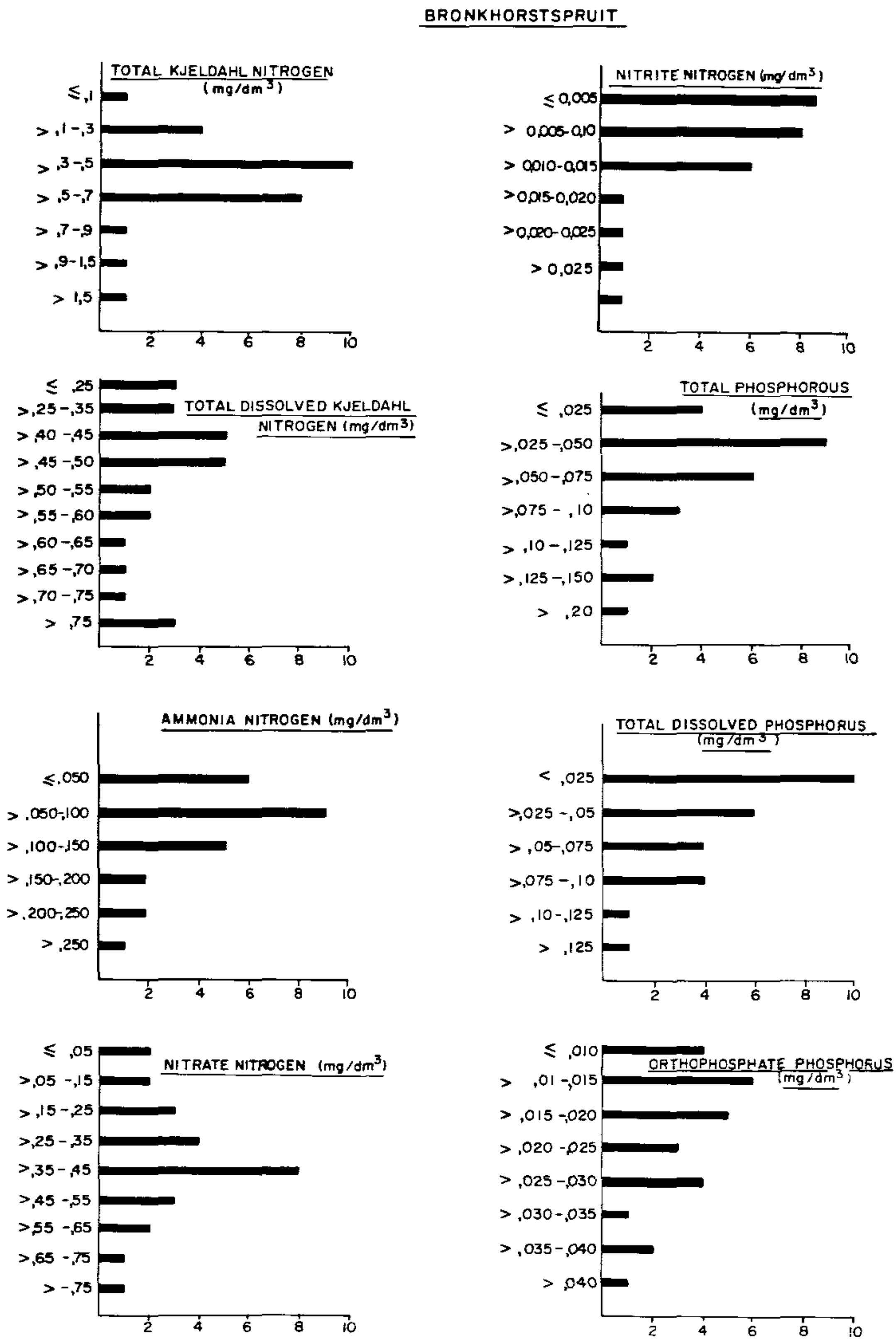

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Bronkhorstspruit Dam.

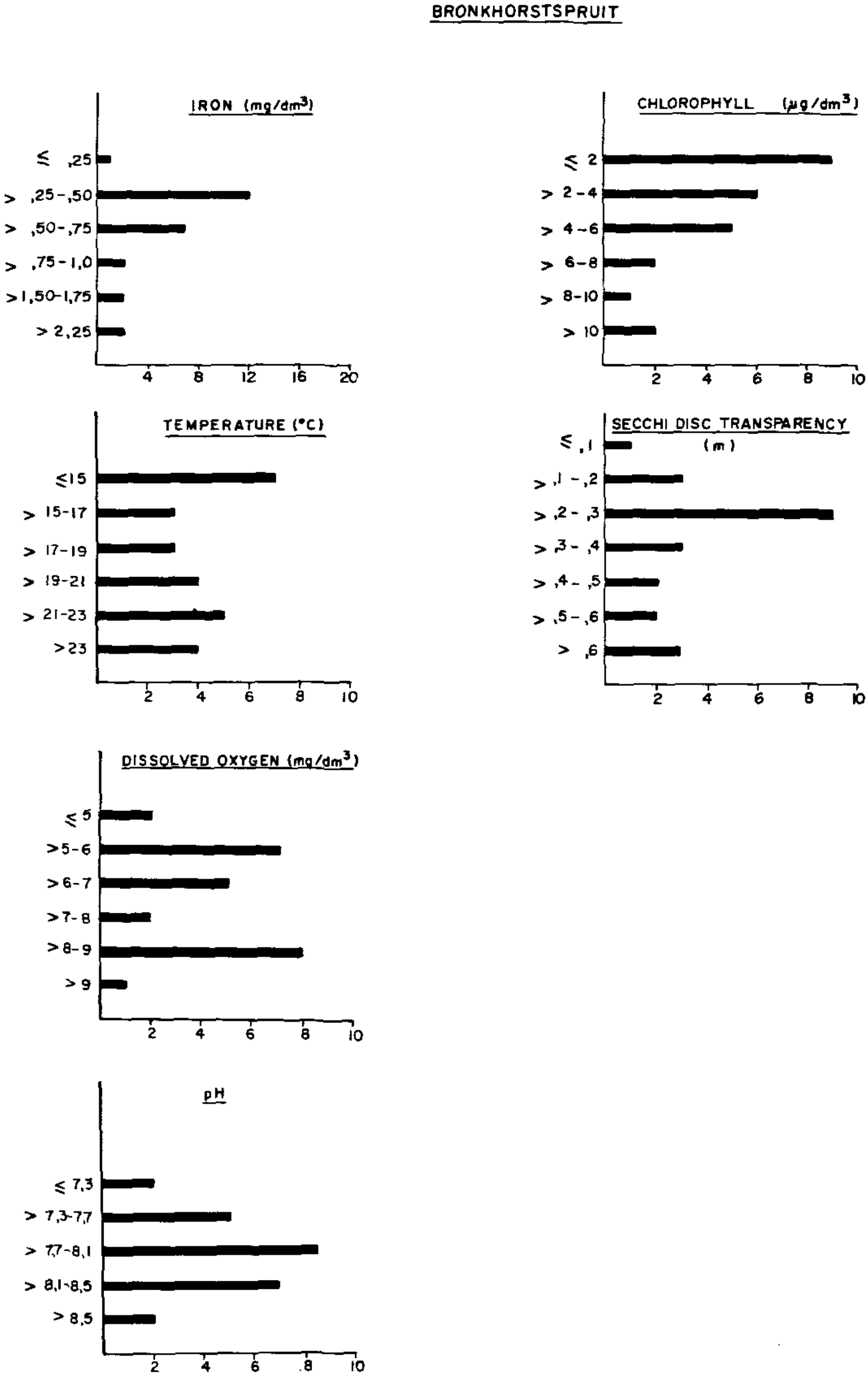

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Bronkhorstspruit Dam.

BRONKHORSTSPRUIT

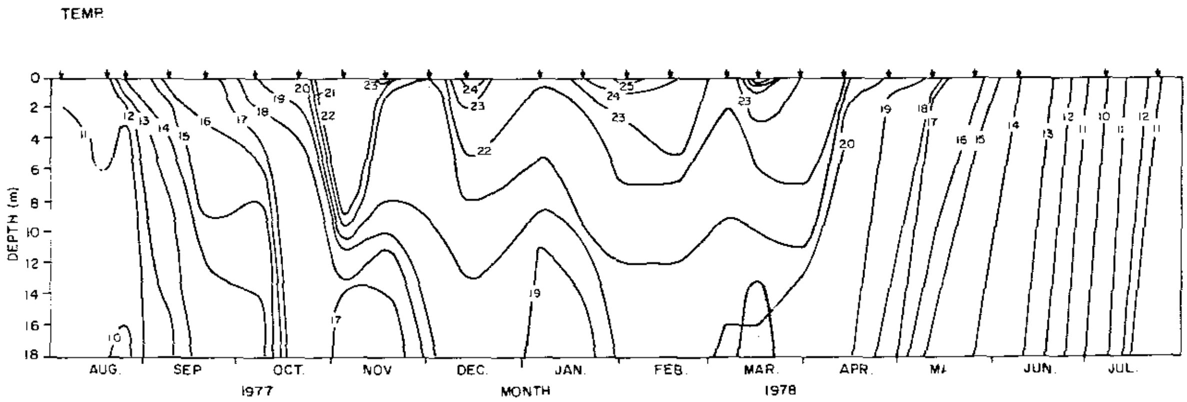

FIGURE 6. Temperature distribution in Bronkhorstspruit Dam (shaded area indicates anaerobic zone).

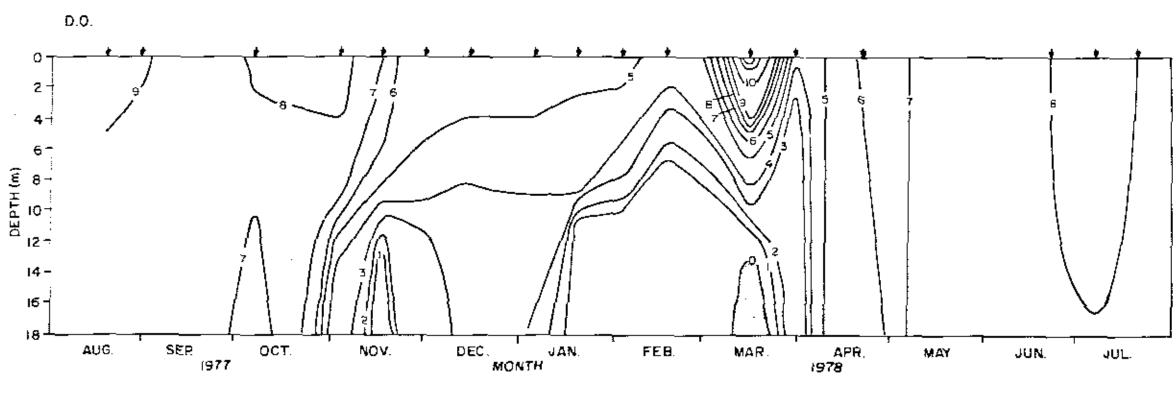

FIGURE 7. Dissolved oxygen distribution in Bronkhorstspruit Dam (shaded area indicates anaerobic zone).

BUFFELSPOORT DAM

by

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INTRODUCTION

The limnology of Buffelspoort Dam has been better defined than many other South African impoundments. In a survey of southern African impoundments which investigated various physical and chemical properties, Schutte and Bosman (1973) found that Buffelspoort Dam had unstable thermal stratification during summer as a result of its low water content. In addition, anaerobic conditions were encountered in the hypolimnion when stratification was present. An algal assay survey of 98 South African impoundments (where algal growth potential ranged between 4 and 660 mg/dm^3) ranked Buffelspoort Dam at 25 mg/dm^3, as having the 47th highest algal growth potential (Toerien *et al.*, 1975). Subsequent more detailed studies on the impoundment and its catchment have resulted in the impoundment being classified as mesotrophic (Walmsley *et al.*, 1978; Walmsley and Toerien, 1979). Walmsley and Toerien (1979) expressed concern about the rapid recreational expansion which had occurred in the catchment and recommended that the system be monitored in order to detect any appreciable changes in trophic status as a consequence of these activities.

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment area are shown in Table 1. Buffelspoort has a small catchment (119 km^2) in which land use is restricted to agricultural small-holdings with no major urban or industrial areas. Hotels and holiday resorts use septic tanks for the disposal of domestic wastes whilst boreholes provide potable water. The inflowing streams and types of land use in the catchment are shown in Figure 1. A Map (Fig. 2) reveals that the impoundment's basin is more steep-sided near the dam wall and along the eastern shore. The impoundment is triangular in shape with a maximum width of 1,4 km and a length of approximately 3 km. Sampling stations for the study are indicated in Figure 2.

Medium-term hydrological characteristics of the impoundment indicate that it experiences a wide variation in hydrological conditions between years (Table 2). The mean water retention time (0,48 years) is low, showing that the impoundment is well-flushed even during dry years, since the water retention time is always below 1,0 year (i.e. the water content is replaced at least once per annum). On the basis of catchment ratios, it has been estimated that the main inflowing stream (Sterkstroom) contributes 80 % of the inflow into the impoundment.

RESULTS AND DISCUSSION

A summary of the monthly hydrological behaviour of the impoundment for the study year (May 1975 – April 1976) shows that Buffelspoort Dam received greater inflow than average (Table 3). Consequently, the mean water retention time was low (0,36 years – Table 5). When monthly inflow was at a maximum, almost 70 % of the impoundment's volume was replaced within one month. Thus, in such situations, water retention time was in actual fact of the order of 35 days.

Chemical analysis of the inflow, outflow and impounded water showed that low levels of dissolved minerals were present (Table 4). The values obtained during the study period showed no differences to those reported for the period February 1973 – April 1975 (Walmsley and Toerien, 1979). Frequency histograms of the impoundment's surface water data are presented in Figures 3, 4 and 5. In most cases the values for parameters did not display a normal distribution. However, the histograms do give an indication of the number of weeks in which a particular range or value was encountered. Of note is the fact that nutrient concentrations (i.e. nitrogen and phosphorus compounds) were at the lower scale of the concentration range for most of the year (Fig. 4). Chlorophyll *a* concentrations of hosepipe samples showed a wide range (2,0 – 20,0 $\mu g/dm^3$), but concentrations were greater than 4,0 $\mu g/dm^3$ for more than 80 % of the study period (Fig. 5).

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Temperature and oxygen isopleths (Figs. 6, 7) indicated that the impoundment developed a stable thermal layering in the early summer months. Flooding of the system between January and March 1976 resulted in the loss of thermal layering, although the impoundment remained stratified until overturn in early May 1976. During winter, oxygen was distributed evenly within the water column (Fig. 7) whilst in summer an extensive anaerobic hypolimnion was present. The anaerobic layer was re-oxygenated on two occasions after floods when inflowing water penetrated the impoundment as underflows.

Nutrient loading rate estimates for orthophosphate phosphorus and inorganic nitrogen (0,18 $g.m^{-2}.a^{-1}$ and 6,8 $g.m^{-2}.a^{-1}$ respectively – Table 5) differ from those estimated by Walmsley *et al.* (1978) for the 1973/74 (0,94 $g.m^{-2}.a^{-1}$ and 5,71 $g.m^{-2}.a^{-1}$ respectively) and the 1974/75 years (0,73 $g.m^{-2}.a^{-1}$ and 4,42 $g.m^{-2}.a^{-1}$ respectively). This difference can be attributed to the more intensive sampling schedule of this study which involved weekly sampling. These loading rates are not high and are typical of those obtained for runoff from undeveloped areas (Vollenweider, 1968).

In conclusion, results obtained for Buffelspoort Dam between May 1975 and May 1976 confirm the mesotrophic classification of the impoundment. The highest concentration of chlorophyll *a* (20,9 $\mu g/dm^3$) cannot be considered as a level which represents nuisance proportions. The surface waters can be considered of good quality and no measurable evidence was detected of the effects of increased recreational activities.

ACKNOWLEDGEMENTS

The Department of Water Affairs is gratefully acknowledged for providing the hydrological data. We also thank the numerous colleagues who helped with the sampling programme and the Analytical Division of the National Institute for Water Research who completed the chemical analyses.

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TABLE 1. Characteristics of Buffelspoort Dam and its catchment

Geographical location	25° 46'S; 27° 29'E
Magisterial district	Rustenburg
Catchment type	Farmland, grassland, holiday resorts
Usage of dam	Irrigation, recreation
Catchment area	119 km^2
Inflowing rivers	Sterkstroom, Swartspruit
Dam wall completed	1935
*F.S.L. volume	10,7 x 10^6 m^3
F.S.L. area	1,35 km^2
F.S.L. maximum depth	23 m
F.S.L. mean depth	7,9 m

*F.S.L. = full supply level

TABLE 2. Hydrological characteristics of Buffelspoort Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	6,94	47
Area km^2	1,05	26
Mean depth m	6,6	19
Annual inflow x 10^6 m^3	14,36	126
Annual outflow x 10^6 m^3	14,26	109
Retention time a	0,48	53

*Average mean is based on monthly values and an annual cycle
Period: May to April (1968–1978)
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Buffelspoort Dam (May 1975 – April 1976)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	10,7	7,40	9,7	13	30
Area km^2	1,35	1,05	1,26	12	20
Mean depth m	7,9	7,0	7,7	8	17
Monthly inflow x 10^6 m^3	7,11	0,62	2,25	86	88
Monthly outflow x 10^6 m^3	7,20	0,43	2,19	87	85

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from the inflowing rivers (Sterkstroom and Swartspruit), the outflow and a dam station (D1) on Buffelspoort Dam. Values are based on weekly samples collected between May 1975 and May 1976

PARAMETER	DAM STATION								STERKSTROOM				SWARTSPRUIT				OUTFLOW			
	TOP				BOTTOM															
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	1,0	8,0	2,1	65	1,0	5,0	1,9	40	1,0	5,0	1,9	36	1,0	5,0	2,4	39	1,0	4,0	2,0	30
K	0,5	5,4	1,2	57	0,2	5,4	1,3	62	0,3	2,7	0,9	39	0,2	2,5	0,9	50	0,6	2,2	1,1	28
Ca	2,0	4,0	2,9	20	2,0	5,0	2,9	24	1,0	4,0	2,3	30	1,0	8,0	3,3	40	1,0	6,0	3,1	29
Mg	2,0	4,0	2,4	22	1,0	5,0	2,4	27	1,0	3,0	1,8	25	1,0	5,0	2,6	40	1,0	4,0	2,5	26
SO_4	2,00	5,00	4,87	12	2,00	7,00	5,06	13	2,00	6,00	4,89	12	2,00	6,00	4,89	13	3,00	9,00	5,13	15
Cl	2,00	8,00	4,94	16	2,00	5,00	4,83	14	2,00	6,00	4,87	13	2,00	7,00	4,90	14	3,00	5,00	4,95	6
Si	3,00	5,70	4,10	16	3,20	6,10	4,54	16	3,40	8,00	5,36	17	1,90	11,10	6,98	31	3,40	6,20	4,49	16
Cond	3,00	6,60	4,69	15	3,40	8,50	4,95	19	2,13	10,40	4,22	28	2,60	8,40	5,16	27	3,60	11,40	5,11	25
Alk	10,00	37,00	21,08	30	10,00	42,00	23,73	39	10,00	42,00	18,54	35	10,00	48,00	23,90	37	10,00	57,00	22,66	41
Tot Kj-N	0,20	6,30	1,54	82	0,20	5,00	1,54	74	0,200	7,80	1,38	87	0,20	5,90	1,39	78	0,30	5,40	1,53	82
Dis Kj-N																				
NH_4-N	0,006	0,410	0,102	84	0,010	0,620	0,267	61	0,007	0,500	0,089	103	0,008	0,875	0,112	126	0,009	1,200	0,242	88
NO_3-N	0,002	0,409	0,111	100	0,002	0,600	0,137	85	0,025	0,500	0,257	46	0,002	0,800	0,085	139	0,002	1,000	0,190	98
NO_2-N	0,001	0,050	0,007	107	0,002	0,075	0,010	111	0,002	0,055	0,007	112	0,002	0,025	0,006	78	0,002	0,400	0,018	356
Tot P																				
Tot dis P																				
PO_4-P	0,002	0,026	0,006	83	0,002	0,068	0,012	115	0,002	0,054	0,010	92	0,002	0,046	0,009	75	0,002	0,050	0,010	90
Fe																				
Mn																				
Temp	12,5	25,4	19,8	20	10,5	19,7	15,7	17	13,2	26,2	20,5	15	14,0	24,5	20,3	14	11,3	12,8	12,0	5
DO	2,4	8,1	6,9	18	0	8,2	3,1	99												
Tu	2,0	8,0	3,9	41	2,2	73,0	19,6	84	2,5	72,0	6,3	15,3	1,5	34,0	5,9	80	20	18,0	6,7	74
pH	6,5	8,4	7,4	7	6,3	7,2	6,8	3	6,4	8,1	7,1	4	6,4	7,5	6,9	4	6,4	6,7	6,6	3
SS	1,2	8,1	4,0	37	1,9	85,2	18,2	99	0,06	141,3	6,4	313	0,2	22,2	3,9	102	0,3	21,1	5,6	90

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Buffelspoort Dam (May 1975 — May 1976)

Mean depth m		7,7	
Retention time a		0,36	
Hydraulic load m/a		21,4	
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P		0,18	
Total P		7,710	
Inorganic nitrogen		—	
Total nitrogen		6,80	
	Maximum	**Minimum**	**Mean**
Chlorophyll *a* $\mu g/dm^3$	20,9	1,5	6,40
Secchi depth m	3,2	0,80	1,40

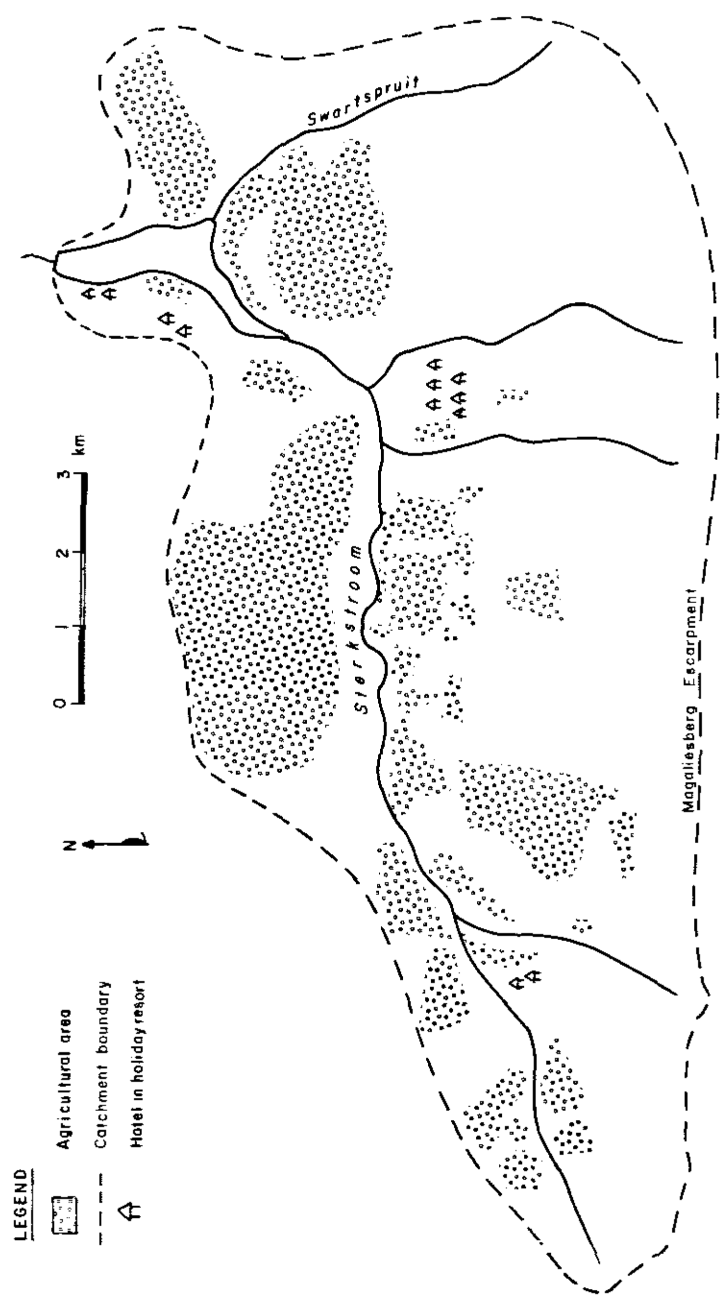

FIGURE 1. Buffelspoort Dam catchment.

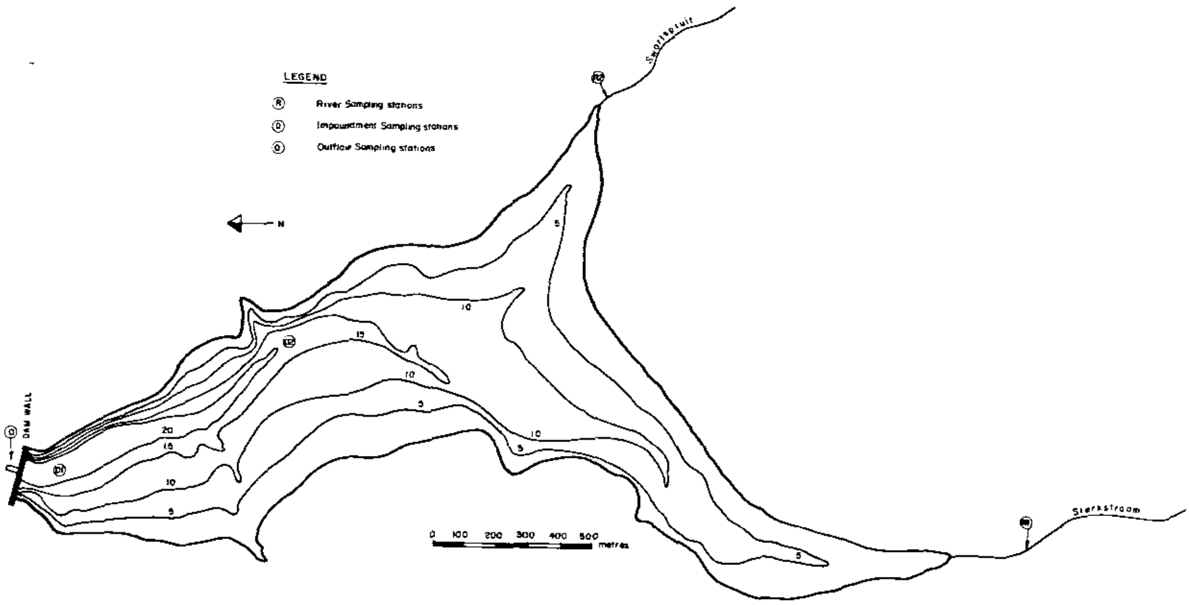

FIGURE 2. Map of Buffelspoort Dam showing sampling stations.

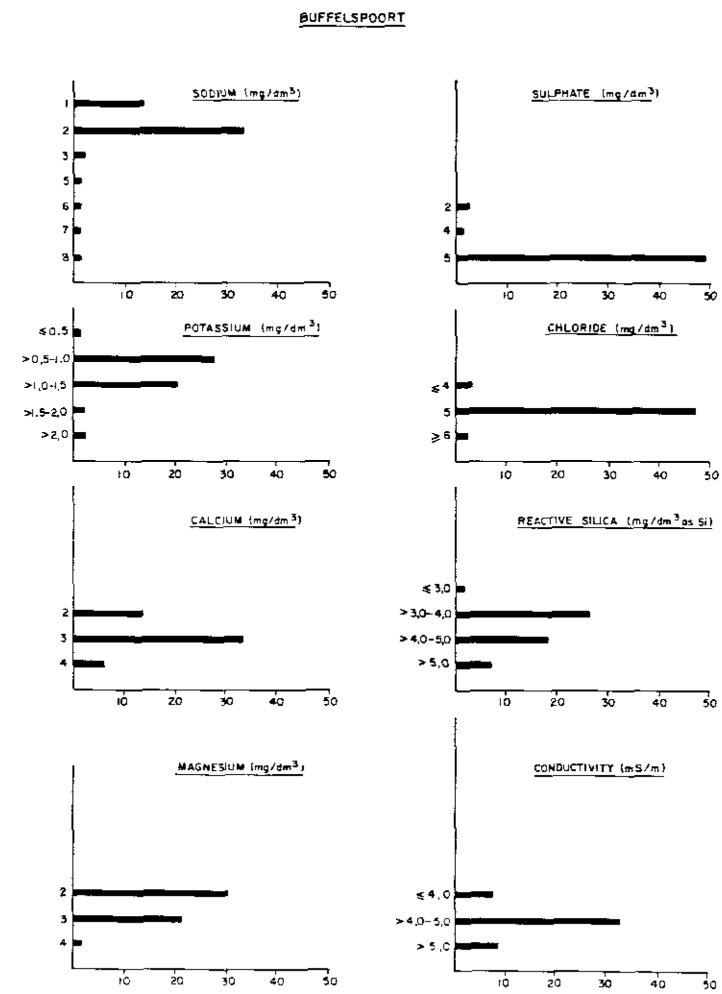

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Buffelspoort Dam.

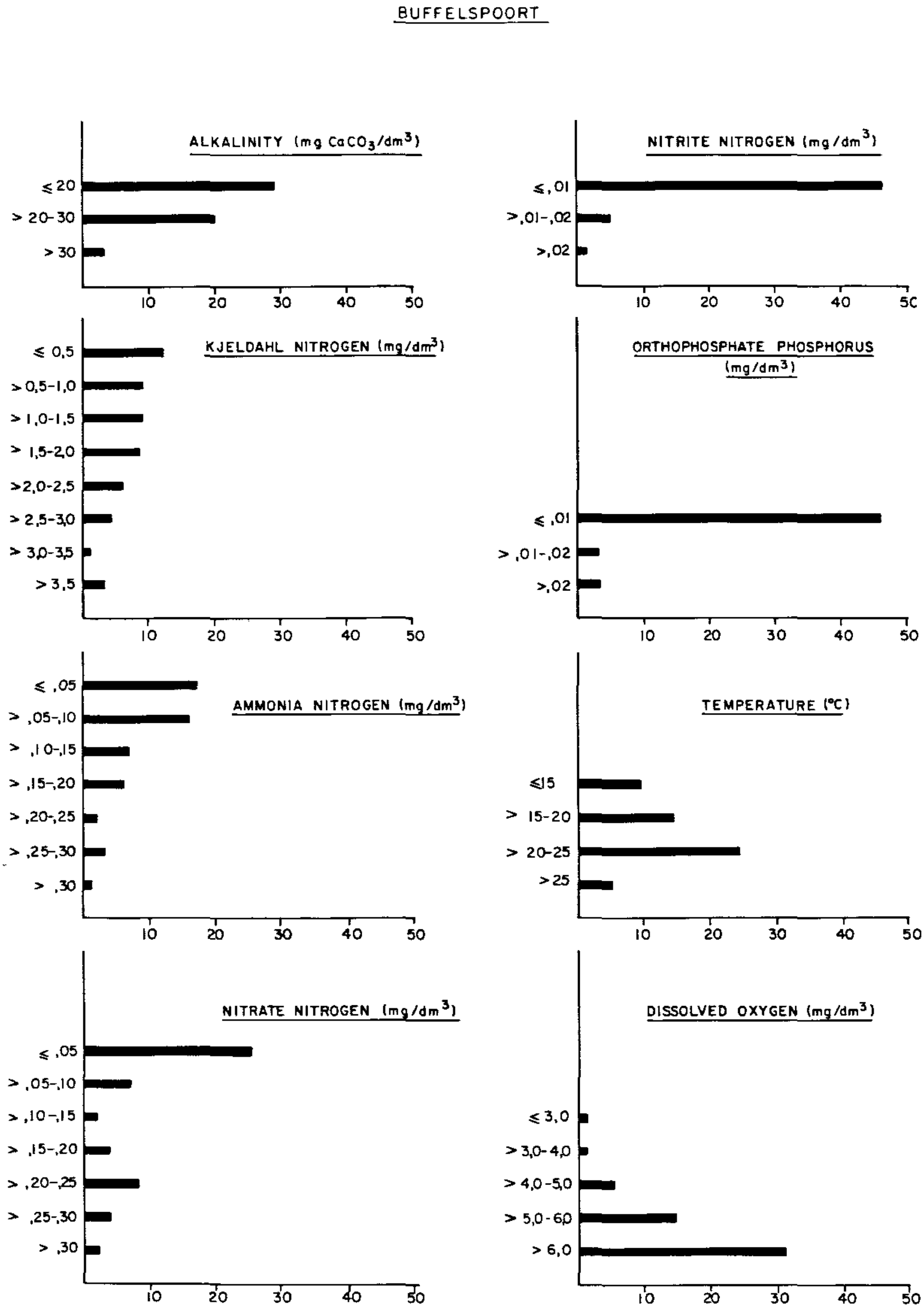

FIGURE 4. **Frequency histograms for selected parameters pertinent to the surface waters of Buffelspoort Dam.**

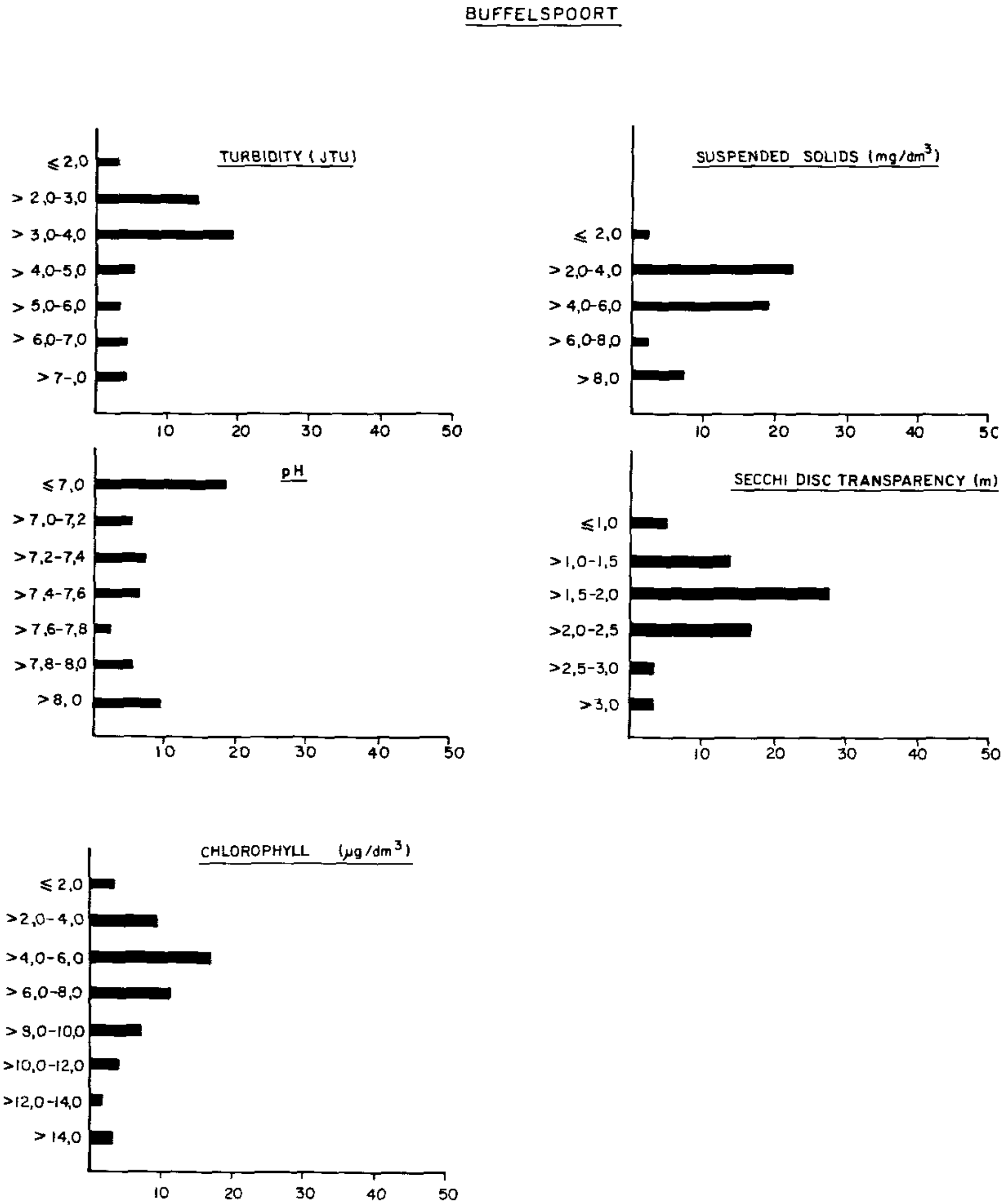

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Buffelspoort Dam.

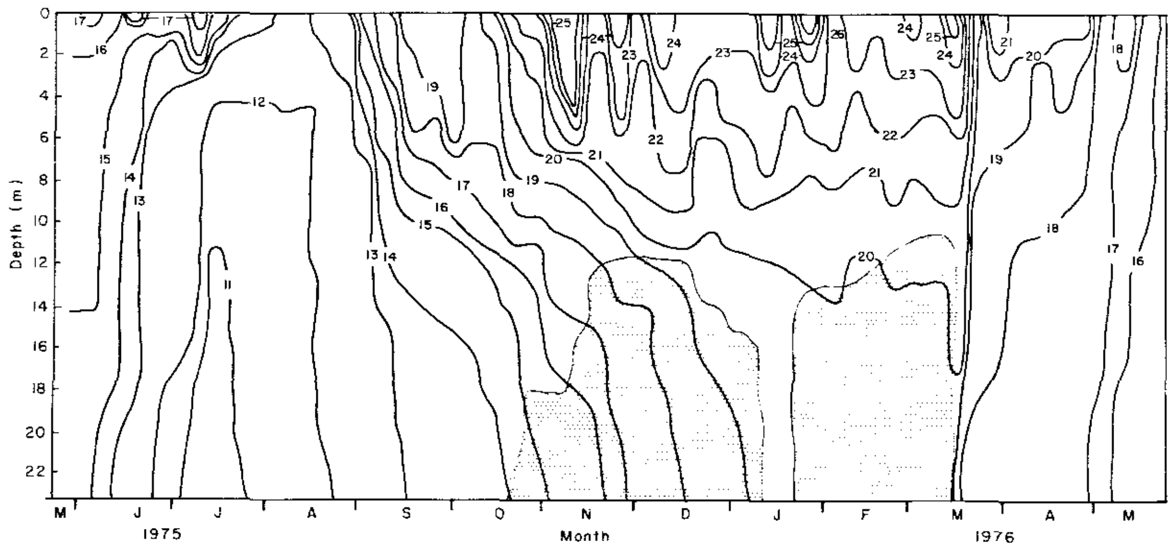

FIGURE 6. **Temperature distribution in Buffelspoort Dam** (shaded area indicates anaerobic zone).

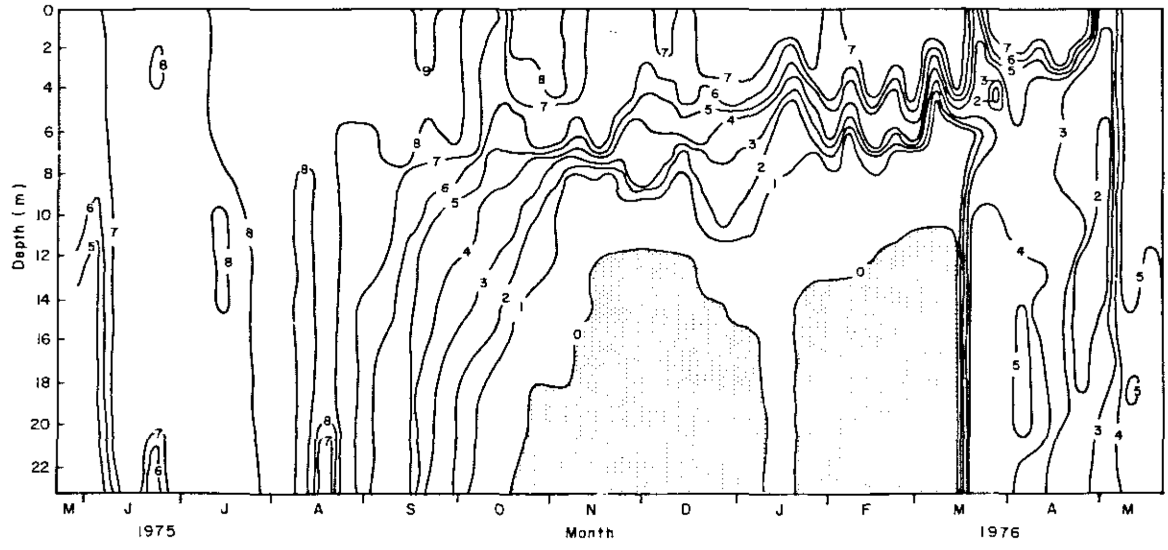

FIGURE 7. **Dissolved oxygen distribution in Buffelspoort Dam** (shaded area indicates anaerobic zone).

LINDLEYSPOORT DAM

by

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INTRODUCTION

Lindleyspoort Dam is situated in an area of South Africa which is susceptible to a high degree of erosion (Rooseboom, 1978). Consequently, the impoundment was selected for study since it represented a system in which water transparency would be low due to a high suspended solids content. No previous routine limnological studies have been conducted on Lindleyspoort Dam, although the impoundment has been included in two limnological surveys. Schutte and Bosman (1973), investigating the physical and chemical characteristics of South African impoundments during 1968/69, found that the impoundment was thermally stratified in summer, had an anaerobic hypolimnion and exhibited low water transparency (Secchi depth ranged between 0,15 and 1,00 m). Toerien *et al.* (1975), in an algal assay survey of 98 South African impoundments, ranked the system as being the 79th highest with respect to the algal growth potential of its waters (60 mg/dm^3). They also found that phosphate was the growth-limiting nutrient. This report presents a summary of limnological information for the impoundment during an annual period May 1975 to May 1976.

DESCRIPTION OF THE AREA

The catchment of Lindleyspoort Dam is largely devoted to agriculture, particularly the cultivation of sunflowers and maize. Most of this agricultural activity occurs south of the catchment near Koster (Fig. 1). Urban areas consist of a small part of Koster, Kaffirskraal (a native location), the Mazista Township and Swartruggens which is the major town. The population of Swartruggens was estimated at approximately 3 000 in 1970 and the total population of the district at 15 000 (Department of Statistics, 1970). Swartruggens does not have a conventional sewage treatment plant and raw sewage is transferred from conservancy tanks to oxidation ponds. The effluent is then used to irrigate pasture land. Industrial development in the catchment is restricted to small diamond mines which are situated north of Swartruggens (Fig. 1).

At full supply level, the impoundment has a water content of 14,2 x 10^6 m^3, an area of 1,75 km^2, a maximum depth of 22 m and a mean depth of 8,1 m (Table 1). A depth contour map for the impoundment at full supply level indicates that the basin is steep-sided and that there are very few flat areas (Fig. 2). The impoundment has a sinuous shape with a maximum width of 700 m and a length of approximately 5 km. Hydrological conditions are extremely variable between years (Table 2), but the impoundment has a mean water retention time of 0,45 years. This means that on the average, the water content of the system is replaced at least twice during an annual cycle.

RESULTS AND DISCUSSION

The annual water inflow into Lindleyspoort Dam during the study year was much higher than the average ($>$156 % — Table 3). Monthly inflow volumes showed a wide range (0 – 55,785 x 10^3 m^3) and the maximum monthly inflow was almost 4 times greater than the full supply water content of the impoundment. As a consequence of this higher annual inflow, the mean water retention time for the study year was 0,12 years (Table 5). Under these hydrological conditions, the water content of the impoundment was replaced approximately 8 times during the study year.

A summary of the chemical characteristics of the inflow, outflow and impounded waters is presented in Table 4. A comparison of these data with that of Schutte and Bosman (1973) indicated that the chemical composition of these waters has changed very little since the date of their study in 1968. Frequency histograms showing the ranges of values encountered for certain physical and chemical parameters are presented in Figures 3, 4 and 5. A normal distribution around the mean was only displayed by certain conservative constituents and parameters, e.g. sodium, magnesium, conductivity and alkalinity. Orthophosphate concentrations were usually greater than 0,01 mg/dm^3 whilst nitrate nitrogen was always greater than 0,25 mg/dm^3. This indicates that available nitrogen was always present whereas available phosphate might have been present in limiting proportions at times. This is consistent with the conclusions of Toerien *et al.* (1975) who reported that phosphorus was the growth-limiting nutrient in Lindleyspoort. The mean available nitrogen:available phosphate ratio of the inflowing waters (based on the inorganic nitrogen and orthophosphate phosphorus loading rates – Table 5) was approximately 27,8, a figure which certainly does suggest phosphate limitation (Vollenweider, 1968).

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Temperature isopleths (Fig. 6) show that circulation occurred during winter (May — Aug.) and that a stable thermal layering developed in early summer. After mid-December 1975, large inflows of water were experienced and evidence of density current underflows were recorded in the temperature profiles. From January 1976, thermal stratification was affected considerably by the hydrological events and in mid-March, one particularly large flood almost caused a complete mixing of the water column. Overturn in the impoundment occurred in early May 1976. Dissolved oxygen showed a seasonal pattern which was related to the thermal cycle (Fig. 7). A uniform oxygen distribution was recorded during winter circulation whereas during summer stratification an oxygen deficit was always present. Density current flow during the rainy season had pronounced effects on the oxygen content of the bottom waters on three occasions. Despite the summer oxygen deficit, anaerobic conditions were only encountered once toward the end of summer (a week before overturn).

Nutrient loading rates were extremely high and, based on criteria of nutrient loading (Vollenweider, 1968), the impoundment should be considered highly eutrophic (Table 5). However, algal populations were not very high (mean chlorophyll *a* of 3,25 $\mu g/dm^3$) and more characteristic of a mesotrophic situation (Table 5). The reasons for this may be:

(i) The high turbidity of the system (turbidity of 20 JTU for over 90 % of the year) which restricts light penetration and effects algal growth. The turbidity characteristics of Lindleyspoort Dam and their possible effects on the ecosystem have been discussed in more detail by Walmsley (1978);

(ii) The high flushing rate which was obviously fairly rapid (water retention time of ± 3 days during the rainy season). Oglesby (1977) states that when the flushing rate is similar to the growth rate of natural phytoplankton populations, the incoming load can be regarded as being ineffectual and a 'flush out' effect is observed.

Lindleyspoort Dam may therefore be described as a turbid impoundment with the potential to develop algal growth problems. However, due to the modifying influence of turbidity and the high flushing rate, the impoundment displays the characteristics of a mesotrophic system.

ACKNOWLEDGEMENTS

The Department of Water Affairs is gratefully acknowledged for providing the hydrological data. Thanks are also due to the Analytical Division of the National Institute for Water Research who made the chemical analyses and Miss M. Pistorius and Mrs A. Engelbrecht for their important part in the data processing.

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TABLE 1. Characteristics of Lindleyspoort Dam and its catchment

Geographical location	25 ° 29', 26 ° 4' 4'E
Magisterial district	Swartruggens
Catchment type	Farmland
Usage of dam	Irrigation
Catchment area	704 km^2
Inflowing river	Elands
Dam wall completed	1938
*F.S.L. volume	14,2 x 10^6 m^3
F.S.L. area	1,76 km^2
F.S.L. maximum depth	22,23 m
F.S.L. mean depth	8,09 m

*F.S.L. = full supply level

TABLE 2. Average term hydrological characteristics of Lindleyspoort Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	10,51	30
Area km^2	1,49	20
Mean depth m	6,9	14
Annual inflow x 10^6 m^3	38,78	80
Annual outflow x 10^6 m^3	36,28	89
Retention time a	0,45	60

*Average mean is based on monthly values and an annual cycle
Period: May to April (1970 — 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Lindleyspoort Dam (May 1975 to April 1976)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	14,855	11,268	13,673	6,6	30
Area km^2	1,802	1,513	1,710	6	15
Mean depth m	8,2	7,44	7.99	6	16
Monthly inflow x 10^6 m^3	55,785	0	8,292	196	156
Monthly outflow x 10^6 m^3	56,276	0,426	8,239	199	172

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from the inflowing river (Elands), the outflow and the dam station (D1) on Lindleyspoort Dam. Values are based on weekly samples collected over an annual cycle between May 1975 and May 1976.

PARAMETER	DAM STATION								ELANDS RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	3,0	13,0	6,3	24	2,0	9,0	5,4	30	2,0	11,0	7,3	27	2,0	9,0	5,7	27
K	1,2	3,2	1,9	20	1,3	2,9	1,9	18	0,5	9,0	1,6	72	0,9	3,7	1,9	28
Ca	6,0	18,0	10,6	20	3,0	16,0	9,2	32	3,0	28,0	13,7	40	3,0	17,0	10,2	29
Mg	5,0	9,0	6,8	15	2,0	9,0	6,1	31	2,0	20,0	9,7	37	2,0	9,0	6,8	25
SO_4	4,0	14,0	6,0	32	4,0	12,0	6,1	32	4,0	15,0	5,9	33	5,0	14,0	7,3	36
Cl	4,0	10,0	5,3	19	2,0	7,0	5,0	13	4,0	12,0	5,8	28	5,0	10,0	5,6	25
Si	4,2	7,0	5,1	12	3,2	6,9	4,8	17	3,6	55,0	6,1	114	3,3	7,5	5,0	17
Cond	7,8	17,1	13,6	14,5	3,8	15,6	11,8	26	3,9	90,0	17,9	67	4,5	16,3	12,7	23
Alk	42,0	73,0	58,3	12	20,0	77,0	52,5	25	29,0	164,0	75,2	34	13,8	71,0	52,9	29
Tot Kj-N	0,3	3,7	1,6	49	0,2	4,7	1,7	65	0,2	7,1	1,6	86	0,2	3,5	1,4	61
Dis Kj-N																
NH_4-N	0,008	0,900	0,146	136	0,011	0,800	0,114	127	0,007	0,400	0,089	89	0,004	0,590	0,125	114
NO_3-N	0,156	1,000	0,528	46	0,250	0,960	0,544	34	0,015	1,200	0,482	66	0,054	1,000	0,549	40
NO_2-N	0,003	0,036	0,010	69	0,001	0,032	0,010	59	0,002	0,047	0,010	77	0,003	0,034	0,012	59
Tot P																
Tot dis P																
PO_4-P	0,004	0,200	0,028	137	0,005	0,400	0,030	186	0,002	0,200	0,021	157	0,002	0,210	0,022	162
Fe																
Mn																
Temp	10,5	24,0	18,6	24	10,2	19,9	14,5	21	13,5	28,1	21,0	15				
DO	0,7	13,3	3,5	70	0,3	6,2	1,4	73								
Tu	17,5	220,0	58,4	71	32,0	325,0	112,2	81	4,5	275,0	60,0	131	40,5	325,0	108,4	99
pH	6,5	7,9	7,5	4	6,3	7,6	7,2	4	6,7	8,0	7,4	4	5,9	7,6	6,9	13
SS	4,5	132,9	17,8	107	2,1	761,8	69,8	170	1,0	561,0	32,7	268	1,0	224,4	28,9	146

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Lindleyspoort Dam (May 1975 — May 1976)

Mean depth m	8,0
Retention time a	0,12
Hydraulic load m/a	66,6
Surface loading rates g/m^2.a^{-1}	
PO_4-P	1,58
Total P	—
Inorganic nitrogen	43,9
Total nitrogen	—

	Maximum	Minimum	Mean
Chlorophyll *a* μg/dm^3	6,90	0,270	3,45
Secchi depth m	0,80	0,05	0,44

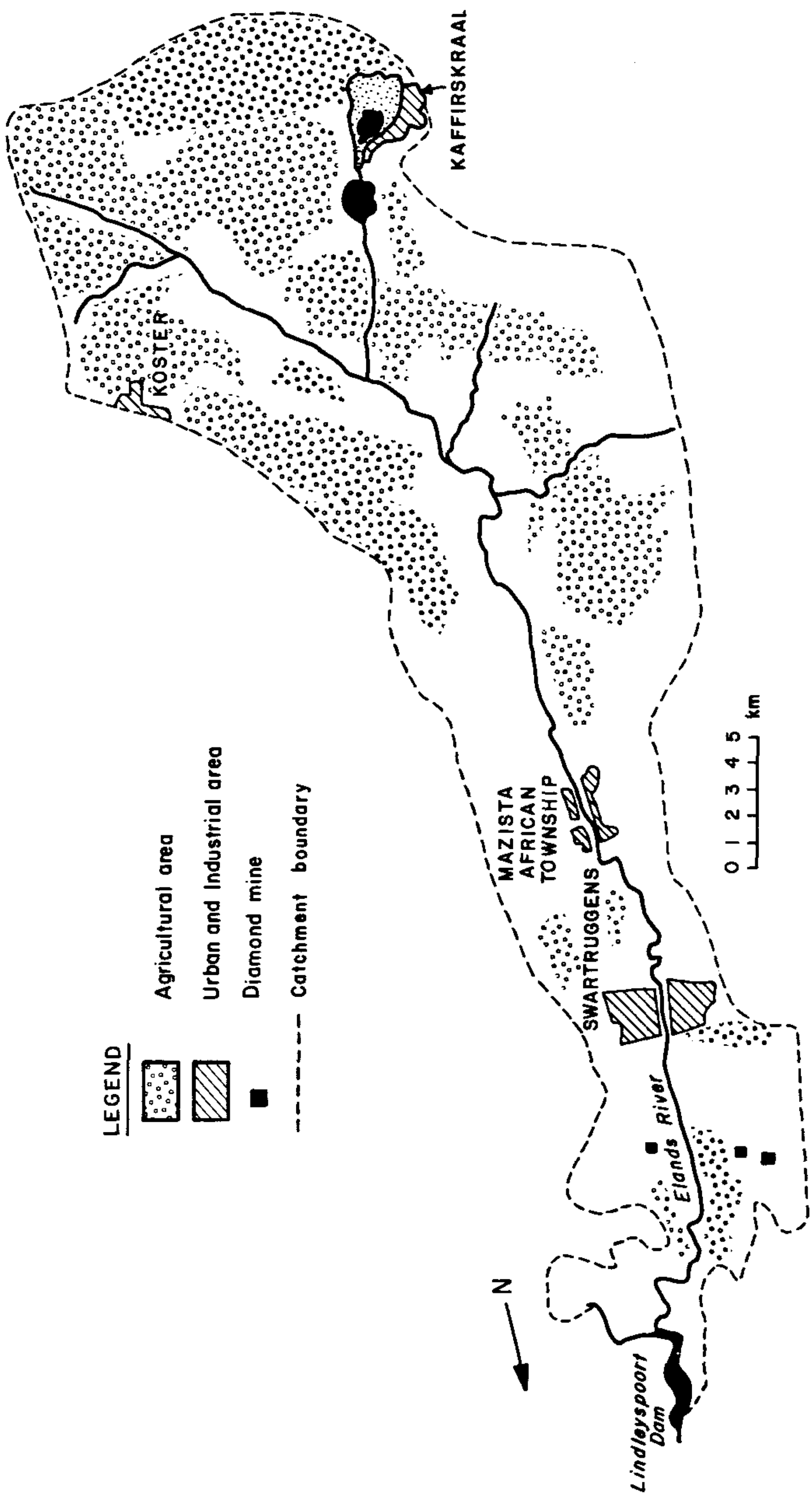


FIGURE 1. Lindleyspoort Dam catchment.

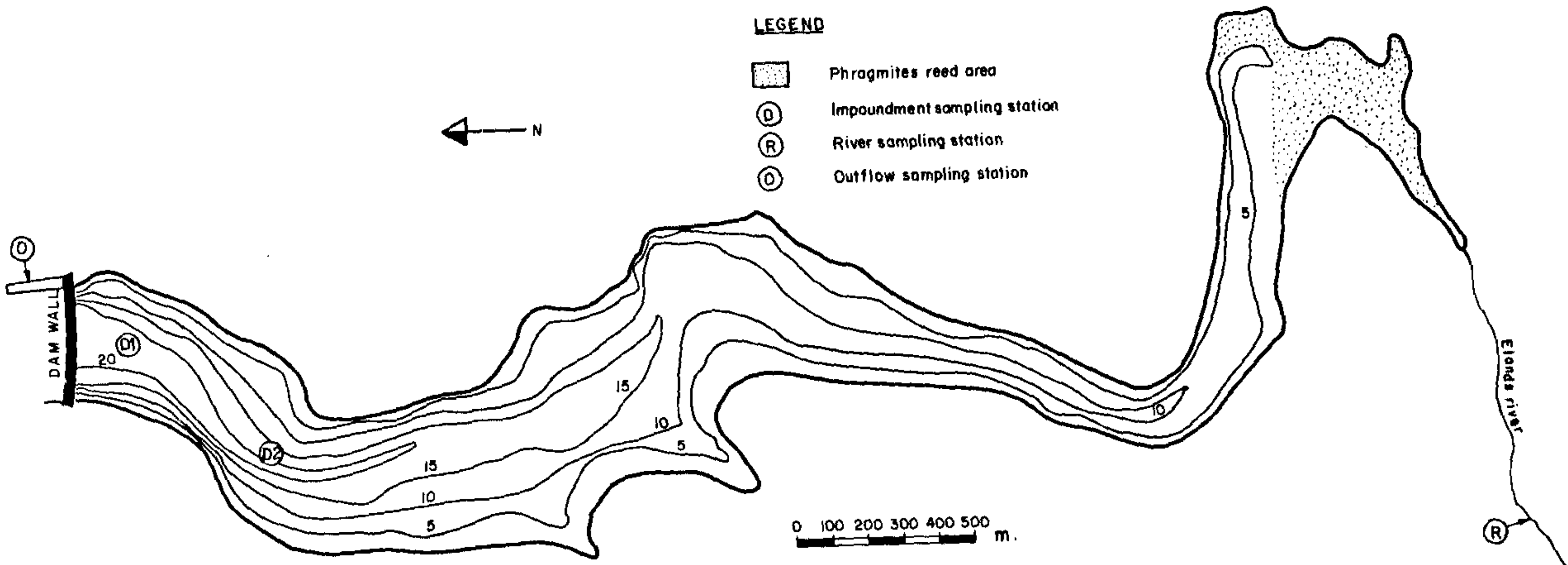


FIGURE 2. Map of Lindleyspoort Dam showing sampling stations.

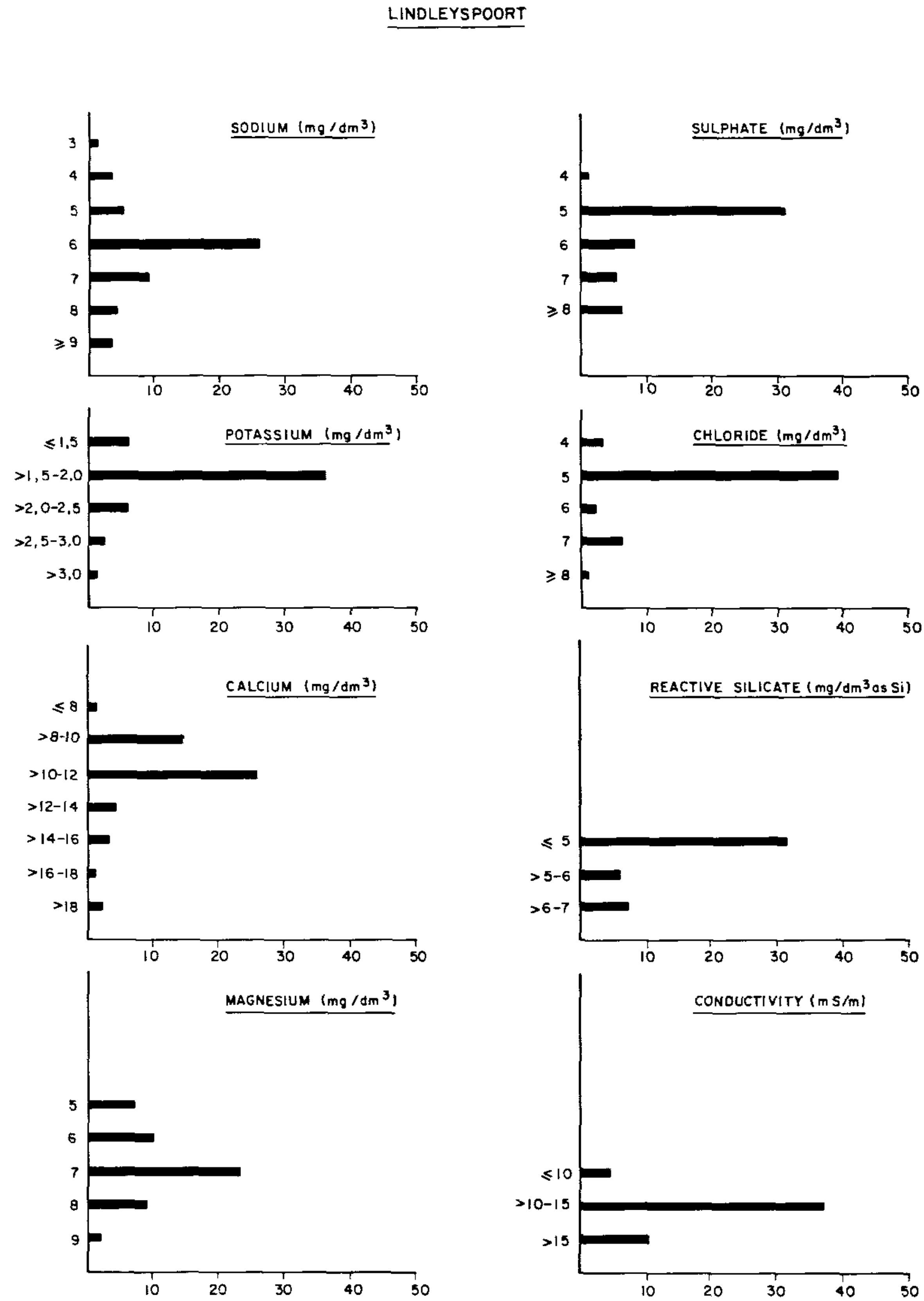
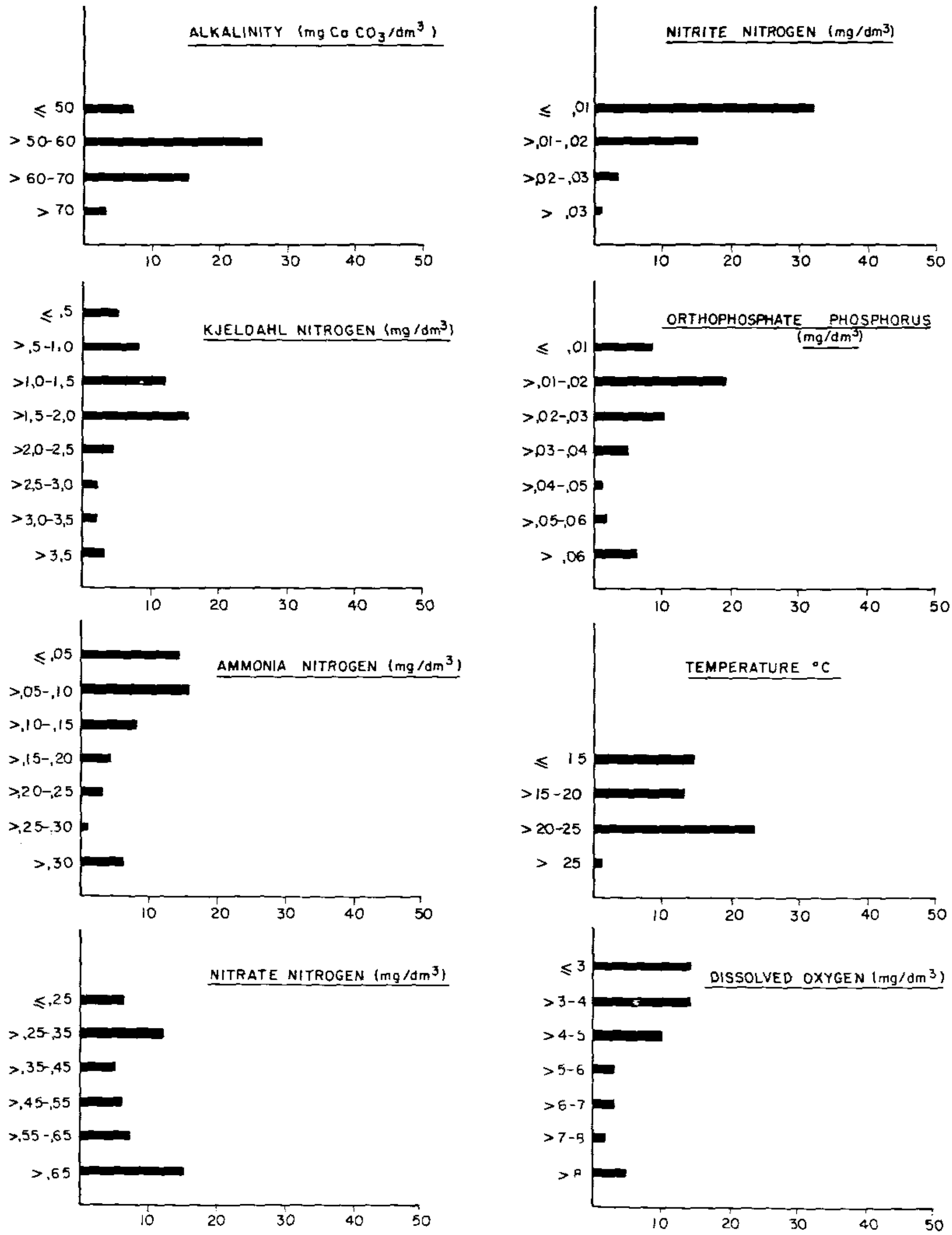


FIGURE 3. **Frequency histograms for selected parameters pertinent to the surface waters of Lindleyspoort Dam.**



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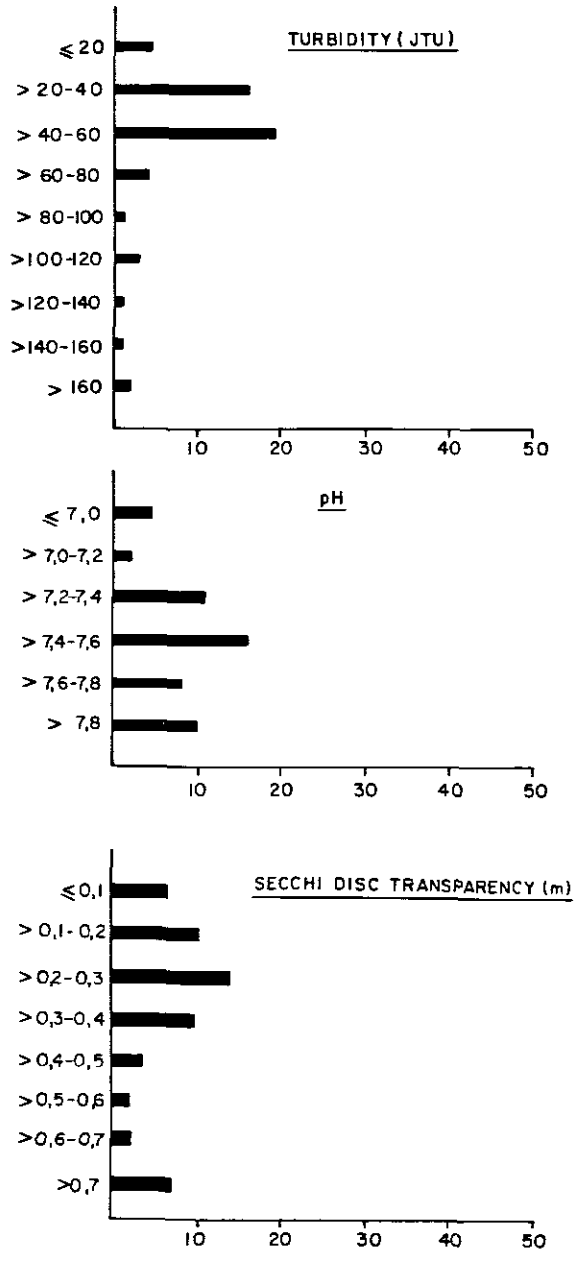

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Lindleyspoort Dam.

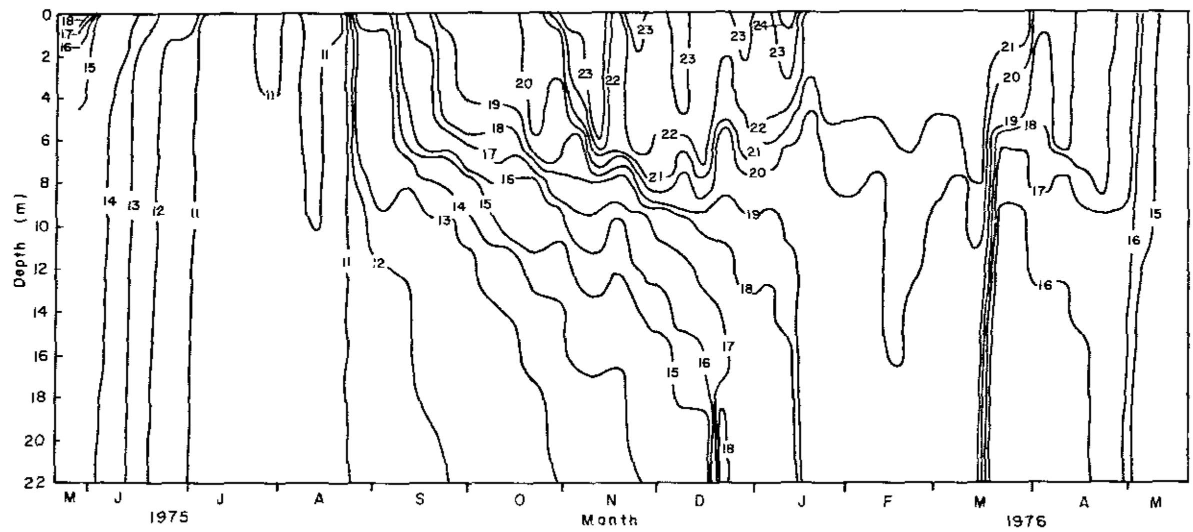

FIGURE 6. **Temperature distribution in Lindleyspoort Dam**

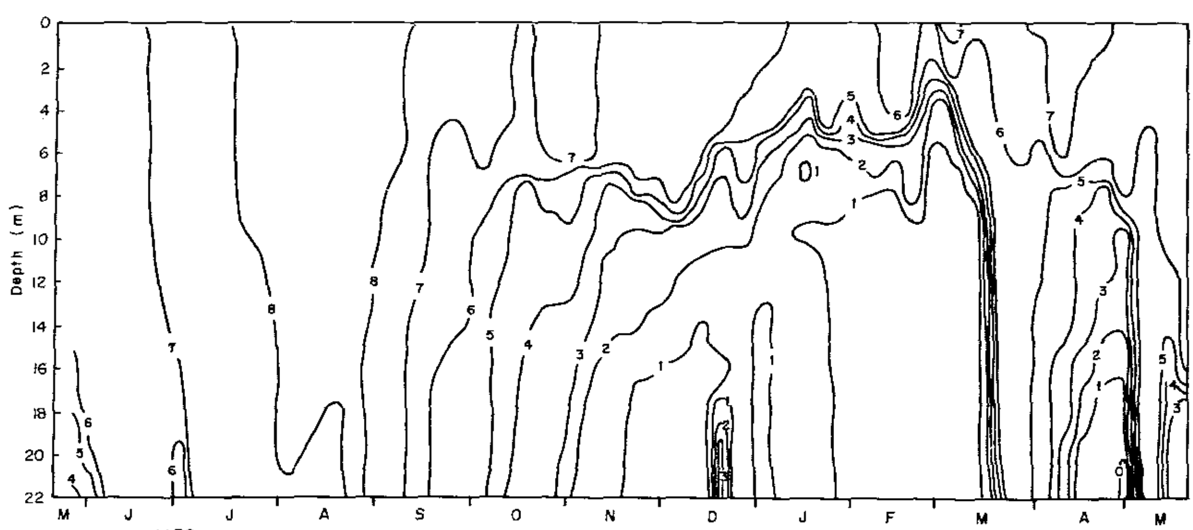

FIGURE 7. **Dissolved oxygen distribution in Lindleyspoort Dam**

LOSKOP DAM

by

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INTRODUCTION

Loskop Dam is an impoundment highly susceptible to water pollution from expanding towns, coal mines, power stations and other industries. Limnological information on the impoundment is limited. In an earlier study by Kruger *et al.* (1970) the zooplankton characteristics of the impoundment were investigated, and the impoundment was classified as eutrophic. A later survey, based on algal assays, established that the impoundment was mesotrophic and indicated that phosphorus was the limiting element for algal growth (Toerien, Hyman and Bruwer (1975)). Schutte and Bosman (1973) found that the system displayed hypolimnetic deoxygenation during summer stratification. This report presents limnological data collected between 1977 and 1978 and discusses their significance with respect to conditions in the impoundment.

DESCRIPTION OF THE AREA

Loskop Dam is situated in the Groblersdal magisterial district approximately 200 km north-east of Pretoria. Characteristics of the impoundment and its catchment are presented in Figure 1 and Table 1. The catchment is extremely large (12 285 km^2) and contains several other impoundments, namely Bronkhorstspruit and New Doringpoort (this series). The catchment is an important agricultural area with approximately one-third being cultivated (Fig. 1). Uncultivated areas consist of mixed bushveld, sourish mixed bushveld and Bankenveld (Acocks, 1975). Urban and industrial development is also extensive with the Witbank-Middelburg area and numerous coal mines being situated in the middle of the catchment.

The impoundment has one source of inflow, the Olifants River, which in turn has two tributaries, the Wilge and the Klein Olifants rivers. Prior to entering the impoundment, the Olifants River passes through a 10 km long gorge and here the river meanders considerably. Loskop Dam is a channel type impoundment, which is unusual in the sense that the dam wall is not situated at the opposite end of the impoundment, but sited along the northern shoreline (Fig. 2).

At present the impoundment is utilized mainly as an irrigation supply but the Department of Nature Conservation has a holiday resort on the north-eastern shore. It has been estimated that approximately 250 000 people visit this resort every year. The perimeter of the impoundment is contained within a nature reserve in which visitors are not allowed.

A summary of medium-term hydrological characteristics of the impoundment is presented in Table 2. Over the ten years 1968 to 1978 Loskop Dam experienced variable hydrological conditions. The water content fluctuated widely resulting in decreases in area and mean depth. The lower variation of outflow by comparison with inflow can be attributed to the heavy demand for irrigation water from the impoundment. The mean water retention time (0,5 years) can be considered to be fairly short by comparison with other large impoundments (e.g. Hartbeespoort where the retention time is ~ 1 year).

RESULTS AND DISCUSSION

Hydrological characteristics for the impoundment during the study year showed that the mean water content was more or less similar to that of the medium-term mean (Table 3). However, inflow was much higher than average indicating that when the impoundment was full, considerable quantities of water entered the impoundment. Consequently, the mean water retention time for the study period was lower than the average (0,36 years).

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Physical and chemical characteristics of the impoundment and the Olifants River inflow are summarized in Table 4. The water of the Olifants River is characterized by a fairly high sulphate content. This is possibly a reflection of drainage from mining areas in the catchment. Serious acid pollution with resultant higher sulphate concentrations and water transparency were observed during the early 1960's (Gieskes, 1960; Allanson, 1962; Botha *et al.*, 1966), but these problems were alleviated when the sources were identified and remedial action taken. Frequency histograms for certain individual limnological characteristics of the impoundment's surface waters are presented in Figures 3, 4 and 5.

The nutrient content of the waters cannot be considered as being high when compared with sewage polluted systems such as Bospoort and Roodeplaat (Butty, Walmsley and Alexander; Pieterse and Bruwer — this document). Nutrient loading rates into the system were 0,85 1,93 11,68 and 21,38 $g.m^{-2}.a^{-1}$ for orthophosphate, total phosphate phosphorus, inorganic nitrogen and total nitrogen respectively (Table 5). Nevertheless, phytoplankton standing crops in the impoundment were generally high (mean chlorophyll concentration of 11,0 $\mu g/dm^3$ — Table 5). The frequency histogram for chlorophyll indicates that values higher than 30 $\mu g/dm^3$ were recorded twice during the year. On these occasions the phytoplankton were therefore at bloom proportions and can be considered as representing a nuisance condition. Dominant algae during such population peaks were *Microcystis aeruginosa* and *Ceratium hirundinella.*

Water transparency in the impoundment ranged between 0,3 and 2,0 m and the mean value was 0,8 m (Table 5). The impoundment can therefore be considered as being of medium transparency by comparison with clearer and more turbid impoundments (e.g. Buffelspoort and New Doringpoort respectively — this document).

The ratio of inorganic nitrogen:orthophosphate phosphorus in the inflowing waters (~ 14:1) suggests a system where, nutrient-wise, algal growth is limited by phosphate. This agrees with the conclusions of Toerien *et al.* (1975) from algal bioassay studies.

The impoundment showed a thermal cycle which is typical of Transvaal impoundments, in that during winter isothermal conditions were encountered whilst in early summer thermal layering was prominent (Fig. 6). A pronounced thermocline was observed between 8 and 14 m from October 1977 to mid-January 1978. Thereafter floods penetrated the impoundment, and, although the water column remained stratified, no clear demarcation into the classical epi-, meta- and hypolimnion could be discerned. Overturn occurred at the end of April 1978. Dissolved oxygen followed a similar seasonal pattern to that of temperature in that during winter, oxygen distribution over the water column was almost uniform whereas in summer an oxygen minima was associated with the thermocline (Fig. 7). Anaerobic conditions in the bottom layers were recorded in December 1977, but with the advent of the summer floods in early January slight reoxygenation occurred, obviously as a consequence of density current flow in the bottom waters. Anaerobic conditions redeveloped, but these were again affected by flood waters at the end of January 1978 and again in February 1978. Overturn at the end of April 1978 resulted in an increased oxygen content over the water column.

Loskop Dam may be classified as a eutrophic system on the basis of the algal standing crops found in the surface waters. At present the water quality is compatible with usage, but careful consideration should be given to future development in the catchment since the impoundment is in an extremely sensitive position with regards to pollution by sewage and industrial effluents.

ACKNOWLEDGEMENTS

The help of Mrs A. Engelbrecht, Mr P.A. Joubert, Miss M. Pistorius and Mrs K. van Niekerk with the data collection and processing is gratefully acknowledged. Hydrological data were compiled from records of the Department of Water Affairs and the chemical analyses were done by the Chemical Division of the National Institute for Water Research. We also thank the Department of Nature Conservation who granted permission to enter the dam and nature reserve.

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TABLE 1. Characteristics of Loskop Dam and its catchment

Geographical location	25 ° 25'S; 29 ° 21,25'E
Magisterial district	Groblersdal
Catchment type	Agricultural, urban, mines
Usage of dam	Irrigation
Catchment area	12 285 km²
Inflowing river	Olifants
Dam wall completed	1937
*F.S.L. volume	180 x 10^6 m³
F.S.L. area	16,9 km²
F.S.L. maximum depth	36 m
F.S.L. mean depth	10,7 m

*F.S.L. = full supply level

TABLE 2. Average hydrological characteristics of Loskop Dam

	*Average mean	*C.V.
Volume x 10^6 m³	141,6	31,84
Area km²	14,44	19,53
Mean depth m	9,45	16,73
Annual inflow x 10^6 m³	304,5	104,3
Annual outflow x 10^6 m³	282,8	83,9
Retention time a	0,50	—

*Average mean is based on monthly values and an annual cycle:
Period: August to July (1968 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Loskop Dam (August 1977 – July 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m³	176,3	88,6	144,0	22,9	1,7
Area km²	16,53	11,57	14,74	13,2	2,1
Mean depth m					
Monthly inflow x 10^6 m³	132,46	3,60	36,23	118,0	42,8
Monthly outflow x 10^6 m³	101,24	14,42	32,98	91,6	39,9

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers, the outflow and dam station on Loskop Dam. Values are based on fortnightly samples collected between August 1977 and July 1978.

PARAMETER	DAM STATION								OLIFANTS RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	8,0	24,0	13,2	38	8,0	20,0	14,5	26	8,0	42,0	16,6	55	8,0	27,0	14,1	43
K	2,0	4,0	3,0	17	2,0	4,0	3.0	21	2,0	6,0	3,2	28	2,0	4,0	3,2	18
Ca	8,0	16,0	11,9	18	10,0	16,0	13,2	12	10,0	27,0	14,6	31	7,0	16,0	12,0	21
Mg	5,0	14,0	6,8	26	6,0	10,0	7,2	15	6,0	10,0	7,3	17	5.0	9,0	6,8	16
SO_4	11,0	47,0	28,5	36	16,0	40,0	30,0	23	5,0	100,0	40,8	67	15,0	71,0	32,5	49
Cl	5,0	14,0	9,0	36	6,0	13,0	9,7	27	6,0	37,0	14,1	60	5,0	29,0	10,5	56
Cond	12,5	25,0	17,3	24	13,0	21,0	16,3	15	14,3	33,0	19,9	29	13,0	24,0	19,3	19
Alk	21,0	138,0	46	47	38,0	67,0	52,8	18	13,0	59.0	41,5	29	13,0	156,0	48,2	59
Tot Kj-N	0,090	0,800	0,436	43	0,240	1,190	0,612	45	0,120	1,275	0,695	48	0,180	1,200	0,592	51
Dis Kj-N	0,034	0,775	0,390	46	0,026	1,025	0,521	48	0,160	1,360	0,668	51	0,180	0,900	0,484	43
NH_4-N	0,010	0,202	0,070	60	0,030	0,800	0,280	76	0,030	1,20	0,218	132	0.002	0,700	0,146	107
NO_3-N	0,040	0,410	0,196	51	0,002	0,475	0,	87	0,162	1,9	0,600	81	0,100	1,3	0,151	87
NO_2-N	0,003	0,022	0,009	43	0,001	0,043	0,010	105	0,002	0,017	0,008	51	0,003	0,029	0,010	63
Tot P	0,002	0,118	0,044	70	0,011	0,235	0,051	90	0,006	0,170	0.051	75	0,006	0,114	0,043	76
Tot dis P	0,010	0,093	0,040	57	0,007	0,235	0,047	98	0,003	0,136	0,043	74	0,004	0,114	0,040	71
PO_4-P	0,002	0,054	0,017	86	0,006	0,179	0,027	127	0,002	0.102	0,018	121	0,002	0,097	0,018	113
Fe	0,025	1,730	0,587	73	0,028	1,080	0,538	56	0,094	1,980	0,500	102	0,025	0,200	0,546	74
Mn	0,025	0,170	0,035	92	0,025	2,110	0,645	99	0,025	0,120	0,041	68	0,025	0,200	0,062	101
Temp	13,5	28,0	21,63	23	10,80	21,00	16,53	19	12,00	30,00	19,17	45	14,00	26,00	21,39	18
DO	5,35	10,40	7,31	20	0,0	7,40	2,5	16,8								
Tu	3,6	32,0	15,2	55	4,6	53,0	23,4	47								
pH	6,22	9,16	8,11	8	6,68	8,15	7,39	4	7,02	8,56	7,70	6	7,02	8,32	7,66	5

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Loskop Dam (Aug. 1977 – Jul. 1978)

Mean depth m	9,6
Retention time a	0,36
Hydraulic load m/a	26,4
Surface loading rates g/m^2.a^{-1}	
PO_4-P	0,85
Total P	1,93
Inorganic nitrogen	11,68
Total nitrogen	21,38

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	38,0	3,0	11,0
Secchi depth m	2,0	0,3	0,8

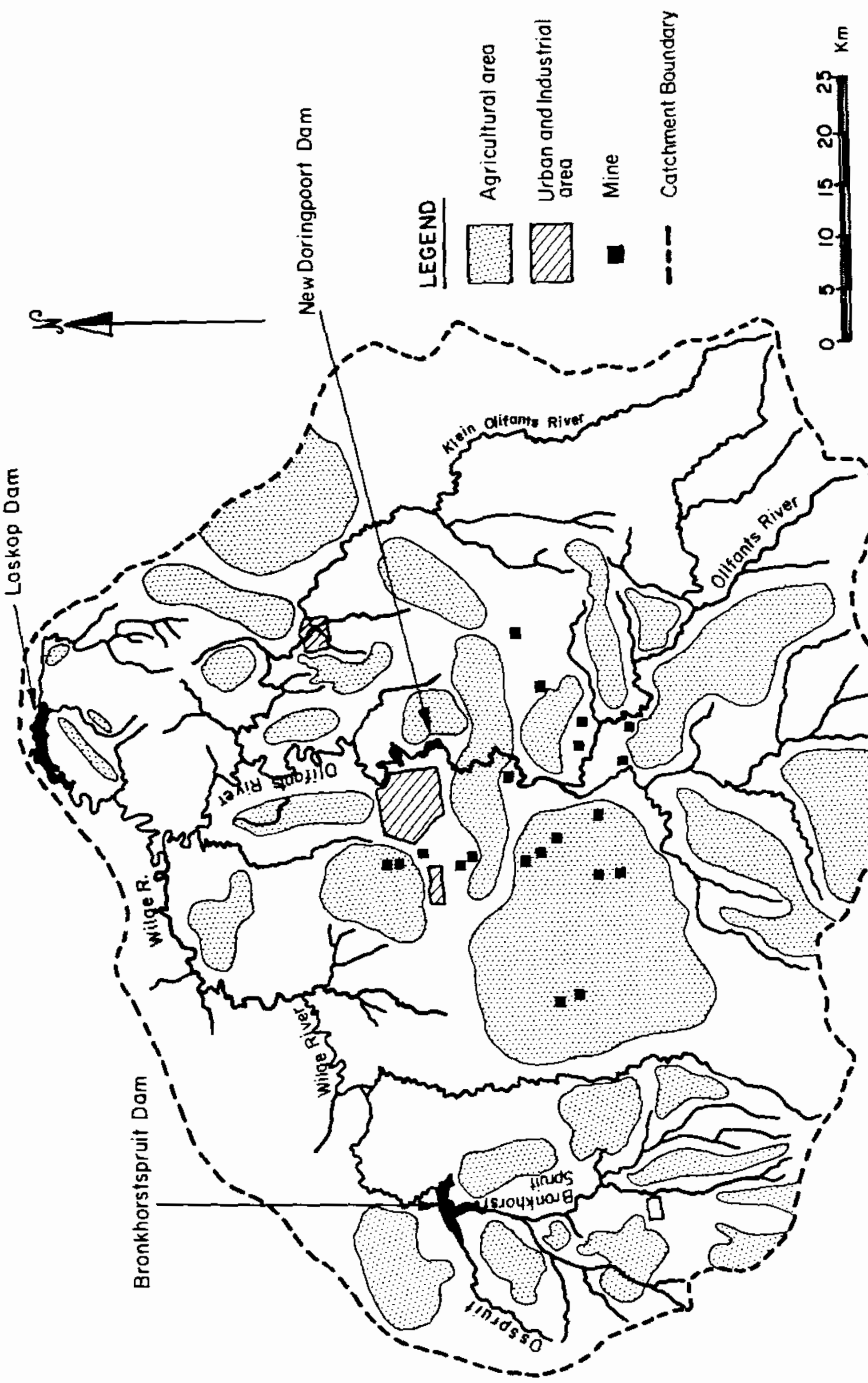


FIGURE 1. Loskop Dam catchment.

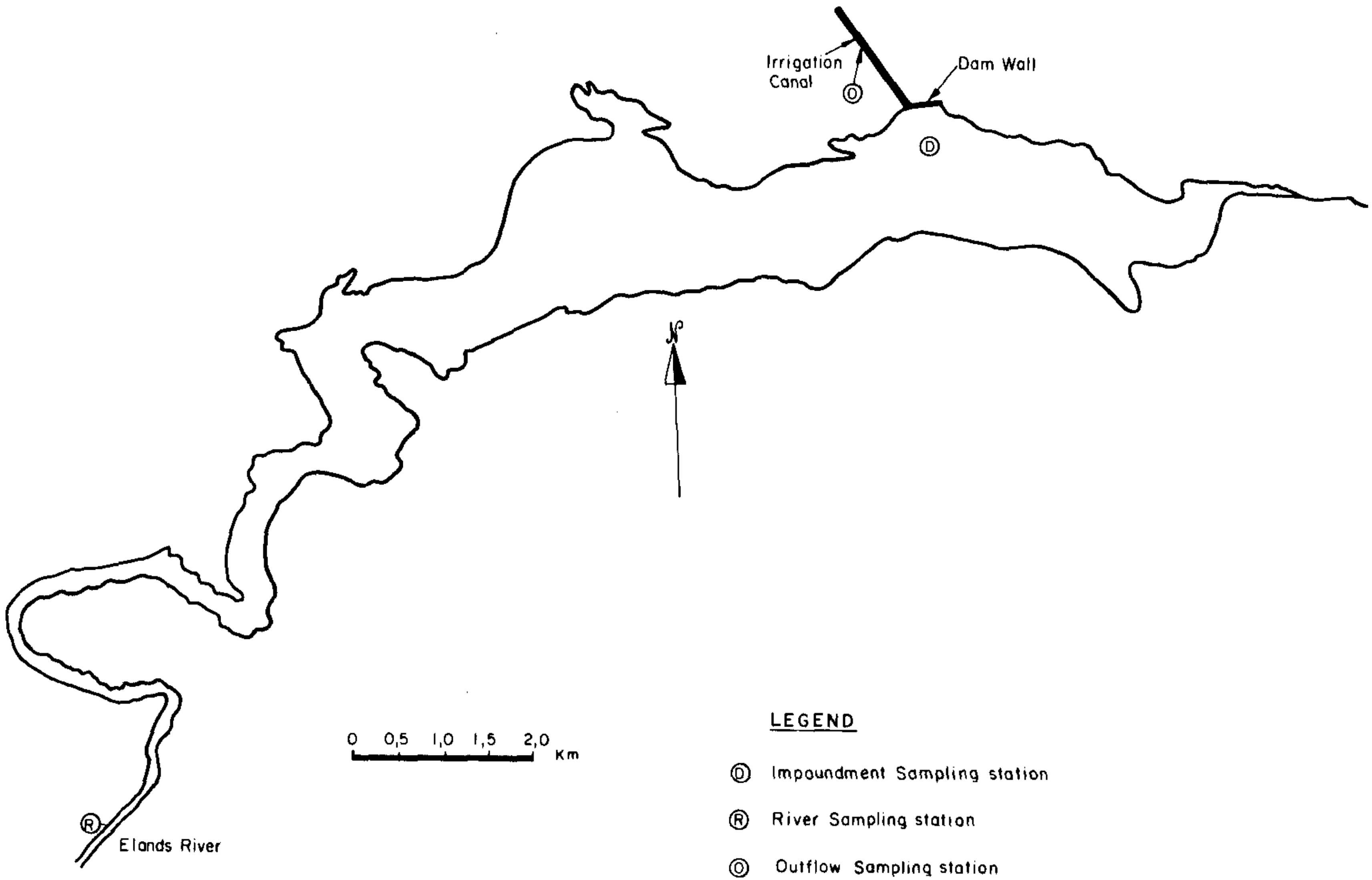


FIGURE 2. Map of Loskop Dam showing sampling stations.

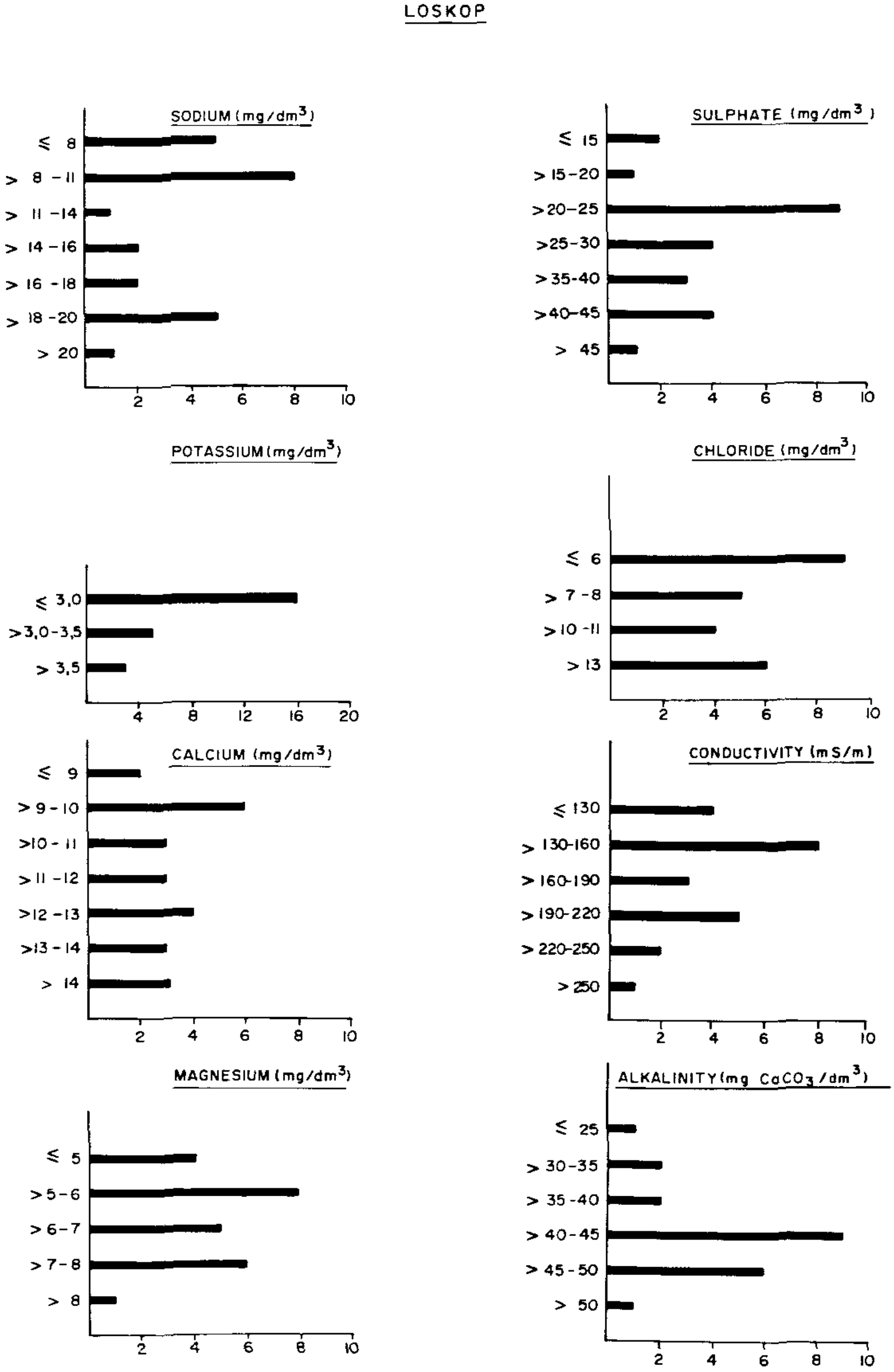
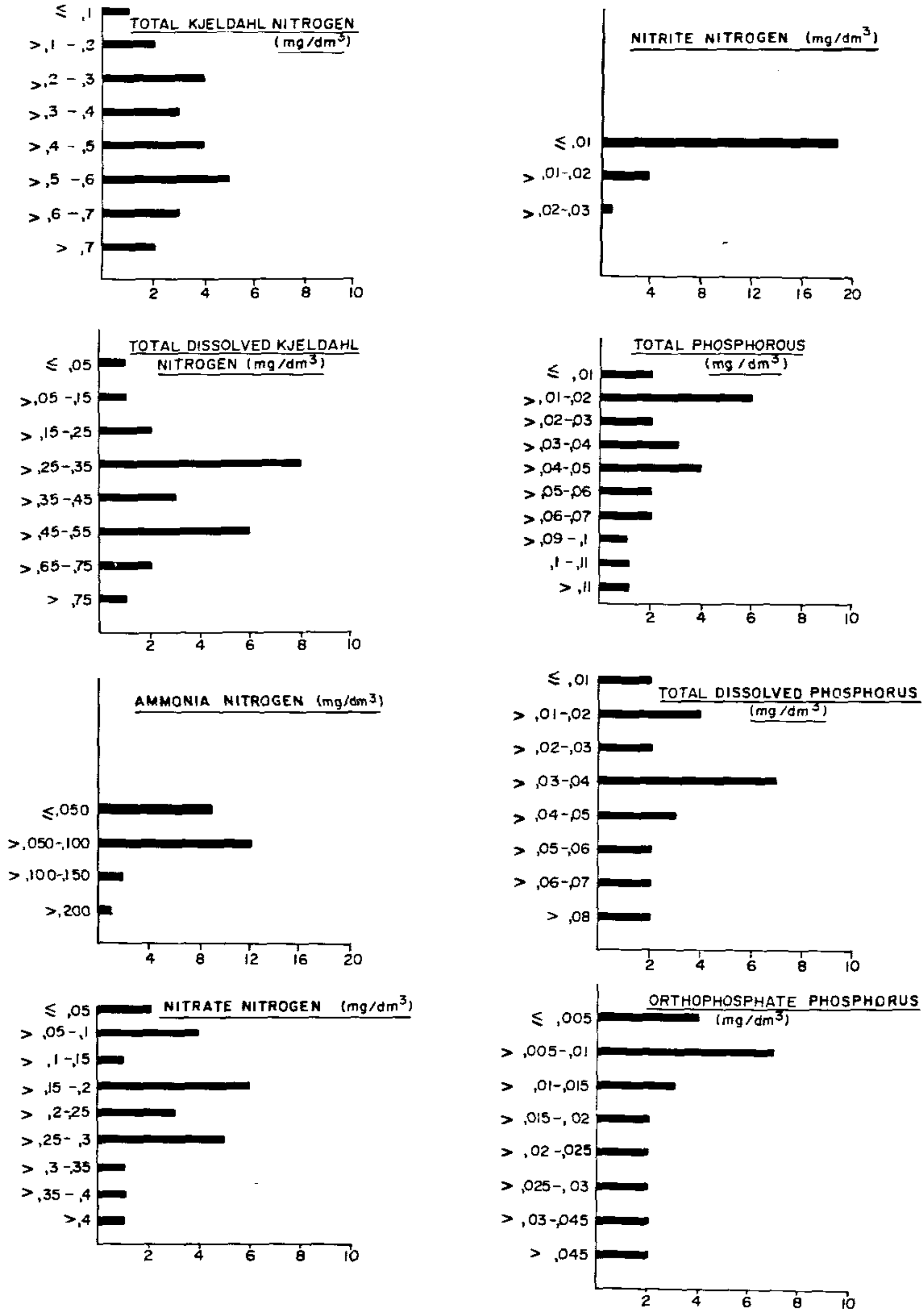


FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Loskop Dam.

LOSKOP



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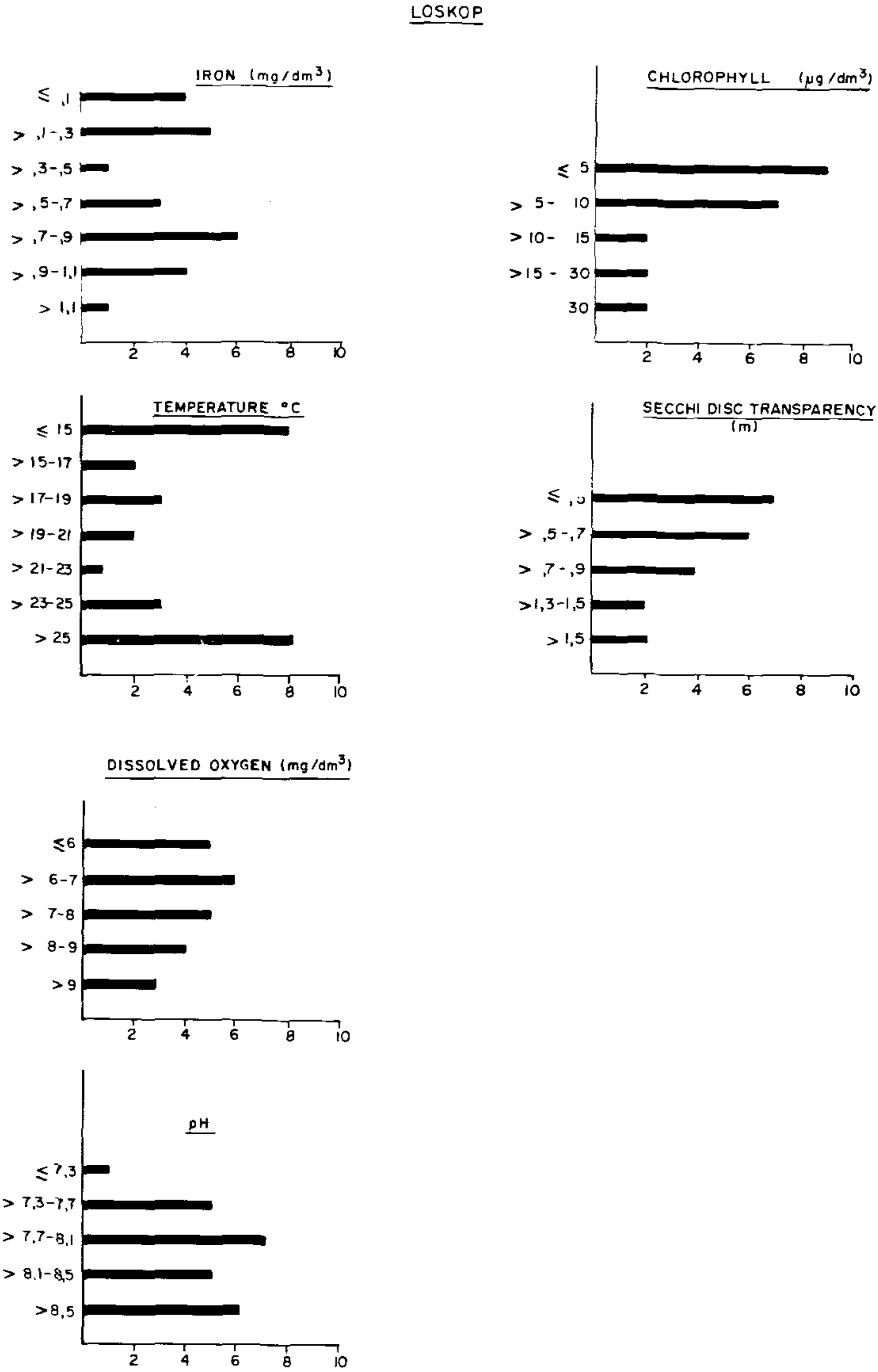

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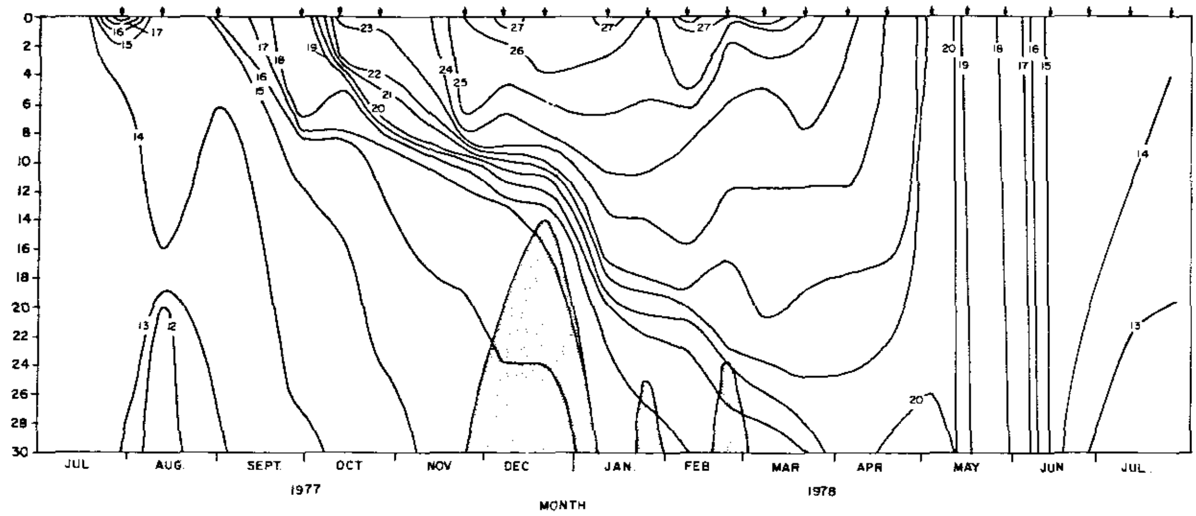

FIGURE 6. Temperature distribution in Loskop Dam (shaded area indicates anaerobic zone).

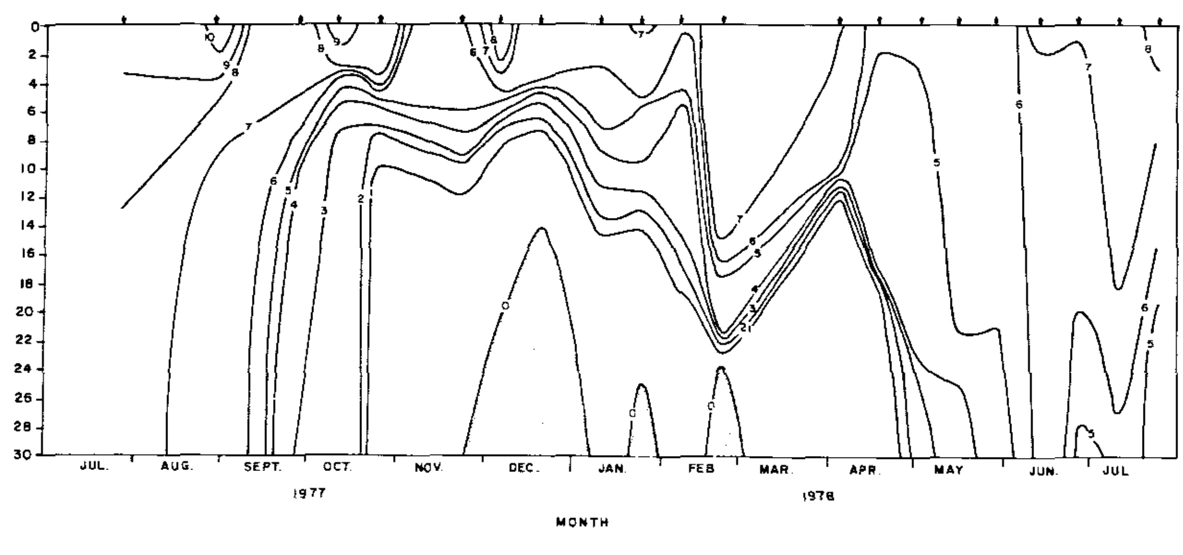

FIGURE 7. Dissolved oxygen distribution in Loskop Dam (shaded area indicates anaerobic zone).

OLIFANTSNEK DAM

by

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INTRODUCTION

Olifantsnek Dam is an impoundment which has not been studied previously. The impoundment is privately owned by the Olifantsnek Water Board and utilized to irrigate small citrus orchards. This report presents data collected from this impoundment during a limnological survey between August 1977 and July 1978.

DESCRIPTION OF THE AREA

Olifantsnek Dam is situated in the Magalies mountain range in the western Transvaal, approximately 15 km south of Rustenburg. Characteristics of the impoundment and its catchment are presented in Table 1 and Figure 1. The catchment is rural with no urban or industrial development. Approximately 20 % of the area comprises cultivated land whilst the remainder is a mixture of Bankenveld and sourish mixed bushveld (Acocks, 1975). The impoundment has two inflowing streams, namely the Rooikloofspruit and the Hex River. Although the water in the impoundment is mainly utilized for irrigation of citrus orchards, a certain amount of angling also occurs. Sampling points on the impoundment are shown in Figure 2. The basin of the impoundment is fairly shallow, having a maximum depth of 13,6 m and a mean depth of 5,5 m.

Medium-term hydrological data for the impoundment between 1968 and 1978 (Table 2) indicate that the system has a low retention time (0,40 a) which means that on the average the water body is flushed approximately 2,5 times per annum. The water content has shown considerable variation over the past ten years (50 % variation).

RESULTS AND DISCUSSION

Hydrological characteristics of the impoundment for the study year are presented in Table 3. Water inflow over this period was far greater than the average (119 %) and consequently the mean water retention time of 0,23 years indicates that the system was flushed approximately 4 times per year. During the rainy season a maximum monthly inflow of 20,032 x 10^6 m^3 was recorded whereas in the dry winter season the minimum inflow was 0,119 x 10^6 m^3. This indicates that the system experienced little disturbance from inflow during the winter, but obviously flooding occurred during the summer.

During the study period, a tributary of the Hex River, the Skoonkloofspruit, was inadvertently sampled instead of the Hex River. Consequently no data were obtained for the Hex River during the study period. To ascertain whether there were any major differences between these tributaries, additional sampling of the Skoonkloofspruit, the Rooikloofspruit and the Hex River was conducted during December 1978 and January 1979. The characteristics of inflowing, outflowing and impounded waters are presented in Tables 4 and 5. Frequency histograms for individual characteristics monitored at the impoundment station are shown in Figures 3 to 5. The levels of anions and cations in the inflowing waters are typical of those encountered in unpolluted waters for this area (Toerien and Walmsley, 1978).

The data collected during December 1978 and January 1979 show that there were differences between the three river systems sampled (Table 5). However, phosphate characteristics were similar and consequently nutrient loading characteristics were calculated by using the data obtained for the Skoonkloofspruit.

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Nitrate levels in the waters of the impoundment were high, possibly due to fertilizer runoff from the catchment. The nutrient loading rates for the impoundment show that orthophosphate phosphorus loading was low by comparison with the nitrogen loading (Table 6).

Olifantsnek Dam can be considered a turbid impoundment since the mean Secchi depth was only 0,33 m (Table 6). Algal standing crops, as measured by chlorophyll *a*, never exceeded 6 $\mu g/dm^3$ (Table 6). The regulating effect of low turbidity on algal growth in this impoundment is not as obvious as in other impoundments (Laing and Bridle Drift dams — this document) because of the low phosphate levels.

The temperature and oxygen distributions in the water column with time are presented in Figures 6 and 7. The impoundment is obviously one which is too shallow to exhibit stable stratification during summer. The maximum temperature gradient over the water column during summer was 3 °C. Dissolved oxygen levels were low in the bottom waters during summer but no anaerobic conditions were encountered (Fig. 7), the minimum concentration in the bottom waters being 1,3 mg/dm^3.

On the basis of the characteristics surveyed during the study period, Olifantsnek Dam can be classified as an oligotrophic-mesotrophic system. At present there are no water quality problems.

ACKNOWLEDGEMENTS

The help of Mrs A. Engelbrecht, Mr P.A. Joubert, Miss M. Pistorius and Mrs K. van Niekerk with the data collection and processing is gratefully acknowledged. Hydrological data were compiled from records of the Department of Water Affairs and the chemical analyses were done by the Chemical Division of the National Institute for Water Research.

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TOERIEN, D.F. and WALMSLEY, R.D. 1978 The dissolved mineral composition of the water flowing into and out of the Hartbeespoort Dam. *Water SA* 4, 25—38.

TABLE 1. Characteristics of Olifantsnek Dam and its catchment

Geographical location	25 ° 47' S; 27 ° 15,5'E
Magisterial district	Rustenburg
Catchment type	Rural
Usage of dam	Irrigation
Catchment area	563 km^2
Inflowing rivers	Hex, Rooikloofspruit
Dam wall completed	1929
*F.S.L. volume	14,2 x 10^6 m^3
F.S.L. area	2,56 km^2
F.S.L. maximum depth	13,6 m
F.S.L. mean depth	5,5 m

*F.S.L. = full supply level

TABLE 2. Average hydrological characteristics of Olifantsnek Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	8,637	51,34
Area km^2	1,84	34,87
Mean depth m	4,3	25,74
Annual inflow x 10^6 m^3	25,951	287,56
Annual outflow x 10^6 m^3	21,688	338,26
Retention time a	0,40	—

*Average mean is based on monthly values and an annual cycle
Period: August to July (1968 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of the monthly hydrological characteristics for Olifantsnek Dam

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	14,521	11,307	13,293	8,8	53
Area km^2	2,64	2,20	2,46	6,5	33
Mean depth m	5,5	5,1	5,3	2,6	23
Monthly inflow x 10^6 m^3	20,032	0,119	4,73	15,6	119
Monthly outflow x 10^6 m^3	18,704	0,365	4,591	146,2	154

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers, the outflow and dam station. Values are based on fortnightly samples collected between August 1977 and July 1978.

PARAMETER	DAM STATION								SKOONKLOOFSPRUIT				ROOIKLOOFSPRUIT				OUTFLOW			
	TOP				BOTTOM															
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	4,0	12,0	9,2	22	5,0	12,0	9,12	24	3,0	37,0	15,74	37	6,0	20,0	12,0	28	6,0	12,0	9,6	28
K	1,0	8,0	2,2	60	1,0	8,0	2,3	56	1,0	20,0	2,6	148	1,0	14,0	1,8	139	1,7	8,8	2,6	74
Ca	7,0	36,0	18,4	30	6,0	38,0	17,8	35	8,0	85,0	31,7	42	11,0	38,0	24,2	28	10,0	98,0	23,2	77
Mg	3,0	30,0	15,7	35	3,0	31,0	15,1	40	3,0	49,0	31,5	39	4,0	47,0	22,2	46	8,0	68,0	18,6	61
SO_4	5,0	18,0	11,08	31	6,0	16,0	11,6	31	10,0	26,0	20,1	23	12, 0	26,0	19,3	28	5,0	20,0	11,6	28
Cl	5,0	10,0	5,3	20	5,0	6,0	5,0	4	5,0	8,0	6,2	16	5,0	10,0	6,1	22	5,0	7,0	5,1	9
Cond	16,0	42,0	23,6	2	10,5	40,5	20,8	3	12,0	52,0	33,0	3	13,5	48,0	26,9	3	17,9	26,0	21,5	1
Alk	44,0	156,0	110,0	28	32,0	156,0	104,0	35	38,0	284,0	179,0	37	76,0	232,0	142,0	29	35,0	160,0	117,0	29
Tot Kj-N	0,090	1,025	0,345	61	0,125	0,700	0,335	46	0,080	1,175	0,426	70	0,090	1,025	0,426	55	0,140	0,730	0,326	47
Dis Kj-N	0,060	0,750	0,306	60	0,100	0,640	0,308	45	0,034	0,960	0,395	64	0,080	0,875	0,380	46	0,110	0,900	0,348	59
NH_4-N	0,002	0,230	0,069	77	0,010	0,210	0,078	148	0,003	0,700	0,101	127	0,024	0,160	0,079	170	0,015	0,300	0,092	127
NO_3-N	0,100	8,500	0,701	223	0,010	7,700	0,682	207	0,005	9,40	1,768	103	0,110	0,960	0,380	53	0,007	0,900	0,411	50
NO_2-N	0,002	0,100	0,015	244	0,003	0,043	0,011	88	0,004	0,066	0,021	91	0,003	0,051	0,012	115	0,003	0,100	0,015	138
Tot P	0,006	0,125	0,049	71	0,010	0,521	0,074	139	0,005	0,128	0,044	79	0,004	0,145	0,039	82	0,012	0,175	0,052	85
Tot dis P	0,004	0,100	0,040	74	0,003	0,130	0,048	74	0,002	0,080	0,027	81	0,003	0,075	0,029	69	0,006	0,135	0,044	84
PO_4-P	0,002	0,068	0,016	94	0,002	0,082	0,018	91	0,002	0,036	0,010	74	0,002	0,039	0,010	85	0,002	0,094	0,018	113
Fe	0,008	1,030	0,354	71	0,044	1,400	0,491	73	0,025	0,770	0,174	138	0,054	0,930	0,448	62	0,028	2,800	0,503	120
Mn	0,025	0,045	0,027	18	0,025	0,720	0,063	222	0,025	0,095	0,039	57	0,025	0,095	0,037	48	0,025	0,800	0,092	187
Temp	10,5	25,0	18,9	27	9,2	22,0	17,3	27	8,0	25,6	17,2	30	8,0	23,0	16,6	30	10,5	20,0	15,3	25
DO	5,3	9,4	7,5	14	0	9,11	4,3	76												
Tu	14,0	74,0	37,4	57	20,0	145,0	70,2	62												
pH	6,84	8,80	8,0	4	6,66	8,8	7,8	5	7,12	8,60	7,85	4	7,22	8,48	7,87	3	6,9	8,1	7,7	5

*C.V. = coefficient of variation

TABLE 5. Mean values in mg/dm^3 of the main chemical constituents in the Hex River, Skoonkloofspruit and Rooikloofspruit, December 1978 to January 1979

Constituent	Hex River	Skoonkloof-spruit	Rooikloof-spruit
PO_4-P	0,011	0,012	0,029
Total dissolved P	0,350	0,290	0,270
Total P	0,230	0,230	0,220
Inorganic N	1,2	2,9	0,5
Ammonia	0,057	0,13	0,08
Total Kjeldahl	1,5	1,1	1,0
Total dissolved Kjeldahl	0,8	0,9	0,8
Na	17,0	15,0	16,0
K	1,0	1,35	1,25
Mg	28,0	37,0	30,0
Ca	29,0	28,0	34,0
Cl^-	6,0	8,0	6,0
SO_4^{2-}	17,0	22,0	24,0
Akalinity	220,0	270,0	190,0

TABLE 6. Hydrological characteristics, key-nutrient loading rates, chlorophyll a and water transparency characteristics of Olifantsnek Dam (Aug. 1977 – Jul. 1978)

Mean depth m		5,4	
Retention time a		0,23	
Hydraulic load m/a		23,5	
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P		0,18	
Total P		0,86	
Inorganic nitrogen		14,82	
Total nitrogen		24,27	

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	6,0	2,0	3,0
Secchi depth m	0,90	0,10	0,30

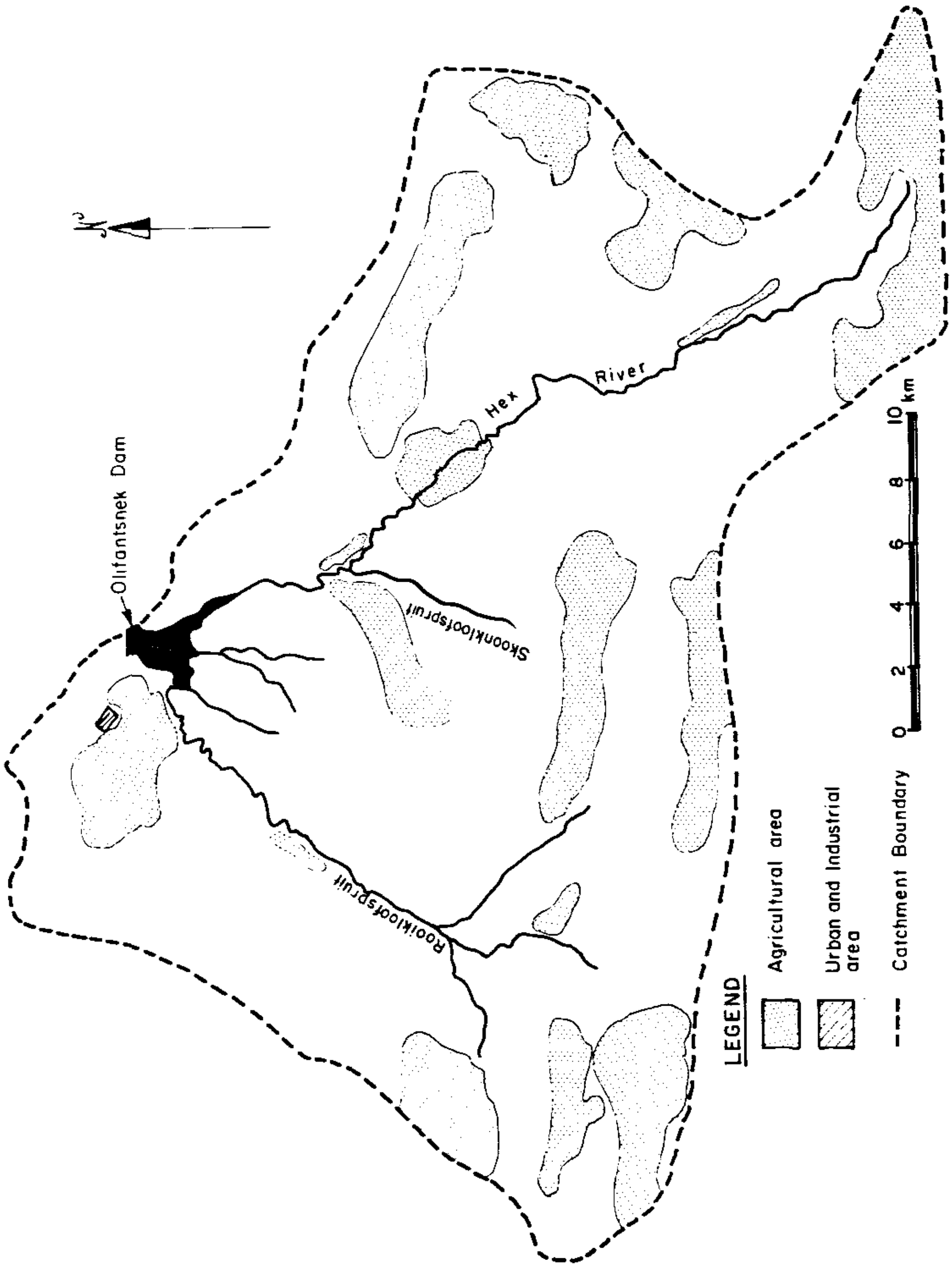

FIGURE 1. Olifantsnek Dam catchment.

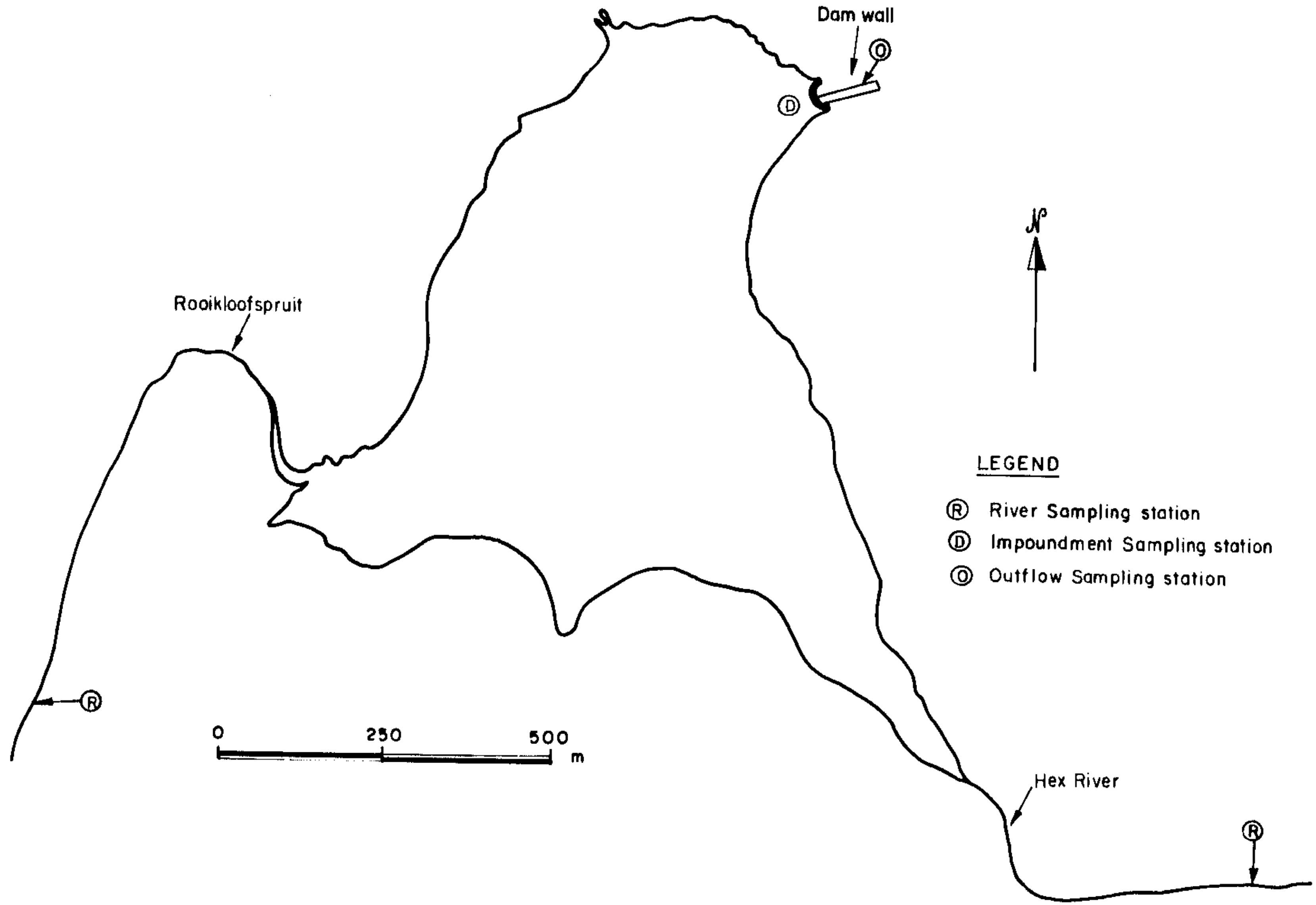

FIGURE 2. Map of Olifantsnek Dam showing sampling stations.

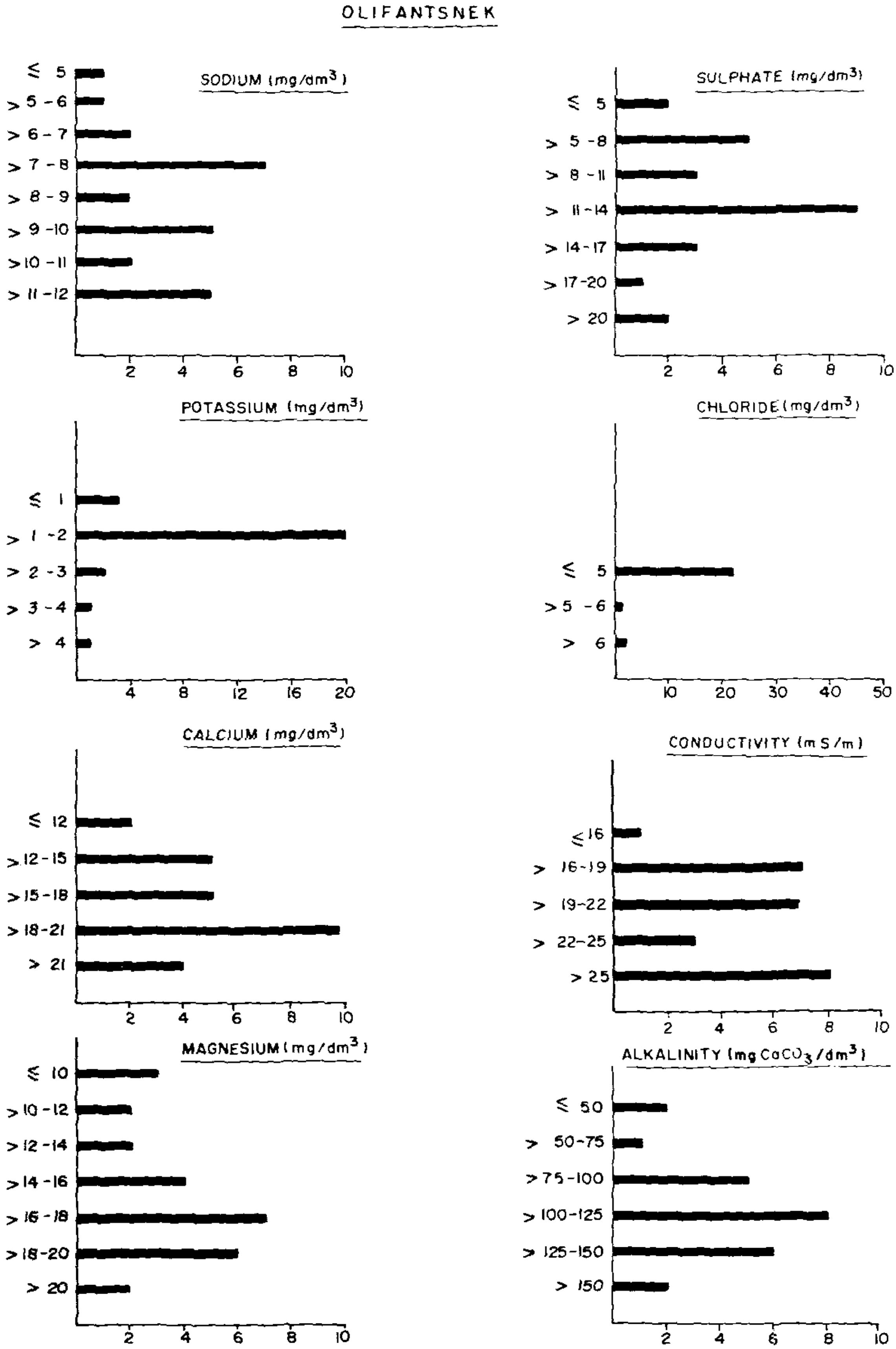

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Olifantsnek Dam.

OLIFANTSNEK

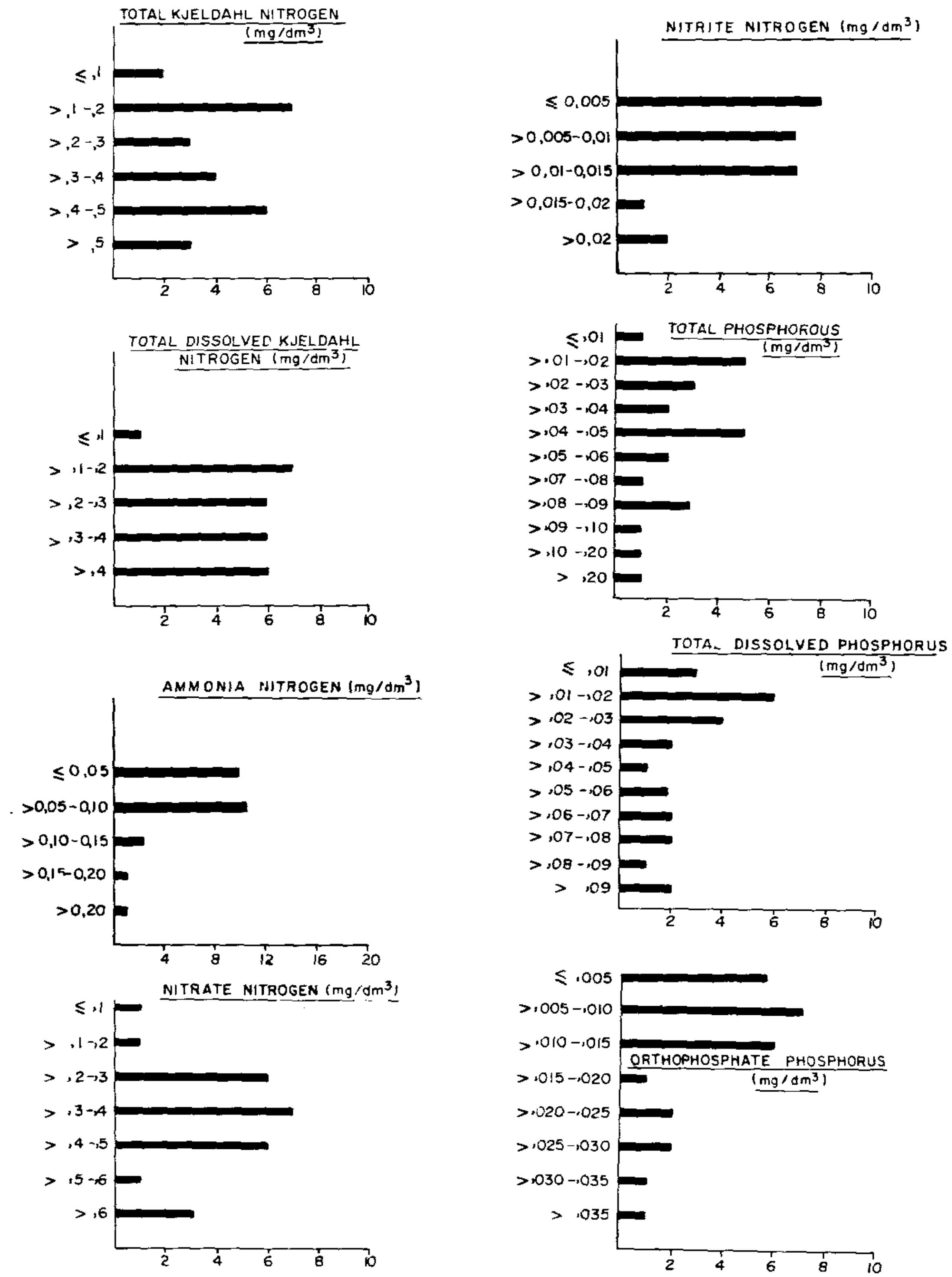

FIGURE 4. **Frequency histograms for selected parameters pertinent to the surface waters of Olifantsnek Dam.**

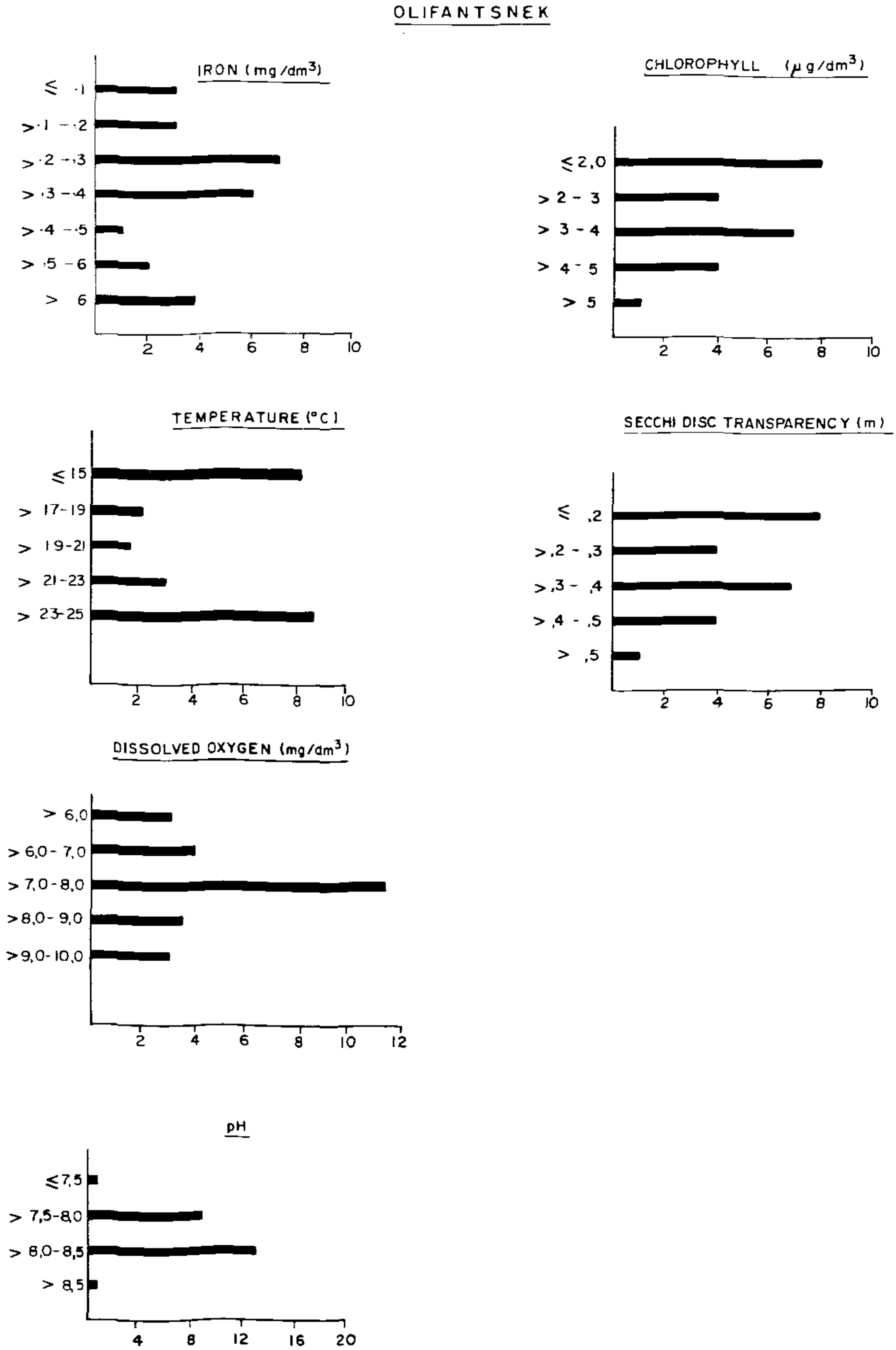

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Olifantsnek Dam.

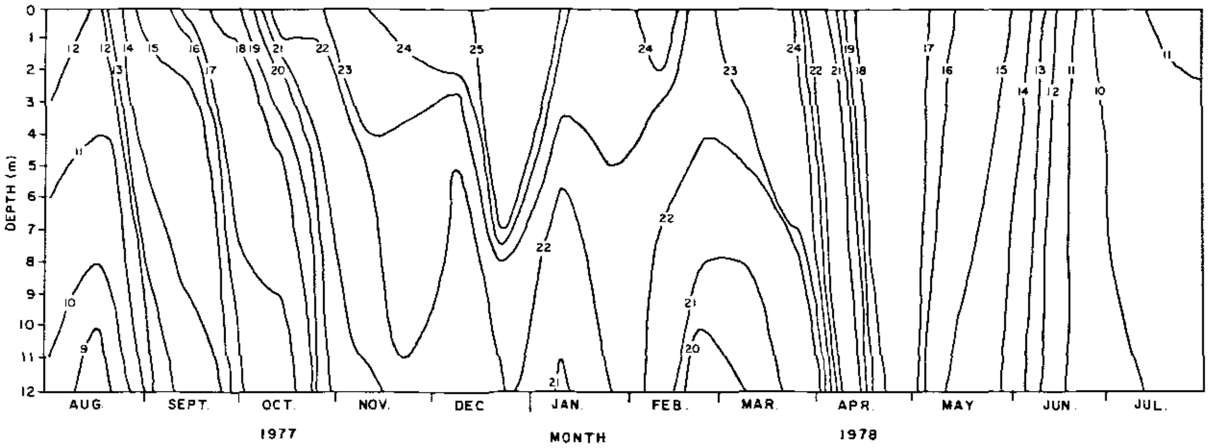

FIGURE 6. Temperature distribution in Olifantsnek Dam

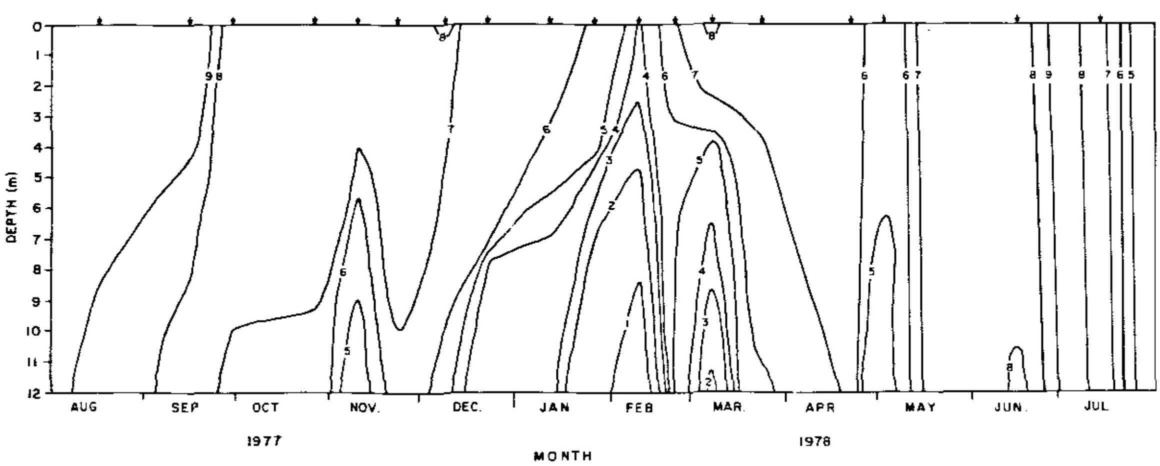

FIGURE 7. Dissolved oxygen distribution in Olifantsnek Dam

RUST DER WINTER DAM

by

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INTRODUCTION

The Rust der Winter Dam has not been the subject of any detailed limnological study. However, it has been included in two surveys, viz. that of Schutte and Bosman (1973) who investigated the physico-chemical characteristics of some 60 South African impoundments and that of Toerien *et al.* (1975) who used an algal assay procedure to classify 98 South African impoundments. Schutte and Bosman (1973) reported that the impoundment experienced oxygen depletion at the sediment-water interface whilst Toerien *et al.* (1975) classified the impoundment as being in a mesotrophic condition on the basis of its algal growth potential (AGP) (32,5 mg/dm^3). This report presents the results of a more detailed limnological investigation of the impoundment during 1977 and 1978.

DESCRIPTION OF THE AREA

Rust der Winter Dam is situated approximately 90 km north of Pretoria. Characteristics of the impoundment and its catchment are shown in Table 1 and Figure 1. The catchment is fairly large (1 147 km^2) and contains little urban or industrial development. Agricultural activity is restricted to an area close to Zonderwater and to farms near the impoundment itself. The greatest proportion of the catchment is undeveloped bushveld which is utilized for cattle ranching. Most of the area surrounding the dam is contained within a nature reserve administered by the Parks Board.

The impoundment has one source of inflow, the Elands River, which flows in a northerly direction. Morphometrically, the impoundment can be divided into two basins, a wide shallow western basin and a narrow deeper eastern basin which leads up to the dam wall (Fig. 2). The impoundment was constructed to provide irrigation water to vegetable farms below the dam, but has in recent years become a popular recreational area for fishing and boating.

Average hydrological characteristics of the impoundment between 1968 and 1978 are presented in Table 2. The impoundment experienced considerable fluctuation in inflow over this period (coefficient of variation ~ 150 %) and the mean annual runoff is obviously higher than the volume of the impoundment. This has resulted in a system where the mean water retention time is low (0,32 years) and which is probably flushed at least three times per annum.

RESULTS AND DISCUSSION

Hydrological characteristics for the study year (Table 3) indicated that the impoundment experienced higher inflow than average (~ 25 %). Consequently, the mean water retention time was lower than normal (0,29 years) and the system was flushed approximately 3,5 times during the study period. During the summer rainy months high inflows were experienced, as indicated by monthly inflow volumes which exceeded the full supply capacity of the impoundment (Table 3).

Chemical characteristics of the inflowing, impounded waters and outflow are summarized in Table 4. Frequency histograms for limnological characteristics of the surface waters in the impoundment are shown in Figures 3 to 5. Chemically the impoundment has changed very little since the time of the survey by Schutte and Bosman (1973). The values found in this system give the overall impression of an unpolluted system. This is not surprising in view of the activities within the catchment. The levels of orthophosphate and nitrate in the waters of the impoundment were extremely low (usually less than 0,01 and 0,20 mg/dm^3 respectively). One item of interest is the observed release of iron and man-

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ganese from the bottom sediments of the impoundment during summer. High levels of iron and manganese (i.e. >1 mg/dm^3) are considered to be undesirable in water, particularly for potable supplies.

Nutrient loading rates for the impoundment are presented in Table 5 along with the ranges in chlorophyll and Secchi depth at the impoundment wall station. If compared with the nutrient loading rates recorded for systems polluted by sewage and industrial effluents these loading rates for Rust der Winter can be considered as being low (c.f. Bospoort Dam in this series). It is therefore not surprising that chlorophyll levels in the impoundment were never greater than 6,0 μg/dm^3. Nevertheless, with a mean concentration of 4 μg/dm^3 the impoundment can be classified as mesotrophic (Walmsley and Butty, 1979).

Water transparency in Rust der Winter Dam can be considered to be relatively high by comparison with other impoundments such as Olifantsnek and New Doringpoort (c.f. Butty *et al.*, 1979). A more detailed study of the factors governing the water transparency in the waters of this impoundment has been reported on by Walmsley *et al.* (1979). It was shown that suspended clay material is the most important factor in regulating water transparency. Most of this material is introduced into the impoundment during summer flooding.

The impoundment displayed thermal stratification between mid-August 1977 and mid-April 1978 (Fig. 6). Associated with this was the development of an oxygen deficit and clinograde oxygen distribution (Fig. 7). Anaerobic conditions were encountered below 16 m during the period January to mid-April 1978. Obviously this zone was responsible for the production of the large quantities of iron and manganese recorded by the chemical analyses.

At present the water quality in Rust der Winter Dam is compatible with its usage and there appear to be few problems with respect to algal growth since the impoundment can be classified as mesotrophic.

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WALMSLEY, R.D., BUTTY, M., VAN DER PIEPEN, H. and GROBLER, D. 1980 Light penetration and the interrelationships between optical parameters in a turbid subtropical impoundment. *Hydrobiologia* (in print).

TABLE 1. Characteristics of Rust der Winter Dam and its catchment

Geographical location	25 ° 14'S; 28 ° 31'E
Magisterial district	Rust der Winter
Catchment type	Rural, urban
Usage of dam	Irrigation
Catchment area	1 147 km^2
Inflowing river	Elands
Dam wall completed	1933
*F.S.L. volume	28,1 x 10^6 m^3
F.S.L. area	4,93 km^2
F.S.L. maximum depth	20 m
F.S.L. mean depth	5,7 m

*F.S.L. = full supply level

TABLE 2. Average hydrological characteristics of Rust der Winter Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	24,97	17,2
Area km^2	4,32	14,4
Mean depth m	5,7	4,3
Annual inflow x 10^6 m^3	80,90	153,7
Annual outflow x 10^6 m^3	77,48	157,0
Retention time a	0,32	—

*Average mean is based on monthly values and an annual cycle
Period: August to July (1968 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Rust der Winter Dam (Aug. 1977 – Jul. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	28,62	24,37	26,85	5,8	7
Area km^2	4,85	4,23	4,59	5,0	6
Mean depth m	5,8	5,7	5,8	0,7	2
Monthly inflow x 10^6 m^3	30,89	0,52	8,04	138,1	24,9
Monthly outflow x 10^6 m^3	30,96	0,41	7,65	136,5	18,5

*C.V. = *coefficient of variation*

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers, the outflow and dam station. Values are based on fortnightly samples collected between August 1977 and July 1978.

PARAMETER	DAM STATION								ELANDS RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	6,0	14,0	8,8	19	6,0	20,0	8,6	30	5,0	13,0	8,3	22	6,0	11,0	8,2	16
K	1,0	5,1	3,2	25	1,0	4,0	2,9	22	1,0	4,5	2,8	32	2,8	4,0	3,2	13
Ca	5,0	31,0	7,7	63	6,0	37,0	8,3	72	5,0	9,0	5,9	17	6,0	11,0	6,8	18
Mg	3,0	35,0	4,6	137	3,0	51,0	5,3	179	2,0	10,0	3,2	47	3,0	4,0	3,2	13
SO_4	5,0	11,0	5,4	25	5,0	9,0	5,3	17	5,0	9,0	5,3	18	5,0	16,0	5,7	45
Cl	5,0	7,0	5,1	8	5,0	10,0	5,3	20	5,0	12,0	5,5	27	5,0	6,0	5,0	4
Cond	4,2	22,0	10,5	41	7,3	22,0	10,5	34	5,1	24,0	10,0	42	0,8	21,0	8,5	67
Alk	33,0	53,0	42,5	10	36,0	64,0	47,8	16	32,0	58,0	41,0	13	36,0	57,0	44,8	10,6
Tot Kj-N	0,140	0,880	0,391	47	0,150	3,500	0,691	97	0,100	1,200	0,404	57	0,130	0,915	0,504	46
Dis Kj-N	0,100	0,950	0,403	47	0,17	1,860	0,620	65	0,048	1,300	0,400	57	0,160	1,000	0,456	49
NH_4-N	0,002	0,256	0,079	69	0,016	1,50	0,358	112	0,012	0,226	0,082	84	0,018	0,720	0,202	118
NO_3-N	0,002	0,850	0,076	217	0,002	4,4	0,215	393	0,013	2,5	0,168	295	0,002	0,189	0,048	92
NO_2-N	0,002	0,028	0,007	80	0,001	0,031	0,006	98	0,002	0,015	0,007	53	0,001	0,011	0,006	62
Tot P	0,008	0,115	0,037	100	0,004	0,237	0,058	95	0,009	0,105	0,045	66	0,008	0,180	0,057	76
Tot dis P	0,004	0,090	0,032	73	0,004	0,225	0,055	101	0,009	0,100	0,040	69	0,005	0,120	0,047	72
PO_4-P	0,002	0,052	0,011	87	0,004	0,171	0,033	138	0,002	0,066	0,015	89	0,002	0,072	0,020	84
Fe	0,078	2,070	0,793	75	0,055	5.330	1,969	86	0,240	3,500	1,458	64	0,250	2,170	1,080	56
Mn	0,025	0,050	0,028	26	0,025	3,080	0,691	108	0,025	0,094	0,034	50	0,025	1,530	0,360	135
Temp	12,5	27,5	20,8	23	10,0	22,0	16,5	23	8,5	29,3	19,9	31	12,5	22	17,0	20
DO	3,7	13,8	7,4	32	0,0	7,5	3,1	91								
Tu	4,2	25,0	12,5	53	6,4	44,0	21,1	51								
pH	6,5	8,3	7,5	6	6,6	7,9	7,0	6	6,8	8,6	7,4	6	6,7	8,4	7,5	6

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Rust der Winter Dam (Aug. 1977 – Jul. 1978)

Mean depth m	5,8		
Retention time a	0,29		
Hydraulic load m/a	20,0		
Surface loading rates g/m^2.a^{-1}			
PO_4-P	0,40		
Total P	1,10		
Inorganic nitrogen	4,58		
Total nitrogen	14,44		
	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	6,0	2,0	4,0
Secchi depth m	3,0	0,6	1,4

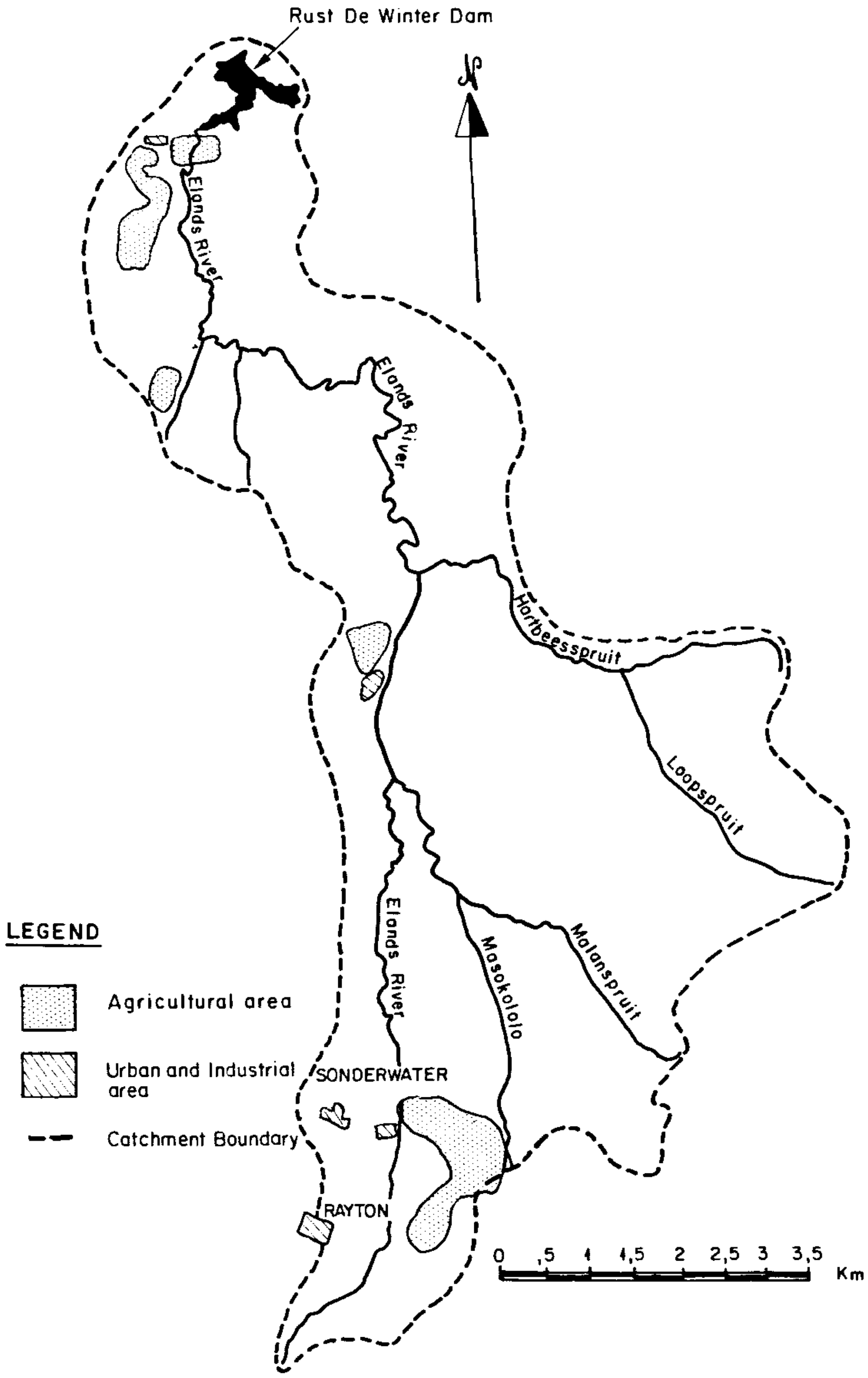

FIGURE 1. Rust der Winter Dam catchment.

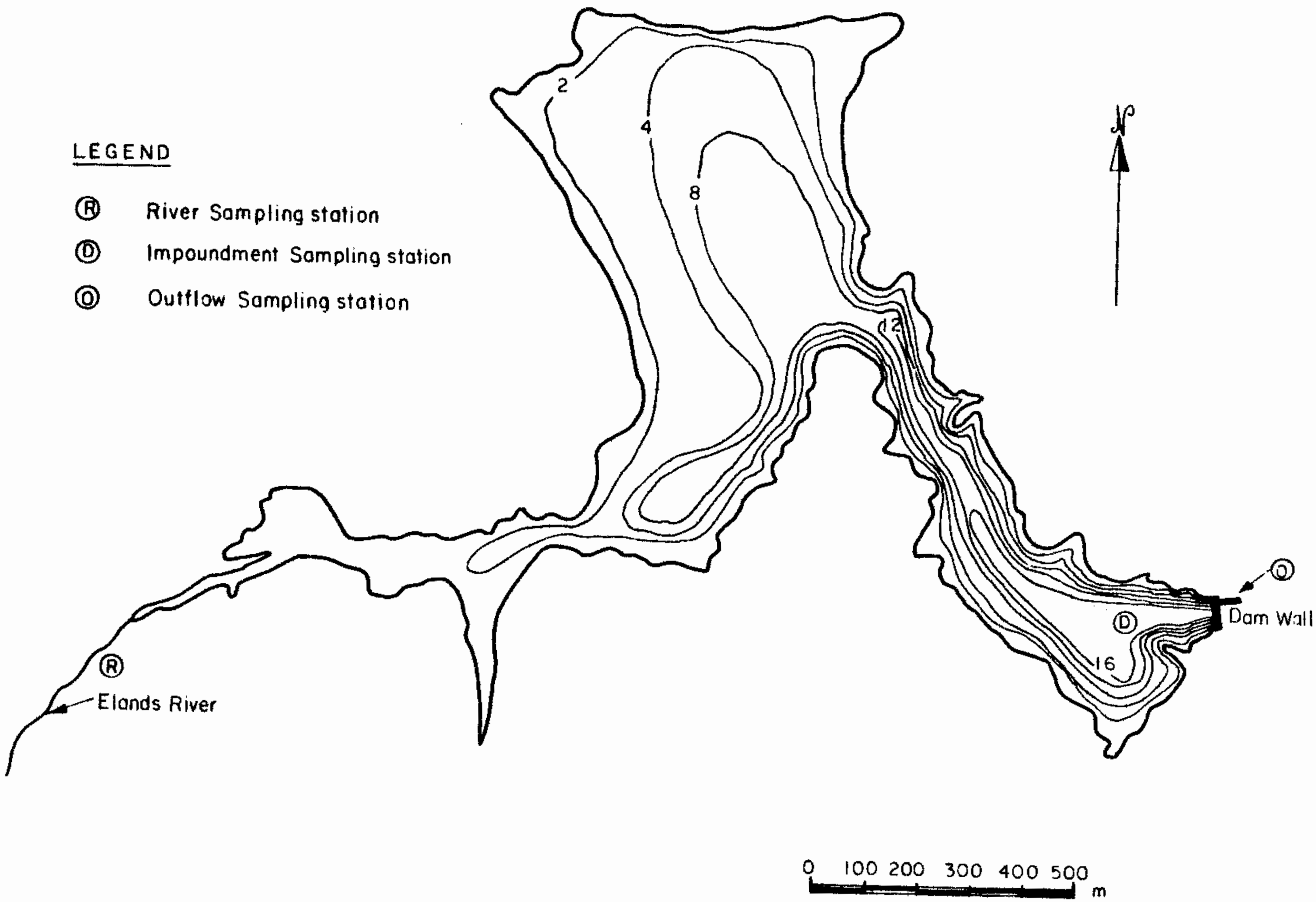

FIGURE 2. Map of Rust der Winter Dam showing sampling stations.

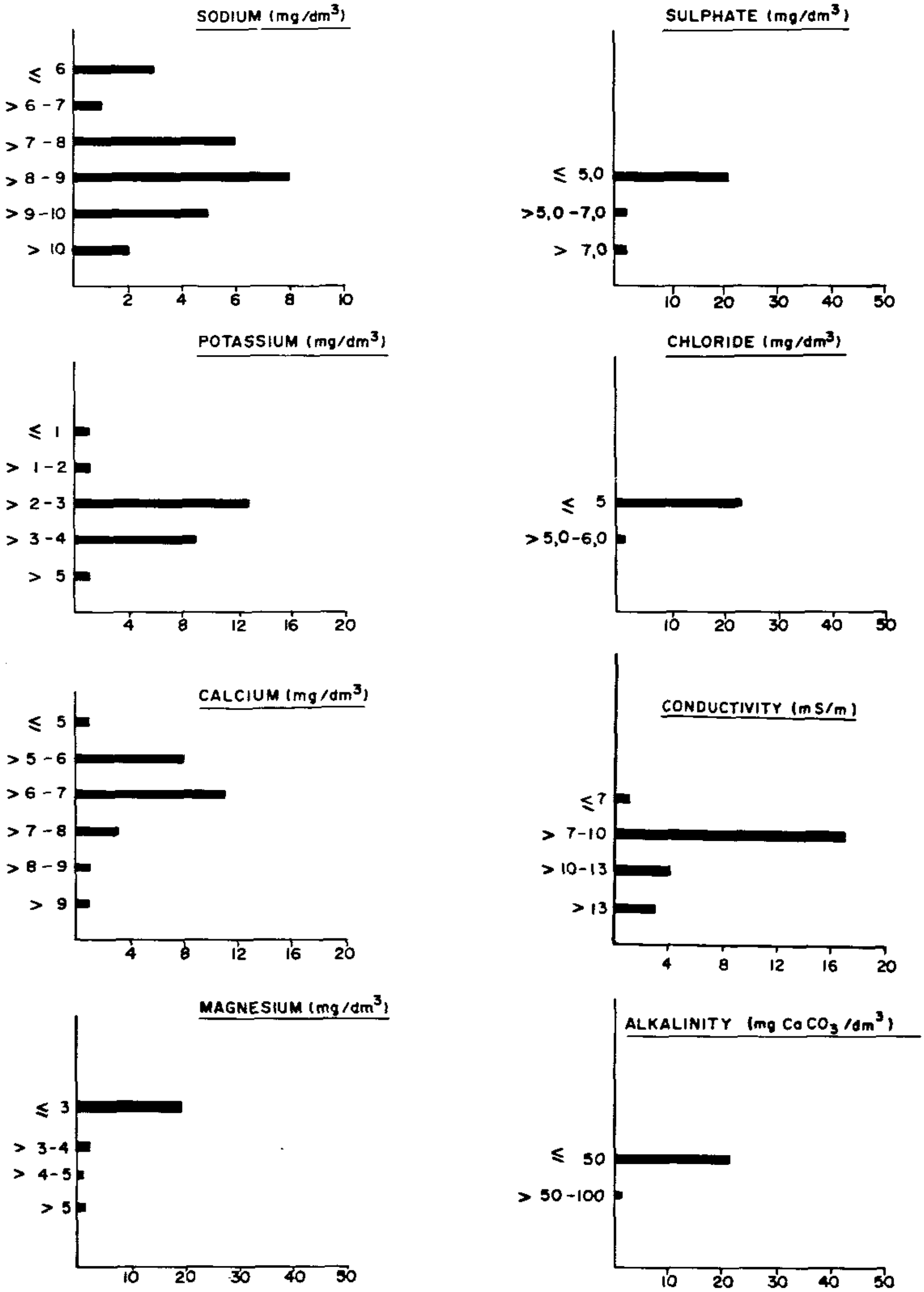

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Rust der Winter Dam.

RUST DER WINTER

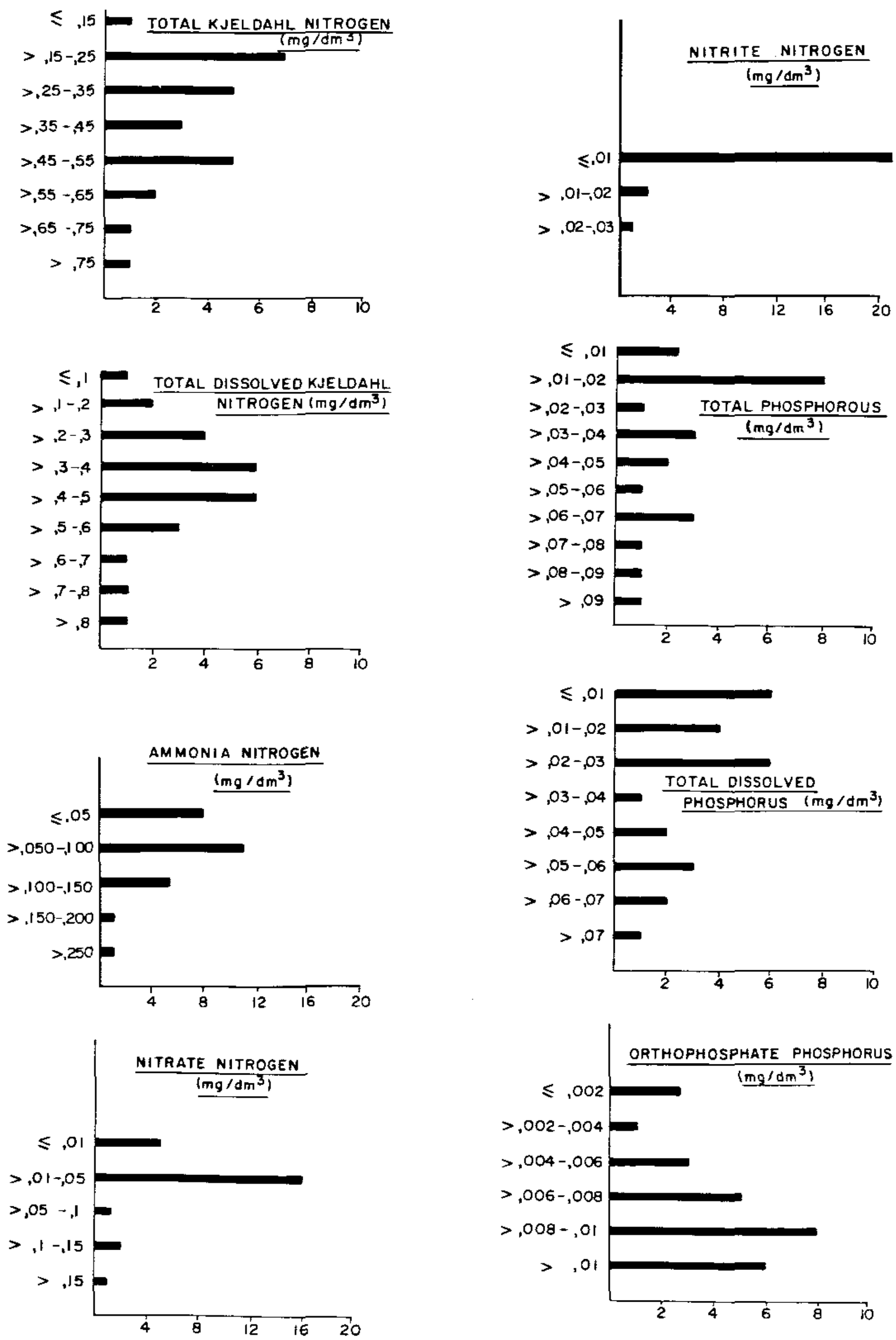

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Rust der Winter Dam.

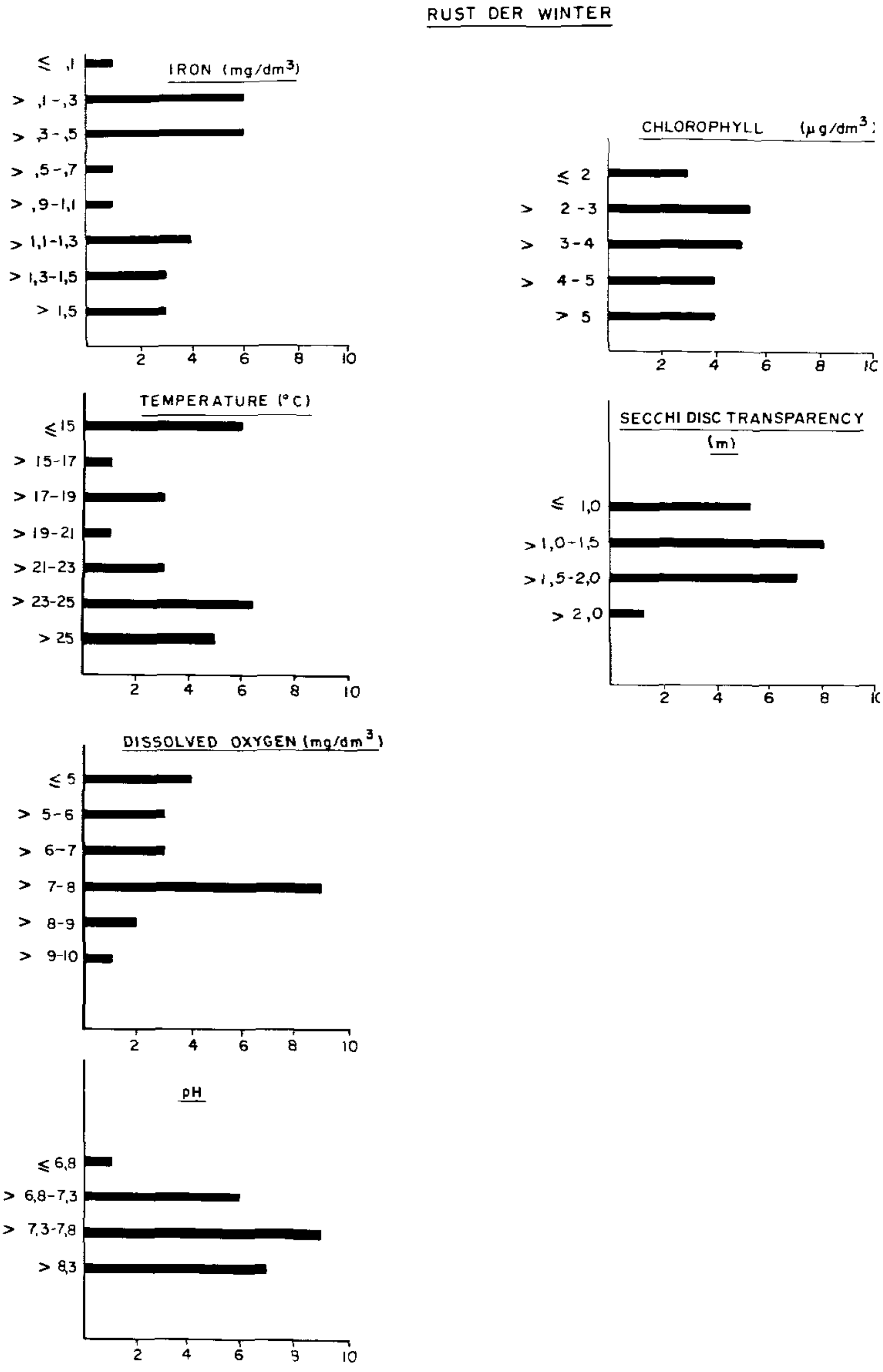

FIGURE 5. **Frequency histograms for selected parameters pertinent to the surface waters of Rust der Winter Dam.**

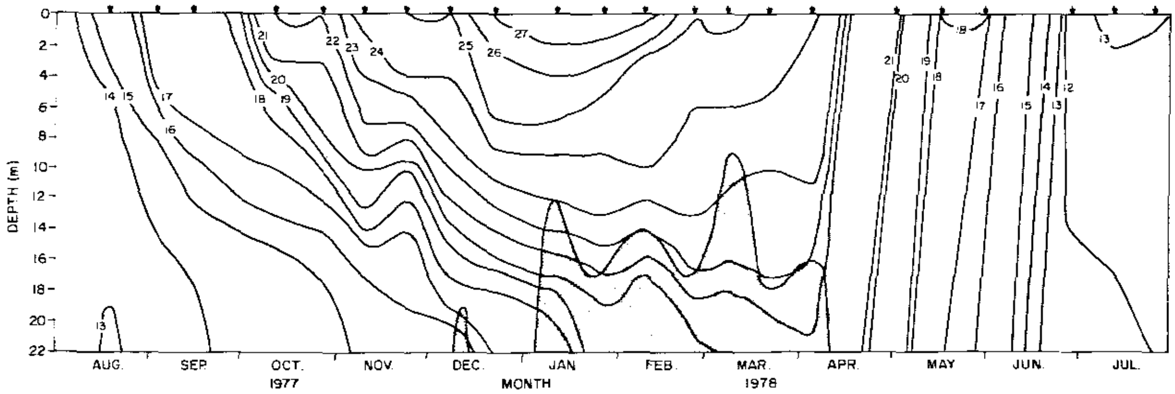

FIGURE 6. Temperature distribution in Rust der Winter Dam (shaded area indicates anaerobic zone).

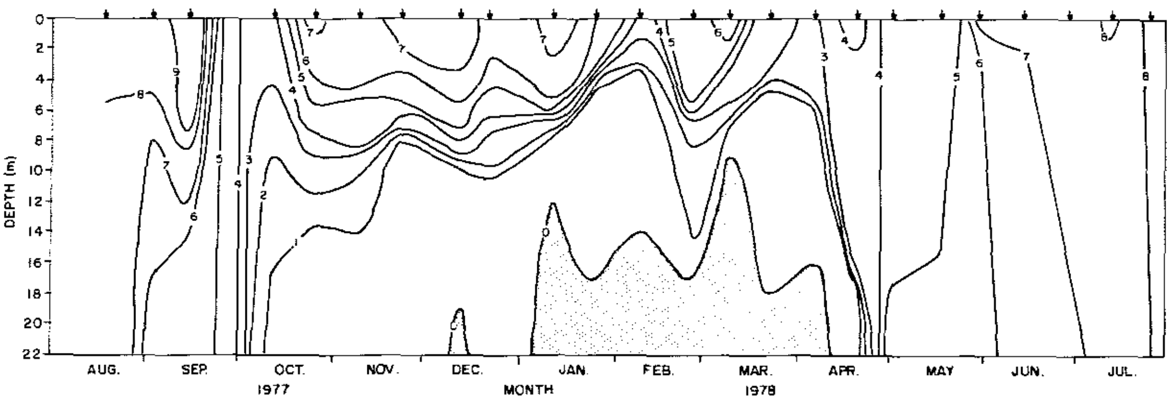

FIGURE 7. Dissolved oxygen distribution in Rust der Winter Dam (shaded area indicates anaerobic zone).

TONTELDOOS DAM

by

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INTRODUCTION

Only limited limnological information is available on Tonteldoos Dam. Apart from being included in an algal survey of 98 South African impoundments (Toerien *et al.*, 1975), no detailed limnological studies have been done on Tonteldoos Dam. The impoundment was selected for study because it represented a small water body with a short water retention time. It was felt that data from such a system would provide valuable insight into the behaviour of highly flushed water bodies under South African conditions. This report presents limnological information on the impoundment covering the period January 1976 to January 1977.

DESCRIPTION OF THE AREA

Tonteldoos Dam is situated on the western edge of the Drakensberg escarpment which separates the highveld climatic zone from that of the lowveld (Department of Transport, 1965). Characteristics of the impoundment and its catchment are presented in Table 1. Because of the mountainous topography most of the catchment is undeveloped and cultivated areas are only found where adequate soil covering occurs (Fig. 1). Two inflowing streams contribute to water flow. (The Tonteldoos River and an unnamed stream — R2 — Fig. 2.) Although the unnamed stream was found to be perennial, runoff from this portion of the catchment was negligible by comparison with that of the Tonteldoos River.

Despite its small size, the impoundment has a maximum depth of 10,5 m, although with a mean depth of 3,9 m, the system can be regarded as extremely shallow (Table 1; Fig. 2). The shoreline has a well established reed cover dominated by *Typha capensis* with small patches of *Phragmites australis.* In the littoral zone, dense beds of *Potamogeton pusillus* occur in areas which are undisturbed by inflowing currents (Fig. 2). Sampling stations on the impoundment and the inflowing streams are indicated in Figure 2.

Medium-term hydrological data for the impoundment indicate that the system has a large variation in its annual runoff (C.V. >60 % — Table 2). The mean annual water retention time for the period 1968/78 was 0,04 years. Therefore, on the average, the system is flushed at least 25 times per annum. In this respect, it can be considered as being a highly flushed system since many other South African impoundments have water retention times varying between 0,5 and 1,0 years (Walmsley, 1977).

RESULTS AND DISCUSSION

During the study period the volume, area and mean depth of the impoundment showed little variation (Table 3). However, monthly inflows ranged between 0,097 and 1,618 x 10^6 m^3 and showed a coefficient of variation of approximately 100 %. By contrast to the average, the study year received greater inflow (>17,6 %) and the mean annual water retention time was 0,033 years (Table 5). In more realistic terms this short retention time means that the entire volume of water in the impoundment was replaced approximately 30 times during the study year.

Chemical characteristics of the waters are presented in Table 4. Bond (1946) has classified the underground waters of this area as being 'pure waters', i.e. with a total solids content <150 parts per million. In this respect the chemical composition showed no deviation from the expected. One feature which should be mentioned is the relatively high silicate content of the waters where values as high as 26 mg/dm^3 were recorded in the Tonteldoos River. Frequency histograms for surface water characteristics are presented in Figures 3, 4 and 5. Based on 26 sampling trips over the study year, they give an indication of the time period in which a given range or a particular concentration of a constituent occurred. They also give an indication of the distribution with respect to the mean values of constituents presented in Table 4. Not all constituents displayed normal distribution and therefore, the mean values in Table 4 should be interpreted with caution and be considered in conjunction with the histograms.

Available nutrients (inorganic nitrogen and orthophosphate) in the surface waters were generally low and the system can possibly be considered oligotrohpic on the basis of its nutrient content (Vollenweider, 1968). Orthophosphate phosphorus concentrations were less than 0,01 mg/dm^3 for almost 70 % of the study period whilst nitrate and ammonia nitrogen were always less than 0,35 mg/dm^3 (Fig. 4).

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Nutrient loading rates were extremely high with orthophosphate phosphorus and inorganic nitrogen loading rates calculated at 1,34 and 30,08 $g.m^{-2}.a^{-1}$ respectively (Table 5). When compared with the nutrient loading models of Vollenweider (1968, 1976), the impoundment can be classified as a highly eutrophic system. However, it should be realised that under hydrological regimes with short retention times (±3 days), a wash-out effect is imposed on phytoplankton growth (Oglesby, 1977). Thus, the total loading cannot be considered as being effective. In Tonteldoos Dam, hydrological data (Table 3) showed that during certain months, water retention time was shorter than 3 days and thus a flushing-out of the system was a regular occurrence. This consideration is supported by the chlorophyll *a* data where a maximum of 2,88 $\mu g/dm^3$ was recorded (Table 5) and where concentrations were less than 2,0 $\mu g/dm^3$ for over 80 % of the year.

Toerien *et al.* (1975) found that the waters of this impoundment were predominantly nitrogen-limited. Nitrogen-limitation may be assumed when the available nitrogen:phosphate ratio of the inflowing water is less than 15:1 by weight (Vollenweider, 1968). On the basis of the loading rates, the ratio of incoming available nitrogen:phosphate was estimated at 23:1, suggesting that for the study period this impoundment was more likely to be phosphate-limited.

Temperature and oxygen isopleths (Figs. 6 and 7) indicated that the impoundment did not exhibit stable thermal stratification. In summer a temperature gradient was always present, but large inflows prevented the establishment of thermal layering. It is obvious that a small water body like Tonteldoos Dam is susceptible to large variations in temperature due to its low heat content and high flushing rate. Dissolved oxygen distribution was governed by the unstable thermal regime and, although concentrations of less than 1 mg/dm^3 were recorded, the bottom waters were never anaerobic. The influence of density currents on the oxygen content is demonstrated by the fluctuation in the oxygen content of the bottom waters during summer stratification.

Water transparency in the system was fairly high (mean Secchi depth of 1,38 m — Table 5), which is somewhat surprising when considering the high flushing rate and the expected transport of clay material into the system. However, the nature of erodable material in the catchment was obviously not of the type which allowed for the prolonged suspension of particles in the water column. This may possibly be attributed to a predominance of larger-sized clay particles which sediment out quite quickly in aquatic systems (Ruttner, 1954).

Tonteldoos Dam can be considered to be oligotrophic on the basis of its nutrient and phytoplankton characteristics. The limnological characteristics of the system are governed to a large degree by the high flushing rate, particularly during the summer rainy season.

ACKNOWLEDGEMENTS

The help of C.J. Alexander, P.A. Joubert and A. Engelbrecht with data collection and processing is gratefully acknowledged. Hydrological data were compiled from records of the Department of Water Affairs. The Chemical Division of the National Institute for Water Research is thanked for its contribution to the chemical analysis of water samples.

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TABLE 1. Characteristics of Tonteldoos Dam and its catchment

Geographical location	25 ° 16'S; 29 ° 56'E
Magisterial district	Stoffberg
Catchment type	Agriculture, undeveloped
Usage of dam	Irrigation
Catchment area	55 km^2
Inflowing river	Tonteldoos
Dam wall completed	1962
*F.S.L. volume	0,174 x 10^6 m^3
F.S.L. area	0,044 km^2
F.S.L. maximum depth	10,5 m
F.S.L. mean depth	3,9 m

*F.S.L. = full supply level

TABLE 2. Average-term annual hydrological characteristics of Tonteldoos Dam.

	*Average mean	*C.V.
Volume x 10^6 m^3	0,157	17
Area km^2	0,039	17
Mean depth m	3,95	0,5
Annual inflow x 10^6 m^3	4,448	62
Annual outflow x 10^6 m^3	4,428	63
Retention time a	0,04	38

*Average mean is based on monthly values and an annual cycle
Period: January to December (1968 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Tonteldoos Dam (Jan. 1976 – Jan. 1977)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	0,176	0,160	0,172	3	9,5
Area km^2	0,044	0,042	0,044	2	13
Mean depth m	3,95	3,85	3,95	1	0
Monthly inflow x 10^6 m^3	1,618	0,097	0,436	101	17,6
Monthly outflow x 10^6 m^3	1,600	0,085	0,430	105	16,5

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of water collected from the inflowing rivers (Tonteldoos River and unnamed stream (R2)), the outflow and the dam station (D) on Tonteldoos Dam. Values are based on fortnightly samples collected over an annual cycle between January 1976 and January 1977

PARAMETER	DAM STATION								TONTELDOOS RIVER				UNNAMED STREAM (R2)				OUTFLOW			
	TOP				BOTTOM															
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	3,0	7,0	5,0	18	3,0	6,0	4,8	19	3,0	7,0	5,0	22	1,0	8,0	6,2	28	3,0	6,0	4,8	20
K	0,1	1,5	0,6	51	0,1	1,3	0,6	52	0,1	1,6	0,5	57	0,1	1,8	0,5	90	0,1	1,6	0,6	54
Ca	10,0	16,0	12,7	12	9,0	17,0	12,5	13	10,0	20,0	13,7	16	10,0	26,0	19,0	25	10,0	27,0	13,3	24
Mg	4,0	8,0	6,2	17	4,0	8,0	6,1	17	5,0	13,0	6,8	24	5,0	20,0	11,3	31	4,0	14,0	6,6	28
SO_4	2,0	9,0	4,2	40	2,0	9,0	4,5	42	2,0	6,0	4,0	34	2,0	6,0	4,0	35	2,0	7,0	4,1	39
Cl	2,0	5,0	4,1	29	2,0	5,0	4,1	29	2,0	6,0	4,0	37	2,0	17,0	4,6	65	2,0	5,0	4,1	30
Si	9,2	23,0	14,5	22	8,1	23,4	14,4	24	10,0	26,0	15,6	22	11,2	25,0	15,6	19	10,0	24,3	15,0	23
Cond	4,7	17,0	12,8	19	8,1	20,7	13,1	19	3,1	21,5	13,7	26	9,4	30,5	17,8	27	9,0	21,2	13,6	19
Alk	52,0	80,0	65,2	11	48,0	82,0	65,1	12	12,0	86,0	67,1	20	30,0	94,0	38,0	74	28,0	83,0	64,3	17
Tot Kj – N	0,10	3,2	1,36	57	0,30	3,3	1,50	49	0,23	5,4	1,38	86	0,45	3,60	1,32	60	0,20	4,5	1,38	67
Dis Kj – N	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
NH_4 – N	0,013	0,460	0,113	92	0,041	0,700	0,226	62	0,015	0,275	0,072	95	0,010	0,400	0,082	108	0,018	0,337	0,107	87
NO_3 – N	0,020	0,660	0,194	75	0,030	0,820	0,219	72	0,040	0,60	0,199	59	0,010	0,400	0,115	105	0,020	0,800	0,186	92
NO_2 – N	0,002	0,073	0,011	137	0,003	0,200	0,016	239	0,002	0,042	0,007	118	0,001	0,020	0,006	87	0,002	0,120	0,011	207
Tot P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tot dis P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PO_4 – P	0,002	0,066	0,013	118	0,002	0,060	0,016	89	0,002	0,050	0,012	92	0,002	0,033	0,010	77	0,002	0,160	0,019	171
Fe	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mn	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Temp	9,6	26,0	17,1	28	8,0	17,2	13,0	21	8,7	26,0	16,1	29	11,2	26,2	17,8	25	–	–	–	–
DO	4,1	9,2	7,1	17	0,08	8,7	4,7	58	–	–	–	–	–	–	–	–	–	–	–	–
Tu	3,8	88,0	14,0	123	7,0	67,0	18,0	73	5,0	44,5	14,0	83	5,6	34,0	15,4	43	4,9	80,5	15,8	102
pH	6,9	8,3	7,6	4	6,7	8,0	7,4	4	7,0	8,2	7,8	4	7,0	8,5	7,8	4	6,9	8,4	7,8	4
SS	0,10	78,5	7,2	246	0,20	47,5	8,2	130	0,92	58,4	9,5	166	0,14	14,5	3,4	127	0,62	42,9	5,6	169

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Tonteldoos Dam (January 1976 to January 1977)

Mean depth m	3,85
Retention time a	0,033
Hydraulic load m/a	116,6
Surface loading rates g/m^2.a^{-1}	
PO_4-P	1,34
Total P	–
Inorganic nitrogen	30,8
Total nitrogen	–

	Maximum	Minimum	Mean
Chlorophyll *a* μg/dm^3	2,88	0,29	1,07
Secchi depth m	2,90	0,10	1,38

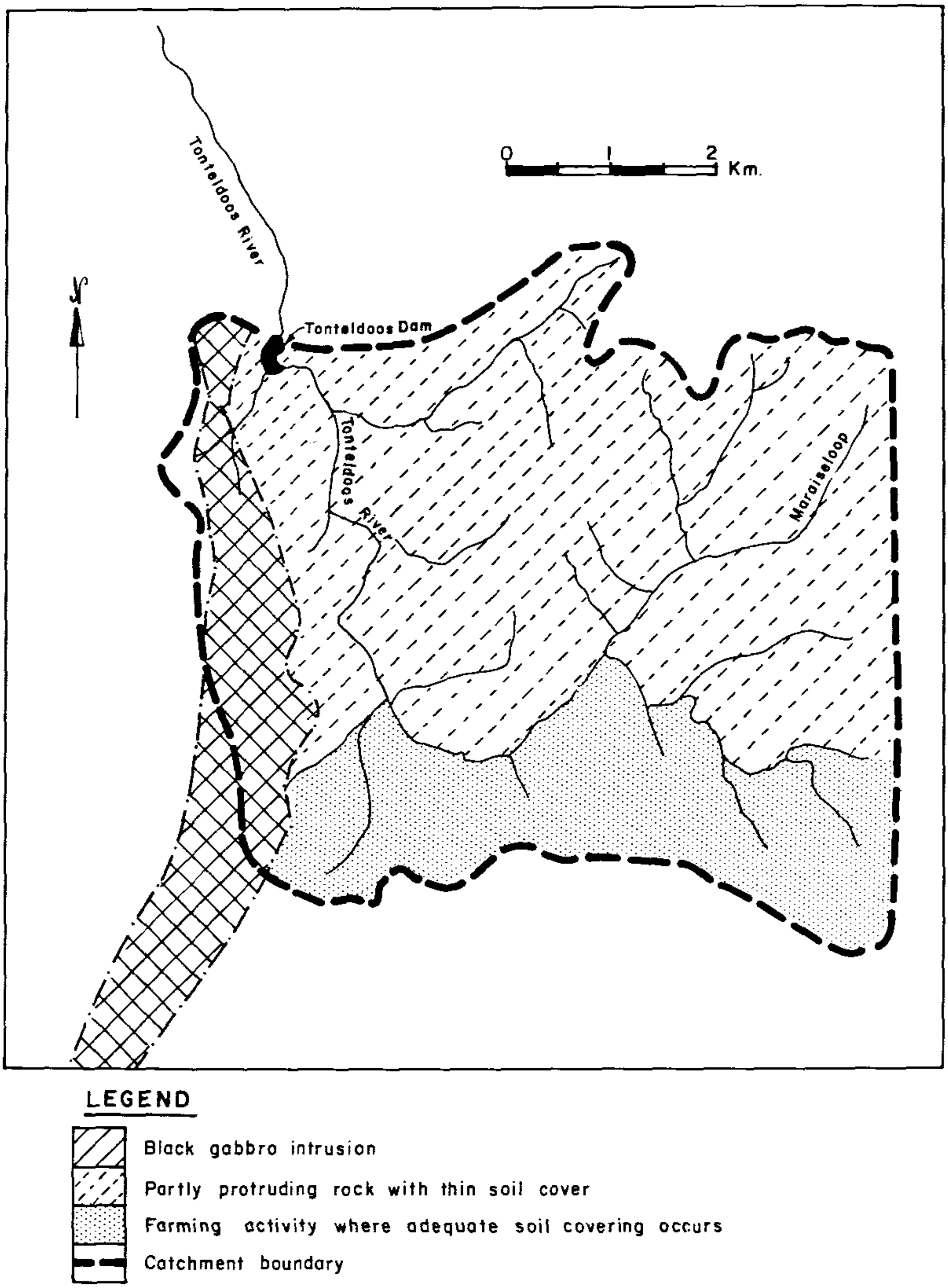

FIGURE 1. Tonteldoos Dam catchment.

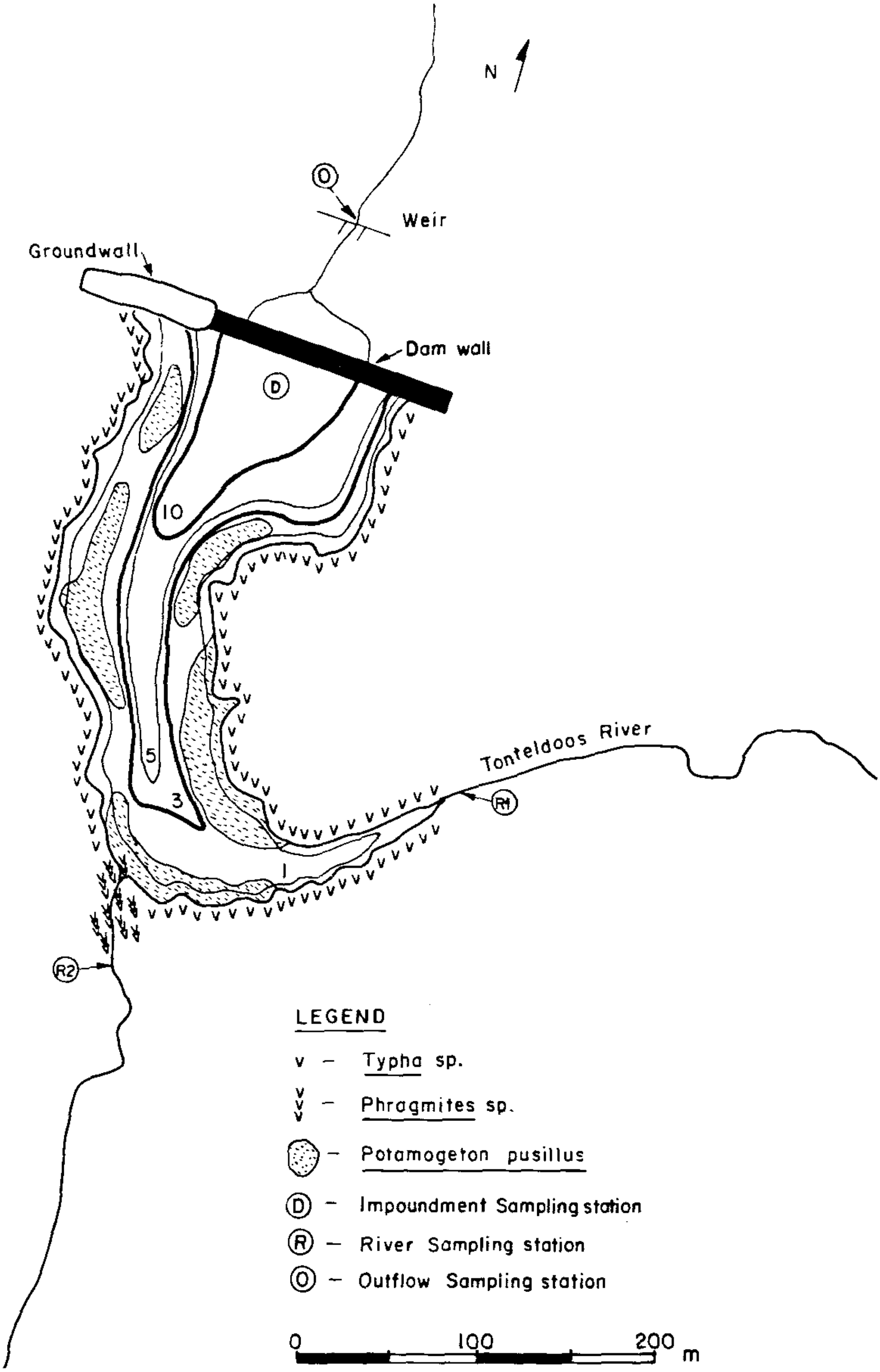

FIGURE 2. Map of Tonteldoos Dam showing sampling stations.

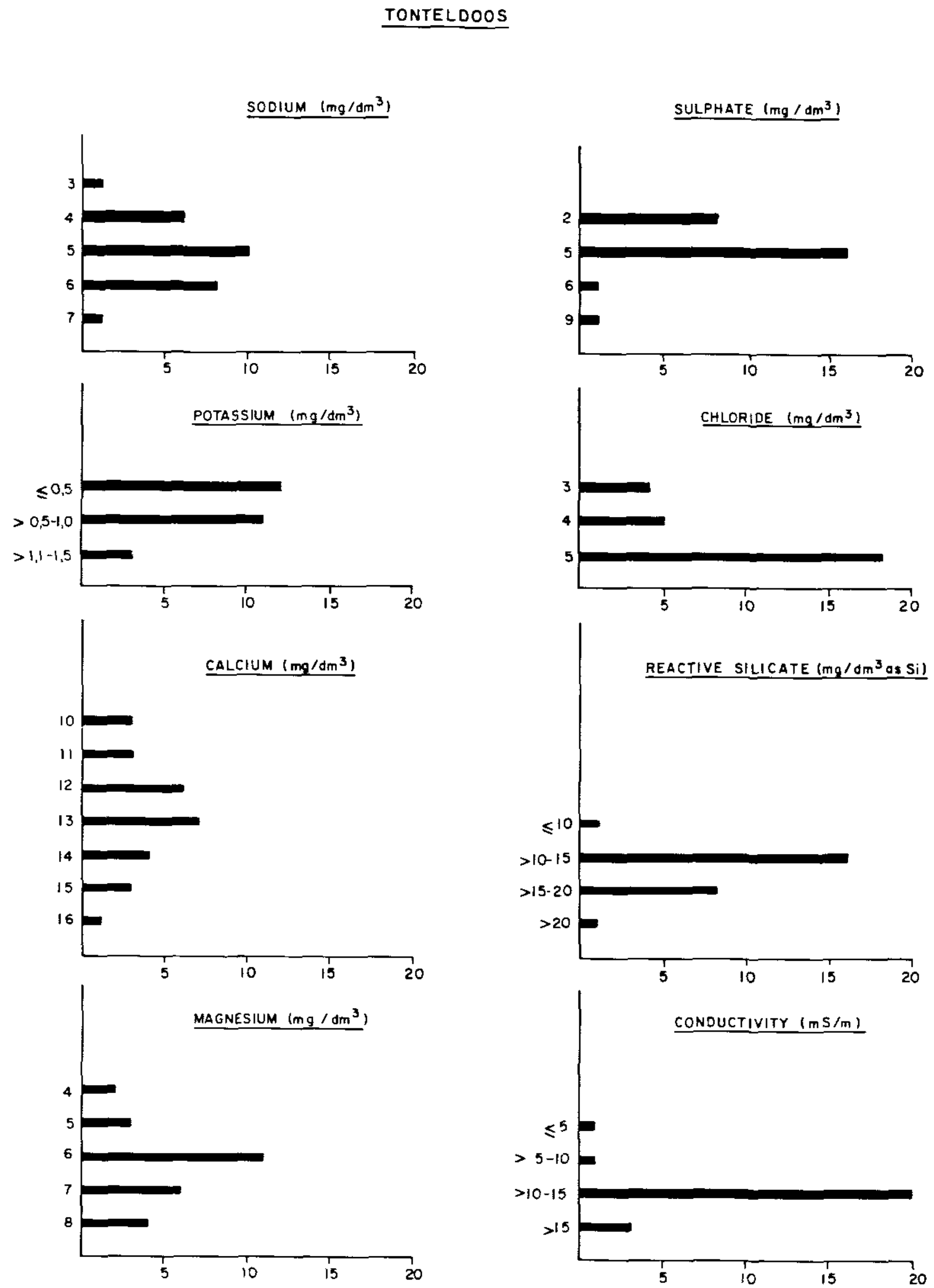

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Tonteldoos Dam.

TONTELDOOS

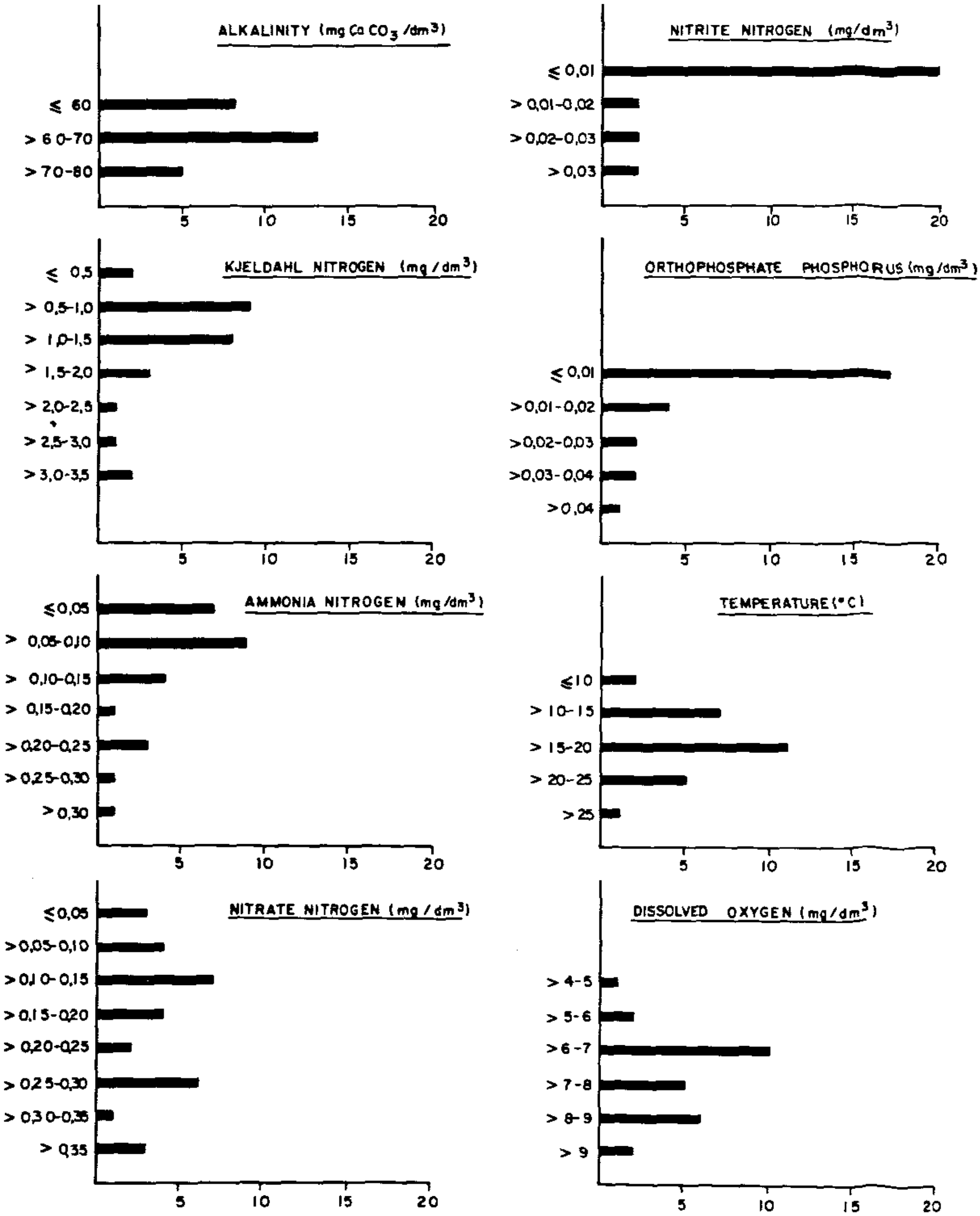

FIGURE 4. **Frequency histograms for selected parameters pertinent to the surface waters of Tonteldoos Dam.**

TONTELDOOS

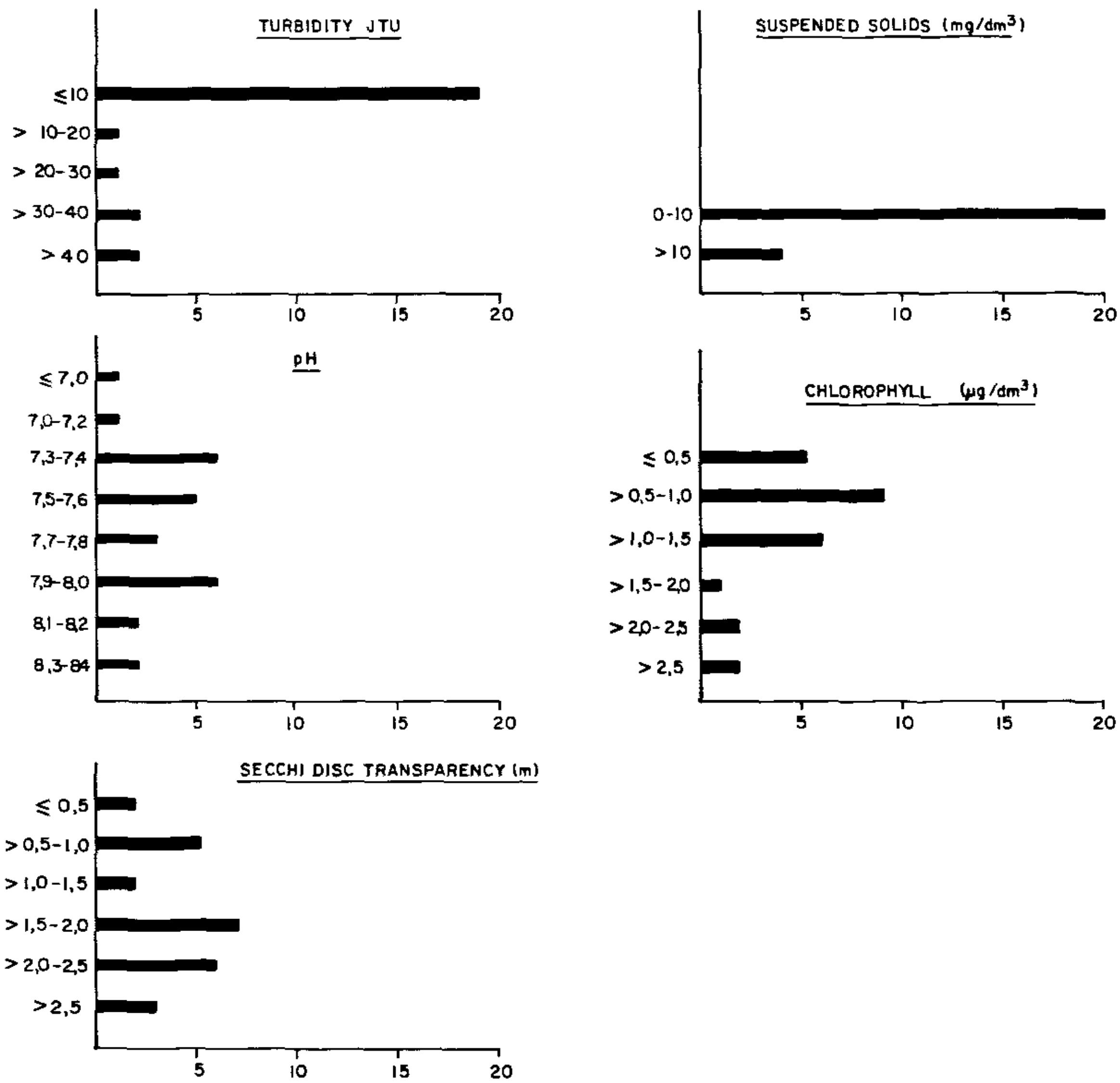

FIGURE 5. **Frequency histograms for selected parameters pertinent to the surface waters of Tonteldoos Dam.**

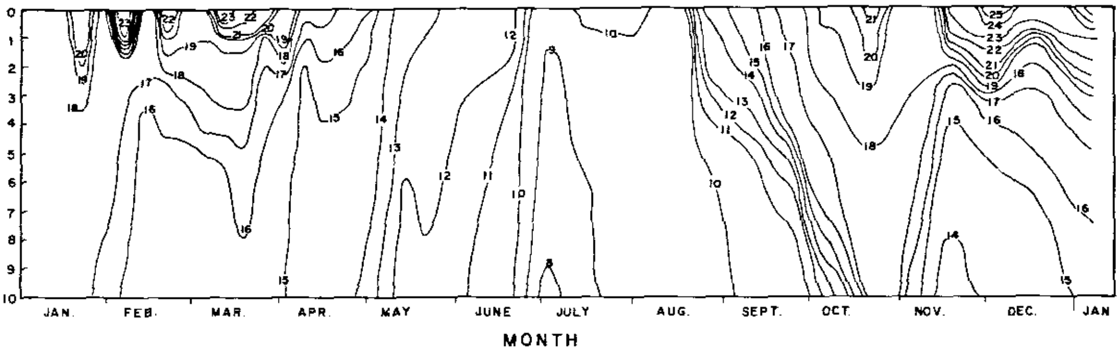

FIGURE 6. Temperature distribution in Tonteldoos Dam (Jan. 1976 — Jan. 1977).

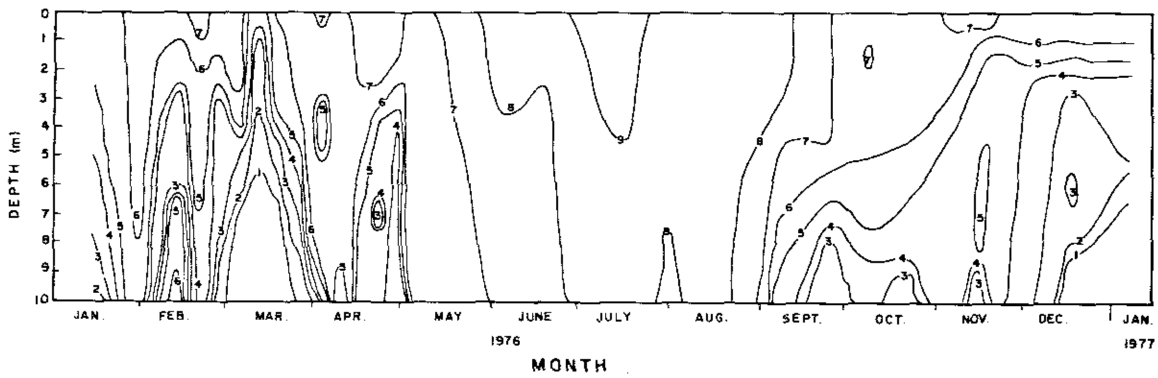

FIGURE 7. Dissolved oxygen distribution in Tonteldoos Dam (Jan. 1976 — Jan. 1977).

NEW DORINGPOORT DAM

by

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INTRODUCTION

New Doringpoort Dam (commonly known as Witbank Dam) is situated in a coal mining area of South Africa and is an important impoundment in that it supplies industrial and potable water to the town of Witbank. In a survey by Schutte and Bosman (1973) the impoundment was found to be highly turbid, showing little tendency toward anaerobic conditions in the hypolimnion and the waters had a high sulphate concentration. These characteristics were recorded before the raising of the dam wall in 1973. This report presents data obtained during a limnological survey between July 1977 and August 1978.

DESCRIPTION OF THE AREA

New Doringpoort Dam is situated approximately 100 km east of Pretoria in the Witbank magisterial district. Characteristics of the impoundment and its catchment area are shown in Figure 1 and Table 1. The catchment consists mainly of cultivated land (maize) and includes a large number of open-cast collieries and mines. Adjacent to these coalfields are a number of power stations which are either operational or in the process of being constructed.

In addition to being utilized as a potable water supply the impoundment also serves as a recreational centre. Near the dam wall there is a holiday resort with camping sites. It is estimated that the number of visitors to the impoundment is in excess of 100 000 per year.

The impoundment has one inflow, the Olifants River, and is sinuously shaped, being shallow in the upper reaches and increasing in depth up to the dam wall (maximum depth 36 m). Sampling sites for the present investigation are shown in Figure 2. Water is regularly released from the dam to maintain a constant water level in an impoundment lower down the Olifants River. A pump house which pumps water to Witbank is situated below the dam wall.

With respect to the general hydrological characteristics of the impoundment at present, it is only possible to compare the years between 1973 and 1978 (Table 2). During these years the impoundment experienced annual inflows which were higher than the full supply volume and consequently the mean water retention time was less than 1 year (0,84 years – Table 2). This suggests that the impoundment is flushed at least once per annum.

RESULTS AND DISCUSSION

Hydrological characteristics for the study period are presented in Table 3. During the study the water inflow was slightly lower than the average (19 % less) and the mean water retention time was 0,88 years. Inflow and outflow showed a wide variation over the year with little water entering the impoundment during the dry winter months and large volumes entering the impoundment during the rainy months. The maximum monthly inflow of 46,49 x 10^6 m^3 is approximately half the volume of the impoundment.

Chemical and physical characteristics of the inflowing, outflowing and impounded waters are summarized in Table 4. Frequency histograms for the limnological characteristics of the surface waters are presented in Figures 3 to 5. The concentrations of cations and anions in the Olifants River above the impoundment can be considered to be low by comparison with other polluted river systems (Pieterse – this document; Crocodile River – Allanson, 1961). Nevertheless,

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concentrations of sulphate were extremely high compared with the other anions. This may possibly be a reflection of acid flow from mines into this system. The concentrations of total iron in these waters were also high with a maximum value of 6,77 mg/dm^3 being recorded.

Nutrient levels in the waters of the Olifants River and the impoundment were not high indicating that no large point source of nutrient supply exists within the catchment. It is interesting to note that orthophosphate phosphorus concentrations in the Olifants River and the impoundment were similar (means of 0,023 and 0,028 mg/dm^3 respectively). This is possibly a reflection of low phytoplankton activity in the impoundment. The frequency histograms indicate that nitrogen and phosphate were always sufficient to support algal growth. Chlorophyll concentrations in the impoundment varied between 1,0 and 21,0 μg/dm^3 with a mean of 3,0 μg/dm^3 (Table 5). The highest concentration coincided with a *Microcystis* bloom which was ultimately washed out of the impouindment after a flood. The low algal standing crop in this impoundment is possibly caused by the high water turbidity which restricts light penetration into the surface waters. Furthermore, the nutrient loading into the system is not high (Table 5) and also indicates that there is at present no large source of nutrient input within the catchment.

The impoundment stratified in the summer months and in mid-summer the maximum temperature gradient over the water column was 8 °C (Feb. 1978 – Fig. 6). During winter isothermal conditions were encountered in the impoundment and a minimum temperature of 10 °C was recorded. Dissolved oxygen distribution in the water column showed a seasonal pattern to that of temperature in that an oxygen deficit developed during summer stratification, whereas in winter the oxygen content of the surface was similar to that of the bottom. Anaerobic conditions were not encountered in the impoundment although in March 1978 extremely low values (<1 mg/dm^3 O_2) were recorded in the bottom waters (Fig. 7).

The New Doringpoort Dam is an impoundment which can be classified as oligotrophic to mesotrophic (Walmsley and Butty, 1979). However, it does display certain eutrophic symptoms (e.g. bloom development and oxygen deficit) and undesirable water quality characteristics (e.g. high sulphate and iron concentrations). These may perhaps cause problems with the usage of the impoundment as a potable water supply and as a recreational centre.

ACKNOWLEDGEMENTS

The help of Mrs A. Engelbrecht, Mr P.A. Joubert, Miss M. Pistorius and Mrs K. van Niekerk with the data collection and processing is gratefully acknowledged. Hydrological data were compiled from records of the Department of Water Affairs and the chemical analyses were done by the Chemical Division of the National Institute for Water Research.

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TABLE 1. Characteristics of New Doringpoort Dam and its catchment

Geographical location	25 ° 53,5'S; 29 ° 18,25'E
Magisterial district	Witbank
Catchment type	Agricultural and mines
Usage of dam	Industrial and potable water supply
Catchment area	3 627 km²
Inflowing river	Olifants
Dam wall completed	1953, raised 1973
*F.S.L. volume	109,1 x 10^6 m^3
F.S.L. area	13,03 km²
F.S.L. maximum depth	36 m
F.S.L. mean depth	10,6 m

*F.S.L. = full supply level

TABLE 2. Average hydrological characteristics of New Doringpoort Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	95,98	12,8
Area km^2	11,29	15,8
Mean depth m	8,5	3,9
Annual inflow x 10^6 m^3	130,31	145,5
Annual outflow x 10^6 m^3	114,20	149,3
Retention time a	0,84	—

*Average mean is based on monthly values and an annual cycle
Period: August to July (1973—1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for New Doringpoort Dam (Aug. 1977 — Jul. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	106,99	79,82	93,35	11,0	— 3
Area km^2	13,07	8,78	10,83	14,9	— 1
Mean depth m	9,0	8,1	8,6	3,9	1
Monthly inflow x 10^6 m^3	46,49	0	8,80	183,74	— 19
Monthly outflow x 10^6 m^3	36,82	0	6,83	157,21	— 29

*C.V. = coefficient of variation

TABLE 4. The physical and chemical characteristics of water collected from inflowing rivers, the outflow **and** dam station. Values are based on fortnightly samples collected between August 1977 and July **1978.**

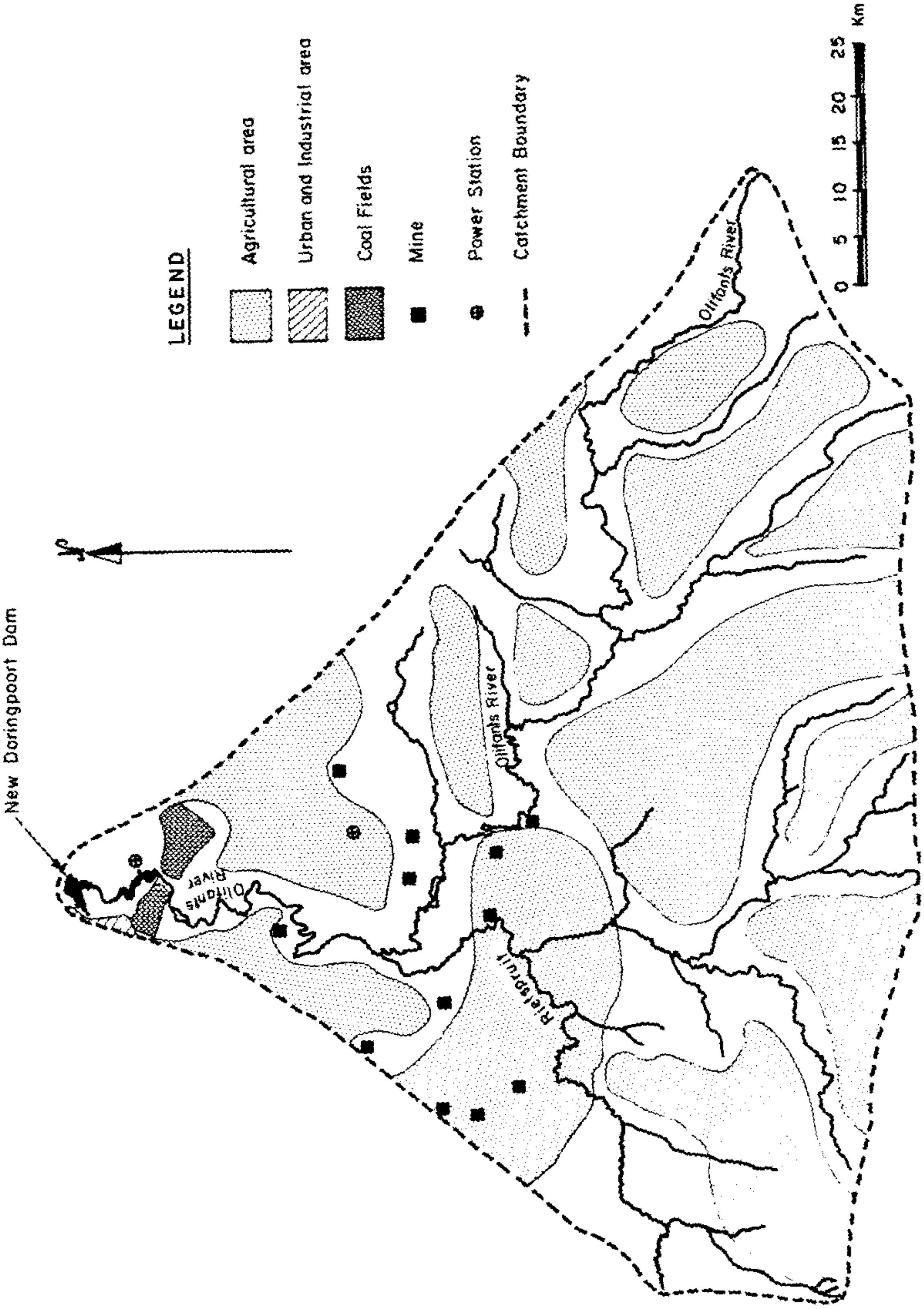
PARAMETER	DAM STATION								OLIFANTS RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	12,0	19,0	14,9	12	12,0	17,0	14,8	9	14,0	127,0	23,7	95	14,0	17,0	15,5	8
K	3,5	5,0	4,0	6	3,8	5,0	4,1	8	4,0	8,0	4,8	16	4,0	4,2	4,1	2
Ca	12,0	26,0	14,0	19	12,0	16,0	13,7	7	10,0	37,0	18,2	27	13,0	15,0	14,2	6
Mg	6,0	15,0	8,0	21	7,0	9,0	7,7	9	5,0	21,0	10,2	32	7,0	9,0	8,0	10
SO_4	12,0	40,0	30,7	19	23,0	50,0	31,3	18	27,0	118,0	48,8	40	25,0	33,0	30,2	10
Cl	7,0	12,0	8,6	16	7,0	13,0	8,5	15	7,0	53,0	14,2	63	8,0	22,0	14,8	44
Cond	13,0	26,0	17,4	16	9,5	18,8	15,3	13	17,5	84,0	25,1	17				
Alk	18,0	111,0	55,2	26	41,0	69,0	56,1	12	42,0	182,0	68,9	40	46,0	69,0	52,0	18
Tot Kj-N	0,160	1,550	0,589	52	0,160	1,570	0,617	60	0,250	1,575	0,744	41	0,260	1,250	0,653	41
Dis Kj-N	0,144	1,100	0,534	39	0,360	1,500	0,643	45	0,300	1,375	0,695	36	0,330	1,200	0,621	37
NH_4-N	0,042	0,270	0,140	47	0,026	0,500	0,158	65	0,020	0,300	0,127	60	0,035	0,250	0,117	53
NO_3-N	0,184	0,8	0,457	35	0,26	0,80	0,478	33	0,014	0,690	0,212	85	0,23	0,72	0,399	33
NO_2-N	0,002	0,027	0,008	73	0,002	0,026	0,007	78	0,002	0,028	0,008	69	0,008	0,027	0,009	79
Tot P	0,039	0,300	0,088	59	0,052	0,290	0,103	47	0,017	0,153	0,081	47	0,042	0,300	0,100	60
Tot dis P	0,021	0,350	0,093	67	0,037	0,425	0,112	69	0,010	0,360	0,074	91	0,042	0,600	0,122	104
PO_4-P	0,007	0,104	0,028	95	0,006	0,130	0,029	104	0,002	0,090	0,023	91	0,006	0,487	0,061	184
Fe	0,195	3,330	0,733	96	0,170	3,510	0,640	106	0,025	6,770	0,649	205	0,390	4,670	1.664	121
Mn	0,025	0,030	0,025	4	0,025	0,235	0,048	103	0,025	0,155	0,066	64	0,025	0,054	0,032	44
Temp	10,5	34,0	17,5	31	9,0	17,8	13,7	21	9,0	28,0	18,12	34				
DO	6,1	8,35	7,2	12	0,1	7,6	4,6	56								
Tu	59,0	87,0	76,4	11	58,0	120,0	90,3	18								
pH	6,66	8,9	7,76	6	7,0	8,5	7,6	5	7,0	8,8	7,7	6				

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of New Doringpoort Dam (August 1977 – July 1978)

Mean depth m	8,1
Retention time a	0,88
Hydraulic load m/a	9,20
Surface loading rates $g/m^2.a^{-1}$	
PO_4-P	0,28
Total P	0,91
Inorganic nitrogen	2,71
Total nitrogen	9,82

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	21,0	1,0	3,0
Secchi depth m	0,25	0,1	0,16


New Doringpoort Dam
N
LEGEND
Agricultural area
Urban and Industrial area
Coal Fields
Mine
Power Station
Catchment Boundary
0 5 10 15 20 25 Km
Olifants River
Olifants River
Olifants River
Rietspruit

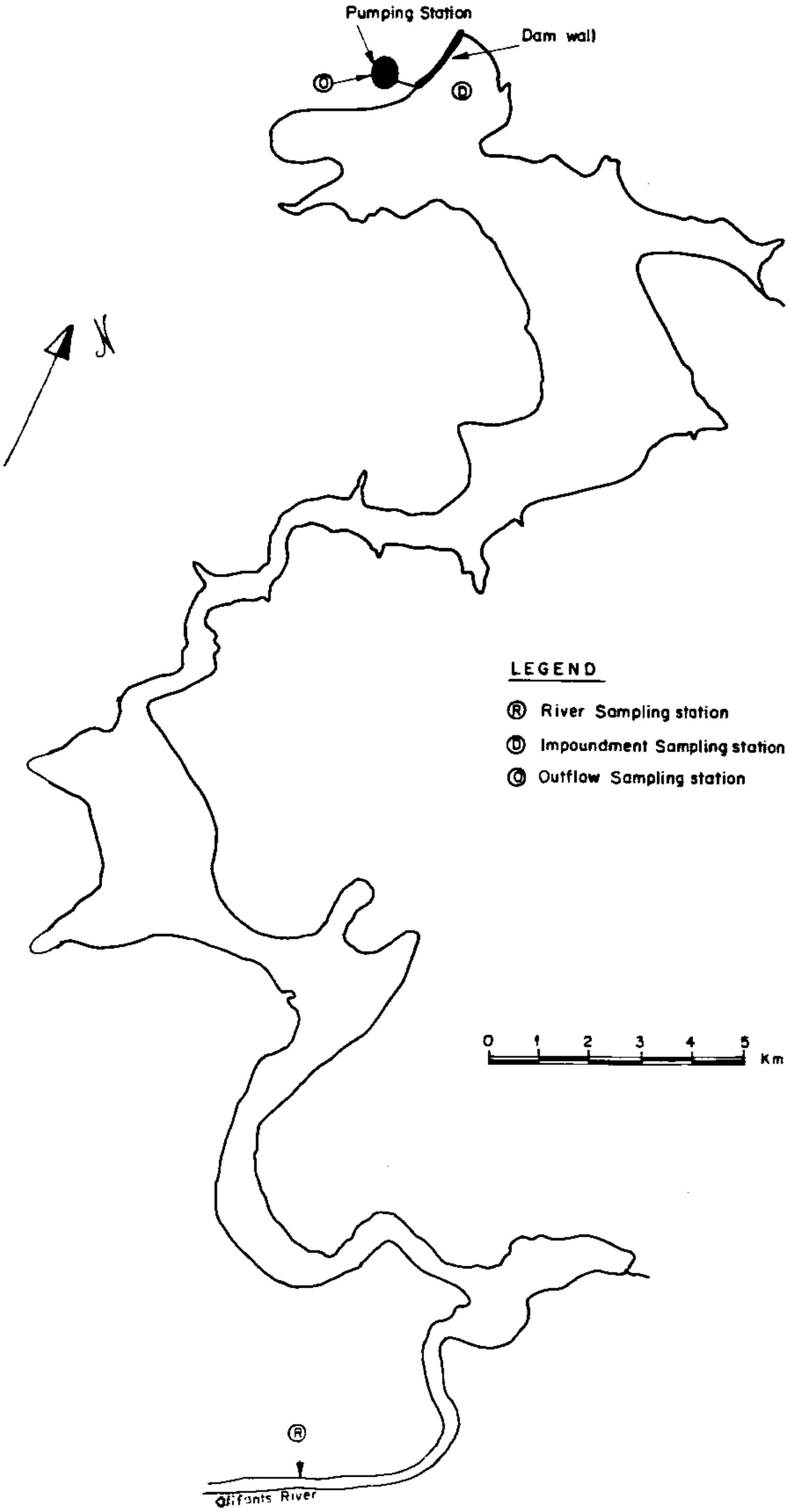


FIGURE 2. Map of New Doringpoort Dam showing sampling station.

NEW DORINGPOORT

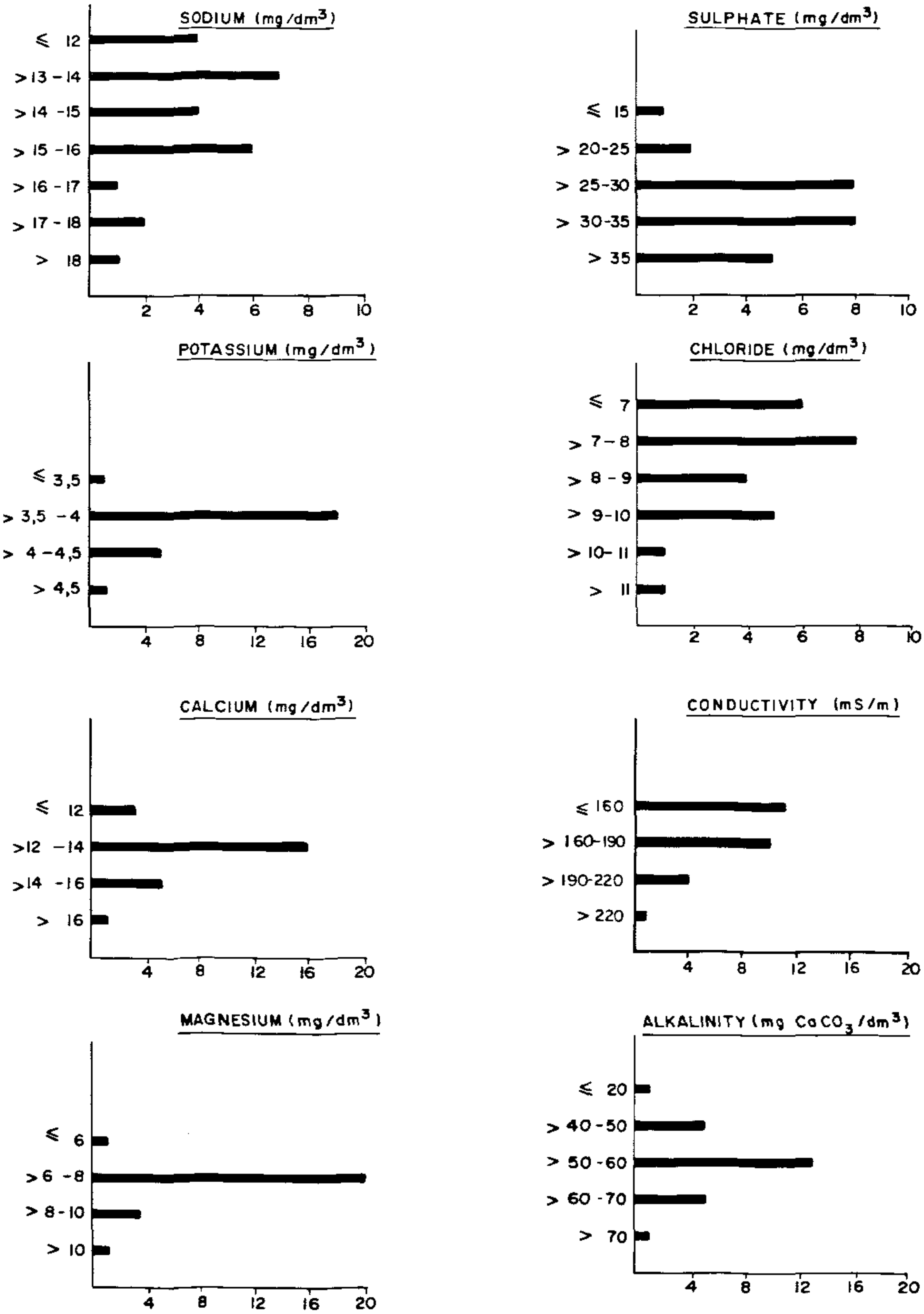


FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of New Doringpoort Dam.

NEW DORINGPOORT

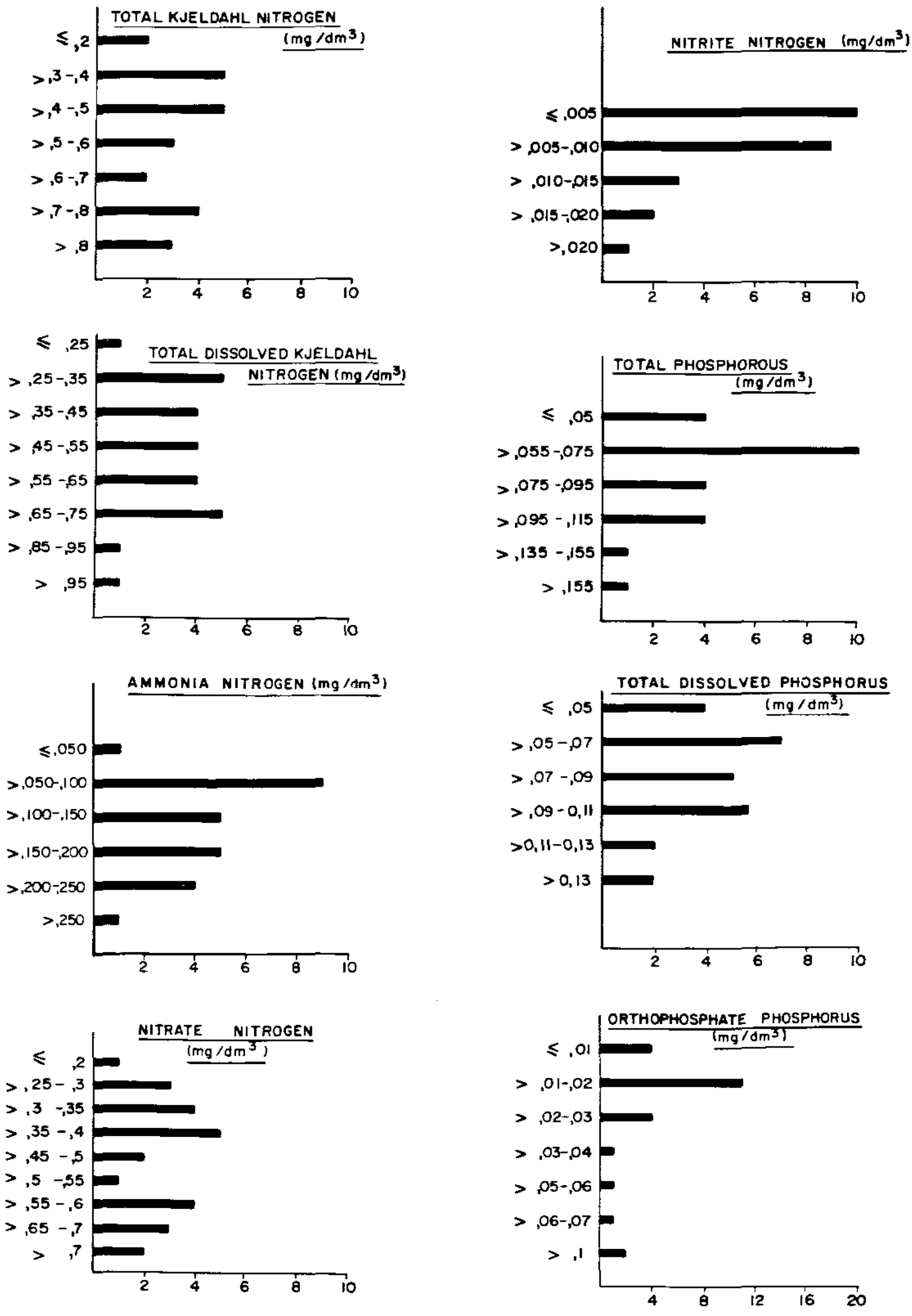


FIGURE 4. **Frequency histograms for selected parameters pertinent to the surface waters of New Doringpoort Dam.**

NEW DORINGPOORT

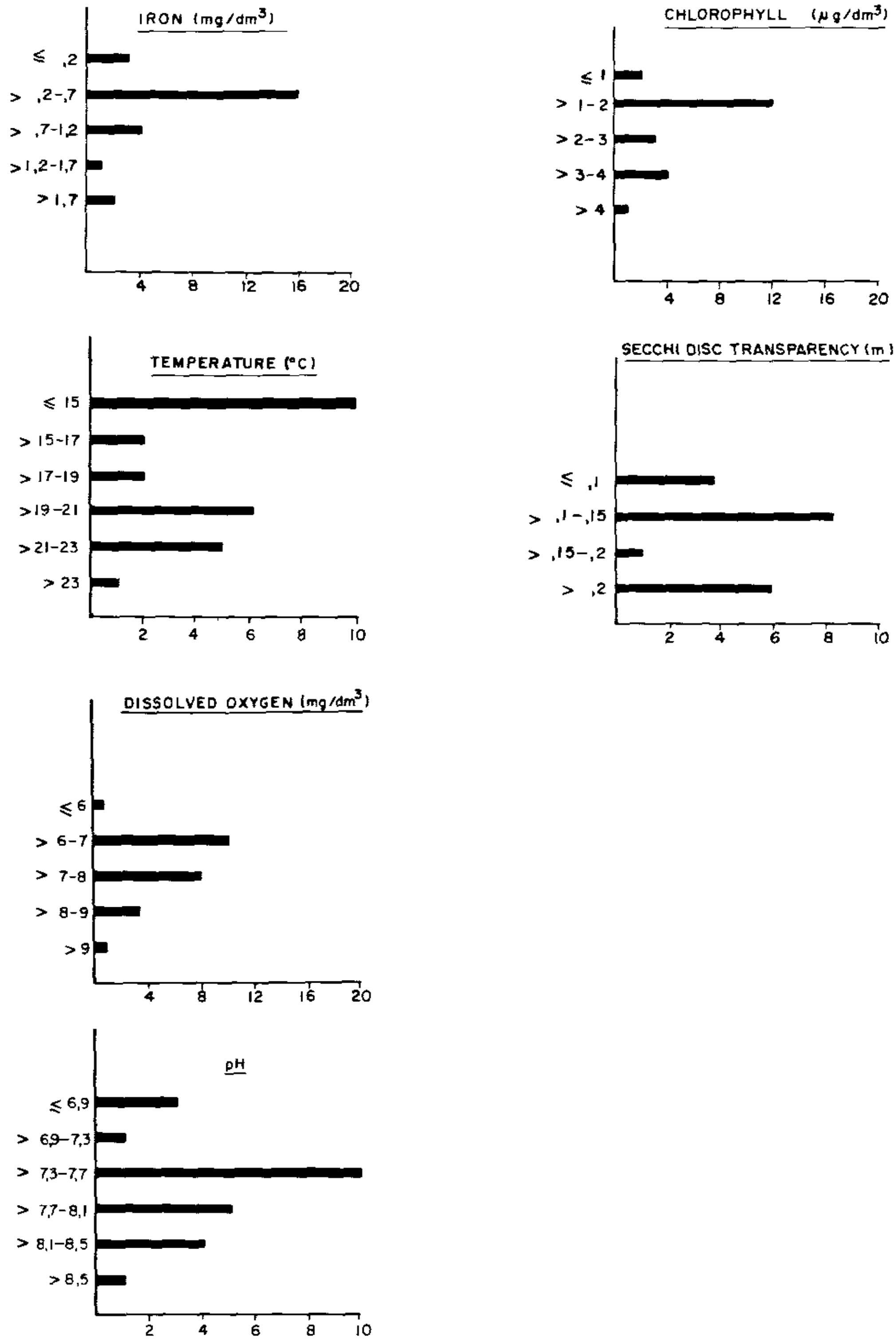


FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of New Doringpoort Dam.

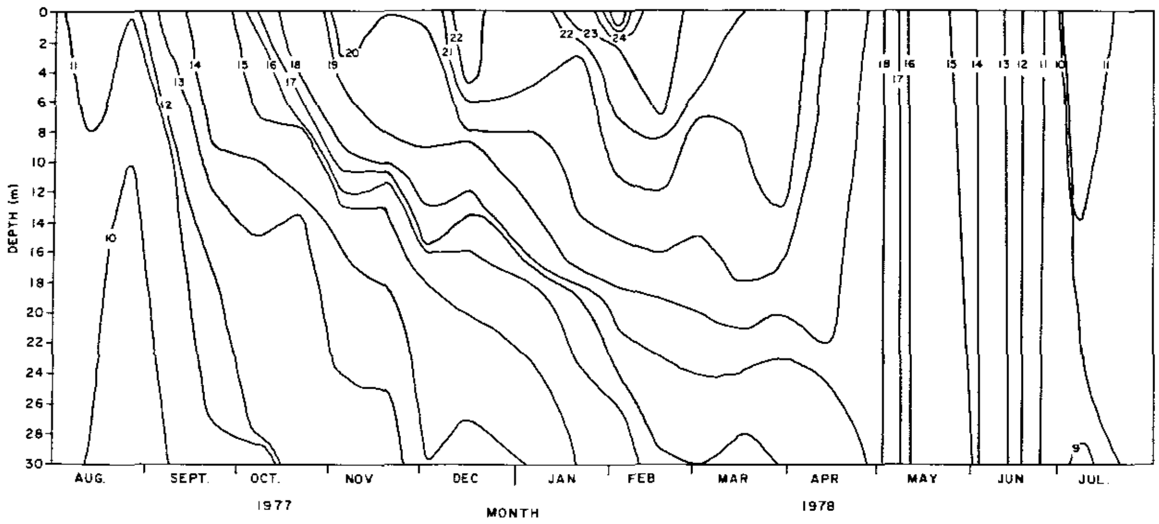


FIGURE 6. Temperature distribution in New Doringpoort Dam.

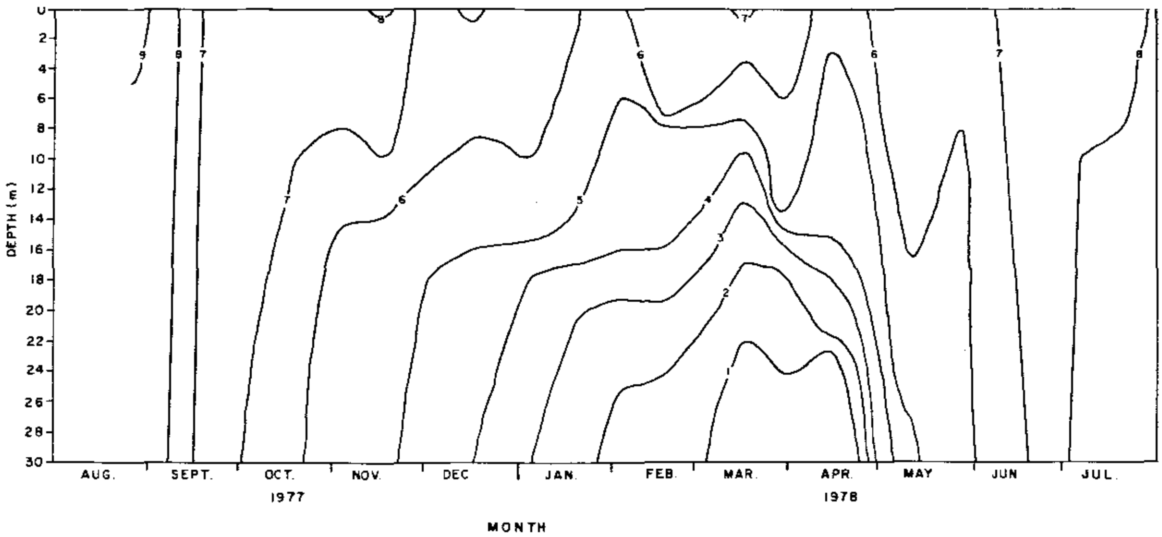


FIGURE 7. Dissolved oxygen distribution in New Doringpoort Dam.

BLOEMHOF DAM

by

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INTRODUCTION

Bloemhof Dam is situated 300 km south-west of the Witwatersrand on the Vaal River. The impoundment is owned by the Department of Water Affairs and is used mainly as an irrigation supply for the Vaalharts Irrigation Scheme. Some domestic water is supplied to the town of Bloemhof and to a minority of users downstream.

An algal bioassay survey of 98 South African impoundments ranked Bloemhof Dam as having the 44th highest algal growth potential (Toerien *et al.*, 1975). On a single visit to the impoundment during March 1971, Schutte and Bosman (1973) found no temperature stratification and only a slight reduction in dissolved oxygen concentration with depth. The occurrence of water hyacinth *(Eichhornia crassipes)* was reported in the Vaal River below Parys and in Bloemhof Dam (Toerien and Walmsley, 1977).

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment are shown in Table 1. The impoundment is fed by two major inflowing rivers, namely the Vaal River and the Vet River (Fig. 1). The Witwatersrand-Vereeniging complex is situated in the Vaal River catchment and water from this area reaches the Vaal via the Klip River. Further to the west the Mooi River drains the Potchefstroom area, also into the Vaal. The Vet River drains a catchment which has agricultural activities such as maize and sunflower cultivation as the major land use. There are also limited mining activities along the Vet and Sand rivers below Allemanskraal and Erfenis dams. Some of the area immediately adjacent to the dam has been developed as nature reserves by the Orange Free State and Transvaal Provincial Administrations. Large areas around the impoundment are also open to the public for fishing and recreational boating.

The impoundment has two sinuous shaped portions originating on each of the two influent rivers and joining near the dam wall. The results in this report represent the river sampling stations R1 and R2 and the impoundment sampling station D1 (Fig. 2). The impoundment is large and shallow with a maximum depth of 18 m and a mean depth of 4,5 m. The narrow sinuous shape of the impoundment does not lend itself to drawing a meaningful bathymetric map.

The mean retention time for the study period indicates that the impoundment has a moderate rate of replenishment compared with other South African impoundments (Walmsley *et al.*, 1978).

RESULTS AND DISCUSSION

A summary of the monthly hydrological characteristics of Bloemhof Dam from October 1977 to September 1978 are given in Table 2. The retention time for this impoundment was 0,55 years.

The results of chemical analyses of water from the two inflowing stations and the impoundment station are presented in Table 3. The mean nutrient levels of the impounded waters were 0,82 mg/dm^3 and 0,10 mg/dm^3 for nitrate nitrogen and orthophosphate phosphorus respectively. The mean conductivity of the impounded waters was 36,0 mS/m which was higher than a value of 23,8 mS/m reported by Schutte and Bosman (1973). The mean chloride value of 18,4 mg/dm^3, however, was much the same as that reported by Schutte and Bosman (1973). The mean Secchi transparency of 0,66 m showed the impoundment to be turbid. The frequency of occurrence of the different chemical constituents of the surface waters of Bloemhof Dam is shown in Figures 3 and 4. Nitrate nitrogen varied between 0,08 and 1,95 mg/dm^3, orthophosphate phosphorus between 0,02 and 0,32 mg/dm^3 and ammonia nitrogen between 0,05 and 0,22 mg/dm^3.

The temperature and dissolved oxygen isopleths for the period October 1977 to September 1978 are shown in Figures 5 and 6 respectively.

There was no pronounced temperature stratification during the study period although for a short period during October 1977 some stratification became evident. This same picture was evident for the dissolved oxygen regime of the impoundment and no anaerobic hypolimnion was detected. There were two periods, however, during which the dissolved oxygen levels dropped, namely during January 1978, and more pronounced during October 1978. The temperature and oxygen regimes are very much a result of the severe wind conditions that reign at Bloemhof Dam.

Of the total annual inflow into Bloemhof Dam only 6,9 % was contributed by the Vet River. Correspondingly only 8,8 % of the total orthophosphate phosphorus and 6,3 % of the total inorganic nitrogen load was contributed by the Vet River. Furthermore 47,3 % of the total annual orthophosphate phosphorus load entered the impoundment during the 3 months January to March 1978.

The orthophosphate phosphorus loading rate for Bloemhof Dam during the study period was 7,85 $g.m^{-2}.a^{-1}$ P and the inorganic nitrogen loading rate was 44,9 $g.m^{-2}.a^{-1}$ N. According to Vollenweider (1968) this would indicate that the impoundment was eutrophic. Coupled with this loading rate was a mean annual chlorophyll *a* value of 22,5 $\mu g/dm^3$ for monthly 5 m hosepipe samples.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to the following people who contributed toward the study: Mr P. van Deventer who assisted with the sampling; the Analytical Section of the Hydrological Research Institute who assisted with the analyses; Miss A. Gerber who did most of the data processing; Mr R.D. Walmsley for his assistance with the computer; and Mr M. Butty for supplying some of the hydrological data.

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TABLE 1. Characteristics of Bloemhof Dam and its catchment

Geographical location	27 ° 40,25'S; 25 ° 37'E
Magisterial district	Bloemhof
Catchment type	Urban, cultivated, uncultivated, mining
Usage of dam	Irrigation, minor domestic
Catchment area	107 911 km²
Inflowing rivers	Vaal, Vet
Dam wall completed	1970
*F.S.L. volume	1 273,0 x 10^6 m^3
F.S.L. area	228,214 km²
F.S.L. maximum depth	18 m
F.S.L. mean depth	4,5 m

*F.S.L. = full supply level

TABLE 2. A summary of monthly hydrological characteristics of Bloemhof Dam (Oct. 1977 – Sept. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3					
Area km²					
Mean depth m					
Monthly inflow x 10^6 m^3	1 717,876	349,513	693,352		
Monthly outflow x 10^6 m^3	–	–	–	–	–

*C.V. = coefficient of variation

TABLE 3. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Bloemhof Dam for October 1977 to September 1978.

PARAMETER	DAM STATION								VAAL RIVER				VET RIVER			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	17,5	32,2	22,1	18	17,9	34,0	22,1	21	18,3	114,1	48,5	69	15,3	58,6	34,7	48
K	2,6	5,2	4,3	16	2,4	5,1	4,3	20	4,05	7,36	5,22	20	3,4	8,3	5,3	32
Ca	23,7	38,7	27,6	15	24,2	39,6	28,7	20	16,0	64,7	35,0	46	21,9	76,6	47,1	43
Mg	11,8	23,3	14,9	24	12,1	24,7	15,0	27	6,9	32,4	16,4	46	10,1	43,3	27,2	46
SO_4	33,2	85,2	47,8	30	31,9	99,4	51,4	39	5,6	109,3	51,0	77	14,7	247,5	125,5	69
Cl	11,4	33,0	18,4	36	10,2	34,9	17,9	40	11,1	192,7	60,5	95	3,4	53,2	25,7	68
Si	0,06	5,24	2,64	85	0,06	5,31	2,79	75	2,06	5,45	4,16	26	0,74	7,9	4,00	66
Cond	31,6	49,1	36,0	13	31,4	53,6	36,3	16	25,1	106,7	50,6	53	26,6	89,8	57,4	40
Alk	86,1	150,8	113,6	16	84,7	143,7	113,2	16	54,3	225,2	146,8	31	92,9	196,1	157,2	20
Tot Kj-N																
Dis Kj-N																
NH_4-N	0,05	0,22	0,13	44	0,09	0,30	0,17	36	0,010	0,120	0,060	56	0,010	0,19	0,07	87
NO_3-N	0,08	1,95	0,82	80	0,12	1,82	0,85	81	0,03	1,57	0,24	192	0,010	1,320	0,350	129
NO_2-N																
Tot P																
Tot dis P																
PO_4-P	0,02	0,32	0,10	92	0,01	0,41	0,10	113	0,060	0,500	0,220	59	0,01	0,46	0,16	114
Fe																
Mn																
Temp																
DO																
Tu																
pH	7,4	8,2	7,7	4	7,3	8,1	7,7	3	7,2	7,6	7,4	2	6,9	8,0	7,5	5
SS																

*C.V. = coefficient of variation

TABLE 4. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Bloemhof Dam (October 1977 — September 1978)

Mean depth m	4,5		
Retention time a	0,55		
Hydraulic load m/a			
Surface loading rates g/m^2.a^{-1}			
PO_4-P	7,85		
Total P			
Inorganic nitrogen	44,9		
Total nitrogen	—		
	Maximum	**Minimum**	**Mean**
Chlorophyll *a* $\mu g/dm^3$	98	5	22,5
Secchi depth m	1,05	0,32	0,66

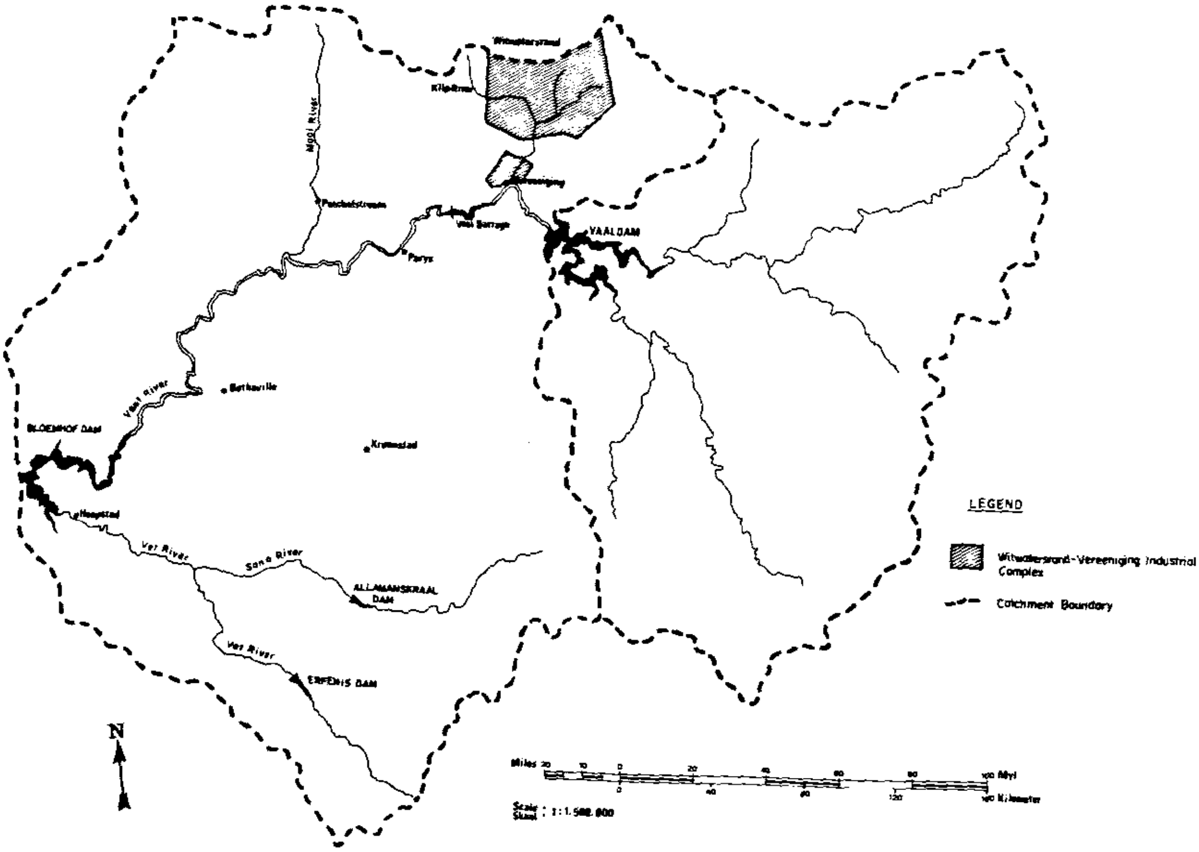

FIGURE 1. Bloemhof Dam catchment.

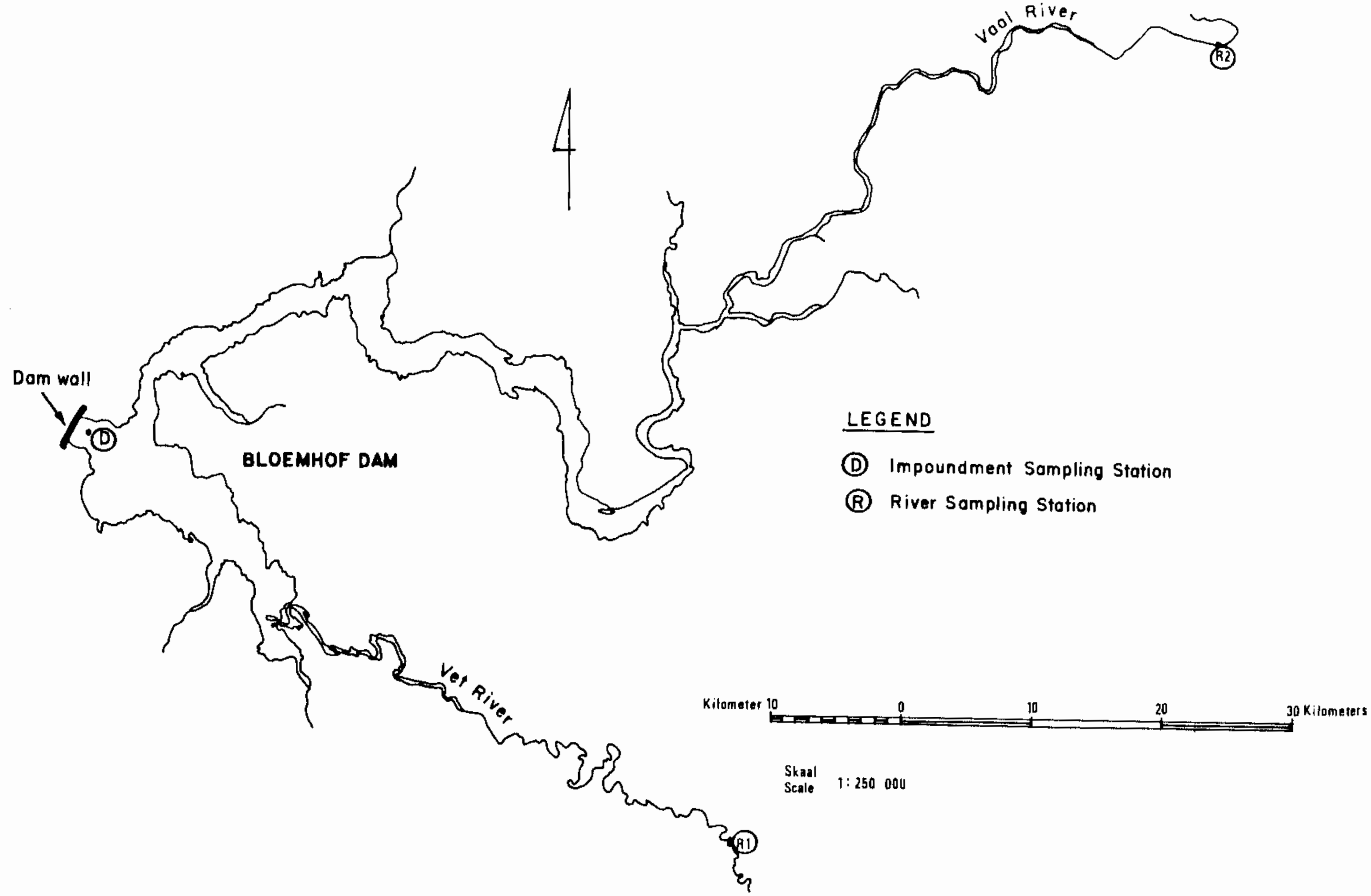

FIGURE 2. Map of Bloemhof Dam showing the location of the two inflow stations and the impoundment station.

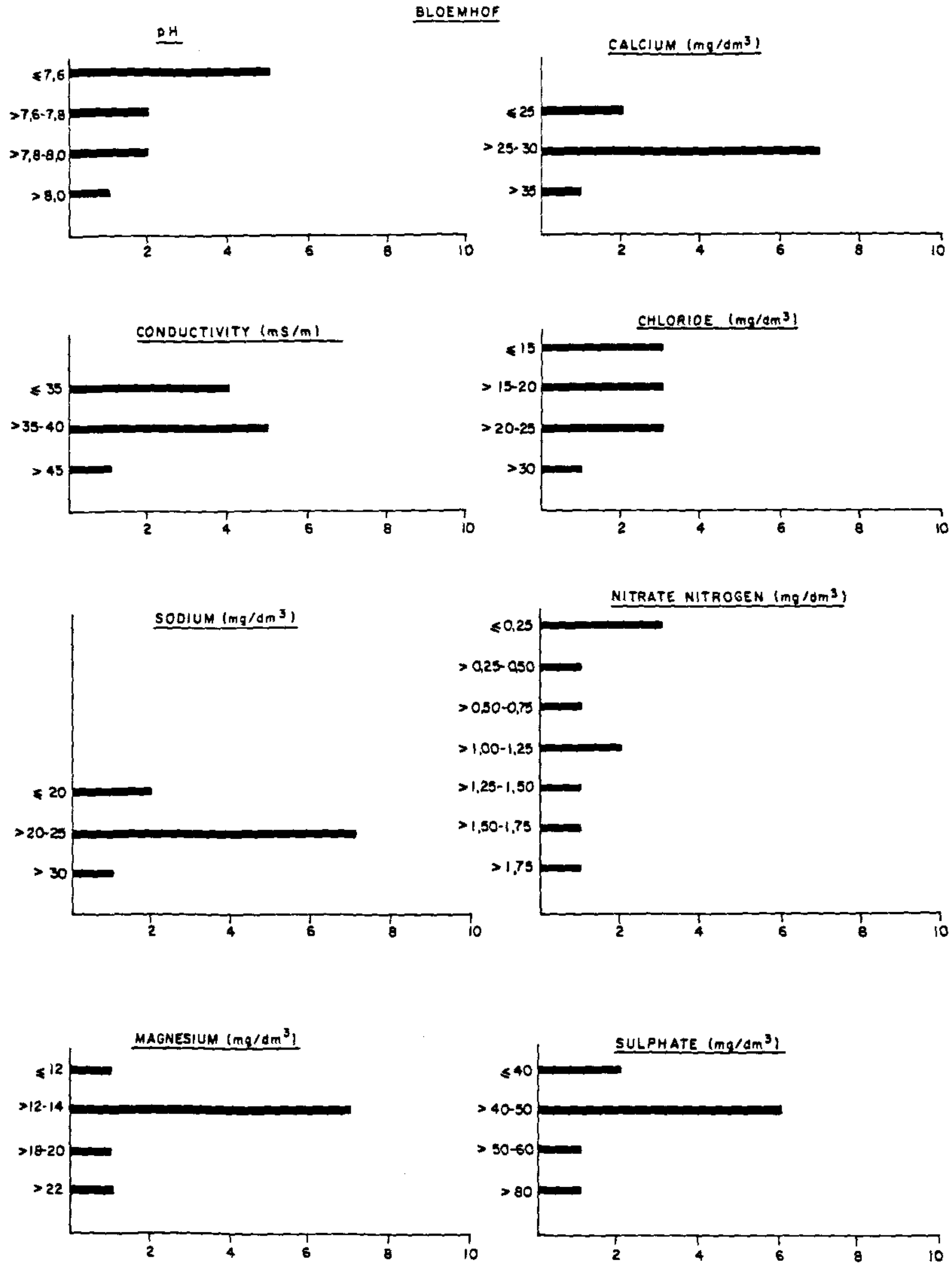

FIGURE 3. Frequency histograms for selected parameters for the surface waters of Bloemhof Dam.

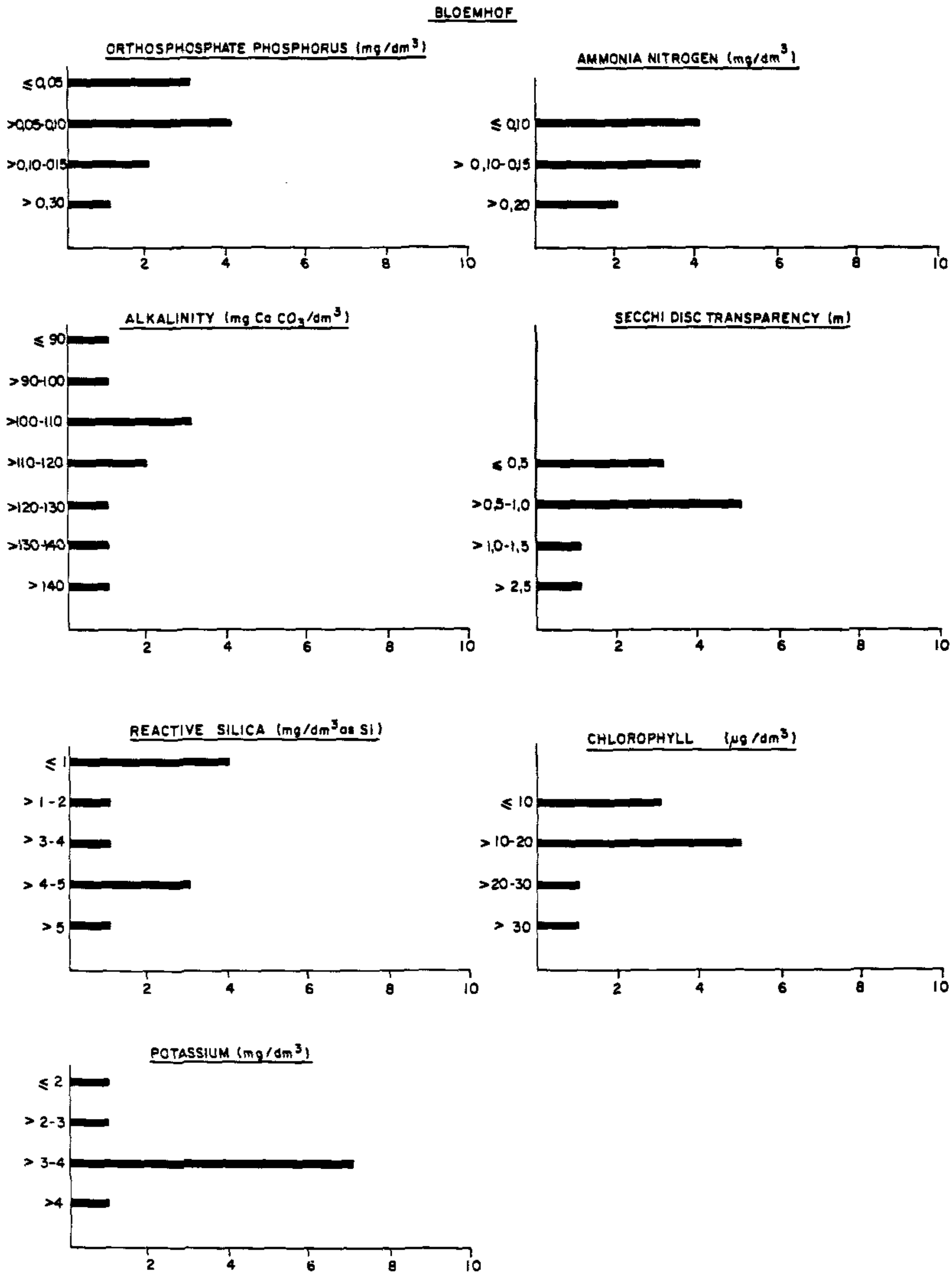

FIGURE 4. Frequency histograms for selected parameters for the surface waters of Bloemhof Dam.

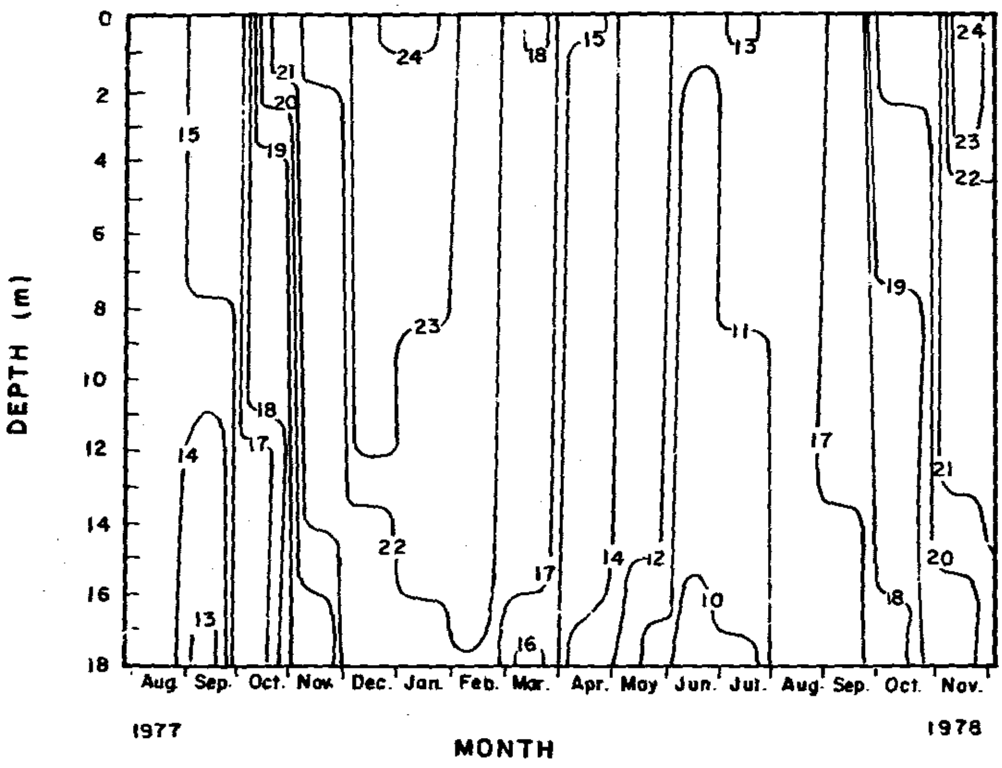

FIGURE 5. Temperature distribution in Bloemhof Dam (Oct. 1977 — Sept. 1978)

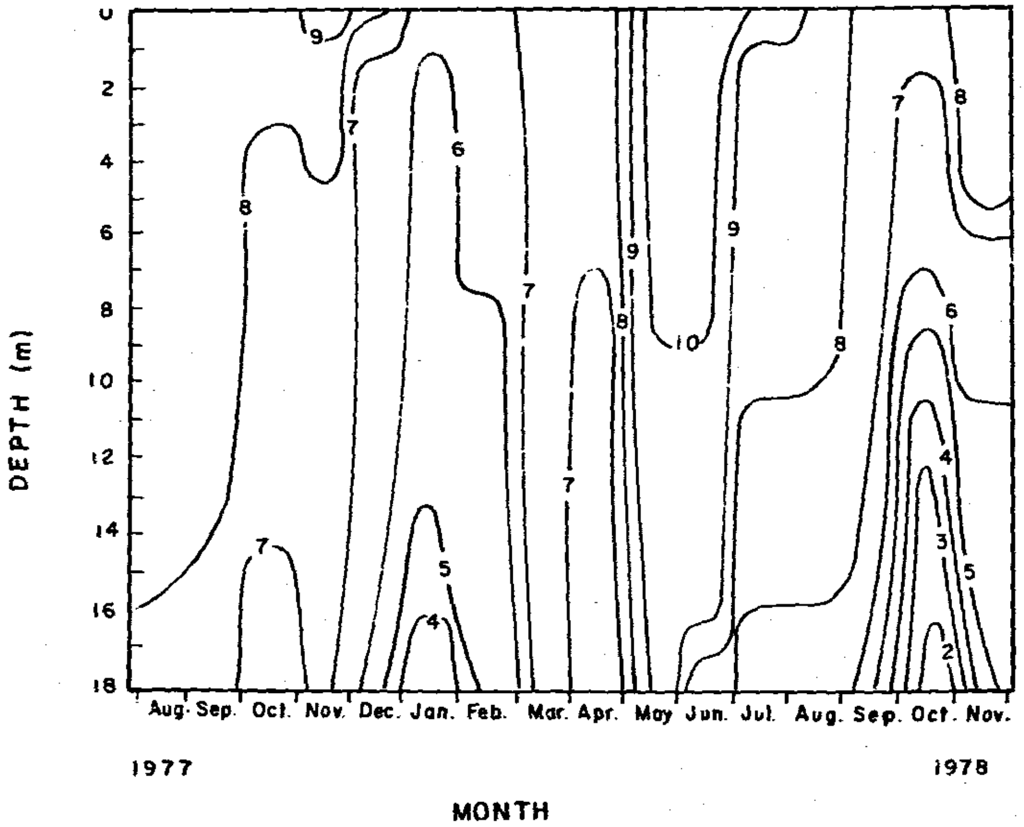

FIGURE 6. Oxygen distribution in Bloemhof Dam (Oct. 1977 — Sept. 1978)

RIETVLEI DAM

by

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INTRODUCTION

The limnology of Rietvlei Dam has been relatively well defined. A survey investigating various physical and chemical properties of southern African impoundments, showed Rietvlei Dam to have unstable thermal stratification and periods of oxygen super-saturation in summer as well as moderately mineralized waters (Schutte and Bosman, 1973). Anaerobic conditions were not encountered in the hypolimnion. A survey of 98 South African impoundments based on algal bioassays, ranked Rietvlei Dam as the most eutrophied impoundment in the country in terms of phosphorus availability, with an algal growth potential of 660 mg/dm^3 (Toerien *et al.*, 1975). Subsequent more detailed studies on the impoundment and its catchment confirmed the highly eutrophic nature of the impoundment and emphasized the variability in the algal populations due to the nitrogen-limited inflowing waters (Steÿn *et al.*, 1975; Ashton, 1976; Wamsley and Ashton, 1977; Walmsley *et al.*, 1978; Ashton, 1979; Toerien and Walmsley, 1979). Excessive algal populations have caused problems at the Rietvlei water purification works (Seaman and Pitt, 1979) and these problems are likely to continue in the foreseeable future.

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment are shown in Table 1. The impoundment is fed by one major inflowing river, the Hennops River, and four small intermittently-flowing streams which drain the area directly to the north and south of the impoundment (Fig. 1). The catchment area of Rietvlei Dam is used predominantly for agricultural purposes, with both cattle ranching and the cultivation of maize being important. The predominant vegetation type of the catchment area is highveld grassland (Acocks, 1975). The southern end of the catchment area contains mainly suburban and industrial areas forming part of the municipalities of Kempton Park and Benoni.

The Kempton Park sewage works are located on the headwaters of the Hennops River (Fig. 1). approximately 25 km upstream of the point where the Hennops River flows into Rietvlei Dam. The effluent from this sewage works contributes between 20 % and 70 % of the water and most of the nutrients that flow into Rietvlei Dam (Walmsley *et al.*, 1978; Toerien and Walmsley, 1979).

Most of the area immediately adjacent to the impoundment has been declared a game sanctuary, the Van Riebeeck Game Reserve. The remainder is open to the public for angling and yachting. The Rietvlei water purification works, located at the dam wall, supply between 10 % and 15 % of the daily water requirements of the city of Pretoria.

The impoundment's basin has a more or less equally shallow slope all the way around the perimeter, with the exception of the area near the dam wall and a portion of the south-eastern shoreline (Fig. 2). The impoundment is irregular in shape, having a length of 3,3 km and a maximum width of approximately 1,6 km. Sampling stations used during the study are indicated in Figure 2. Short-term hydrological characteristics of Rietvlei Dam (Table 2) show that the impoundment experiences a wide variation in hydrological conditions between years. The low mean water retention time (0,37 years) shows that the impoundment is well-flushed even during dry years, possibly as a consequence of the high effluent load from the Kempton Park Sewage Works.

RESULTS AND DISCUSSION

A summary of monthly hydrological characteristics of the impoundment for the study year (Jan. 1976 — Dec. 1976) shows that Rietvlei Dam received lower inflow than average (Table 3). Despite this, the mean water retention time was also low (0,33 years — Table 5). When monthly inflow was at a maximum, approximately 45 % of the impoundment's volume was replaced within one month, giving an actual water retention time of approximately 70 days. During the study, the draw-down of impounded water was initiated as a flood control strategy on 13 February 1976 and continued intermittently throughout the study. An interesting side effect of the draw-down was that the extensive marginal beds of *Potamogeton pectinatus* L. and *Potamogeton schweinfurthii* A. Benn were completely exposed, becoming dried out and succumbing to frost exposure during June and July 1976.

Chemical analysis of the inflow, outflow and impounded water showed that relatively high levels of dissolved nutrients and minerals were present (Table 4). The values obtained during the study showed few differences from those reported for the period February 1973/April 1975 (Walmsley *et al.*, 1978). Frequency histograms for the impoundment's surface water data are presented in Figures 3 and 4. In most cases the values for parameters were not normally distributed. The histograms do, however, give an indication of the frequency that a particular range of concentrations or values was measured. Of particular interest is the fact that nutrient concentrations (in the form of dissolved and particulate nitrogen and phosphorus compounds) were often high (Figs. 3 and 4). Chlorophyll *a* concentrations had a wide range (1,7 to 57,3 $\mu g/dm^3$), with a low mean value of 9,9 $\mu g/dm^3$ (Table 5). The high chlorophyll *a* values reflect the occurrence of discrete algal blooms during the spring and summer months. The wide range of pH values recorded in the impoundment reflects the poor buffering capacity of the waters, whilst the higher pH values are an indication of increased algal growth, particularly of blue-green algae. Secchi depth values showed considerable variation during the study (Fig. 4). The high frequency with which deep Secchi depth readings were recorded (60 % were deeper than 2,5 m) indicates that the impoundment cannot be considered to be turbid.

Temperature and oxygen isopleths (Figs. 5 and 6) indicate that a relatively unstable thermal layering developed in the impoundment during the early summer months. This is partly due to the shallowness of the impoundment and partly to the frequency of wind-mixing and high inflows of flood water. The inflow of flood waters during February 1976 reoxygenated the anaerobic layer as the inflowing water penetrated the impoundment as an underflow. During winter, oxygen was evenly distributed through the water column. However, intense oxygen stratification was recorded during algal blooms in spring and summer (Fig. 6).

Nutrient loading rates for inorganic and total nitrogen and total phosphate phosphorus (Table 5) differ from those estimated by Walmsley *et al.* (1978). This difference can be attributed to the more intensive sampling programme of this study which involved weekly sampling. The loading rates via the inflow for total nitrogen and phosphorus (31,8 $g.m^{-2}.a^{-1}$ and 32,49 $g.m.^{-2}.a^{-1}$ respectively — Table 5) are very high, indicating severe eutrophication (Vollenweider, 1968). The N:P mass ratio is approximately 1:1, demonstrating that the impoundment receives nitrogen-limited waters that will favour the growth of nitrogen-fixing blue-green algae. Measurements of nitrogen fixation rates, demonstrated by nitrogen-fixing blue-green algae, have shown that considerable quantities of nitrogen are fixed under favourable conditions (Ashton, 1979), increasing the calculated nitrogen loading rates for the impoundment. In this study, 9,5 $g.m^{-2}.a^{-1}$ of nitrogen was fixed by blue-green algae, 23 % of the total annual loading.

The results obtained for Rietvlei Dam between January and December 1976 confirm the hypereutrophic classification of the impoundment. The highest concentration of chlorophyll *a* (57,3 $\mu g/dm^3$) can be considered as being a level representing nuisance proportions. However, the short duration of the algal blooms, together with the moderately mineralized character of the surface waters indicates that these waters can also be considered to be of good quality and suitable for potable purposes.

ACKNOWLEDGEMENTS

The staff of the Rietvlei water purification works are acknowledged for providing the hydrological data. Thanks are also due to the colleagues who assisted with the sampling programme and the Analytical Division of the National Institute for Water Research, who carried out all the chemical analyses.

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TABLE 1. Characteristics of Rietvlei Dam and its catchment

Geographical location	25 ° 52,5'S; 28 ° 15,75'E
Magisterial district	Pretoria
Catchment type	Urban-industrial/agricultural
Usage of dam	Water supply, recreation, flood control
Catchment area	492 km²
Inflowing river	Hennops
Dam wall completed	1933
*F.S.L. volume	12,024 x 10⁶ m³
F.S.L. area	1,877 km²
F.S.L. maximum depth	17,17 m
F.S.L. mean depth	6,40 m

*F.S.L. = full supply level

TABLE 2. Short-term annual hydrological characteristics of Rietvlei Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	9,486	23,4
Area km^2	1,613	16,6
Mean depth m	6,03	7,4
Annual inflow x 10^6 m^3	42,245	78,2
Annual outflow x 10^6 m^3	47,019	73,2
Retention time a	0,37	68,5

*Average mean is based on monthly values and an annual cycle
Period: January to December (1975—1977);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Rietvlei Dam (Jan. 1976 — Dec. 1976)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	12,199	6,344	9,312	24	− 6
Area km^2	1,88	1,19	1,55	16	− 4
Mean depth m	6,48	5,32	5,93	7	− 2
Monthly inflow x 10^6 m^3	5,49	1,32	2,68	55	− 29
Monthly outflow x 10^6 m^3	5,31	0,63	3,09	52	− 21

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of water samples collected from the inflowing river (Hennops River), the outflow and a dam station (3) on Rietvlei Dam. Values are based on weekly samples collected between January 1976 and December 1976.

PARAMETER	DAM STATION								HENNOPS RIVER				OUTFLOW			
	TOP				BOTTOM											
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na																
K																
Ca																
Mg																
SO_4	42,0	49,0	46,0	7,8	34,0	40,0	38,0	9,1	52,0	63,0	56,7	10,0	38,0	49,0	42,7	13,3
Cl	20,0	22,0	21,0	4,8	21,0	21,0	21,0	0	19,0	24,0	21,0	12,6	20,0	22,0	21,0	48
Si	1,0	5,6	2,8	39,7	3,8	6,2	4,9	13,5	1,8	9,8	4,9	44,2	1,4	7,6	3,3	35,1
Cond	28,0	52,0	40,7	14,4	30,0	57,0	42,7	15,0	41,4	66,0	51,9	12,5	30,0	58,0	41,2	16,5
Alk	100,0	162,0	124,3	10,6	88,0	192,0	133,6	16,2	114,0	182,0	155,0	10,6	90,0	167,0	126,1	12,8
Tot Kj-N	0,4	4,2	1,8	43,5	1,5	6,4	2,7	32,3	0,8	3,7	1,4	38,1	0,8	3,9	1,8	31,3
Dis Kj-N	0,3	3,6	1,4	55,9	1,3	4,5	2,1	28,6	0,3	1,9	1,1	37,4	0,3	3,2	1,4	35,2
NH_4-N	0,020	0,400	0,107	79,2	0,050	2,500	0,640	92,8	0,046	0,257	0,138	33,7	0,062	0,950	0,251	63,0
NO_3-N	0,010	0,600	0,156	69,6	0,022	0,800	0,309	47,4	0,030	0,700	0,228	56,5	0,020	0,500	0,268	39,1
NO_2-N	0,002	0,030	0,009	70,8	0,002	0,200	0,033	108,2	0,002	0,030	0,009	69,9	0,002	0,180	0,015	172,2
Tot P	0,4	1,9	0,8	37,3	0,5	2,8	1,3	40,8	0,6	3,9	1,7	45,6	0,4	2,0	0,9	35,1
Tot dis P	0,2	1,8	0,65	48,4	0,3	2,5	0,93	50,5	0,5	2,7	1,22	39,7	0,3	1,8	0,72	40,7
PO_4-P	0,165	1,200	0,388	49,1	0,200	1,700	0,607	67,2	0,300	2,000	0,879	52,3	0,200	0,900	0,423	41,2
Fe																
Mn																
Temp	10,1	24,8	18,6	24,7	9,6	21,0	15,3	23,6								
DO	5,4	16,8	9,0	26,3	0	7,0	2,5	89,2								
Tu																
pH	7,75	9,25	8,31	5,4	7,30	8,45	7,70	3,7	7,60	8,30	7,85	2,6	7,50	8,90	8,04	4,1
Chl. *a*	2,7	57,3	9,9	104,2	0	0,3	0,05	228,7								

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Rietvlei Dam (Jan. 1976 — Dec. 1976)

Mean depth m	5,93
Retention time a	0,33
Hydraulic load m/a	17,97
Surface loading rates g/m².a⁻¹	
PO_4-P	15,82
Total P	32,49
Inorganic nitrogen (river)	8,0
Total nitrogen (river)	31,8
Nitrogen fixation	9,5

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	57,3	1,7	9,9
Secchi depth m	4,85	1,10	2,92

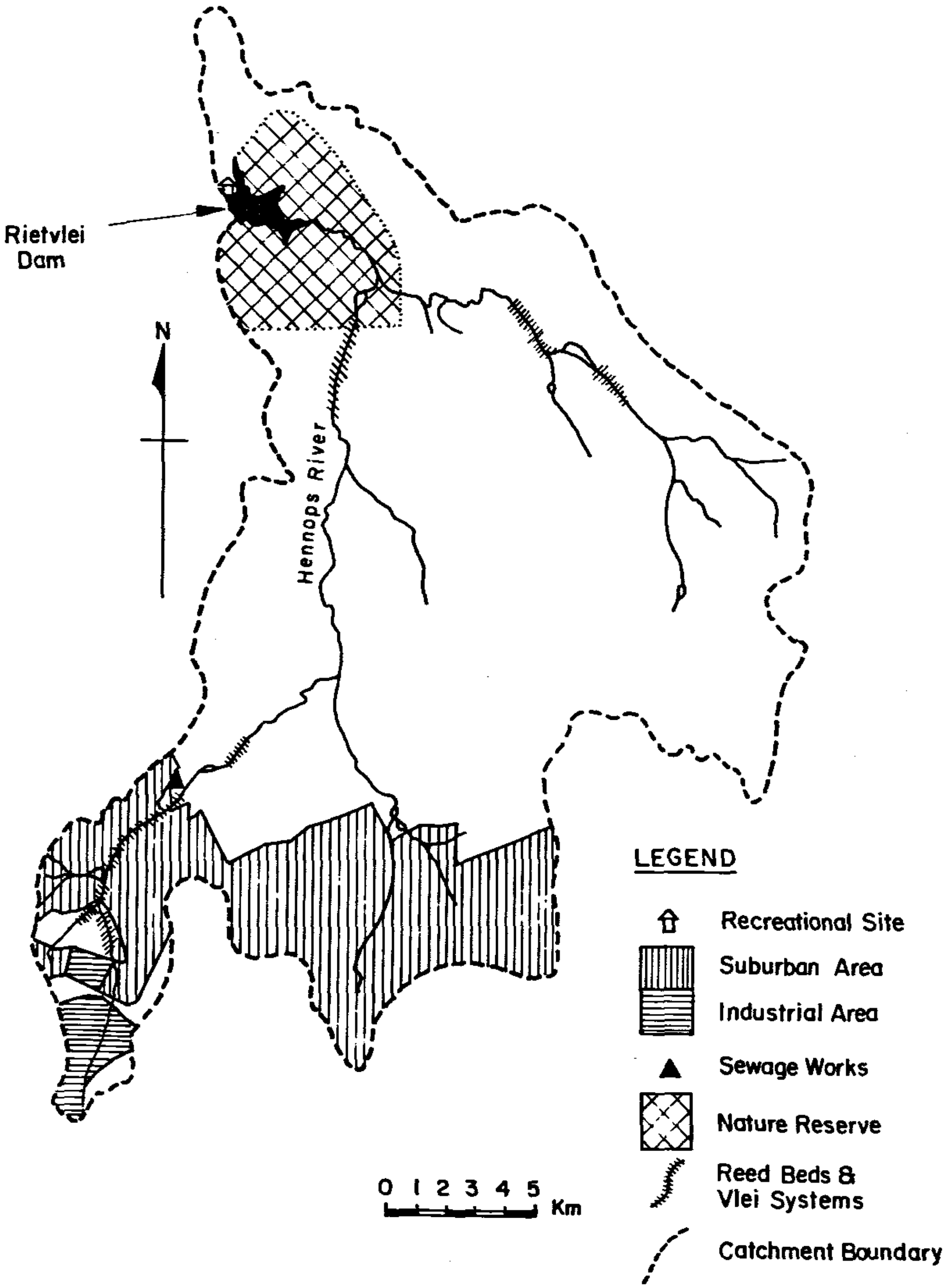

FIGURE 1. Rietvlei Dam catchment.

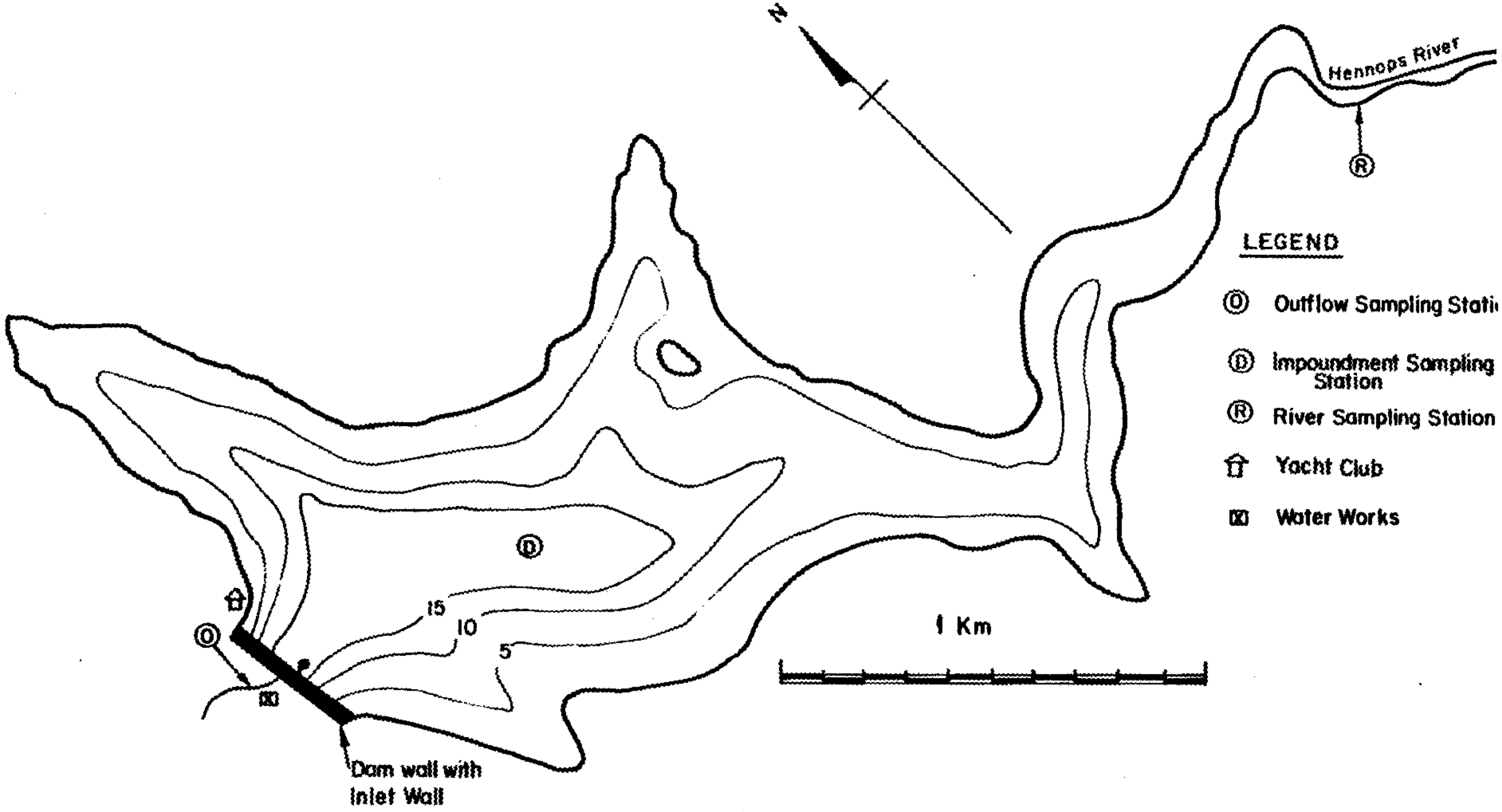

FIGURE 2. Map of Rietvlei Dam, showing depth contours, the location of the old stream and river courses, present lake level and location of inflow, outflow and lake sampling sites.

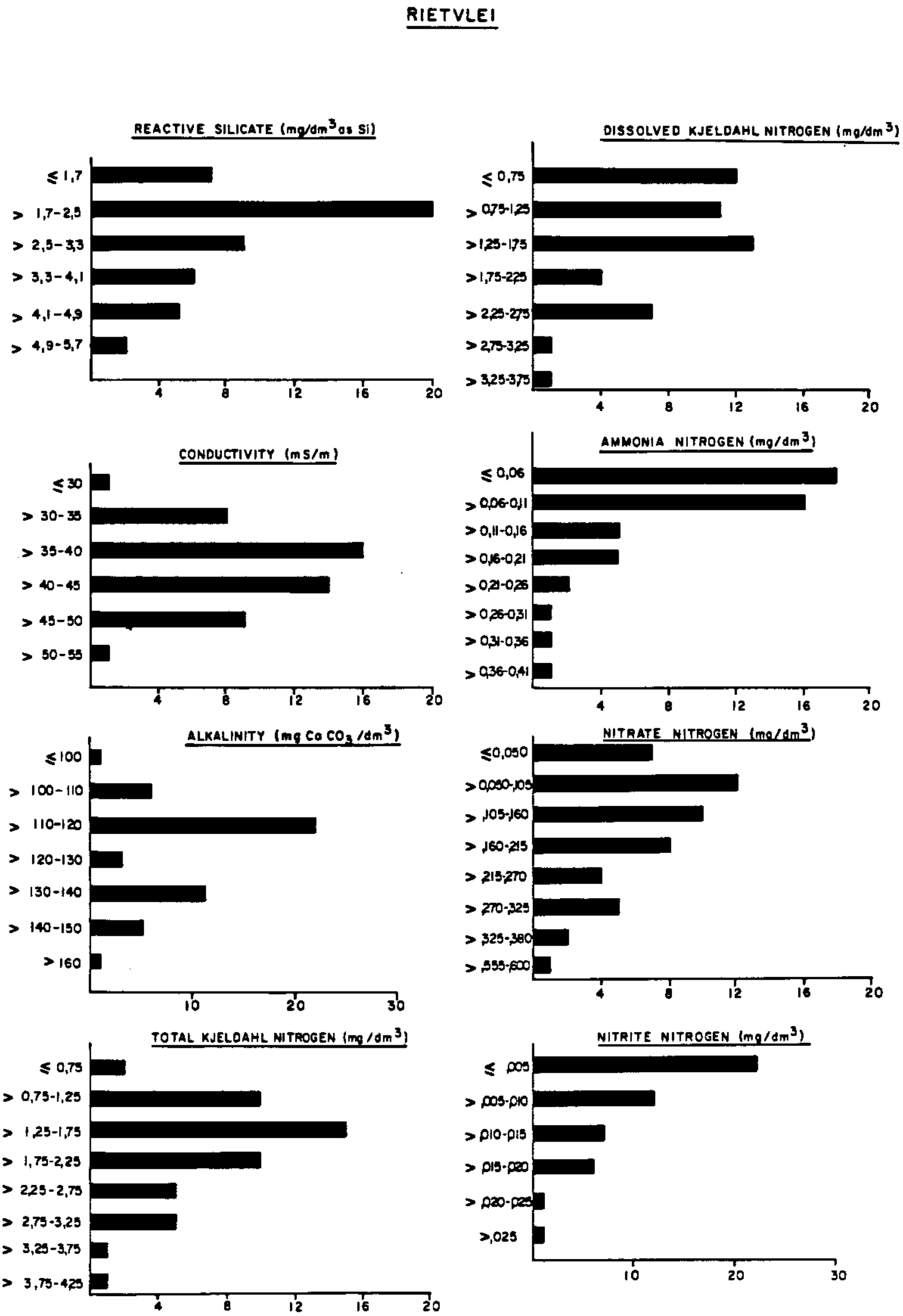

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Rietvlei Dam.

RIETVLEI

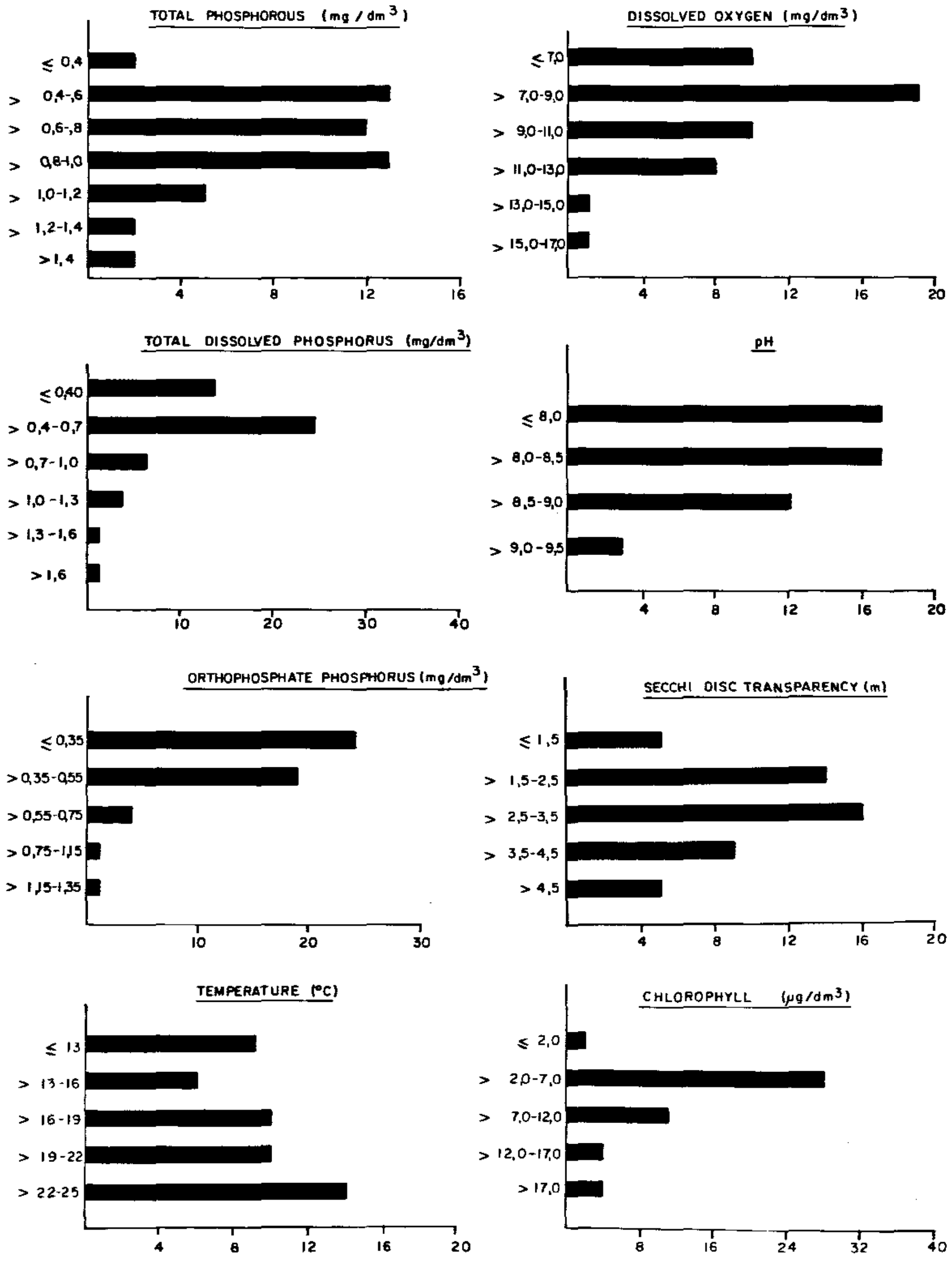

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Rietvlei Dam.

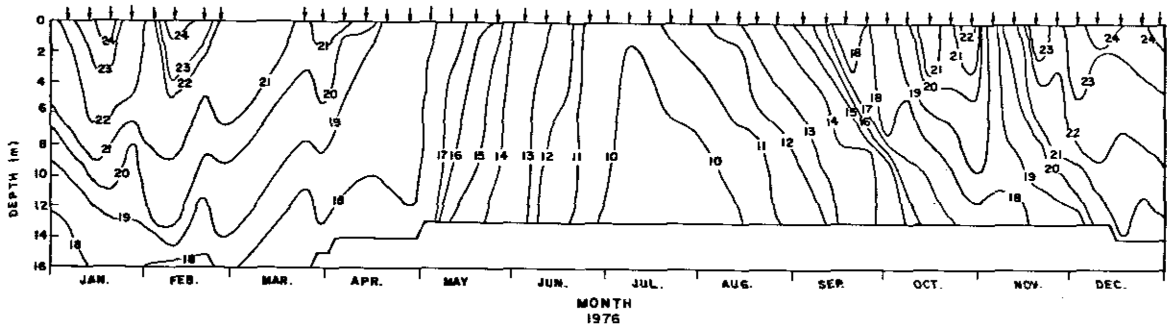

FIGURE 5. Distribution of isotherms in Rietvlei Dam (Jan. 1976 — Dec. 1976)

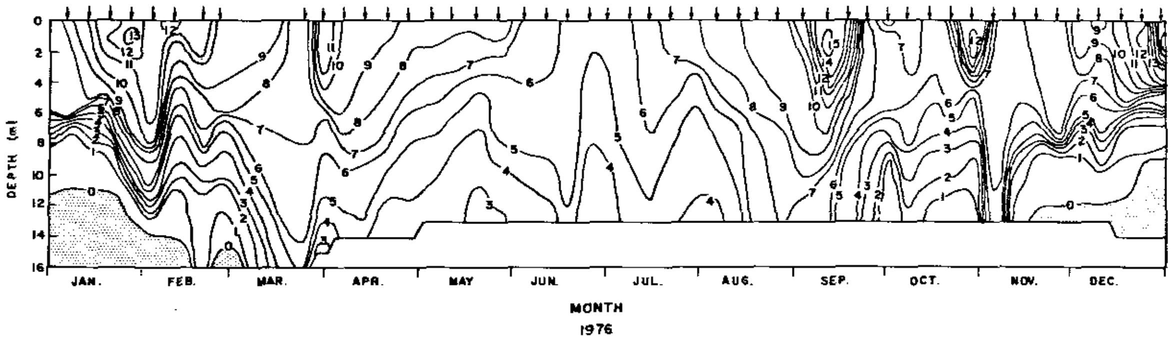

FIGURE 6. Distribution of oxygen isopleths in Rietvlei Dam (Jan. 1976 — Dec. 1976). [Sampling dates are arrowed; Hatched area indicates anaerobic zone; changes in water level are indicated at the bottom of each isopleth.]

ROODEPLAAT DAM

by

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INTRODUCTION

Roodeplaat Dam, situated approximately 20 km from Pretoria, has been studied extensively over a number of years, primarily to describe the limnological characteristics of the impoundment with regard to eutrophication.

On the basis of algal bio-assay studies, Steÿn *et al.* (1976) showed that the water of the Roodeplaat Dam was highly enriched, and Toerien *et al.* (1975) ranked this impoundment as being the third most eutrophic water body of the 98 South African impoundments investigated, and that algal growth is primarily limited by nitrogen. Results of Toerien and Steÿn (1975) indicated that both nitrogen and phosphate could be the primary growth-limiting nutrient depending upon the time of the year, while Pieterse and Toerien (1978) found statistically a better correlation between the average orthophosphate phosphorus and chlorophyll *a* concentrations over a two-year study period.

Toerien (1977) applied Vollenweider's eutrophication model (Vollenweider, 1972) to Roodeplaat Dam results, and showed that this impoundment (like Hartbeespoort and Rietvlei dams) falls well within the eutrophic category.

Walmsley *et al.* (1978b) described considerable horizontal variation in most chemical and biological characteristics of the water body, while Pieterse and Toerien (1978) illustrated gradients in nutrient and algal concentrations on the basis of which the following relationship between orthophosphate and chlorophyll *a* was determined:

$$\log_{10} \text{Chl } a \;=\; 1{,}232\,(\log_{10} PO_4\text{—}P) - 0{,}509$$

$$(r \;=\; 0{,}98; \quad n = 6)$$

where Chl a = mean annual surface chlorophyll a concentration in $\mu g/dm^3$
PO_4-P = mean annual surface orthophosphate phosphorus concentration in $\mu g/dm^3$

Pieterse and Toerien (1978) divided the impoundment into a more productive western and less productive eastern section, and suggested, together with the above regression line, that 26 $\mu g/dm^3$ PO_4-P represents a level beyond which algal nuisance conditions may develop in Roodeplaat Dam.

The present study presents a summary of results on certain physical, chemical and biological observations made during 1977 and 1978 in close proximity to the dam wall, relating it to observations made in the three inflowing streams. The Roodeplaat Dam study, together with several other South African impoundments, was included in a study to develop a eutrophication model applicable to South African conditions, for the following reasons: The impoundment is highly eutrophic due to a specific point source of enrichment; the impoundment has been studied rather intensively for a considerable period of time so that extensive historical data are available; the impoundment is an important recreational site; and it is used as a potable water supply source.

DESCRIPTION OF THE AREA

The Roodeplaat Dam (Fig. 1) is situated in the Pretoria district (23 ° 58'S; 27 ° 43'E). The dam wall was completed in 1959. Since that time the use of the dam for irrigational purposes has been curtailed, and it has become an important recreational site. Potable water from the dam is drawn by the Baviaanspoort Prison and the Department of Water Affairs.

The net capacity of Roodeplaat Dam is 41,9 x 10^6 m^3; it covers an area of 396 ha at full supply level, is 1 314 m above sea level, and has a mean depth of 10,6 m and a maximum depth of 43 m (Table 1).

The catchment (668 km^2) is situated in a summer rainfall region with an average annual rainfall of approximately 700 mm. Approximately 12 % of the catchment is urban/industrial (Fig. 1), 23 % is cultivated land, and the remainder comprises sour grassveld and mixed bushveld (Walmsley and Toerien, 1979).

Each of the three streams flowing into Roodeplaat Dam (Hartbeesspruit, Edendalespruit and Pienaars River), enters at a different point, and the water body has a sinuous shape (Fig. 2).

The Morelettaspruit/Hartbeesspruit system originates in an urban area of Pretoria and bypasses the industrial area of Silverton. The Edendalespruit drains agricultural land and grassland. The Pienaars River originates in a rural area, flows through the Mamelodi Township and then passes the Baviaanspoort Sewage Works which was commissioned in 1966 and which treats effluent from the Mamelodi Township (population 120 000 people in 1975). The sewage works discharges between 220 and 470 x 10^3 m^3 of treated effluent per month into the Pienaars River (Walmsley and Toerien, 1979) contributing up to 25 % of the total water inflow of the dam (Walmsley *et al.*, 1978a), at the same time being the primary nutrient source of the dam contributing up to 75 and 87 % of the dissolved nitrogen and phosphorus annual loading respectively (Walmsley and Toerien, 1979). In general, the inflow is seasonal with heavy flooding of the system occurring during the rainy summer months (Walmsley and Toerien, 1979). Walmsley *et al.* (1978b) estimated the mean water retention time as being 1,5 and 0,6 years for 1973/74 and 1974/75 respectively.

RESULTS AND DISCUSSION

The average mean inflow for the 12-month study period (see Table 3) comprised 110,964 x 10^6 m^3, giving a water retention time of 0,38 years (4,6 months) compared with the average mean annual inflow for the period 1970/78 of 59,01 x 10^6 m^3 (water retention time 0,7 years or 8,4 months; Table 2). The inflow for 1978 was therefore about twice the long-term inflow, indicating an above average wet summer.

A summary of the chemical characteristics of the dam water and the inflowing waters is presented in Table 4 and Figures 3 to 5. The concentration of some constituents were higher in the deep water compared with the surface water at the dam wall (e.g. Kjeldahl-nitrogen, ammonia-nitrogen, Total phosphate, Total dissolved phosphate and orthophosphate phosphorus).

The inflowing streams differed markedly in their chemical composition. In the Edendalespruit water the concentrations were generally lower than in the other inflowing waters, or in the impoundment itself. The mean concentrations of Na, Ca, Mg, SO_4 and Cl in the Hartbeesspruit water were in excess of that of the other two inflowing streams indicating a source of mineralized water. The results of Walmsley and Toerien (1979) were in general similar for the 1973/75 period. Pienaars River water had by far the highest concentrations of N- and P-containing substances. The concentrations of orthophosphate phosphorus, total dissolved phosphate, ammonia-nitrogen; nitrate-nitrogen, nitrite-nitrogen and dissolved Kjeldahl-nitrogen in the Pienaars River were lower than the values reported by Walmsley and Toerien (1979), possibly indicating a dilution effect.

Frequency histograms showing the ranges of values encountered for certain physical and chemical parameters are presented in Figures 3 to 5. A normal distribution around the mean was displayed only by the parameters conductivity and Kjeldahl-nitrogen.

The surface loading rates of phosphate- and nitrogen-containing substances are presented in Table 5. The orthophosphate-phosphorus loading (11,08 $g.m.^{-2}.a^{-1}$) for the 1978 period was higher than that of the 1973/74 (6,8 $g.m.^{-2}.a^{-1}$) and 1974/75 (7,3 $g.m.^{-2}.a^{-1}$) periods studied by Walmsley and Toerien (1979). When the retention time and surface loading rate of Total P are applied to the 1972 Vollenweider model, Roodeplaat Dam still falls well within the eutrophic category.

The mean available nitrogen (ammonia-nitrogen + nitrite nitrogen) to mean (available) orthophosphate phosphorus loading ratio comprised 12,1 compared with a ratio of 13,2 for inorganic nitrogen and orthophosphate phosphorus concentration in the surface water at the dam wall. These results appear to indicate that in Roodeplaat Dam inorganic phosphate would be more important as a growth-limiting nutrient than inorganic nitrogen.

Temperature and oxygen concentration conditions are presented in Figures 6 and 7. The water column appears to be stratified both in temperature and in oxygen between August and April. Temperature destratification occurred partly in January, but the oxygen deficit in the deep water appears to have been large enough so that the oxycline was maintained. From November to March water below the 10 m level was anaerobic, representing a volume of ~ 20 x 10^6 m^3, i.e. ~ 50 % of the total volume of the impoundment.

The incomplete temperature destratification in January was brought about by heavy rains and large inflows. The January inflow amounted to 63,27 x 10^6 m^3 (the highest value for the 1970/78 period) giving a water retention time of 0,6 months (18,6 days). During January, February and March Roodeplaat Dam had been flushed almost 3 times.

The above results clearly illustrate that the inflow volume is variable. Despite the variation in inflow volume the water level, surface area and water volume of Roodeplaat Dam were relatively constant during the study period (see Table 3).

The mean chlorophyll *a* concentration of the surface waters at the dam wall station was 17 $\mu g/dm^3$ (standard deviation

16 $\mu g/dm^3$) for 1978, compared with 19,7 $\mu g/dm^3$ (standard deviation 12,5) for 1976 to 1977 (Pieterse and Toerien, 1978), and ~ 14 $\mu g/dm^3$ for 1973 to 1975 (calculated from Walmsley and Toerien, 1978b). It therefore appears that the annual mean chlorophyll *a* concentration at the dam wall is fairly constant.

A total number of approximately 80 phytoplankton species were identified from the Roodeplaat Dam, while algae like *Microcystis aeruginosa, Anabaena circinalis* and *Melosira granulata* appear to be the dominant populations (Pieterse and Röhrbeck; unpublished results).

ACKNOWLEDGEMENTS

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TABLE 1. Characteristics of Roodeplaat Dam and its catchment

Geographical location	23 ° 58'S; 27 ° 43'E
Magisterial district	Pretoria
Catchment type	Urban/industrial, farmland, mines
Usage of dam	Recreation, potable water
Catchment area	668 km^2
Inflowing rivers	Pienaars River, Hartbeesspruit, Edendalespruit
Dam wall completed	1959
*F.S.L. volume	41,907 x 10^6 m^3
F.S.L. area	3,96 km^2
F.S.L. maximum depth	43 m
F.S.L. mean depth	10,6 m

*F.S.L. = full supply level

TABLE 2. Average term annual hydrological characteristics of Roodeplaat Dam

	*Average mean	*C.V. %
Volume x 10^6 m^3	41,425	3,3
Area km^2	3,898	2,6
Mean depth m	10,57	0,7
Annual inflow x 10^6 m^3	59,01	
Annual outflow x 10^6 m^3	55,68	
Retention time a	0,70	

*Average mean is based on monthly values and an annual cycle:
Period: January to December (1970 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Roodeplaat Dam (Dec. 1977 – Dec. 1978) 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	42,427	41,568	42,184	0,52	
Area km^2	3,969	3,909	3,952	0,34	
Mean depth m	10,6	10,6	10,6	0	
Monthly inflow x 10^6 m^3	63,272	0,075	9,247	198,8	
Monthly outflow x 10^6 m^3	63,780	0,671	9,219	201,8	

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of water collected from the inflowing rivers and dam wall station on Roodeplaat Dam. Values are based on bi-weekly samples collected over an annual cycle between Dec. 1977 and Dec. 1978

PARAMETER	DAM STATION TOP				DAM STATION BOTTOM			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	10,100	27,600	16,238	34	6,700	25,400	14,256	38
K	0,300	3,430	2,213	44	0,300	7,440	2,418	59
Ca	12,00	23,800	19,488	16	1,200	31,100	20,388	35
Mg	7,800	21,400	15,685	20	7,400	21,400	14,364	30
SO_4	7,500	25,000	16,838	31	6,100	22,500	13,748	32
Cl	8,700	41,500	19,946	53	7,400	45,300	18,342	53
Si	0,010	7,030	3,814	64	0,010	6,540	4,873	33
Cond	17,9	41,0	30,9	18	10,3	44,8	29,7	27
Alk	50	140	115	20	28	195	114	31
Tot Kj N	0,050	1,430	0,688	55	0,057	2,940	1,082	67
Dis Kj N	0,020	1,180	0,465	55	0,220	1,880	0,880	61
NH_4 N	0,050	0,966	0,242	102	0,070	2,201	0,665	85
NO_3 N	0,023	1,127	0,444	78	0,016	1,199	0,371	109
NO_2 N								
Tot P	0,030	0,210	0,075	65	0,050	0,730	0,163	96
Tot dis P	0,020	0,120	0,052	55	0,028	0,235	0,091	63
PO_4 P	0,010	0,280	0,052	109	0,010	0,138	0,074	77
Fe	0	0,660	0,281	66	0	0,630	0,276	60
Mn								
Temp	11,9	28,4	20,8	24	11,3	18,5	14,2	19
DO	2,56	14,00	7,61	36	0	5,9	1,24	54
Tu								
pH	7,0	10,1	8,0	7,6	6,5	8,5	7,7	6,8
SS								

PARAMETER	PIENAARS RIVER				HARTBEESSPRUIT				EDENDALESPRUIT			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	7,200	44,700	25,877	45	11,000	78,600	39,615	38	4,800	42,200	14,433	55
K	0,230	4,460	3, 728	74	0,230	6,980	2,317	68	0,120	4,700	1,785	58
Ca	10,000	39,104	10,000	22	15,200	53,500	38,850	23	9,400	43,900	20,013	36
Mg	12,800	27,000	21,919	18	10,500	37,400	27,227	26	8,000	36,9	16,017	35
SO_4	0,600	67,000	33,358	57	11,000	99,800	45,712	41	0	44,700	5,283	170
Cl	2,300	63,100	22,412	60	11,400	99,800	61,969	38	1,300	83,500	12,000	140
Si	0,040	9,870	8,465	24	0,060	9,980	8,012	27	0,030	9,480	8,645	25
Cond	13,6	62,0	43,3	30	17,8	96,0	78,7	33,2	13,8	78,8	30,3	40
Alk	82	213	170	20	78	219	178	21	74	194	136	23
Tot Kj N	0,080	4,560	1,566	59	0,090	2,080	0,675	64	0,030	1,420	0,521	65
Dis Kj N	0,400	5,780	1,571	77	0,200	1,830	0,679	59	0,070	1,100	0,430	64
NH_4 N	0,047	3,593	0,934	95	0,060	2,567	0,416	130	0,054	3,070	0,360	186
NO_3 N	0,200	6,007	2,858	57	0,140	3,416	2,201	50	0,023	4,760	0,663	145
NO_2 N												
Tot P	0,040	4,760	1,463	88	0,030	0,140	0,079	58	0,010	0,215	0,084	80
Tot dis P	0,176	4,540	1,471	85	0,010	0,130	0,045	62	0,010	0,180	0,041	111
PO_4 P	0,030	5,830	1,336	108	0,010	1,573	0,110	285	0	2,940	0,265	272
Fe	0	1,170	0,284	96	0	0,710	0,365	63	0	1,230	0,365	82
Mn												
Temp												
DO												
Tu												
pH	6,5	8,8	8,0	6,3	6,8	8,7	8,0	5,4	7,2	8,7	8,0	5,2
SS												

*C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Roodeplaat Dam (Dec. 1977 – Dec. 1978)

Mean depth m	10,6
Retention time a	0,38
Hydraulic load m/a	27,9
Surface loading rates $g/m^2.a^{-1}$	
PO_4-P	11,08
Total P	14,97
Inorganic nitrogen	134,45
Total nitrogen	156,78

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	52	2	17
Secchi depth m	8,800	1,000	3,492

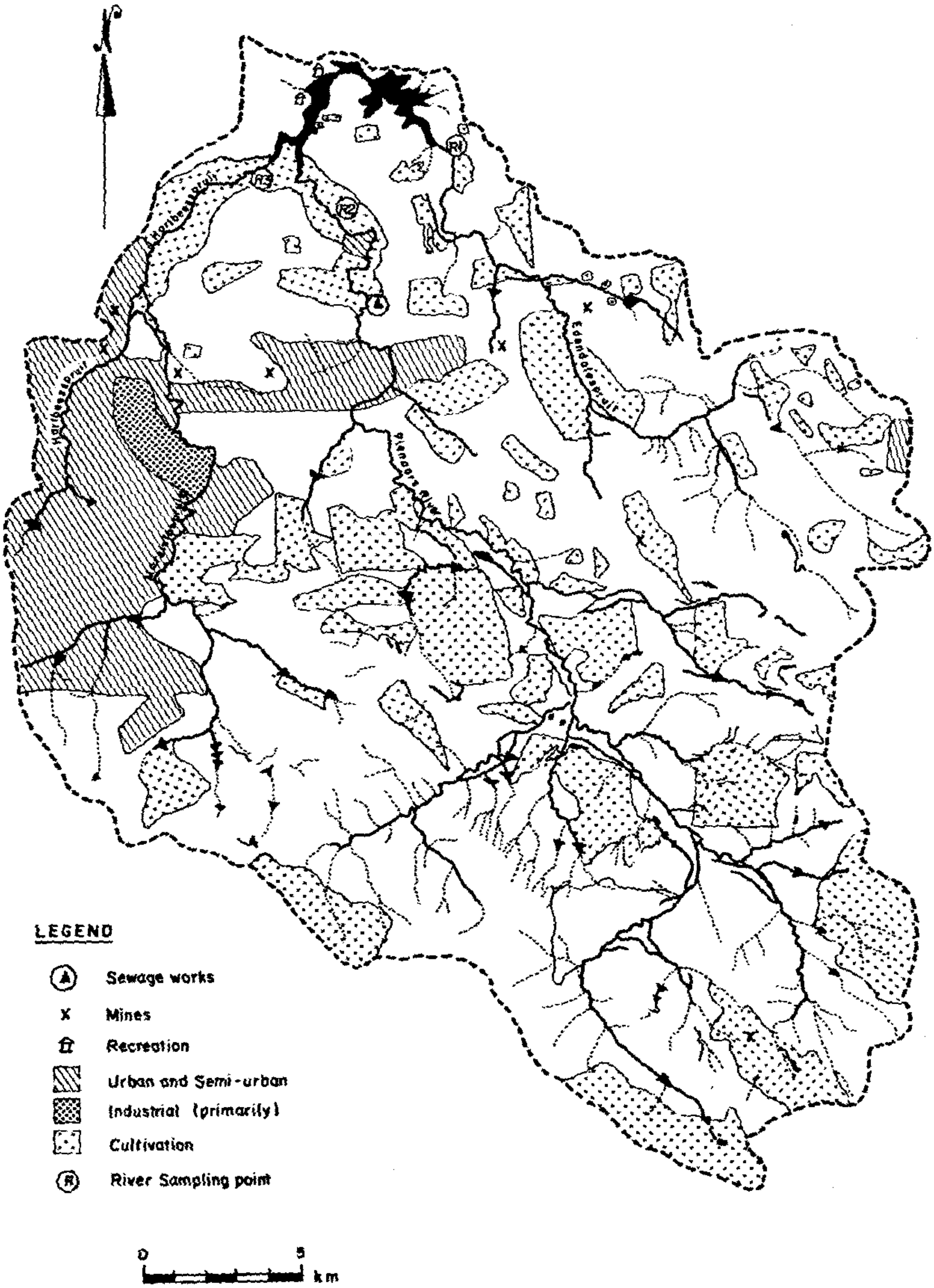

FIGURE 1. Roodeplaat Dam catchment.

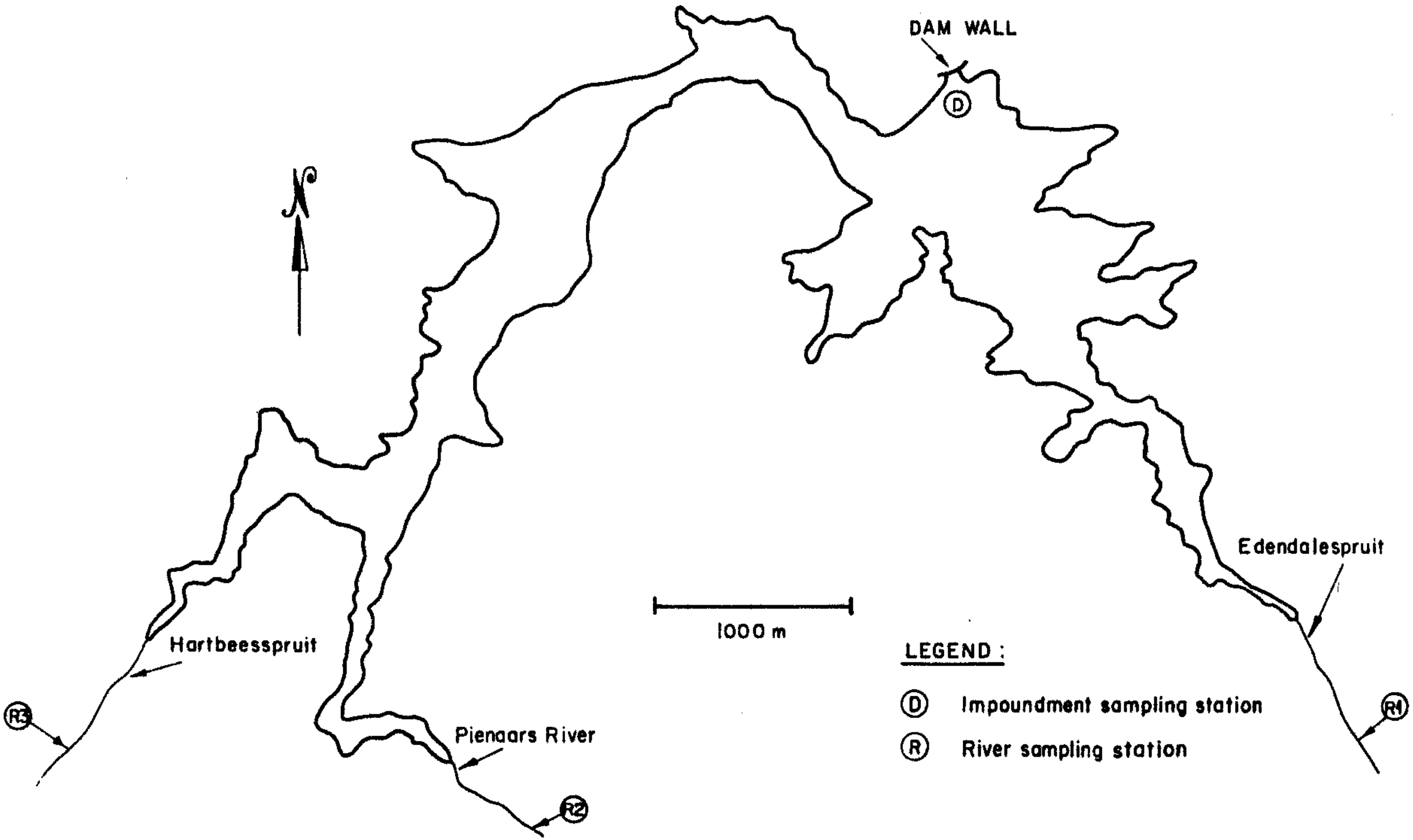

FIGURE 2. Map of Roodeplaat Dam showing sampling stations.

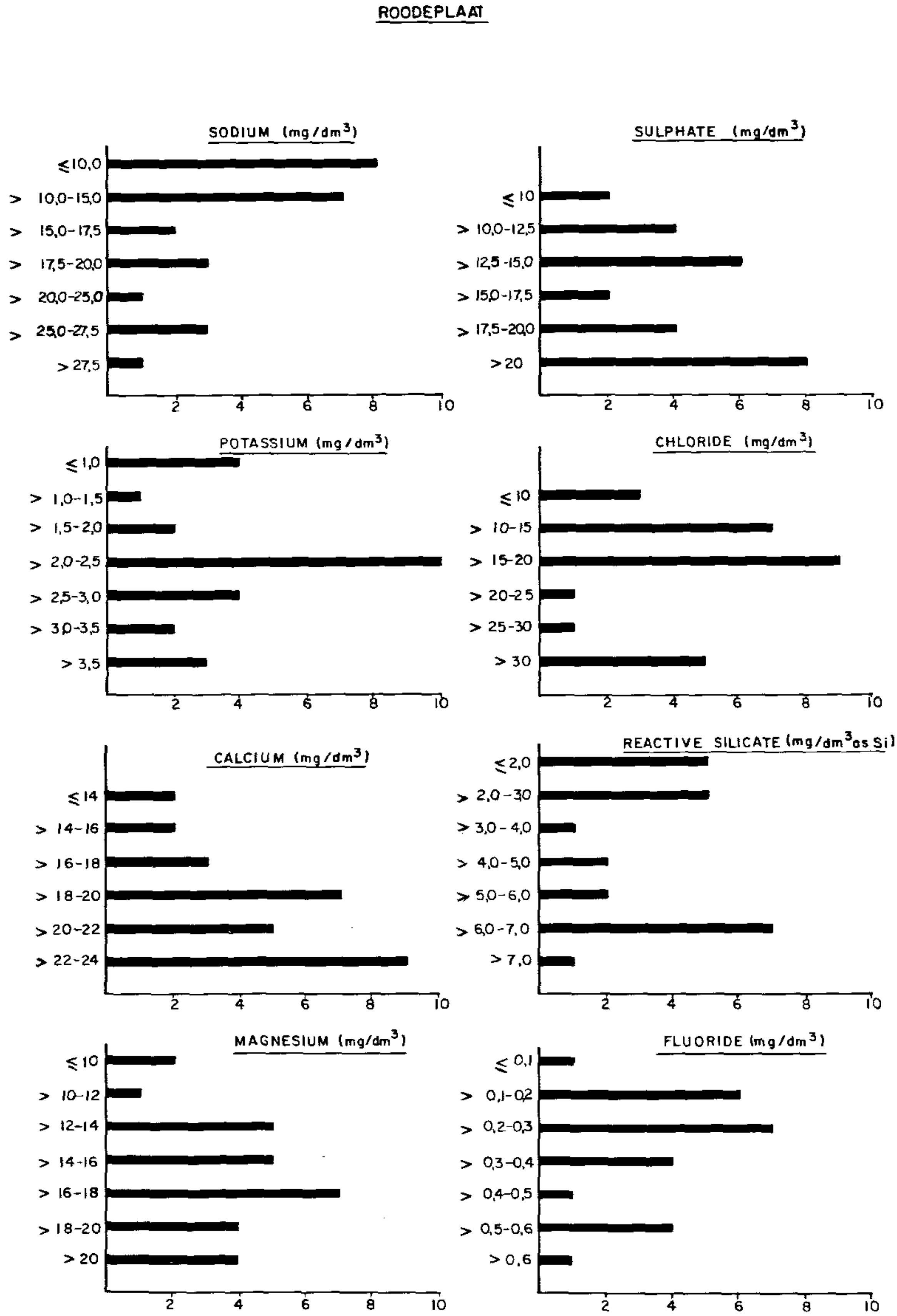

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Roodeplaat Dam.

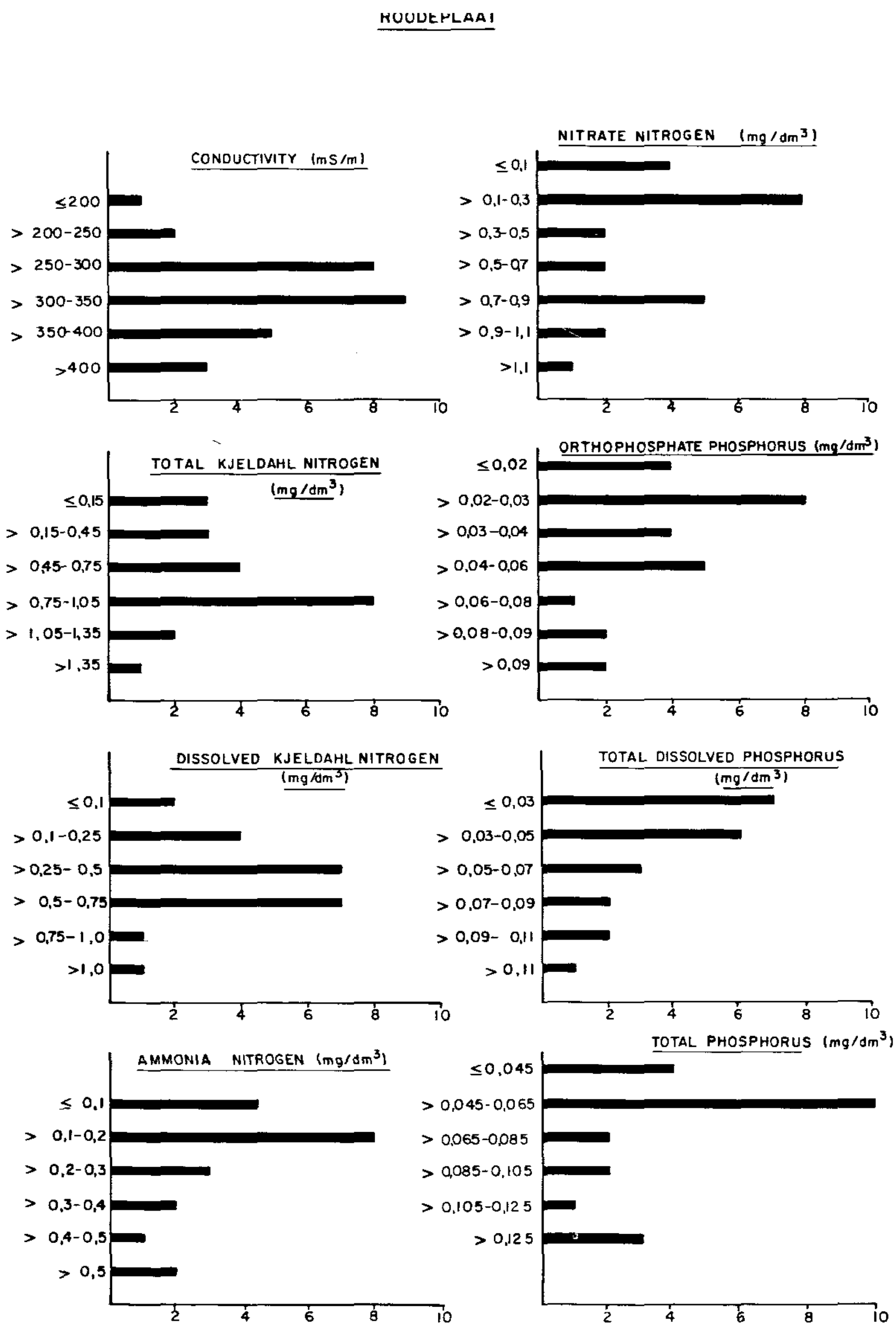

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Roodeplaat Dam.

ROODEPLAAT

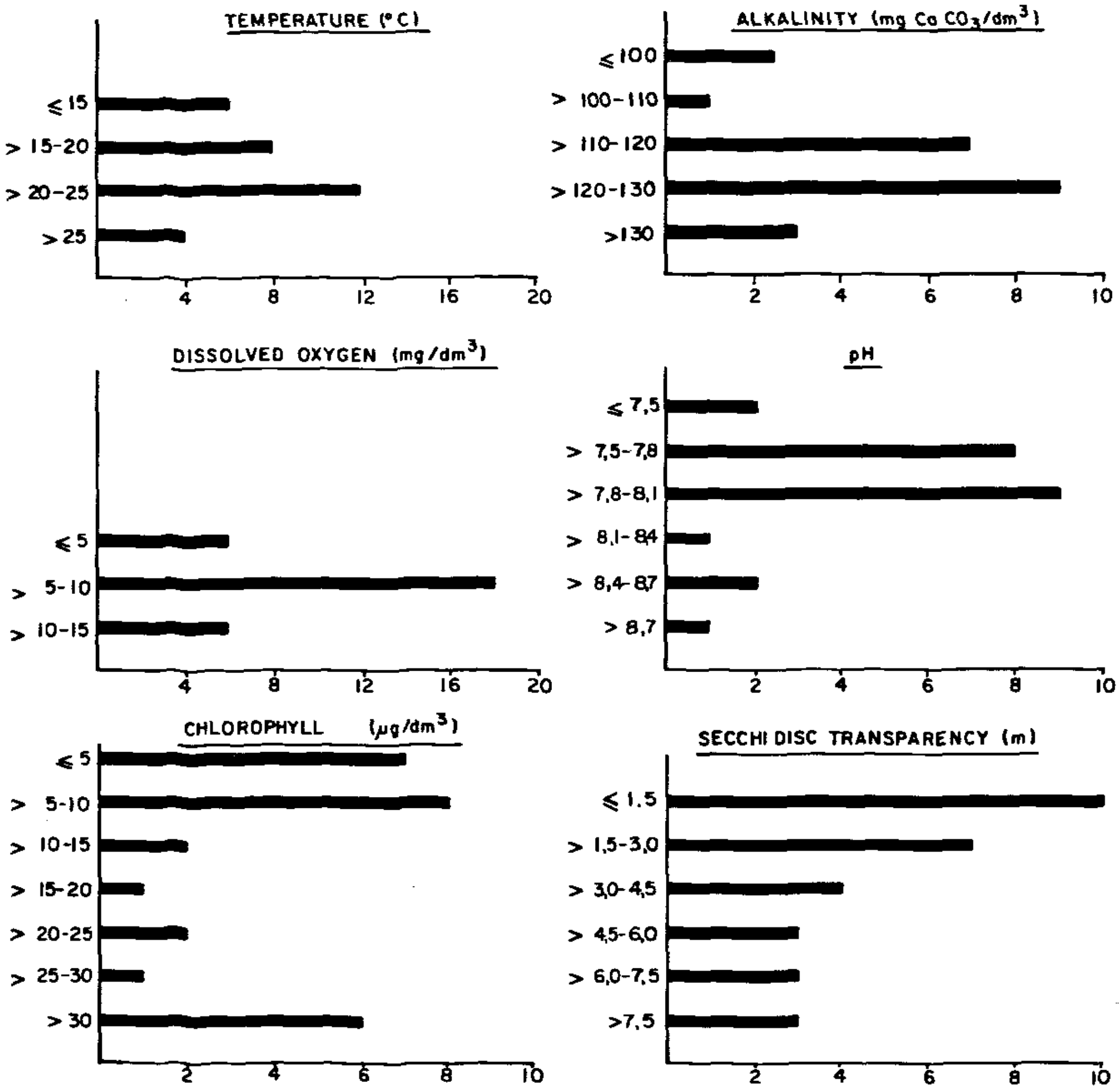

FIGURE 5. **Frequency histograms for selected parameters pertinent to the surface waters of Roodeplaat Dam.**

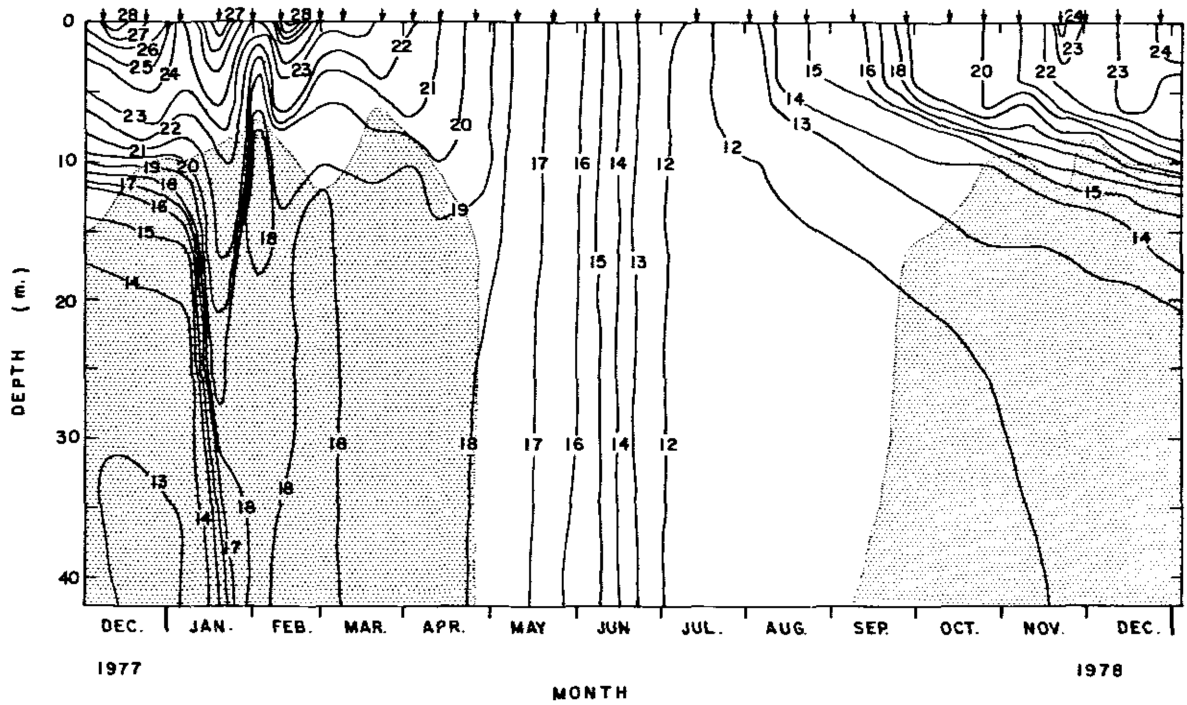

FIGURE 6. **Isopleth diagram for temperature in Roodeplaat Dam** (shaded areas indicate anaerobic zone).

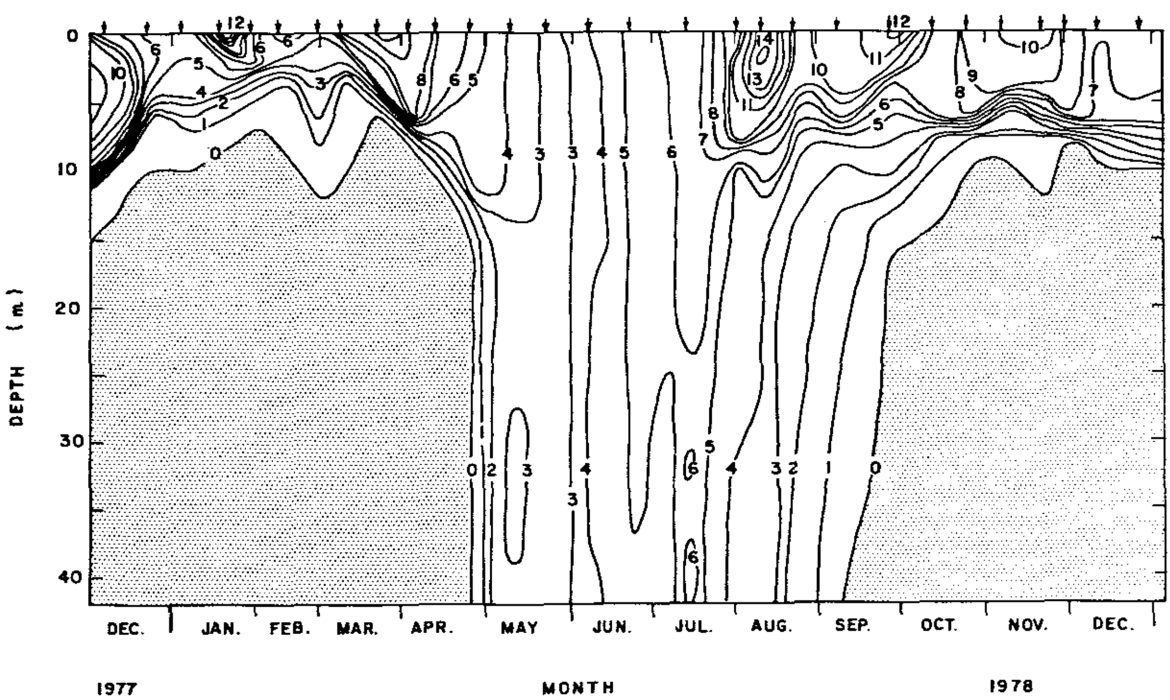

FIGURE 7. **Isopleth diagram for oxygen in Roodeplaat Dam** (shaded areas indicate anaerobic zone).

ALBERT FALLS DAM

by

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INTRODUCTION

Albert Falls Dam was completed in 1976 and is the largest reservoir on the Mgeni River. Situated below Howick between Midmar and Nagle dams it is strategically positioned to serve as part of a major water supply for the Durban-Pietermaritzburg region, in which almost 50 % of the population of the province of Natal reside. It was primarily designed for potable purposes but the controlling authorities designated the dam as another major inland aquatic recreational area because of its proximity to a heavily populated part of Natal. Therefore, to ensure that the diverse interests of parties using the system are well catered for, the water quality of the dam must be maintained by effective management strategies.

DESCRIPTION OF THE AREA

The dam wall is constructed on the bedrock overlooking the Albert Falls on the Mgeni River, near Cramond village where Dwyka shales and sandstones are common. However, most of the submerged area of the dam and a large part of the immediate catchment are dominated by Ecca shales and sandstones which give way to the more recent Beaufort series also of the Karoo system, higher up in the Karkloof range.

The Mgeni River enters the system from the west after leaving Midmar Dam and passing through the town of Howick. This river is the major inflow and it is joined by the large Karkloof tributary a few kilometres upstream from Albert Falls Dam. Soluble reactive phosphate values have always been low (less than 0,006 mg/dm^3 P — Hemens *et al.*, 1976). Nitrate-nitrogen values fluctuated between 0,149 mg/dm^3 N and a maximum of 1,202 mg/dm^3 N during periods of high flows in the wet season. Since Midmar discharge never exceeded 0,300 mg/dm^3 N it has been assumed that there was a considerable runoff from the catchment between Howick and the Albert Falls Dam leading to increased concentrations at certain times.

The Doringspruit enters the dam from the south-west and drains the Otto's Bluff region while the Nculwane which drains the greater Cramond valley, reaches the dam from the north-west. Both rivers were low in suspended solids and soluble reactive phosphate concentrations for most of the year but nitrate levels often exceeded 2 mg/dm^3 N particularly during the wet season. The high concentrations associated with the early runoff from the lands may be related to the more sophisticated and intensive use of fertilizers in the Karkloof and Nculwane catchments (Fig. 1).

In 1967 the catchment area between Albert Falls and Midmar Dam supported approximately 20 000 people of whom the great majority were rural (Van der Zel, 1975). Over 50% of the region can be considered undeveloped veld while agricultural interests include a small amount of sugar cane, citrus and other cash crops. Dairy and beef herds together with poultry, sheep and pigs represent the livestock of economic importance in the area.

Together with Midmar Dam this system is destined to be a major recreational centre as well as being an important water resource. The Natal Parks Board has jurisdiction over much of the peripheral land and resort developments have been in progress for some time.

A bathymetric map of Albert Falls Dam indicates that the dam is a wide expanse of relatively shallow water without any striking morphological features. Unlike the dendritic nature of Midmar Dam there is a shallow inlet leg which expands and gradually slopes into the main basin with irregular depth contours. A small shallow inlet leg on the north-west side of the dam demarcates the boundary of the flooded Nculwane valley. The positions of the sampling stations on the rivers and the station near the dam wall are indicated on the bathymetric map of Albert Falls Dam (Fig. 2).

RESULTS AND DISCUSSION

The basic characteristics of the impoundment and its catchment are shown in Table 1. Albert Falls Dam was completed in 1976 and therefore there is no average term (10-year) hydrological record. However, the figures are quoted from hydrological data available since records were started in 1976. Table 2 gives a summary of the monthly hydrological behaviour of the system during the study year from November 1977 until the end of October 1978.

The total inflow to Albert Falls Dam of 190,33 x 10^6 m^3 during the period of the investigation is made up from the Mgeni (82,9 %), the Nculwane (11,0 %) and the small Doringspruit (6,1 %). The input from the precipitation during the same period was calculated as 25,37 x 10^6 m^3 which may make a significant contribution to the nutrient load entering the dam.

Based on the net outflow from the dam during the study period the retention time was calculated as 1,54 years (564 days) which is the longest retention period of all the systems investigated in Natal. The flushing rate is therefore only 0,64 times per year. Although the volume did alter slightly during the study, the surface area remained unchanged and the mean depth was constant (coefficient of variation 1 %).

The measure of control exercised on the hydrological regime of Albert Falls Dam is indicated by the absence of a marked seasonal variation in the inflow and outflow. The controlled discharge from Midmar Dam provided a reasonably constant input via the Mgeni River (mean monthly inflow, 13,15 x 10^6 m^3; coefficient of variation 23 %) and despite a small winter decrease the Mgeni inflow overrides any fluctuations in the Nculwane and Doringspruit contributions which remain small and uncontrolled. The nitrogen loading pattern was not markedly seasonal since 58 % of the total nitrogen load entered the dam during summer and yet 71 % of the total phosphate load reached the dam during the same period. This was attributed to the marked increase in total phosphate concentrations in the rivers during the high surface runoff periods and short-term flow maxima in summer.

Frequency histograms for surface water data are presented in Figures 3 to 5.

Calcium was frequently the dominant cation followed closely by sodium and thereafter magnesium and potassium. Soluble phosphate concentrations in the surface waters were always low with more than 80 % of the observations being less than 0,002 mg/dm^3 P. Total phosphate (unfiltered) values never exceeded 0,030 mg/dm^3 P. The organic nitrogen fraction never exceeded 0,600 mg/dm^3 N but the nitrate levels were always less than 0,125 mg/dm^3 N and 70 % of the observations were less than 0,025 mg/dm^3 N. The indications were that there was a sporadic nitrate loading on the system but rapid immobilization by algal growth reduced the nitrate levels and maintained low ambient concentrations. Soluble silica levels were very low during periods of diatom growth and about 50 % of the observations were below 1,0 mg/dm^3 Si. Chlorophyll *a* concentrations did not reach high levels but ranged between 2 to 10 μg/dm^3 and for 60 % of the study period the levels were less than 6 μg/dm^3.

Albert Falls Dam can be classed as a warm monomictic system which displayed the normal pattern of summer stratification, autumn turnover and isothermal winter conditions during the period of investigation.

Although the thermocline was not strongly defined it was reasonably stable at the 8,0 m mark where the temperature gradient steepened. Wind-induced turbulence briefly interrupted the upper layers but during calmer summer days surface temperatures reached 28 °C. A 10 °C differential between surface and bottom water occurred frequently during stratification.

Oxygen isopleths clearly differentiate the well oxygenated epilimnion extending from 8,0 m upwards and the larger oxygen deficient hypolimnion. Anaerobic conditions prevailed from the end of January 1978 until the end of April. Hydrogen sulphide odours were frequently strong at the surface of the dam while manganese or iron precipitations were evident in the Mgeni River below the discharge. Algal photosynthesis was probably responsible for supersaturation of the surface waters from November 1977 to February 1978 and again from early August until November 1978. For over 80 % of the period of investigation the oxygen content of the surface waters exceeded 7,5 mg/dm^3.

Surface pH values ranged between 7,1 and 8,2 and nearly 75 % of the observations lay between 7,5 and 8,0 indicating a steady photosynthetic production over a long period of time. The suspended solids in the dam were always low even during periods of high chlorophyll *a* concentrations in April and November. Secchi depth values were amongst the highest recorded in Natal reservoirs and reached a maximum of 437 cm in July. Turbidity values never exceeded 6,0 Jackson Turbidity Units and water transparency was influenced more by suspended silt from feeder streams than by algal concentrations. Unlike Midmar Dam, turbidity of the water did not increase in the winter months although Albert Falls Dam is also often exposed to wind.

The phytoplankton population of Albert Falls Dam was rich in species diversity and very variable in numerical dominance from month to month. A more complete analysis is desirable but some of the most common species recorded from the dam during the year include *Mycrocystis* and *Anabaena: Melosira granulata* (Ehreb.) Ralfs was the dominant diatom but other forms such as *M. granulata var. angustissima* Müll *Melosira distans* (Ehrenb.) Kützing, were recorded. *Fragilaria* and *Cyclotella* species were frequently observed. *Ankistrodesmus Braunii* (Naeg.) Brunnthaler, a small *Cosmarium* species and *Staurodesmus sebaldi* Reinsch were the most common Chlorophyta. A large Peridinium species was present during summer while the Cryptomonads were prevalent during winter.

Albert Falls Dam also has a large diversity of zooplankton of which *Thermocyclops oblongatus* (Sars.) was numerically dominant. *Diaphanosoma excisum* Sars. was the most abundant Cladoceran during summer and autumn while *Bosmina longirostris* (O.F. Müller) was very common throughout the year. *Daphnia pulex* Leydig and *Daphnia longispina* O.F. Müller increased in numbers during the winter months.

The most common of the rotifers were *Hexarthra* species and *Brachionus calyciflorus* Pallas during the summer and autumn months.

Nutrient loading rates for orthophosphate (0,02 $g.m^{-2}.a^{-1}$ P) and inorganic nitrogen (2,80 $g.m^{-2}.a^{-1}$ N) have been estimated for the study period and represent some of the lowest aerial loading figures for Natal reservoirs. However, these low nutrient loading rates are counteracted to some degree by the relatively long retention period of Albert Falls Dam. The total phosphate loading rates (0,25 $g.m^{-2}.a-1$ P) and total nitrogen loading rates (4,83 $g.m^{-2}.a^{-1}$ N) represent a tenfold increase relative to orthophosphate loading, and nearly twice the rate for inorganic nitrogen, showing that a substantial component of the nutrient load may be introduced into the system in a form not readily available for algal growth.

Albert Falls Dam is a young unstable system with a high diversity of both phytoplankton and zooplankton species. It can be classified as a clear water, oligotrophic, phosphate-limited system. There was no measurable evidence of deterioration in the water quality of the Mgeni River in its passage from Midmar Dam through Howick to Albert Falls Dam.

ACKNOWLEDGEMENTS

The Department of Water Affairs is gratefully acknowledged for providing the hydrological data. We also wish to thank Messrs W.D. Turner and B.D. Gardner for computerization of the data.

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TABLE 1. Characteristics of Albert Falls Dam and its catchment

Geographical location	29 ° 26'S; 30 ° 25'E
Magisterial district	Howick
Catchment type	Forestry, grasslands, timber, dairy, scrub thornveld
Usage of dam	Potable, recreation
Catchment area	728 km^2
Inflowing rivers	Mgeni 556 km^2, Nculwane 74 km^2, Doringspruit 41 km^2
Dam wall completed	1976
*F.S.L. volume	293,64 x 10^6 m^3
F.S.L. area	23,85 km^2
F.S.L. maximum depth	24,6 m
F.S.L. mean depth	12,3 m

*F.S.L. = full supply level

TABLE 2. A summary of monthly hydrological characteristics for Albert Falls Dam (Nov. 1977 – Oct. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	293,64	293,04	293,33	–	–
Area km^2	23,63	23,63	23,63	–	–
Mean depth m	12,4	12,4	12,4	–	–
Monthly inflow x 10^6 m^3	23,40	11,03	16,03	–	–
Monthly outflow x 10^6 m^3	22,44	12,14	15,72	–	–

*C.V. = coefficient of variation

TABLE 3. A summary of physical and chemical characteristics of water collected from the inflowing rivers (Mgeni, Nculwane and Doringspruit), the outflow and a dam station (D1) on Albert Falls Dam. (Values are based on fortnightly samples collected between November 1977 and October 1978)

PARAMETER	DAM STATION								MGENI				NCULWANE				DORINGSPRUIT				OUTFLOW (MGENI)			
	TOP				BOTTOM																			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na																								
K																								
Ca	4,9	5,4	5,1	3	4,7	6,3	5,4	8	0,2	5,4	4,2	23	0,6	4,9	3,9	20	7,0	11,7	8,8	14	4,9	6,0	5,3	6
Mg	2,6	3,5	3,0	9	2,6	4,5	3,3	13	1,8	3,5	2,5	15	0,1	3,8	3,0	22	4,3	7,1	5,6	13	2,8	4,4	3,2	11
SO_4																								
Cl																								
Si	0,3	2,1	1,2	54	1,4	3,8	2,3	28	3,7	7,0	4,6	15	3,3	6,6	6,1	10	6,9	9,1	8,4	6	1,3	2,5	1,9	17
Cond	6,3	8,5	7,1	8	6,1	9,0	7,3	10	3,8	6,9	5,9	10	1,3	8,4	6,5	19	9,0	15,0	12,2	11	6,2	8,6	7,2	8
Alk	19	31	27	7	25	38	30	13	14	27	22	13	2	25	18	25	34	66	47	19	22	35	28	10
Tot Kj - N	0,153	0,557	0,277	33	0,275	1,022	0,527	38	0,147	0,526	0,264	33	0,096	0,700	0,217	52	0,136	1,200	0,336	60	0,219	0,671	0,381	26
Dis Kj - N	0,115	0,233	0,181	18	0,205	0,754	0,369	40	0,106	0,508	0,175	44	0,024	0,255	0,130	35	0,078	0,302	0,179	31	0,181	0,416	0,266	22
NH_4-N	0,003	0,090	0,032	99	0,069	0,653	0,227	73	0,005	0,032	0,014	45	0,004	0,025	0,011	45	0,003	0,035	0,014	45	0,067	0,292	0,124	53
NO_3 - N	0,002	0,119	0,033	109	0,001	0,085	0,043	65	0,149	1,202	0,289	73	0,004	1,134	0,554	51	0,010	2,404	0,606	107	0,009	0,116	0,053	60
NO_2 - N	0,001	0,003	0,001	47	0,001	0,005	0,002	69	0,001	0,006	0,003	51	0,001	0,005	0,002	49	0,001	0,012	0,003	68	0,001	0,007	0,002	.73
Tot P	0,005	0,026	0,013	38	0,008	0,092	0,025	71	0,006	0,087	0,030	59	0,001	0,077	0,018	81	0,010	0,116	0,036	75	0,003	0,023	0,012	41
Tot dis P	0,001	0,021	0,003	97	0,001	0,020	0,004	89	0,004	0,013	0,007	28	0,002	0,015	0,005	60	0,003	0,052	0,010	92	0,001	0,017	0,004	96
PO_4 - P	0,001	0,002	0,001	36	0,001	0,015	0,002	150	0,001	0,007	0,002	72	0,001	0,006	0,001	80	0,001	0,010	0,005	70	0,001	0,013	0,002	138
Fe																								
Mn																								
Temp	13,9	29,0	21,5	21	13,4	21,2	17,1	14																
DO	6,0	9,5	8,2	11	0,1	8,2	3,7	83																
Tu	1	5	2	50	1	44	13	80	3	61	17	78	1	35	9	93	5	140	27	123	1	21	7	98
pH	7,1	8,2	7,7	4	6,6	7,5	7,1	4	7,1	7,9	7,6	2	6,3	7,8	7,4	4	7,6	9,3	8,3	6	7,2	7,8	7,5	2
SS	1	7	2	62	1	103	19	106	1	89	19	104	1	64	11	113	3	146	29	119	1	14	4	82

*C.V. = coefficient of variation

TABLE 4. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Albert Falls Dam (Nov. 1977 – Oct. 1978)

Mean depth m	12,4		
Retention time a	1,54		
Hydraulic load m/a	8,05		
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P	0,02		
Total P	0,25		
Inorganic nitrogen	2,80		
Total nitrogen	4,83		
	Maximum	**Minimum**	**Mean**
Chlorophyll *a* $\mu g/dm^3$	9,2	2,2	5,4
Secchi depth m	4,37	1,50	2,51

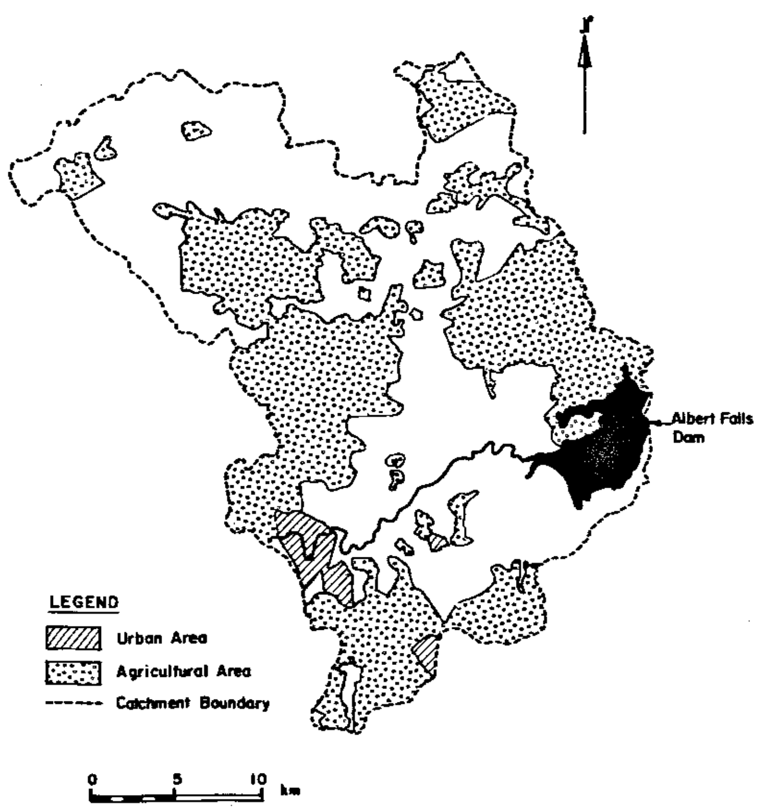


FIGURE 1. Albert Falls Dam catchment.

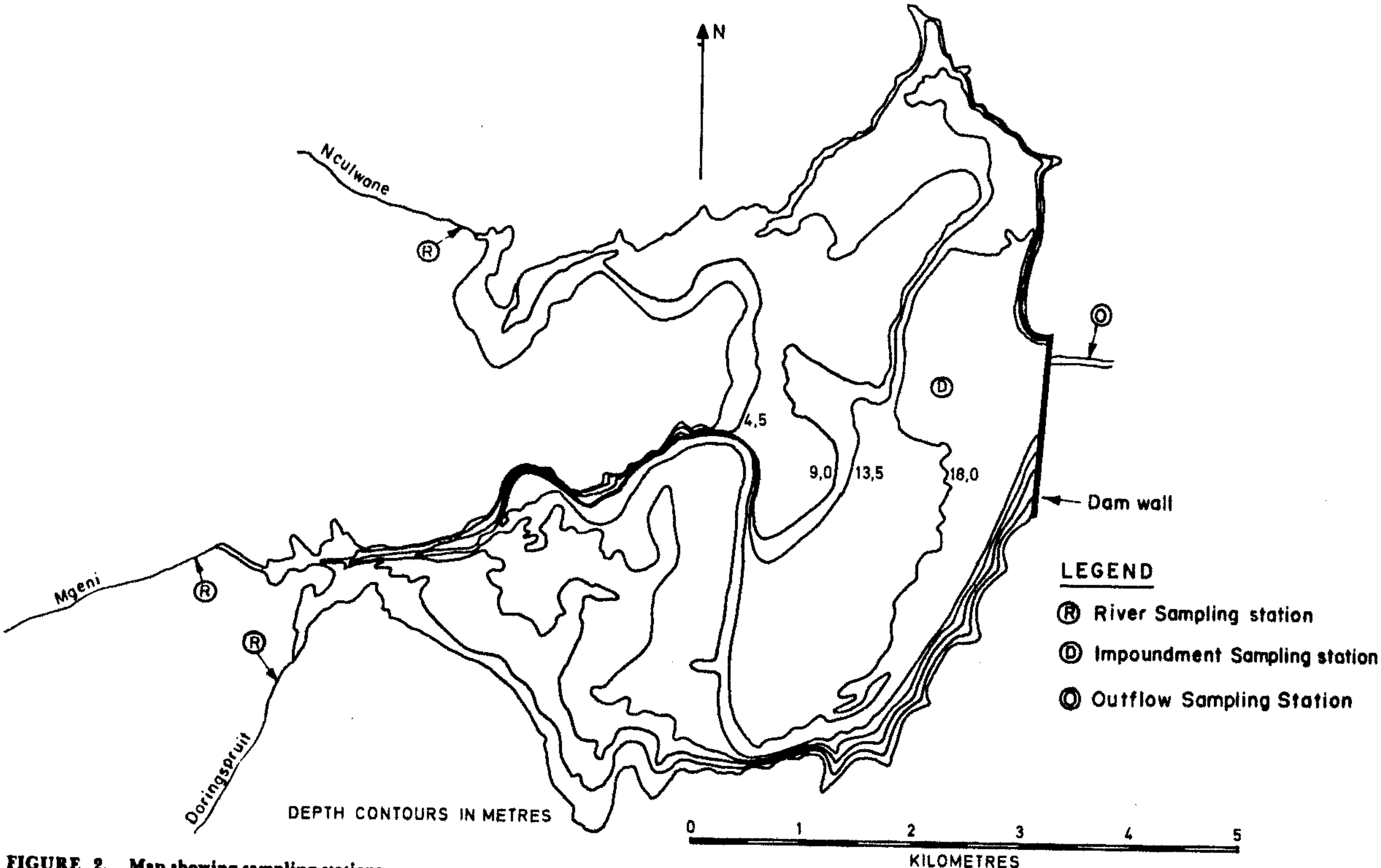


FIGURE 2. Map showing sampling stations.

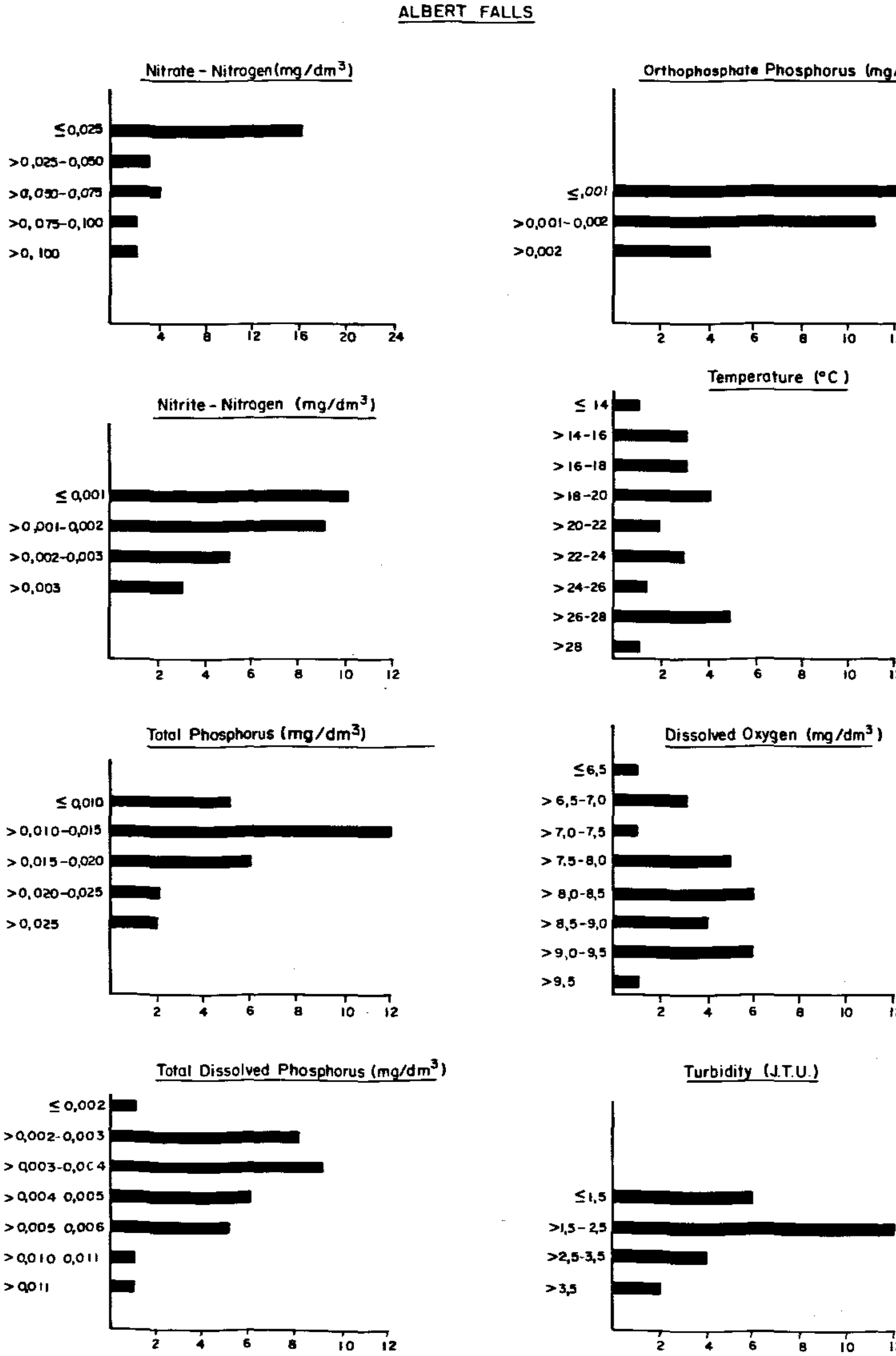
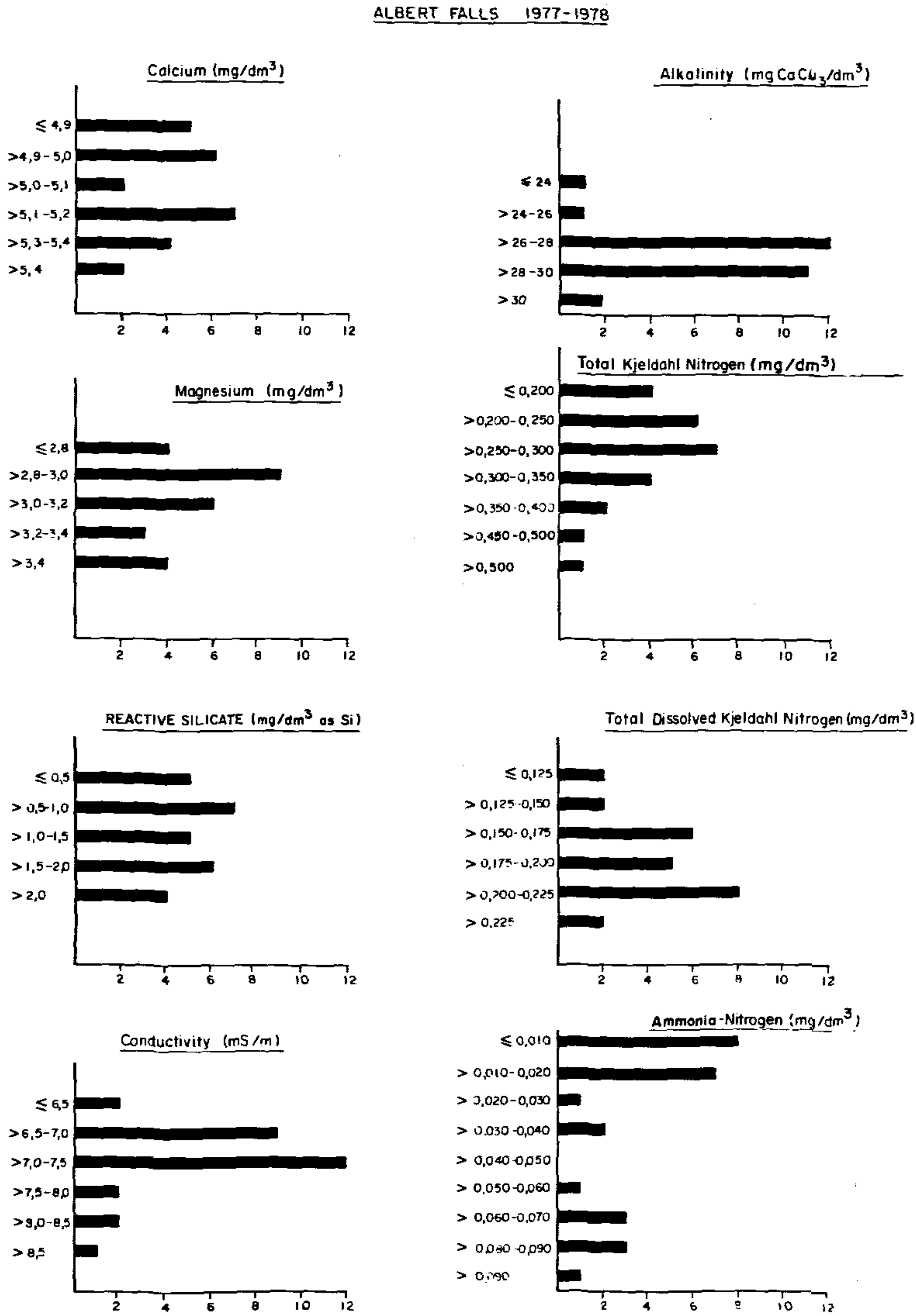


FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Albert Falls Dam.



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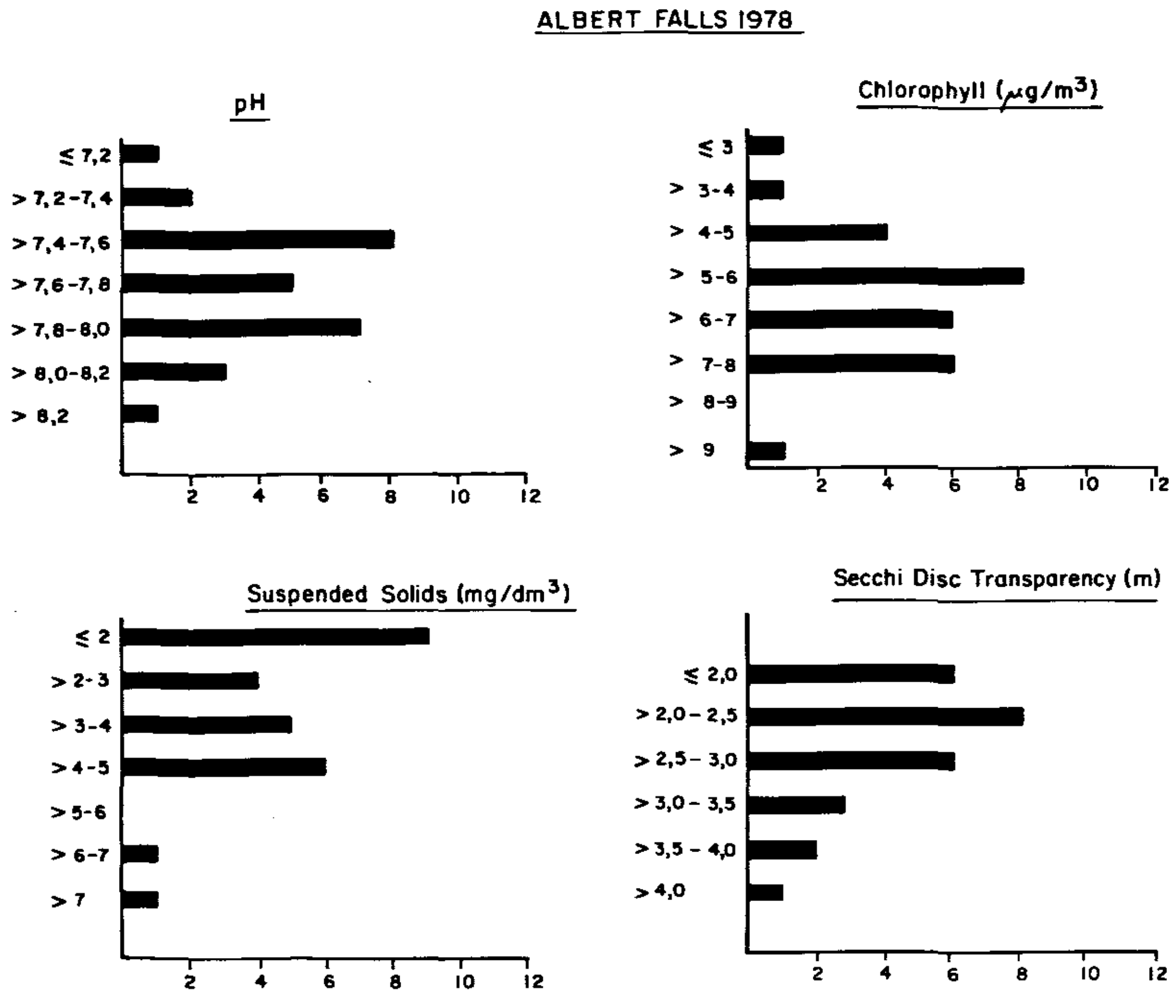

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Albert Falls Dam.

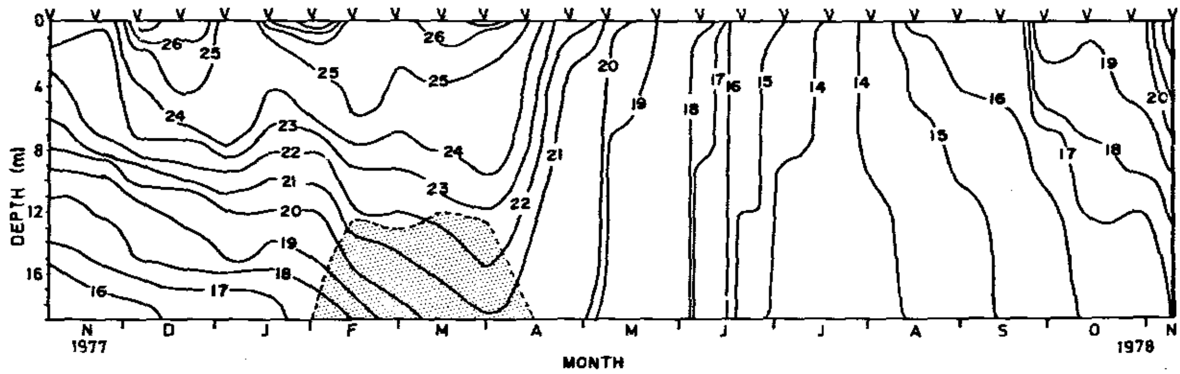

FIGURE 6. **Temperature distribution in Albert Falls Dam** (Nov. 1977 – Nov. 1978)

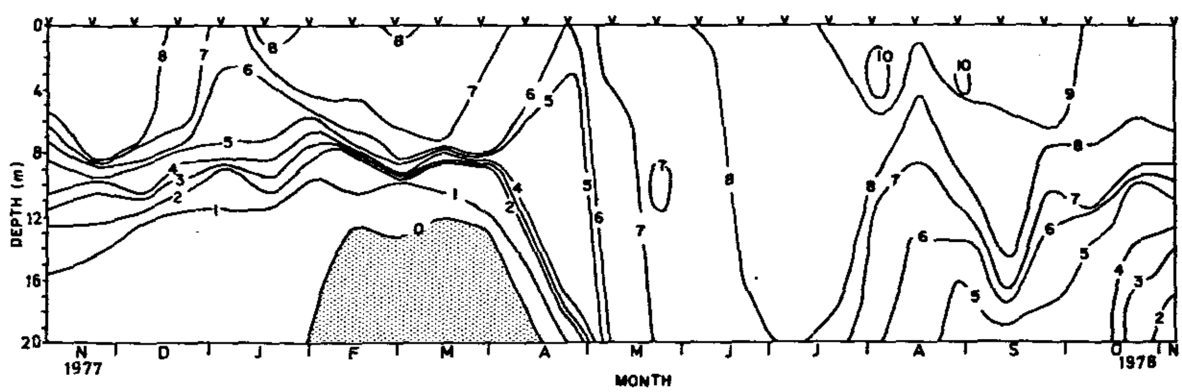

FIGURE 7. **The distribution of dissolved oxygen in Albert Falls Dam** (Nov. 1977 – Nov. 1978)

HAZELMERE DAM

by

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INTRODUCTION

Hazelmere Dam is one of the few large coastal reservoirs situated in a catchment dominated by sugar cane cultivation. In Natal there is a distinct possibility that agricultural practices related specifically to sugar cane cultivation may be responsible for considerable nutrient enrichment of reservoirs. The dam was completed in 1977 and therefore is the youngest system in Natal.

The reservoir was built to cater for the anticipated increase in demand for water by the greater Verulam area after the scheduled completion of the international airport near La Mercy on the north coast of Natal. However, adverse economic factors have slowed down the progress of the airport project and its associated development. Therefore it will be a long time before optimal use is made of the impounded water at Hazelmere. Effective control and management of this system is now necessary to reduce the accumulation of nutrients and excessive silt loads derived from an undeveloped upper catchment.

DESCRIPTION OF THE AREA

The dam wall is situated in a gorge a few kilometres upstream from the town of Verulam, in a region characterised by Dwyka sandstones which give way to older quartzites of the Table Mountain series of the Cape System in the immediate catchment. The upper reaches of the catchment include areas of ultra metamorphic rocks from the Natal belt of metamorphism and granitization.

The Mdloti River is the only major input to the dam and therefore greatly influences the chemical composition of the system. The river drains a catchment of 376 km^2 in which there is no industrial development. Most of the catchment remains undeveloped grassland but sugar cane cultivation is the dominant agricultural interest. Heavy fertilization of the lands at certain times of the year could lead to rapid enrichment of the system after runoff from the steep hill slopes (Fig. 1).

The nutrient input to the dam via the Mdloti River increased considerably when silt loads were high after heavy rains resulted in flow maxima. Orthophosphate concentrations were always low but the total phosphorus reached abnormally high levels on 2 occasions. The nitrate levels showed an equally large range (0,12 mg/dm^3 N — 1,178 mg/dm^3 N) and the total Kjeldahl nitrogen values increased markedly during high flows. Soluble silica inputs were among the highest recorded with an annual mean of 9,6 mg/dm^3.

A bathymetric map of the dam shows the riverine characteristics of the dam which is steeply contoured in places where rocky cliffs existed in the old river course. The upper reaches of the dam are relatively shallow ($<$6,9 m) but towards the wall the deeper region exceeds 30,0 m. There are only minor ephemeral inputs draining the 'blind' valleys on the northern banks of the dam. Sampling stations of the inflowing rivers are indicated on the bathymetric map of the dam and the immediate catchment (Fig. 2).

Recreational facilities are being planned by the controlling authorities. Water skiing is presently the major recreational activity but fishing by the locals is also a popular pastime.

There is no doubt that Hazelmere Dam will be a major water resource for Verulam and the surrounding area in the future, and therefore information from this system is of vital importance in the development of a management strategy. This is particularly important when it is fully appreciated that the major part of the catchment lies in an area in which soil conservation is limited. Poor conservation has manifested itself in the very high silt loads which are discharged in the dam via the Mdloti River. High siltation rates and possible increases in nutrients from sugar cultivation are a twin threat to the Hazelmere Dam.

RESULTS AND DISCUSSION

Hazelmere Dam is a new system and therefore there are no average-term hydrological data available. However, Table 2 gives a summary of the monthly hydrological behaviour of the system during the study year.

In the absence of recorded inflows an estimate of the daily flows was based on a regression curve of rainfall on runoff for 9 measured points (coefficient of determination r^2 = 0,896; Pearson, Department of Water Affairs, personal communication). The total inflow from the Mdloti catchment was calculated as 67,61 x 10^6 m^3 from November 1977 to October 1978. Based on this input the retention time was calculated as 0,35 years (128 days) which gives a flushing rate of 2,85 times per year. About 65 % of the inflow occurred during the summer months between November 1977 and April 1978, bringing with it 90 % of the total nitrogen load and 71 % of the total phosphorus load.

Frequency histograms for the impoundment's surface water data are presented in Figures 3 to 5.

Calcium levels always exceeded magnesium concentrations but on some occasions the sodium concentrations were exceptionally high. Soluble reactive phosphate concentrations reached a maximum of 0,022 mg/dm^3 but for more than 50 % of the time the levels were less than 0,005 mg/dm^3. More often than not the total phosphate concentrations lay between 0,03 and 0,07 mg/dm^3 and reached a maximum of 0,093 mg/dm^3 in the surface waters after good rains in May.

Nitrate levels in the surface waters fluctuated markedly during the period of investigation and the lowest concentrations prevailed during the summer period when algal growth had occurred. Although some high total Kjeldahl concentrations were observed these did not always match the decreasing nitrate levels during algal growth periods, indicating the major influence of the Mdloti River on the system as a whole. Despite the fact that diatoms were consistently present in the surface waters and often formed a major part of the phytoplankton population, the soluble silica levels never decreased below 8,0 mg/dm^3 but exceeded 9,0 mg/dm^3 for over 60 % of the time.

Although Hazelmere Dam has riverine characteristics the temperature profiles near the dam wall followed the pattern of a warm monomictic system. A shallow thermocline developed at about 5 m because of the turbid water which persisted for most of the summer stratification period.

Oxygen isopleths of Hazelmere Dam showed that there was an extensive hypolimnetic zone of oxygen-deficient water. A short-lived anaerobic zone developed in February but was disrupted in April by the well oxygenated inflow from the Mdloti River. The epilimnetic water (0 – 6 m) showed a rapid transition from the anaerobic zone to a supersaturated surface water which persisted for the greater part of summer stratification. During isothermal winter conditions the oxygen concentrations increased at the bottom but stratification rapidly reformed during the next summer period.

Hazelmere was a turbid system for most of the year. Turbidity readings exceeded a value of 20 Jackson Turbidity Units for more than 60 % of the investigation. Secchi disc readings only exceeded 2,0 m on one occasion, and were frequently less than 1,0 m. The suspended solids values, which often exceeded 20 mg/dm^3 during the study were a further indication of the high silt load content of the dam water. Extremely high values were obtained from some bottom water samples (annual mean 490 mg/dm^3).

Chlorophyll *a* concentrations were frequently between 4 and 8 μg/dm^3 but never exceeded 15 μg/dm^3 despite the development of a *Microcystis* bloom during the summer of 1978.

Rooted macrophytes were restricted to the margins of the upper reaches of the dam which escaped the recent flooding after completion of the dam wall. No major development of free-floating macrophytes has yet been observed.

Phytoplankton populations were dominated by the diatoms *Melosira distans* (Ehrenb.) Kützing, *Synedra rumpens* Kützing and less frequently by *Cyclotella* species. The blue-green algal group was represented by an early development of a coiled planktonic form of *Oscillatoria* and a *Microcystis* bloom at the end of 1978.

Although the calanoid copepod *Tropodiaptomus spectabilis* (Kiefer) was frequently present amongst the zooplankton, the numerically dominant species was *Thermocyclops oblongatus* (Sars.), especially during summer. *Daphnia pulex* Leydig and *D. longispina* O.F. Müller were present in larger numbers during winter but *Daphnia laevis* Birge and *Ceriodaphnia dubia* Richard were dominant in summer and spring respectively. A small *Hexarthra* species was abundant throughout the study period but other rotifers such as *Branchionus calyciflorus* Pallas were dominant during summer. The predatory larvae of a *Chaoborus* species were present in large numbers during spring and summer.

Nutrient loading rates for orthophosphate (0,13 $g.m^{-2}.a^{-1}$ P) and inorganic nitrogen (20,57 $g.m^{-2}.a^{-1}$ N) indicate that phosphate is likely to be the limiting nutrient in Hazelmere Dam. The higher soluble nitrogen input may be related to sugar cane cultivation in the catchment, since almost 90 % of the nitrogen load entered the dam during summer when heavy fertilization can occur. However, the total N:P ratio of 8,8 indicates that much more phosphate is derived from silt loads after runoff from the catchment but it may be in a form which is not available for immediate algal growth.

Hazelmere is a very new system and therefore the trophic status cannot be clearly defined with the limited amount of data at our disposal. It is one of the most turbid systems in Natal and therefore has a high siltation rate. The riverine nature of the system, the flushing rate and the high turbidity of the water may offset to some extent the large summer nutrient input and consequent algal growth. Management strategies should cater for the twin threat of high siltation rates and a diffuse nutrient input.

ACKNOWLEDGEMENTS

The Department of Water Affairs is gratefully acknowledged for providing the hydrological data. Messrs W.D. Turner and B.D. Gardner are also thanked for computerization of the data.

TABLE 1. Characteristics of Hazelmere Dam and its catchment

Geographical location	29 ° 36'S; 31 ° 02'E
Magisterial district	Verulam
Catchment type	Undeveloped grasslands, sugar-cane
Usage of dam	Potable, recreation
Catchment area	377 km^2
Inflowing river	Mdloti 376 km^2
Dam wall completed	1977
*F.S.L. volume	23,44 x 10^6 m^3
F.S.L. area	2,18 km^2
F.S.L. maximum depth	30,6 m
F.S.L. mean depth	10,8 m

*F.S.L. = full supply level

TABLE 2. A summary of monthly hydrological characteristics for Hazelmere Dam (Nov. 1977 – Oct. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3					
Area km^2					
Mean depth m					
Monthly inflow x 10^6 m^3	12,36	2,30	5,63	53	
Monthly outflow x 10^6 m^3					

*C.V. = coefficient of variation

TABLE 3. A summary of physical and chemical characteristics of water collected from the Mdloti River inflow, the outflow and a station D1 on Hazelmere Dam. Values are based on fortnightly samples collected between November 1977 and October 1978

PARAMETER	DAM STATION OUTFLOW								MDLOTI TOP				OUTFLOW (MDLOTI) BOTTOM			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na																
K																
Ca	4,4	6,9	5,4	9	2,1	6,8	5,1	19	0,3	6,4	4,7	28	3,8	6,7	5,3	14
Mg	3,5	5,6	4,3	11	2,3	5,2	4,1	19	2,4	4,8	3,9	14	2,9	5,3	4,3	13
SO_4																
Cl																
Si	8,3	9,9	9,1	4	5,2	9,7	8,4	13	2,9	11,6	9,6	18	7,4	10,2	9,1	7
Cond	12,8	16,7	14,4	7	7,8	16,4	13,0	17	4,8	15,7	13,3	17	10,1	16,4	14,1	11
Alk	26	43	34	13	11	45	30	27	3	38	29	29	23	42	33	14
Tot Kj-N	0,272	1,240	0,462	43	0,256	3,720	1,327	71	0,070	3,290	0,523	115	0,270	1,510	0,531	59
Dis Kj-N	0,179	0,288	0,236	11	0,168	0,950	0,342	55	0,058	0,343	0,170	31	0,174	0,587	0,247	30
NH_4-N	0,006	0,041	0,015	52	0,009	0,724	0,130	143	0,003	0,038	0,014	48	0,008	0,345	0,036	181
NO_3-N	0,015	0,828	0,413	75	0,001	0,969	0,497	63	0,120	1,178	0,655	35	0,141	0,967	0,575	41
NO_2-N	0,001	0,012	0,004	58	0,001	0,012	0,005	65	0,001	0,012	0,003	82	0,001	0,011	0,004	56
Tot P	0,019	0,093	0,048	35	0,049	2,100	0,350	125	0,010	0,910	0,106	164	0,041	0,580	0,105	117
Tot dis P	0,007	0,038	0,019	39	0,007	0,157	0,034	127	0,003	0,085	0,013	120	0,009	0,095	0,025	79
PO_4-P	0,001	0,022	0,008	66	0,001	0,026	0,008	69	0,001	0,010	0,003	63	0,001	0,022	0,008	56
Fe																
Mn																
Temp	16,0	28,6	22,9	18	15,0	23,7	18,6	15								
DO	5,1	13,3	8,3	20	0,1	6,4	2,8	76								
Tu	2	69	28	64	19	260	104	87	12	185	51	88	20	270	68	99
pH	7,0	8,5	7,6	5	6,2	7,5	6,9	5	5,5	8,0	7,5	6	6,9	7,7	7,5	2
SS	3	78	20	88	16	2,337	490	119	1	1,762	152	221	7	696	90	166

*C.V. = coefficient of variation

TABLE 4. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Hazelmere Dam (Nov. 1977 – Oct. 1978)

Mean depth m	10,8
Retention time a	0,35
Hydraulic load m/a	30,86
Surface loading rates $g/m^2.a^{-1}$	
PO_4-P	0,13
Total P	4,58
Inorganic nitrogen	20,57
Total nitrogen	40,34

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	12,6	0,30	5,7
Secchi depth m	2,04	0,24	0,79

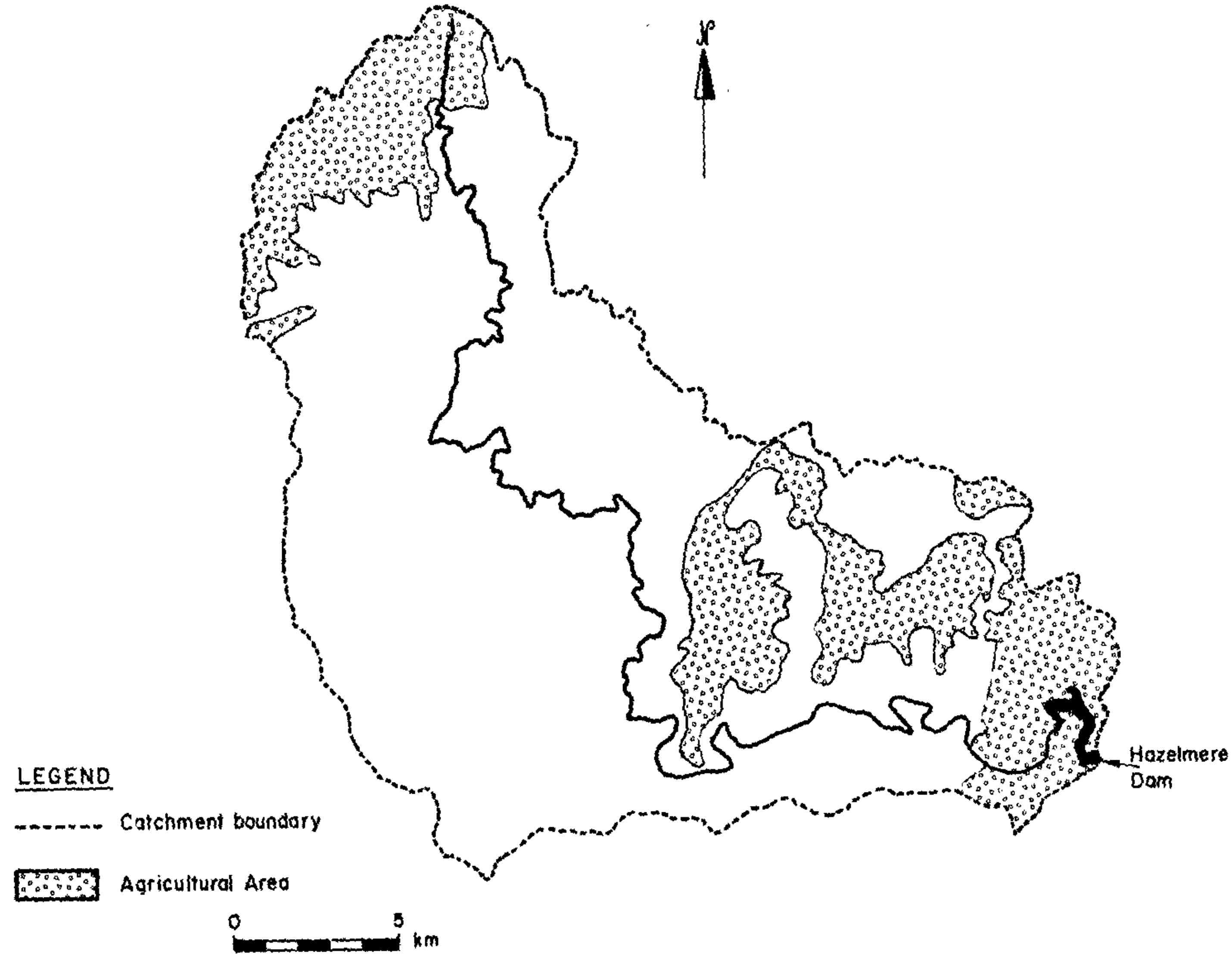

FIGURE 1. Hazelmere Dam catchment.

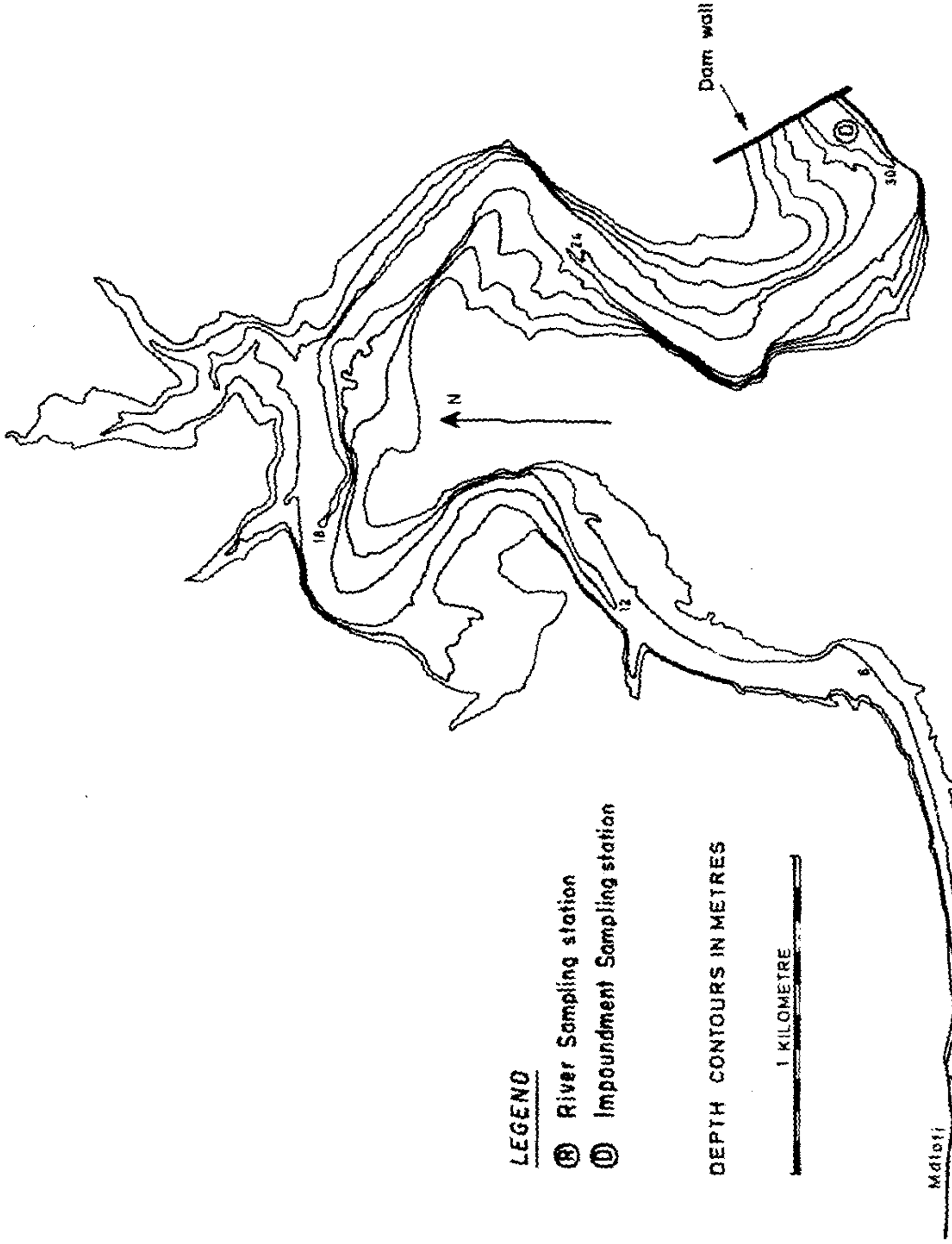

FIGURE 2. Map of Hazelmere Dam showing sampling stations.

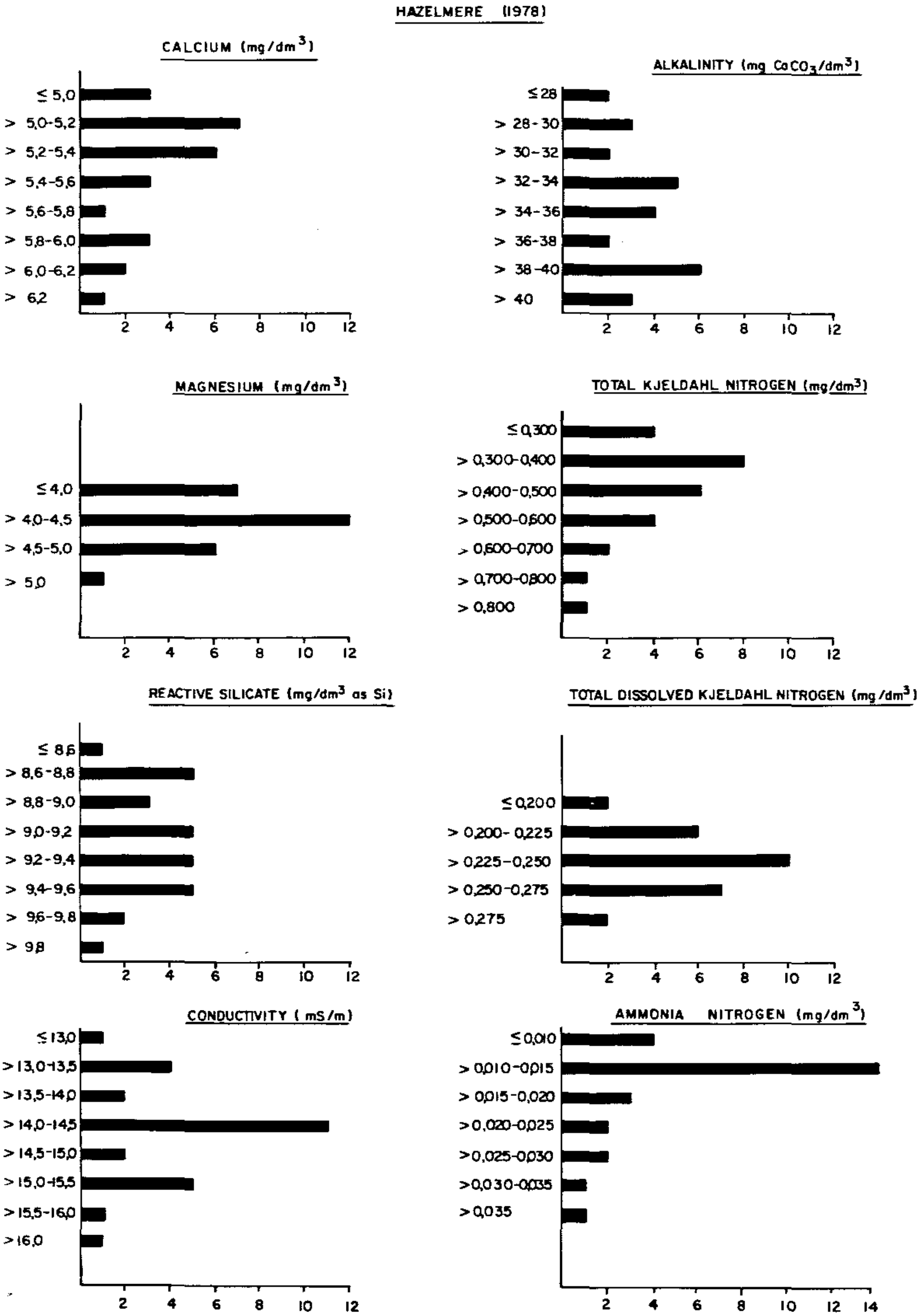

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Hazelmere Dam.

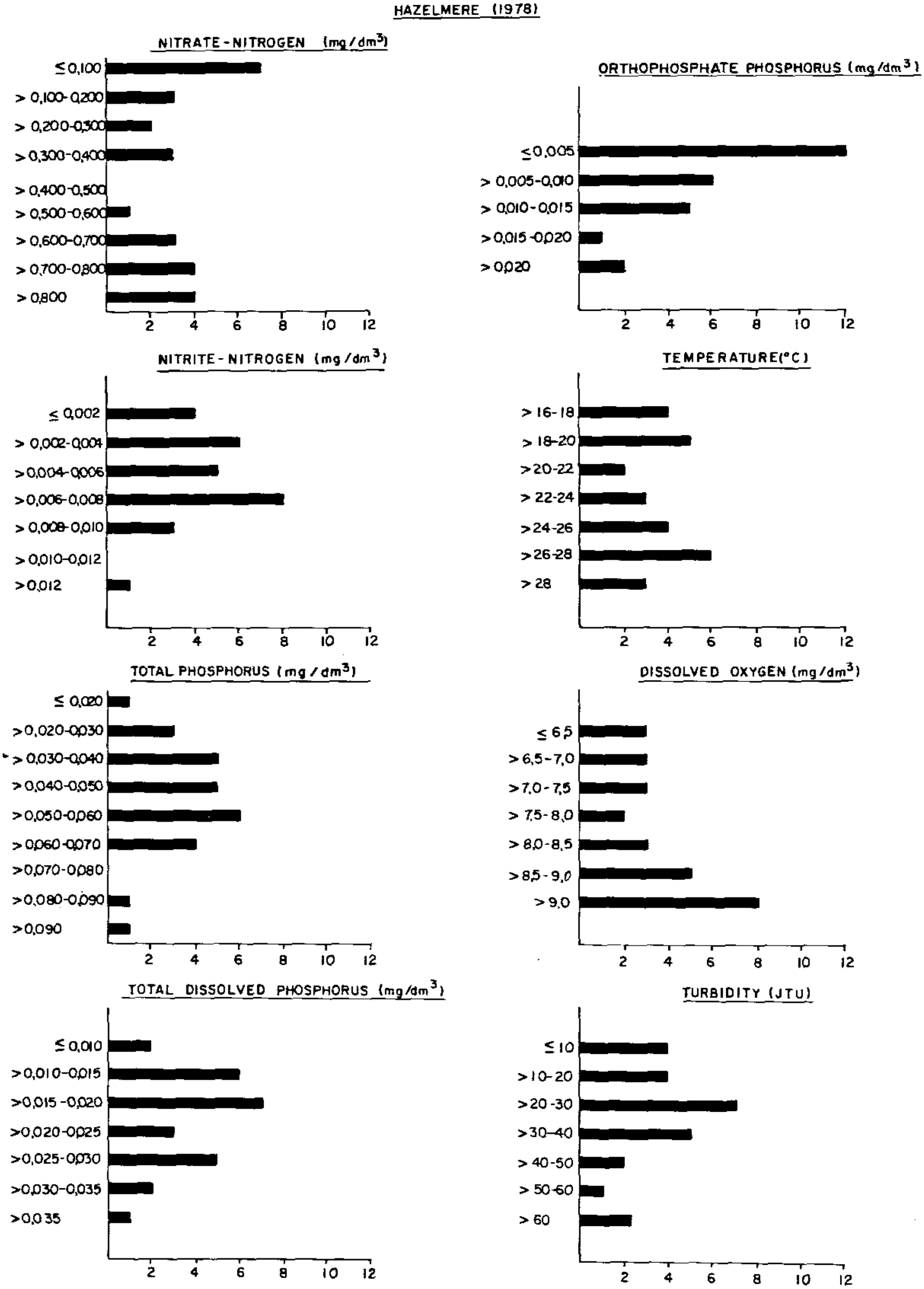

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Hazelmere Dam.

HAZELMERE

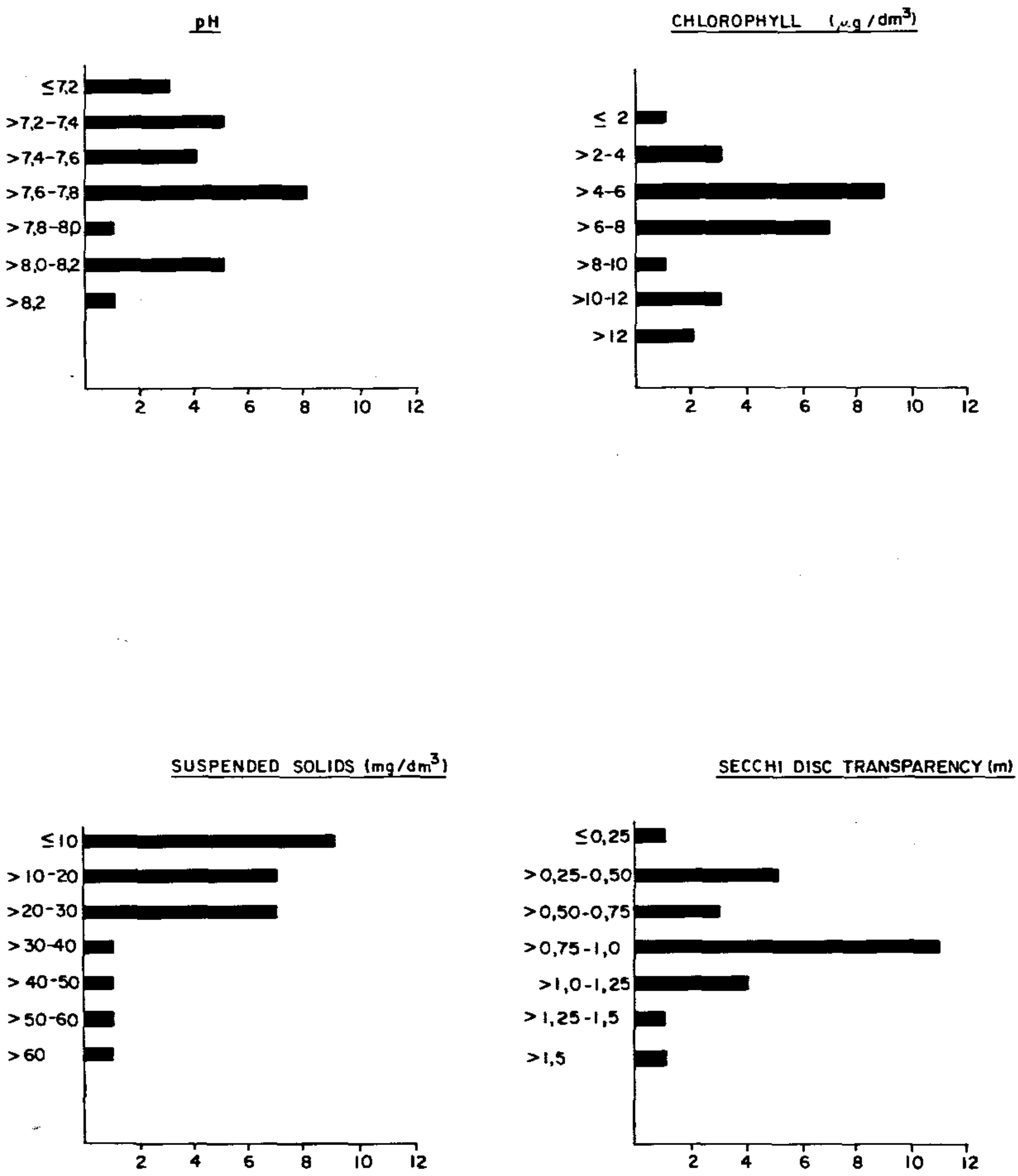

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Hazelmere Dam.

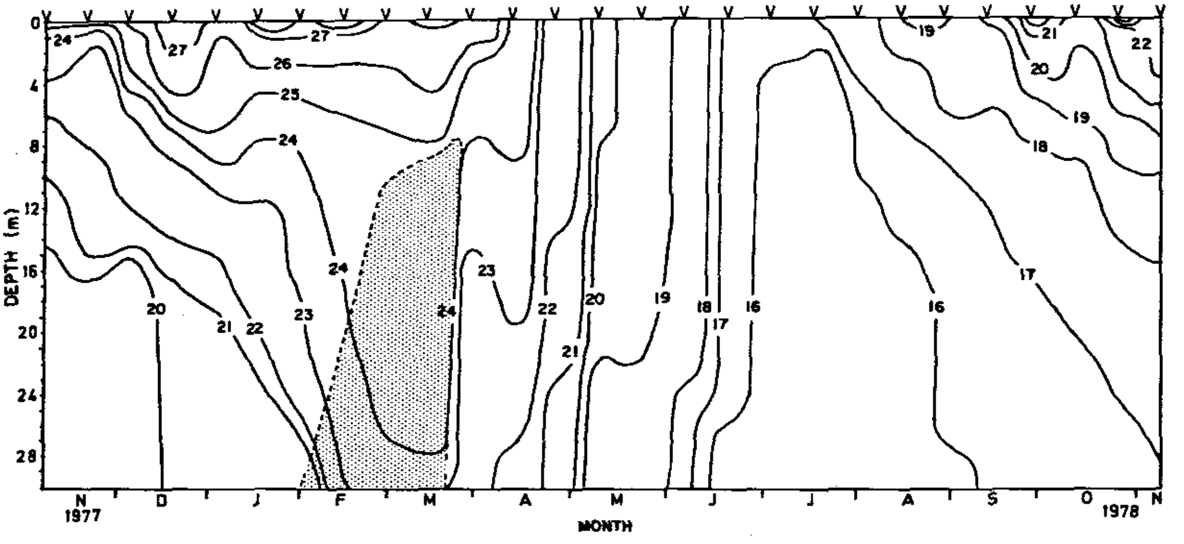

FIGURE 6. Temperature distribution in Hazelmere Dam (Nov. 1977 – Oct. 1978)

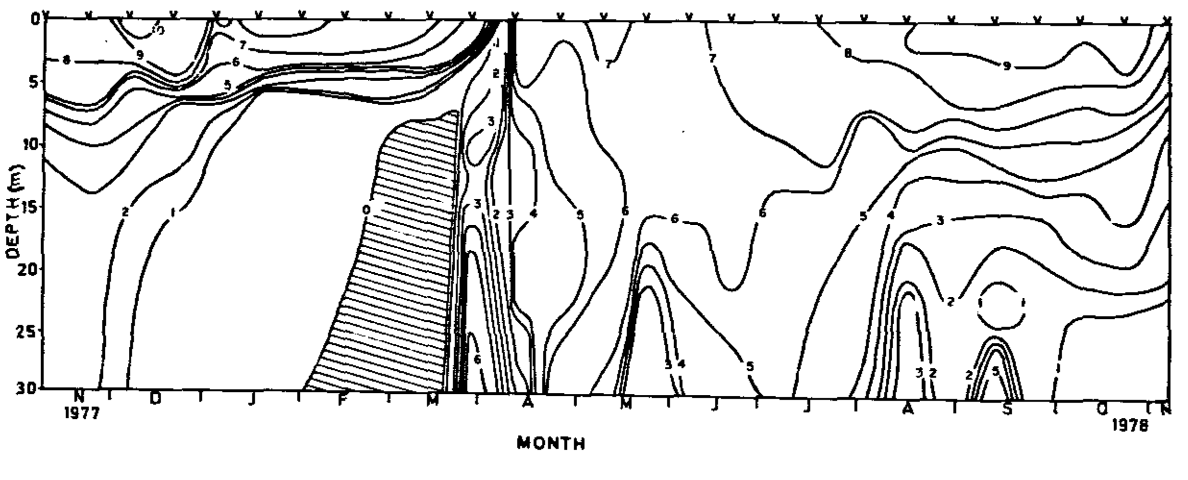

FIGURE 7. The distribution of dissolved oxygen in Hazelmere Dam (Nov. 1977 – Oct. 1978)

HENLEY DAM

by

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INTRODUCTION

Henley Dam is situated on the Msunduze River which, together with a few small tributaries, drains a catchment area of 219 km^2, most of which now falls under the kwaZulu administration. Although the Natal Legislative Assembly Act 13 of 1900 empowered the city of Pietermaritzburg to abstract water from the Msunduze, Henley Dam was only built between 1941 and 1943 after other water supply schemes had proved inadequate.

The original gravity section mass concrete dam had a capacity of 2,77 x 10^6 m^3 which provided an assured yield of 10,59 x 10^6 m^3/a (0,029 x 10^6 m^3/d). Between 1957 and 1959 the Henley Dam wall was raised from 18,3 m to 25,3 m by the Coyne system of post stressing, thereby increasing the storage capacity of 6,77 x 10^6 m^3 and ensuring an annual yield of 14,24 x 10^6 m^3 (0,039 x 10^6 m^3/d). Although the mean annual runoff has been estimated at 40,99 x 10^6 m^3 the maximum assured yield to be derived from the Msunduze catchment is insufficient for the needs of Pietermaritzburg and therefore the city has had to turn to Midmar Dam as a supplementary source.

DESCRIPTION OF THE AREA

The dam wall is sited below the original confluence of the Msunduze River and Msunduzane stream in an area characterized by shales and sandstone of the Ecca series, which give way to the more recent erodible sandstones, shales and mudstones of the Beaufort series in the upper reaches of the Msunduze catchment. The Msunduze enters the dam from the south and the other streams join the system on the western shore nearer the dam wall, while the discharge flows eastwards. The basic features of the impoundment and its catchment are given in Table 1 and Figure 1.

With a mean annual runoff 7 times the capacity of Henley Dam, the Msunduze is the major inflow and therefore greatly influences the quality of the water in the system. The suspended silt load of the river had a marked seasonal fluctuation and reached a maximum (980 mg/dm^3) during the wet summer period. All three inflows had high nitrate concentrations which frequently exceeded 1 mg = dm3^3 during the year. Soluble reactive phosphate concentrations in the rivers remained low throughout the study period but the total unfiltered phosphate concentrations increased during the short periods of high silt loads. High average concentrations of silica (6,7, 5,1 and 6,3 mg/dm^3) from all 3 river inputs maintained high levels of soluble silica in the dam itself.

A bathymetric map of the dam shows that it is characterized by the long shallow Msunduze inlet (max. depth 9,0 m) with gently sloping banks. This inlet broadens into a deeper region near the dam wall where a maximum depth of 18,8 m has been recorded at full supply level. During the dry season prior to the first summer rains drawdown produced an extensive mud bank with a deep central channel through which the Msunduze passed. A silt survey carried out by the City Engineers Department of Pietermaritzburg in December 1977 revealed that the storage capacity had been reduced to 5,79 x 10^6 m^3 giving a reduced surface area of 71 ha and a mean depth of 8,2 m . Sampling stations of the inflowing rivers are indicated on the map of the dam and the immediate catchment (Fig. 2).

Recreational facilities have been limited to a small canoe club (approx. 200 members) situated on the eastern shore of the main basin and picnic facilities for the general public. However, it is a controlled area and entry permits are required by the Pietermaritzburg Corporation authorities.

Henley Dam is a major water resource for Pietermaritzburg and its industrial development within the greater city area. The dam is part of the Umgeni River reservoir system but it is threatened by the uncontrolled, rapidly expanding squatter development in the catchment. It is therefore necessary to determine the critical nutrient loads which can be tolerated by such a reservoir before it is too late.

RESULTS AND DISCUSSION

The basic morphometric characteristics of the impoundment and its catchment are shown in Table 1. Table 2 gives a summary of the monthly hydrological behaviour of the dam from November 1977 until the end of October 1978.

The Msunduze River was the major inflow to the system and discharged 42,68 x 10^6 m^3 during the period of investigation and this represented 83 % of the total inflow. The Msunduzane (13 %) and the Thenjane (3 %), together with the rainfall, contribute the remaining inflow to the dam. The total inflow of 51,63 x 10^6 m^3 for the 12-month period under investigation gives a theoretical retention time of 0,11 years (41 days) and a flushing rate of 8,5 times per year. From January to April 1978 the total inflows per month were each sufficient to replace the entire volume of the dam and therefore the system was well flushed during the summer period. A summary of the average term annual inflows to the dam indicates that during the study period the dam received more water than the average. Therefore, although nutrient loading rates may be higher than in previous years this disadvantageous condition may have been offset by the greater flushing rate during summer when about 70 % of the nitrogen and 90 % of the phosphate load reached the system.

Frequency histograms for the surface water data are presented in Figures 3 to 5. The histograms give an indication of the number of weeks in which a particular range or value was encountered.

Soluble phosphate concentrations in the dam fluctuated in conjunction with the seasonal variation of the input from the Msunduze River. Although 50 % of the observations of soluble reactive phosphate phosphorus were 0,002 mg/dm^3 or less, values were generally higher in Henley Dam than in other Umgeni River reservoirs. Total phosphate phosphorus (unfiltered) reached levels of 0,06 mg/dm^3 which was about three times the maximum concentration observed in Midmar Dam which lies in the adjacent catchment.

Ambient nitrate-nitrogen concentrations were also high despite the absence of an obvious point source of sewage effluent disposal in the catchment. More than 75 % of the observations exceeded 0,7 mg/dm^3 N and a maximum surface value of 1,041 mg/dm^3 was recorded.

Concentrations of soluble silicate were maintained within a narrow range (5,2 — 6,7 mg/dm^3) by the continuous high input via the rivers and by the absence of a major diatom bloom.

Henley Dam is a warm monomictic impoundment in which there is a long period of summer stratification, a short overturn and a period of isothermal conditions before reformation of summer stratification. The dam is sheltered in the hills above the city of Pietermaritzburg and therefore high surface temperatures were measured in summer (maximum 29 °C). The stable thermocline which developed between 4 and 6 m was temporarily disrupted in February by a sudden high inflow via the Msunduze River.

Oxygen isopleths of Henley Dam showed that an extensive anaerobic bottom zone had developed by late November 1977 and reached 7,0 m from the surface. High inflows in February also disrupted the anaerobic bottom waters which were temporarily replaced by well oxygenated waters from the Msunduze River. The anaerobic condition reappeared for a brief period before the isothermal winter conditions. Deoxygenation of the bottom waters occurred again at the end of October 1978. The surface waters of Henley Dam were frequently supersaturated in the warmer months with a mean value between 80 and 90 % for the winter period. pH values fluctuated between 6,7 and 7,9 and the chlorophyll *a* levels never exceeded 12 μg/dm^3.

Henley Dam was turbid for most of the summer season and therefore Secchi depth readings were low (19 — 25 cm) until the dry winter period when the clarity of the water improved to give a maximum Secchi reading of 333 cm in August. Turbidity values during the spring and summer season reached 67 Jackson Turbidity Units and poor light penetration during this period contributed to the relatively low algal growth response in the system. The turbidity of the system was an indication of the high silt load introduced via the rivers because of uncontrolled activities in the immediate catchment.

The phytoplankton population of Henley Dam was dominated by a large *Peridinium* species which was frequently present all year and occurred in large numbers during the late summer season of 1977/78. A *Dinobryon* (Chrysophyta) species increased in number during spring at the same time that large numbers of *Ankistrodesmus Braunii* (Naeg.) Brunnthaler were observed. Blue-green algal groups were not well represented and *Microcystis* was rarely recorded during the study. The diatoms too were poorly represented and, unlike most of the other Mgeni River reservoirs, *Melosira* species were rare. *Synedra rumpens* Kützing and a few *Cyclotella* species were often the dominant diatoms.

Thermocyclops oblongatus (Sars.) was numerically dominant in Henley Dam, while no calanoid copepods were found during the study. *Daphnia pulex* Leydig and *D. longispina* O.F. Müller were dominant among the Cladocerans particularly during winter while *Ceriodaphnia reticulata* Richard increased in numbers during autumn. *Moina dubia* Richard was abundant during the summer months. *Brachionus falcatus* Zacharias and an *Ascomorpha* species were both abundant throughout the year but *Filinia opoliensis* Zacharias and a *Hexarthra* species increased in importance (numerically) during the summer and autumn respectively.

Nutrient loading rates for Henley Dam were estimated for orthophosphate (0,23 $g.m^{-2}.a^{-1}$ P) and inorganic nitrogen (73,19 $g.m^{-2}.a^{-1}$ N) and indicated that a very large amount of nitrogen was introduced into the dam during the study period in a readily assimilable form. However, the total N:P ratio of 14 indicates that, in addition to large quantities of nitrogen, there is a large amount of phosphate associated with the high silt loads carried into the dam, especially during summer after runoff from the catchment.

CONCLUSIONS

Henley Dam is a small turbid impoundment which experienced a high flushing rate during the study period. In the absence of an obvious point source of enrichment the high nitrogen loads and consequent high in-system nitrogen concentrations were characteristic features of the dam. Henley Dam may be classified as oligo-mesotrophic although during dry years adverse conditions are likely to develop.

ACKNOWLEDGEMENTS

The City Engineers Department of Pietermaritzburg is gratefully acknowledged for providing the hydrological data. Messrs W.D. Turner and B.D. Gardner are also thanked for computerization of the data.

TABLE 1. Characteristics of Henley Dam and its catchment

Geographical location	29 ° 37'S; 30 ° 15'E
Magisterial district	Pietermaritzburg
Catchment type	Undeveloped grasslands, timber
Usage of dam	Potable, yachting
Catchment area	219 km^2
Inflowing rivers	Msunduze 181 km^2, Msunduzane 30 km^2, Thenjane 8 km^2
Dam wall completed	1959
*F.S.L. volume	5,79 x 10^6 m^3
F.S.L. area	0,71 km^2
F.S.L. maximum depth	18,8 m
F.S.L. mean depth	8,2 m

*F.S.L. = full supply level

TABLE 2. A summary of monthly hydrological characteristics for Henley Dam (Nov. 1977 — Oct. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	5,86	3,96	5,54	10,65	
Area km^2	0,72	0,49	0,68		
Mean depth m	8,74	8,08	8,15		
Monthly inflow x 10^6 m^3	8,65	1,34	4,30	62	
Monthly outflow x 10^6 m^3					

*C.V. = coefficient of variation

TABLE 3. A summary of physical and chemical characteristics of water collected from the inflows (Msunduze, Msunduzane, Thenjane), the outflow and a station (D1) on Henley Dam. Values are based on fortnightly samples collected between November 1977 and October 1978.

Parameter	DAM STATION								MSUNDUZE				MSUNDUZANE				THENJANE				OUTFLOW (MSUNDUZE)			
	TOP				BOTTOM																			
	Min	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**
Na																								
K																								
Ca	2,9	5,4	4.4	14	2,1	6,8	4,6	25	2,2	7,0	4,6	27	2,5	6,0	3,5	25	3,2	7,4	5,5	21	2,1	8,1	4,4	31
Mg	1,9	4,0	2.8	20	1,3	4,8	3,0	31	1,2	3,8	2,8	24	1,4	4,9	2,6	32	2,7	5,2	3,9	17	1,0	4,2	2,6	25
SO_4																								
Cl																								
Si	5,2	6,7	5,8	7	3,7	6,8	5,8	14	4,3	7,7	6,7	13	3,2	6,9	5,1	14	4,6	7,1	6,3	12	3,7	8,4	6,2	15
Cond	4,1	9,1	6.8	13	3,3	9,8	7,1	21	3,7	9,2	6,9	19	3,7	10,3	6,4	23	5,5	10,9	8,6	16	4,2	9,4	6,9	19
Alk	14	29	22	17	7	41	25	32	7	32	22	32	10	23	16	19	11	22	16	18	7	42	24	32
Tot Kj−N	0,263	0,484	0,381	14	0,359	1,505	0,856	36	0,136	1,650	0,469	70	0,124	0,539	0,278	37	0,122	0,692	0,269	56	0,122	1,665	0,473	62
Dis Kj−N	0,117	0,377	0,262	24	0,162	0,997	0,509	44	0,073	0,496	0,224	38	0,103	0,281	0,185	29	0,078	0,366	0,165	41	0,099	0,571	0,264	36
NH_4−N	0,011	0,187	0,102	58	0,026	0,811	0,338	61	0,004	0,106	0,037	71	0,012	0,119	0,051	50	0,003	0,044	0,016	65	0,013	0,335	0,093	72
NO_3−N	0.475	1,041	0,774	19	0,006	1,008	0,554	57	0,489	1,263	0,954	22	0,427	1,202	0,770	26	0,510	1,022	0,793	15	0,103	1,049	0,667	44
NO_2−N	0.001	0,113	0,009	231	0,001	0,017	0,005	82	0,002	0,011	0,005	46	0,003	0,020	0,007	55	0,001	0,070	0,006	215	0,001	0,016	0,005	60
Tot P	0,005	0,063	0,024	64	0,007	0,563	0,096	130	0,012	0,690	0,093	168	0,005	0,050	0,023	60	0,009	0,324	0,035	171	0,006	0,725	0,054	248
Tot dis P	0,002	0,019	0,008	55	0,002	0,138	0,019	167	0,004	0,101	0,013	139	0,002	0,021	0,006	65	0,002	0,032	0,008	75	0,002	0,116	0,014	168
PO_4−P	0.001	0,008	0,002	91	0,001	0,119	0,007	298	0,001	0,012	0,003	89	0,001	0,007	0,001	82	0,001	0,007	0,002	57	0,001	0,031	0,003	167
Fe																								
Mn																								
Temp	11,6	29,0	19,1	24	10,1	20,0	14,4	22																
DO	4,4	9,6	7,8	16	0,3	7,1	3,3	72																
Tu	2	67	19	89	7	305	83	114	4	300	57	145	2	38	12	85	2	26	6	85	1	270	34	169
pH	6,7	7,9	7,3	4	6,4	7,4	6,9	4	6,9	7,8	7,4	3	7,0	7,7	7,4	2	6,9	7,6	7,3	2	6,8	8,5	7,6	5
SS	1	51	16	91	1	743	123	139	4	980	121	196	1	38	12	92	1	80	10	159	1	1108	60	346

*C.V. = coefficient of variation

TABLE 4. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Henley Dam (Nov. 1977 – Oct. 1978)

Mean depth m	8,2		
Retention time a	0,11		
Hydraulic load m/a	74,5		
Surface loading rates g/m^2.a			
PO_4-P	0,23		
Total P	7,64		
Inorganic nitrogen	73,19		
Total nitrogen	107,34		
	Maximum	**Minimum**	**Mean**
Chlorophyll *a* μg/dm^3	11,4	0,7	4,0
Secchi depth m	3,33	0,19	1,00

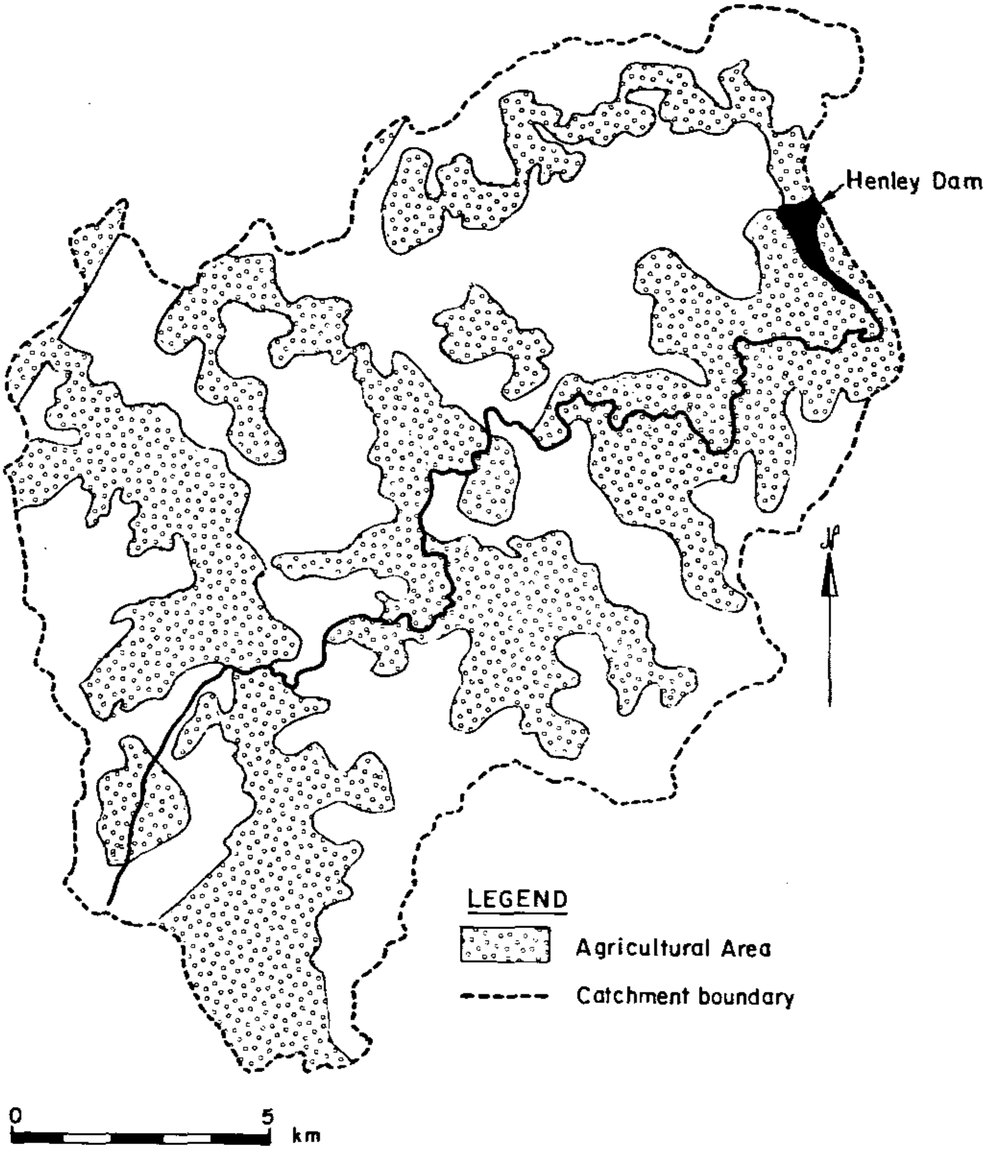

FIGURE 1. Henley Dam catchment.

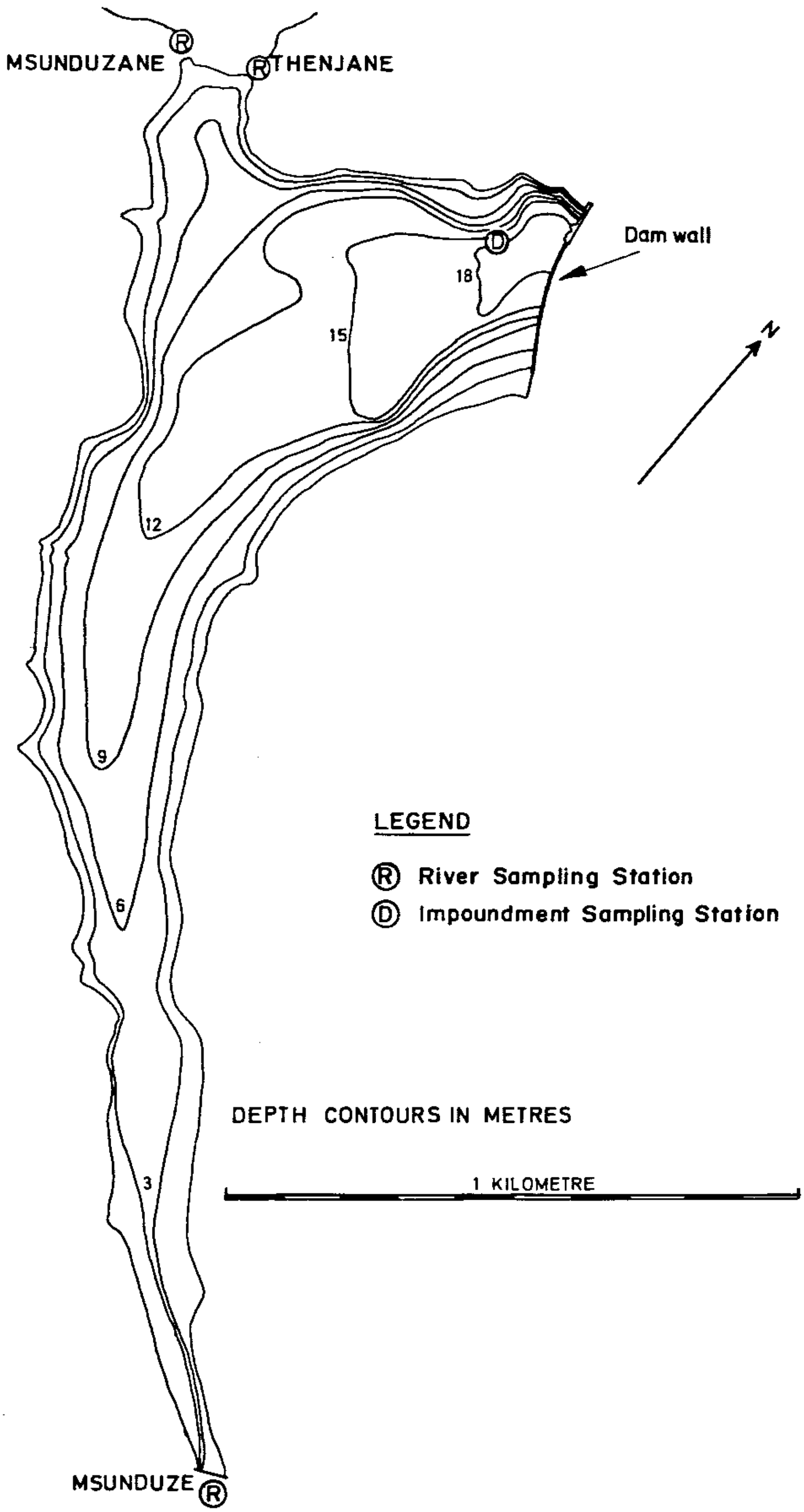

FIGURE 2. Map of Henley Dam showing sampling stations.

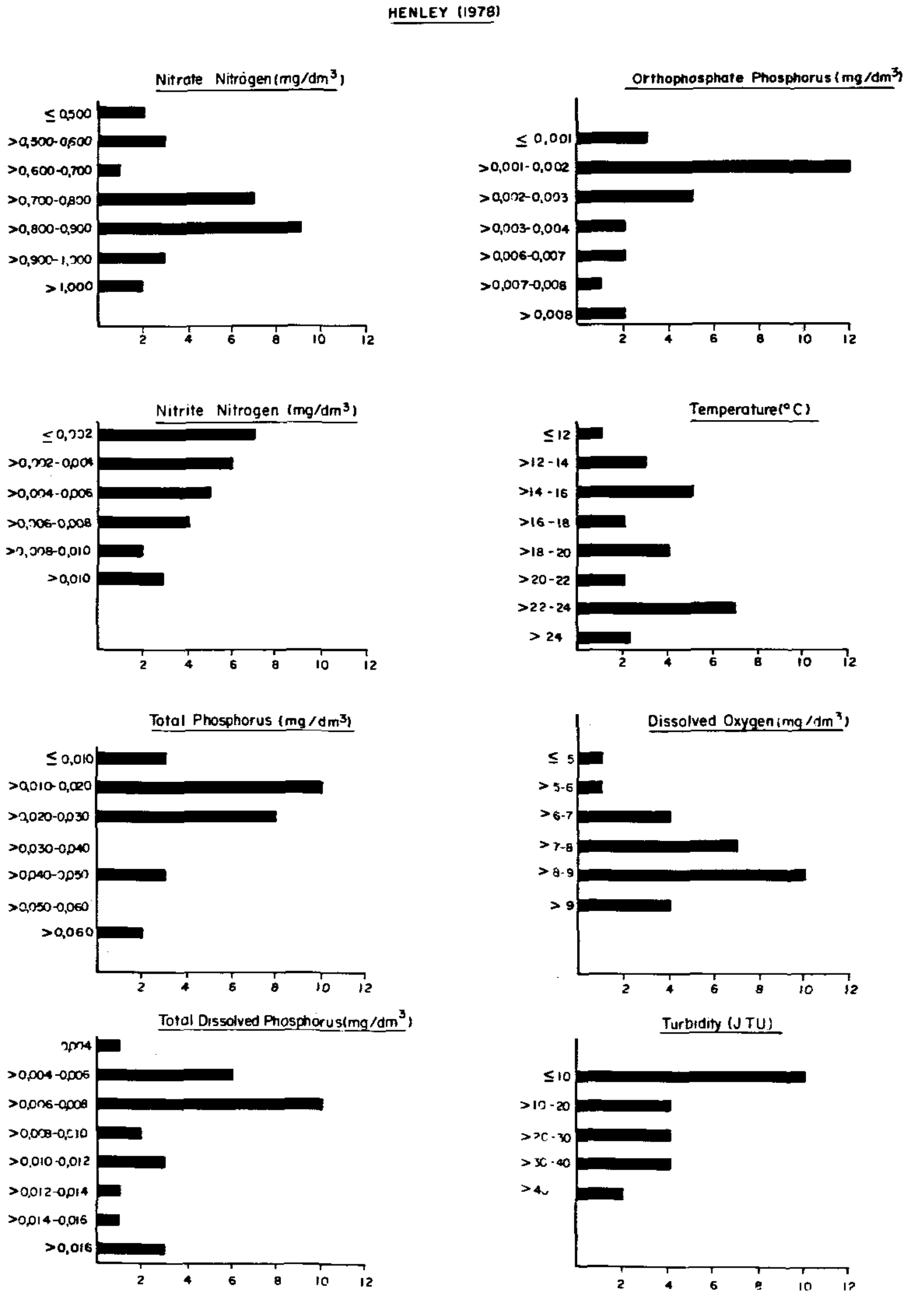

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Henley Dam.

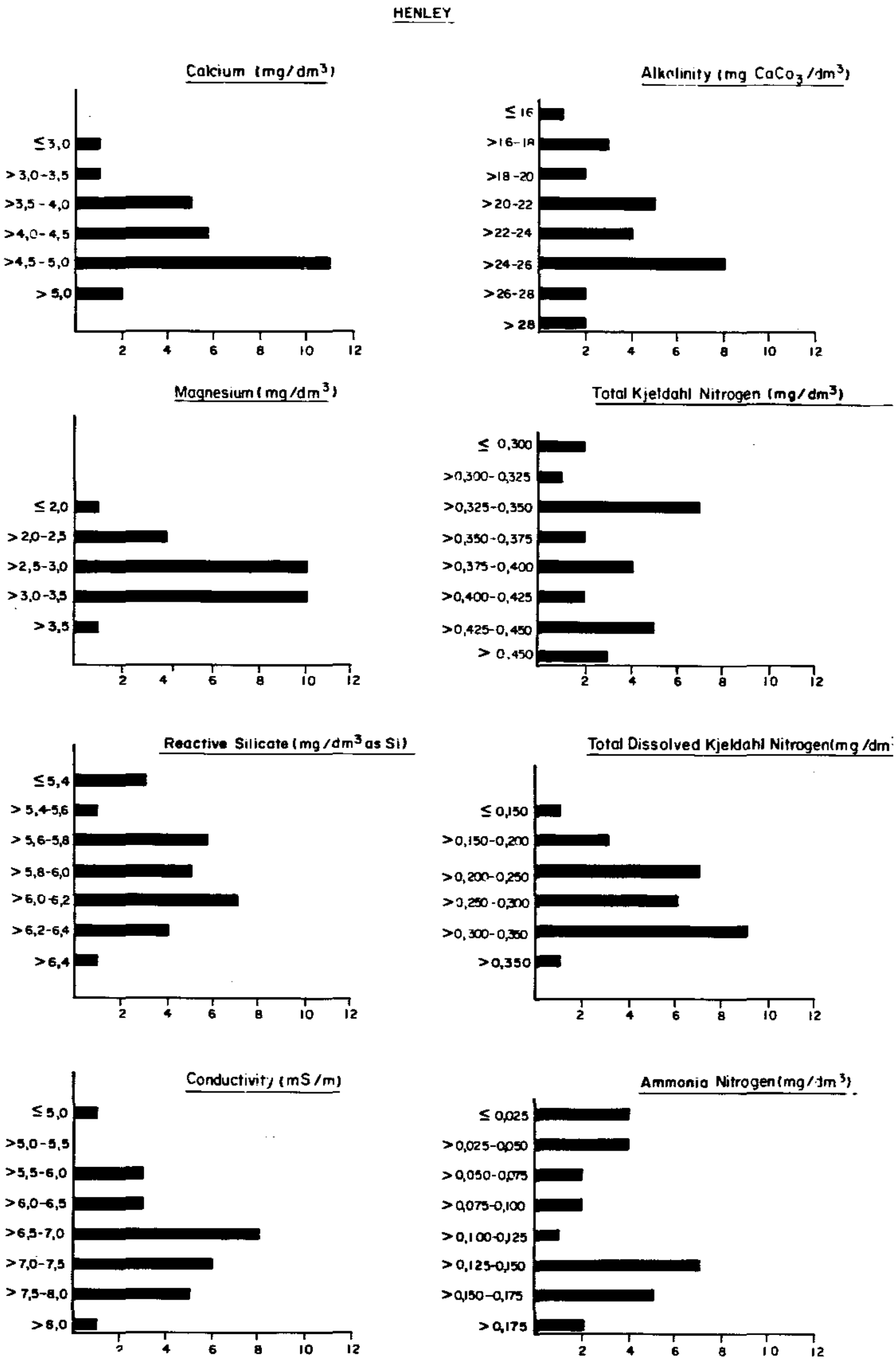

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Henley Dam.

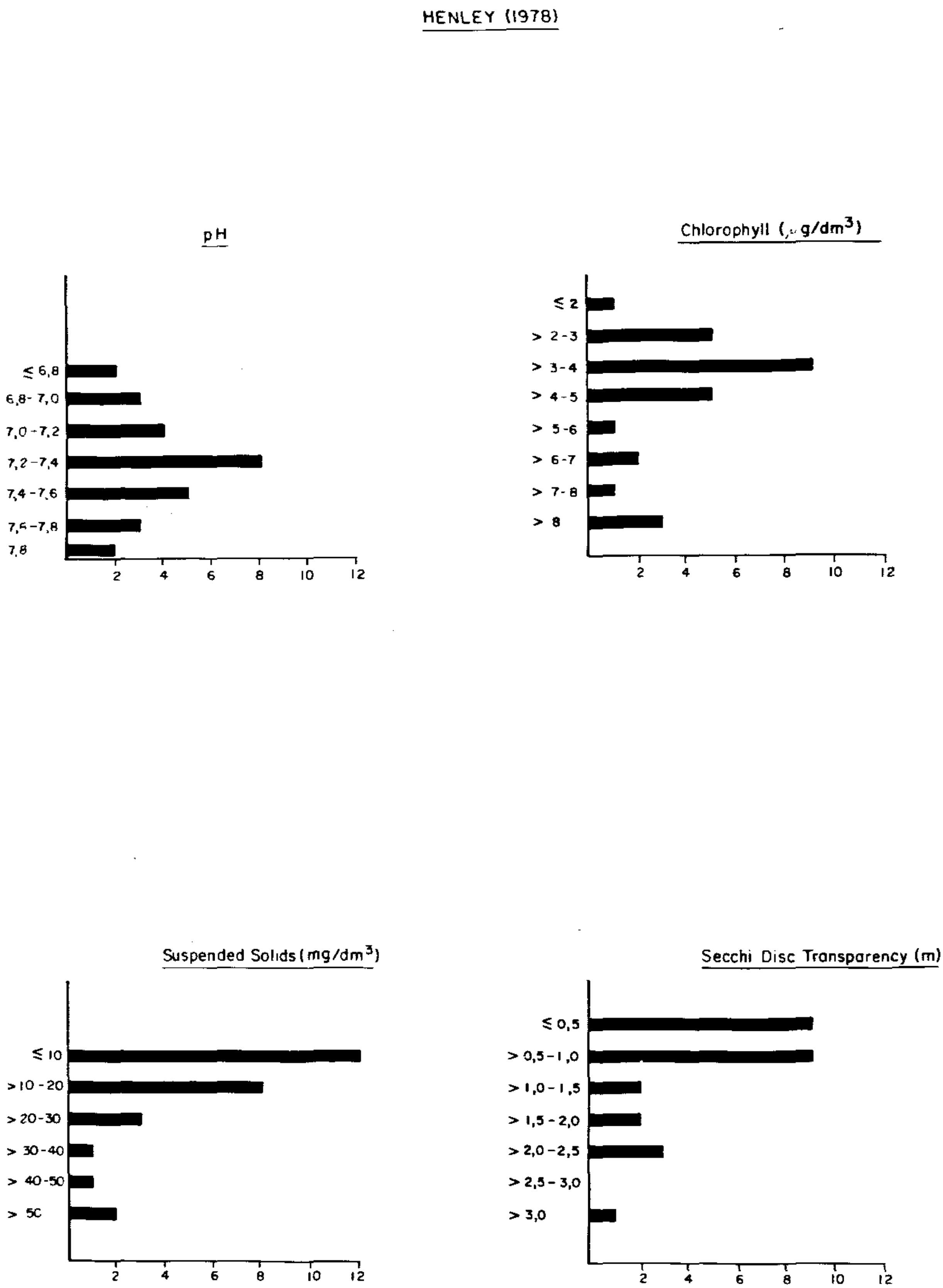

FIGURE 5. **Frequency histogram for selected parameters pertinent to the surface waters of Henley Dam.**

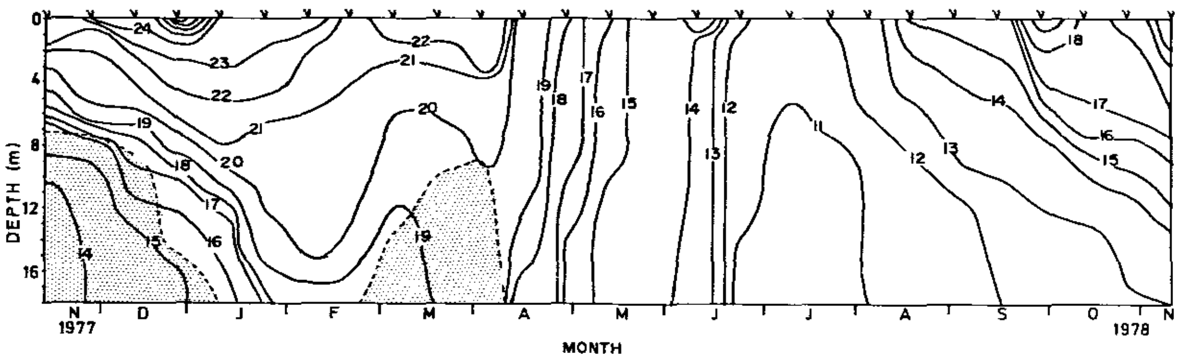

FIGURE 6. Temperature distribution in Henley Dam (Nov. 1977 — Oct. 1978)

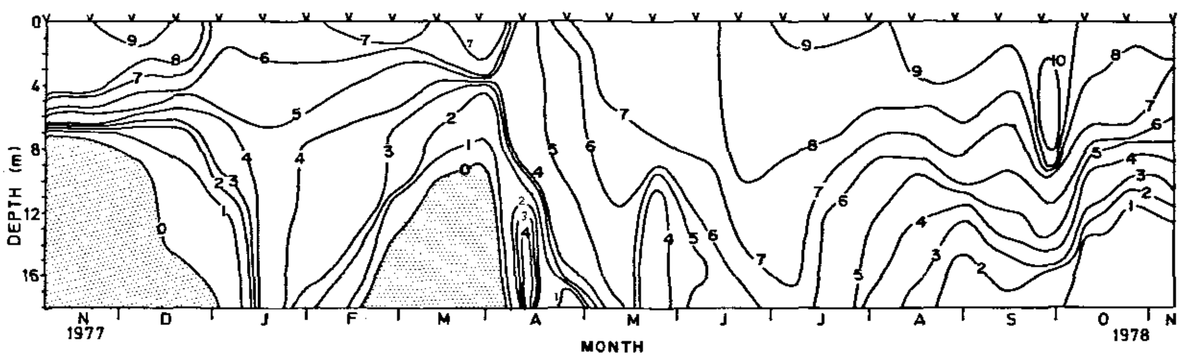

FIGURE 7. The distribution of dissolved oxygen in Henley Dam (Nov. 1977 — Oct. 1978)

MIDMAR DAM

by

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INTRODUCTION

The Mgeni River system (catchment 4 418 km^2) stretches from the foothills of the Drakensberg to the metropolitan area of Durban where it enters the Indian Ocean. This perennial river is considered one of the most reliable of the larger rivers in South Africa (Van der Zel, 1975), and provides the water needs of a region in which 45 % of the population of Natal reside and it is responsible for 20 % of the industrial output of South Africa.

Midmar Dam was completed in 1964 and lies in the upper Mgeni River catchment at the head of a chain of reservoirs situated along the river course. It is anticipated that Midmar Dam together with Albert Falls, Nagle, Henley (Msunduze tributary) and a proposed fifth system near Inanda will provide for the predicted demand of 1,6 x 10^6 m^3/d (584 x 10^6 m^3/a) by the turn of the century.

However, the present rapid rate of urban and industrial development in the drainage basin presupposes that eutrophication of the Mgeni reservoirs will be greatly accelerated. Therefore it is important to improve our understanding of these impoundments and to develop nutrient loading patterns and limits so that management procedures can be implemented for optimal utilization.

DESCRIPTION OF THE AREA

Midmar Dam wall is sited in a broad valley in the upper Mgeni catchment, upstream of Howick, where erodible sandstones and shales of the Ecca series (Karoo system) prevail. The four flooded valleys of Midmar Dam form a multi-lobed system extending into a broad, well exposed central basin which is approximately 6 km^2 in area. The Mgeni River which enters the system from the north, has an estimated mean annual runoff of 158,5 x 10^6 m^3 of good quality water with low suspended solids, low total dissolved solids and low nutrient concentrations. Phosphate concentrations are particularly low since the soils of the Mgeni-Lions catchment are known to have a high phosphate binding capacity (Scotney, 1976) and therefore the phosphate load may be relatively small (Furness, 1974). However, the upper Mgeni-Lions river catchment has been given a high rating for intensive agriculture by Scotney (1970) who has also provided a detailed account of land use and soil characteristics of the region. Land use includes forestry, agriculture and stock raising but more than 50 % of the area remains undeveloped grassland (Hemens *et al.*, 1970; van der Zel, 1975 – Fig. 1).

The concentrations of nutrients entering the dam via the smaller streams were generally low with the exception of the Umthinzima which drains the Mpophomeni township. Soluble reactive phosphate concentrations in this stream reached 0,067 mg/dm^3 P and the maximum nitrate-nitrogen concentration was 0,69 mg/dm^3 N. Both the proposed greater Mpophomeni township and parts of the existing Zenzele township on the eastern shore of the main basin present a severe threat to the water quality of Midmar Dam since it is unlikely that the population in these areas will ever decrease.

Midmar Dam is the major inland water resort of Natal and it has been estimated that over 450 000 people visited the dam during the 1977/78 financial year. Recreation at Midmar Dam includes swimming, fishing, waterskiing and yachting; the latter activity involves a considerable financial outlay by the participants. The Natal Parks Board has jurisdiction over the entire periphery of the dam with the exception of the security area near the dam wall. Large camping grounds and holiday chalets have been constructed on both the eastern and western shores of the main basin. A small game park has been established on the peninsula bordered by the drowned Kwagqishi and Nguku valleys and that bordered by the drowned Nguku and Umthinzima valleys.

Most of the land adjacent to the periphery of the dam is owned by farmers who are primarily involved in dairy production and the cultivation of fodder crops and to a lesser extent vegetables. The proximity of the larger dairy farms presents the danger of possible localised enrichment from uncontrolled dairy washings.

The overall increase in user demand and the undesirable developments taking place in the immediate catchment of Midmar Dam make it imperative that effective management be introduced to offset the anticipated problems. The increase in sewage discharge alone from the recreational facilities may have a detrimental effect on the water quality of the Mgeni River below Midmar Dam.

RESULTS AND DISCUSSION

A bathymetric map of the system indicates the relatively shallow nature of the dam which has a deep central basin following the old river course. The Mgeni River inlet is deeper than the broad and shallow southern legs of the Kwagqishi, Nguku and Umthinzima rivers. The positions of the sampling stations on the rivers and the station near the dam wall are indicated on the bathymetric map of Midmar Dam (Fig. 2).

The basic morphometric characteristics of the impoundment and its catchment are shown in Table 1. The essential annual hydrological characteristics of the system are given in Table 2 for an average term (10-year period), while Table 3 gives a summary of the monthly hydrological behaviour of the dam for a 12-month period from November 1977 to the end of October 1978.

The total inflow of 183,17 x 10^6 m^3 during the period of investigation was more than the average annual input of 160,35 x 10^6 m^3 (Hemens *et al.*, 1977) and therefore the dam received more water than during an average year. Based on the net annual outflow from the dam the retention period was calculated as 1,04 year (380 days) which represents a flushing rate of 0,96 years. Although the dam was only 90 % full at the start of the investigation in November 1977 the volume did not fluctuate greatly during the study (Table 3). There was a marked seasonal variation, however, in the inflow, 78 % of which entered the dam during summer bringing with it 88 % of the total nitrogen load and 89 % of the total phosphate load.

Midmar Dam has been described as oligo-mesotrophic by Hemens *et al.*, (1977) from a cursory investigation of the system during 1973, and as an oligotrophic phosphate-limited impoundment by Toerien *et al.*, (1975) after completing algal assays on snap samples from the dam. Walmsley (1977) confirmed these general observations. More specific studies of Midmar using isolation columns as an experimental system have led Twinch and Breen (1978a, 1978b) to doubt whether phosphate is really the limiting nutrient. Frequency histograms of surface water data are presented in Figures 3 to 5. Analyses of the water chemistry throughout the period of investigation indicated that the nutrient levels remained low both in surface and bottom waters (Table 4). The concentrations were comparable to the levels which were measured in 1973 by Hemens *et al.* (1977), indicating that there has been no obvious change in the water quality for the past five years (Figs. 3 – 5). Nitrate-nitrogen levels were frequently less than 0,25 mg/dm^3 in surface and bottom waters. Soluble reactive phosphorus concentrations never exceeded 0,007 mg/dm^3 and the histograms show that over 75 % of the measurements were 0,003 mg/dm^3 P or less. Although the phytoplankton population was dominated by diatoms for most of the year the silicon concentrations did not show marked fluctuations. Only 25 % of the measurements were less than the mean concentration of 3,2 mg/dm^3 Si indicating that no major diatom blooms occurred during the investigation.

Total dissolved phosphate (unfiltered) and total Kjeldahl nitrogen values showed no distinct seasonal trends and therefore no excessive or dramatic biological growths occurred in the system. This was substantiated by the small changes in pH, dissolved oxygen, free carbon dioxide concentrations and chlorophyll *a* levels throughout the year.

The reservoir can be considered a warm monomictic system although the isotherms of the water near the dam wall indicated that the thermocline was weakly defined between 6 and 8 m and that summer stratification was unstable. Although there was an obvious seasonal trend the values for maximum temperatures were lower than expected because the sampling of the system frequently occurred before 09h00 (Fig. 5.)

Oxzygen isopleths indicated the existence of a short-lived anaerobic zone which developed below 12,0 m at the end of January and persisted until the overturn in mid-April. Supersaturation of the surface waters was very infrequent (Fig. 6).

Although the waters of Midmar Dam cannot be considered turbid by South African standards it was interesting to note that the turbidity of the water increased during the dry winter months. Both the suspended solids (winter increase) and Secchi depth readings (winter decrease) confirmed this unusual trend. Secchi depth values never exceeded 2,25 m and more than 70 % of the observations were less than 1,50 m. The increase in suspended solids during winter was attributed to a combination of a fine silt suspension derived from loose marginal and bottom sediments and intense water circulation of the wind-exposed system.

Phytoplankton population densities were never excessively high and seldom exceeded 500/cm^3. ***Melosira granulata*** (Ehrb.) Ralfs and *Melosira granulata* var. *angustissima* Müll were often the most prolific diatom species with the latter assuming numerical dominance during late winter and early spring. *Cyclotella* species, particularly ***Cyclotella stelligera***

Cl. n. Grun, and *Fragilaria familiaris* were frequently present in the diatom-dominated phytoplankton. Chlorophyta were represented by species of *Crucigenia, Pediastrum* and very small *Chlamydamonads. Cryptomonads* were prevalent during winter months during periods of increased turbidity — a physical phenomenon which may have selectively favoured flagellated organisms. However, other members of the Pyrrophyta such as *Peridinium* were not well represented and were only recorded on rare occasions. Trachelomonads were also rare. Members of the blue-green algal groups were seldom present in large numbers but *Microcystis, Oscillatoria* and *Anabaena* species were recorded occasionally.

The total zooplankton population showed only small fluctuations during the year except in May when large numbers of an *Ascomorpha* (Rotifera) species caused a deviation from the general pattern of declining total numbers of zooplankton. *Thermocyclops oblongatus* (Sars.) and *Tropodiaptomus spectabilis* (Kiefer) were the numerically dominant copepods reaching maximum numbers in mid-summer. *Daphnia pulex* Leydig and *Daphnia longispina* O.F. Müller were the dominant Cladoceran species but the population was generally of low density, never exceeding 3 000/m^3 of filtered water. Among the Rotifera the mid-summer dominant was a species of *Hexarthra* but an *Ascomorpha* species increased dramatically during late April and May. The low population density of the zooplankton in Midmar Dam was a significant feature of the impoundment.

Although the shoreline development is rather high (D_L = 3, Hemens *et al.* 1977) littoral macrophytic growth has been confined to isolated patches of *Potamogeton schweinfurthii* A Benn, and emergent macrophytes such as *Phragmites mauritianus* Kunth because of the substantial annual fluctuation in water level.

Nutrient loading rates for orthophosphate and inorganic nitrogen (0,05 $g.m^{-2}.a^{-1}$ P and 3,11 $g.m^{-2}.a^{-1}$ N) have been estimated for the study period. The loading rates for the total (unfiltered) phosphate and total nitrogen are given as 0,46 $g.m^{-2}.a^{-1}$ P and 9,18 $g.m^{-2}.a^{-1}$ N respectively. These figures appear to be in agreement with Hemens *et al.* (1977) who gave loading rates of 0,62 $g.m^{-2}.a^{-1}$ P and 8,49 $g.m^{-2}.a^{-1}$ N for total unfiltered phosphate and total nitrogen values respectively. However, during the investigation of Midmar in 1973 the total inflow of 320 x 10^6 m^3 was nearly double the inflow of the 1977/1978 study period.

CONCLUSIONS

Midmar Dam is the most important multi-purpose water resource in Natal. It remains a clear-water, oligo-mesotrophic phosphorus-limited impoundment with no measurable evidence of increased recreational pressure. However, the system is seriously threatened by the unwarranted development of a township within the immediate catchment.

ACKNOWLEDGEMENTS

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TABLE 1. Characteristics of Midmar Dam and its catchment

Geographical location	29 ° 30'S; 30 ° 12'E
Magisterial district	Howick
Catchment type	Grasslands, timber, dairy, forest
Usage of dam	Potable, recreation
Catchment area	928 km^2
Inflowing rivers	Mgeni 803 km^2, Kwagqishi 61 km^2, Nguku 29 km^2, Umthinzima 19 km^2
Dam wall completed	1964
*F.S.L. volume	177,20 x 10^6 m^3
F.S.L. area	15,59 km^2
F.S.L. maximum depth	22,3 m
F.S.L. mean depth	11,4 m

*F.S.L. = full supply level

TABLE 2. Average term annual hydrological characteristics of Midmar Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	166,50	9
Area km^2	15,27	5
Mean depth m	10,8	4
Annual inflow x 10^6 m^3	198,1	120
Annual outflow x 10^6 m^3	198,8	117
Retention time a	0,87	

*Average mean is based on monthly values and an annual cycle
Period: January to December 1968 – 1978
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics for Midmar Dam (Nov. 1977 – Oct. 1978)

	Maximum	Minimum	Mean	*C.V. %	Deviation of mean from average %
Volume x 10^6 m^3	179,09	160,54	173,35	3	
Area km^2	16,06	14,76	18,63	3	
Mean depth m	11,2	10,9	11,1	1	
Monthly inflow x 10^6 m^3	52,17	3,13	15,26	94	
Monthly outflow x 10^6 m^3	42,68	5,18	13,62	92	

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of water collected from the inflowing rivers, the outflow and a dam station (D1) on Midmar Dam. Values are based on weekly samples collected between November 1977 and October 1978.

Parameter	DAM STATION								*MGENI*			
	TOP				BOTTOM							
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na												
K												
Ca	3,3	4,4	4,0	7	3,6	5,2	4,3	11	3,1	5,9	4,4	19
Mg	1,8	3,1	2,3	13	1,8	3,2	2,3	15	1,2	2,8	2,2	17
SO_4												
Cl												
Si	1,5	4,2	3,2	29	1,8	4,2	3,5	20	3,2	5,7	5,1	10
Cond	4,0	7,4	5,6	14	4,7	7,3	5,7	14	2,2	7,6	5,5	18
Alk	18	25	21	6	20	27	22	10	12	30	23	18
Tot Kj – N	0,162	0,382	0,225	22	0,176	1,240	0,457	59	0,135	0,566	0,285	44
Dis Kj – N	0,101	0,217	0,160	14	0,116	0,461	0,188	45	0,084	0,310	0,159	33
$NH_4 - N$	0,005	0,056	0,015	72	0,005	0,322	0,045	158	0,006	0,043	0,017	54
$NO_3 - N$	0,119	0,309	0,203	30	0,006	0,310	0,194	43	0,111	0,759	0,200	72
$NO_2 - N$	0,001	0,006	0,002	55	0,001	0,005	0,002	67	0,001	0,014	0,003	87
Tot P	0,009	0,024	0,015	23	0,014	0,260	0,061	107	0,008	0,116	0,028	86
Tot dis P	0,003	0,020	0,007	47	0,003	0,300	0,008	80	0,002	0,028	0,008	67
$PO_4 - P$	0,001	0,006	0,001	61	0,001	0,006	0,002	67	0,001	0,012	0,002	98
Fe												
Mn												
Temp	10,2	25,0	18,0	25	10,9	20,1	15,7	19				
DO	6,0	9,2	7,9	12	0,1	8,6	5,2	52				
Tu	2	13	8	29	10	140	40	89	2	94	13	137
pH	7,2	7,8	7,4	2	6,7	7,5	7,1	4	6,7	7,6	7,3	3
SS	1	11	5	51	7	424	75	145	1	89	14	143

Parameter	*KWAGQISHI*				*GNUKU*				*UMTHINZIMA*				*OUTFLOW (MGENI)*			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na																
K																
Ca	5,0	12,1	8,3	27	3,6	9,9	6,5	25	3,9	11,0	7,2	23	3,7	4,9	4,1	7
Mg	2,4	6,1	4,3	25	2,4	5,8	4,1	23	2,8	7,4	5,3	21	1,6	3,3	2,2	15
SO_4																
Cl																
Si	6,3	10,5	8,7	10	7,1	8,9	7,6	6	6,5	8,6	7,4	6	2,0	4,2	3,4	21
Cond	5,2	13,5	9,7	20	5,5	11,6	8,9	18	7,5	17,0	11,0	21	4,3	7,2	5,6	12
Alk	19	58	42	25	23	53	36	23	24	61	43	19	12	27	21	12
Tot Kj – N	0,111	0,478	0,275	34	0,114	0,562	0,216	46	0,203	3,580	0,665	104	0,160	0,702	0,279	42
Dis Kj – N	0,067	0,296	0,148	36	0,084	0,472	0,141	51	0,152	2,700	0,435	114	0,115	0,517	0,170	27
$NH_4 - N$	0,004	0,045	0,018	55	0,005	0,024	0,012	43	0,004	1,520	0,166	182	0,008	0,084	0,024	79
$NO_3 - N$	0,098	0,753	0,249	66	0,056	0,818	0,349	46	0,227	0,690	0,416	35	0,119	0,286	0,201	25
$NO_2 - N$	0,001	0,009	0,004	43	0,001	0,011	0,003	76	0,001	0,119	0,021	121	0,001	0,006	0,002	62
Tot P	0,013	0,073	0,034	45	0,003	0,055	0,017	72	0,034	0,435	0,114	86	0,010	0,041	0,021	34
Tot dis P	0,002	0,049	0,010	84	0,002	0,012	0,006	52	0,008	0,119	0,032	87	0,003	0,026	0,007	64
$PO_4 - P$	0,001	0,010	0,003	74	0,001	0,007	0,002	86	0,004	0,067	0,014	90	0,001	0,007	0,001	73
Fe																
Mn																
Temp																
DO																
Tu	6	56	24	61	1	48	12	90	8	65	24	62	7	25	12	30
pH	7,4	8,1	7,7	3	7,4	8,1	7,7	3	7,0	8,1	7,4	3	6,9	7,5	7,3	2
SS	6	71	27	69	1	78	13	122	8	109	37	81	3	31	12	62

*C.V. = coefficient of variation

TABLE 5. *Hydrological characteristics, nutrient loading rates, chlorophyll a and water transparency* characteristics of Midmar Dam (Nov. 1977 — Oct. 1978)

Mean depth m		11,1	
Retention time a		1,04	
Hydraulic load m/a		10,66	
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P		0,05	
Total P		0,46	
Inorganic nitrogen		3,11	
Total nitrogen		9,18	
	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	3,9	0,9	2,5
Secchi depth m	2,00	0,59	1,31

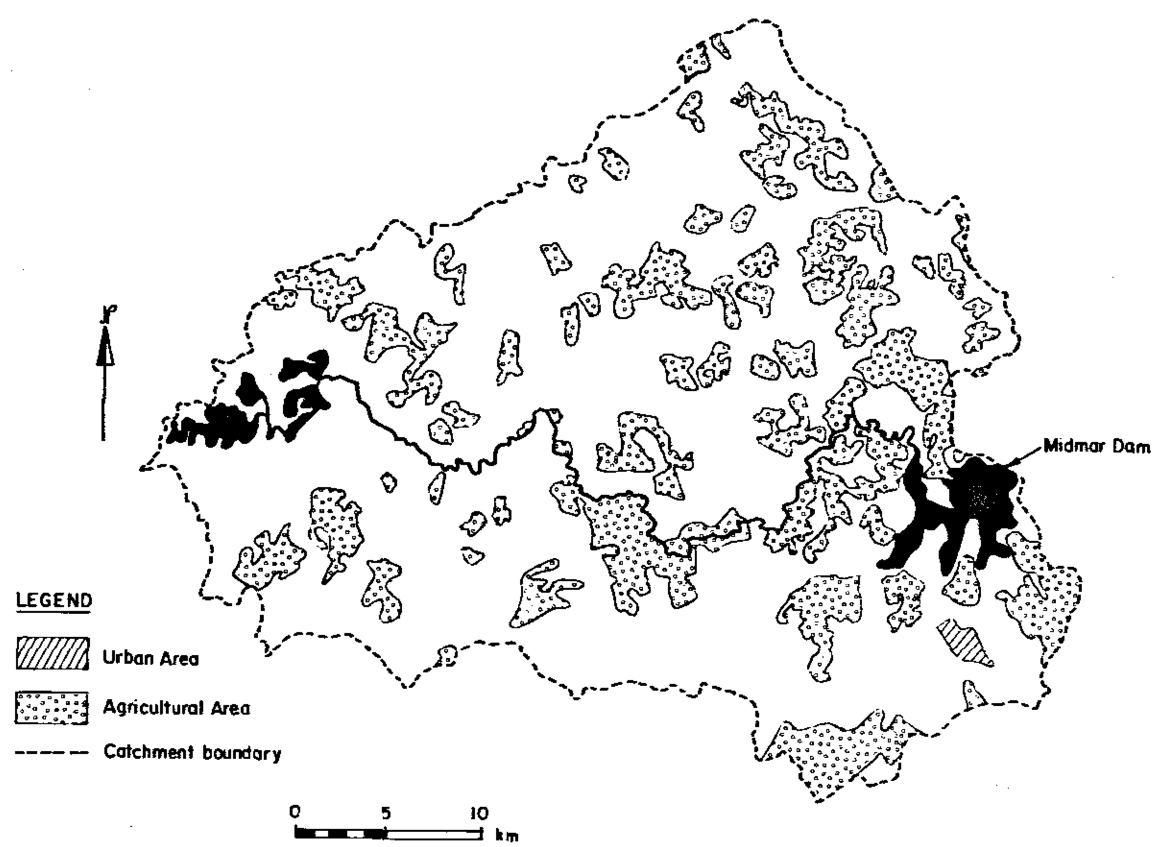

FIGURE 1. Midmar Dam catchment.

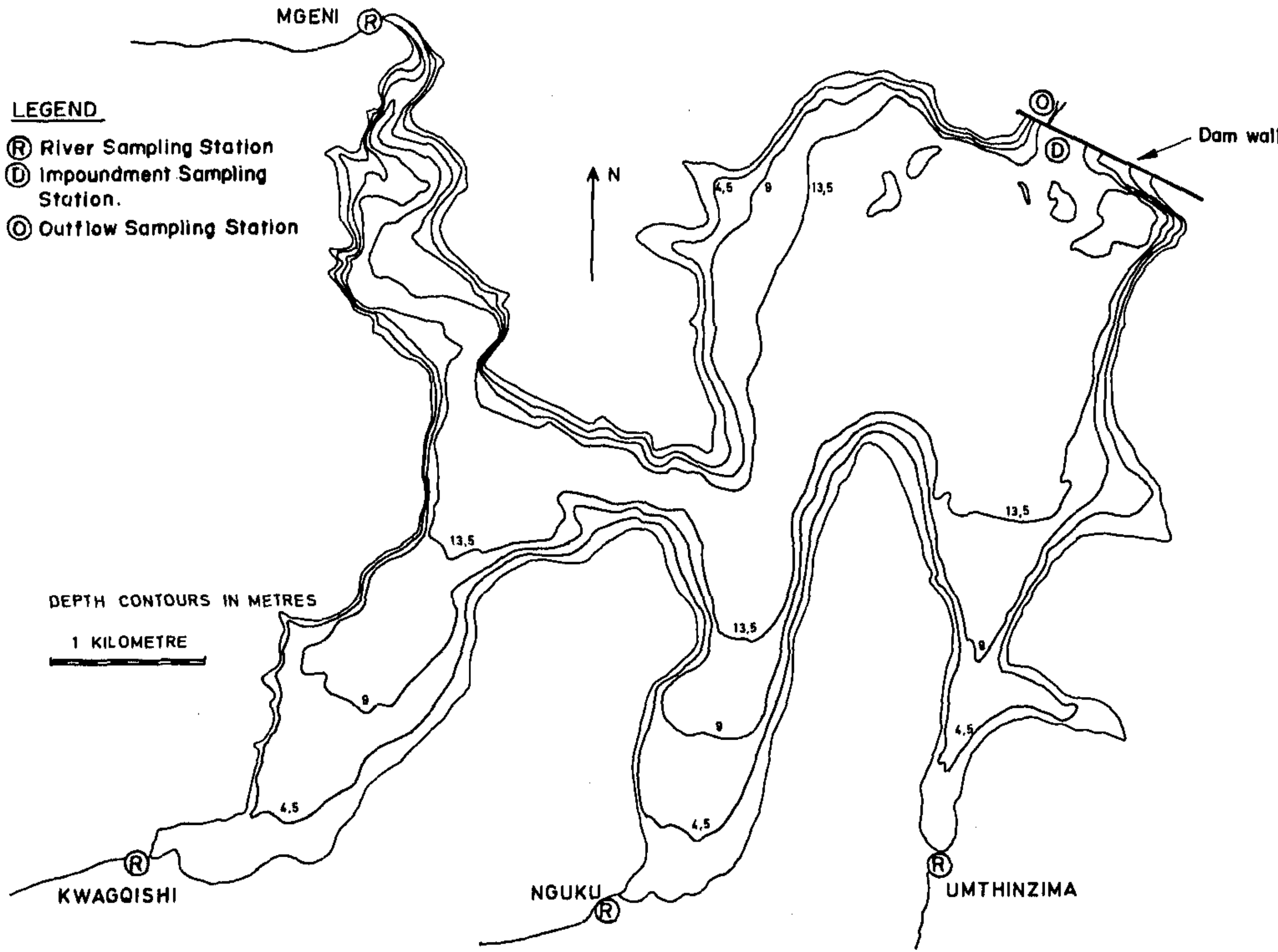

FIGURE 2. Map of Midmar Dam showing sampling stations.

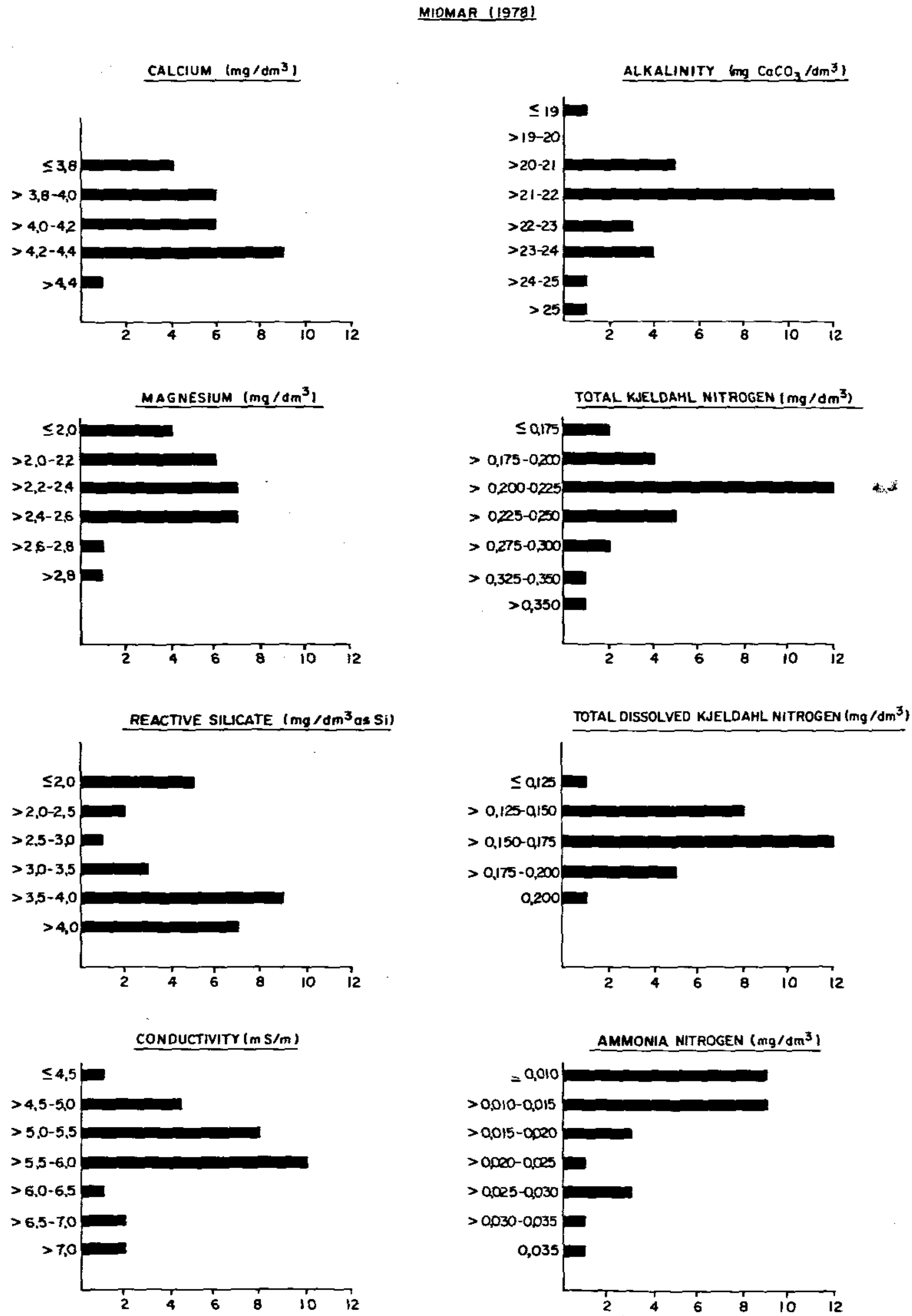

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Midmar Dam.

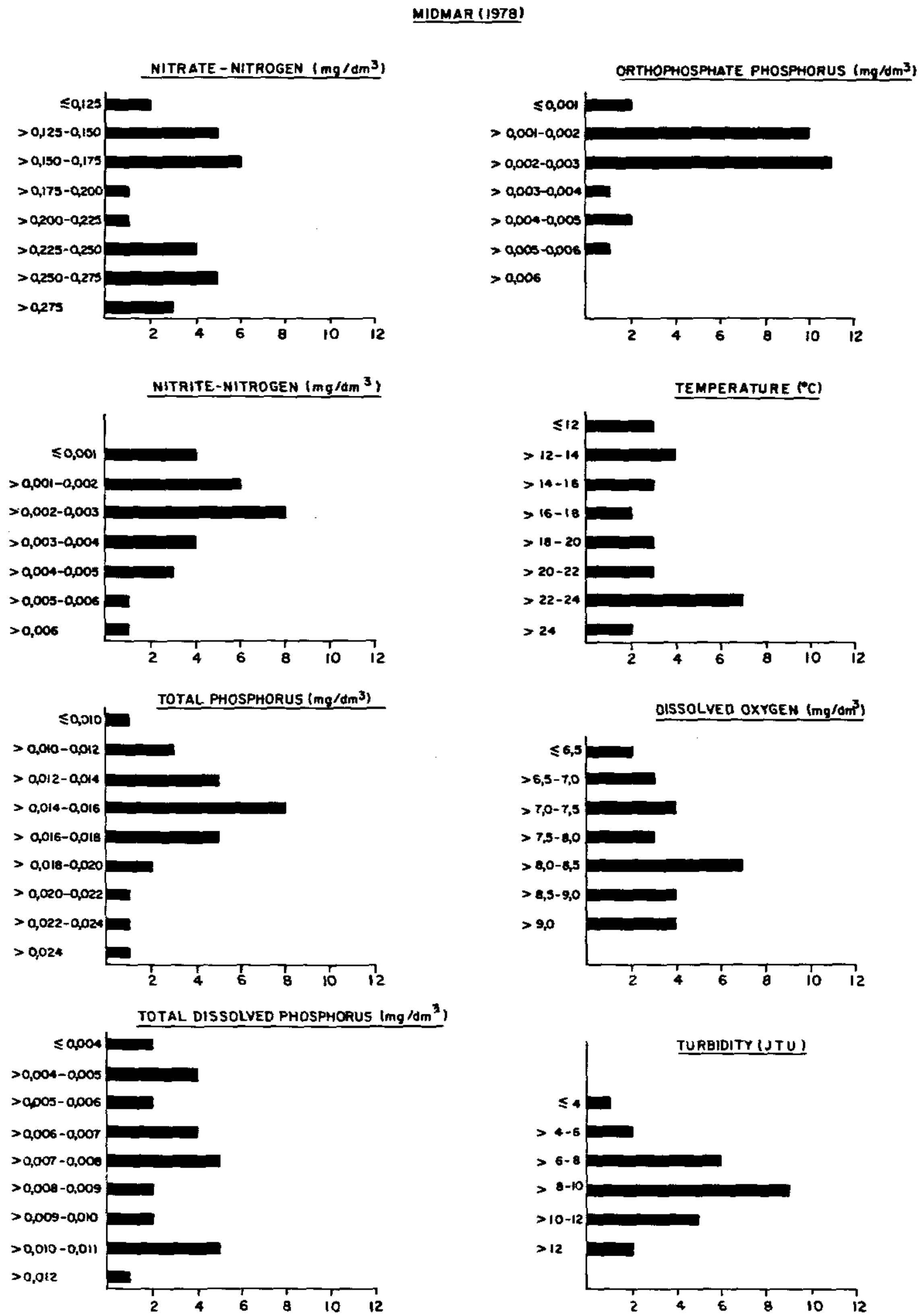

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Midmar Dam.

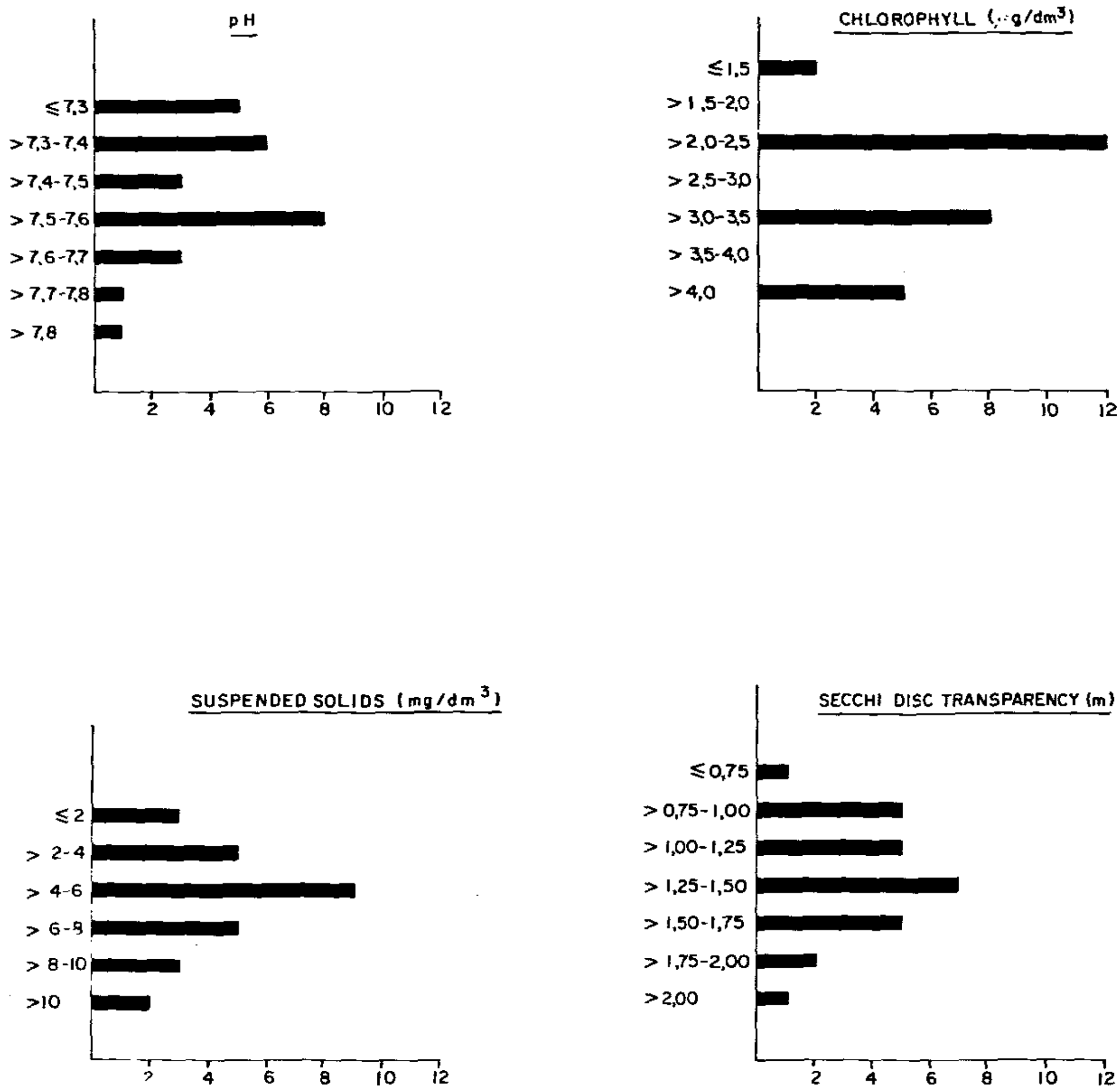

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Midmar Dam.

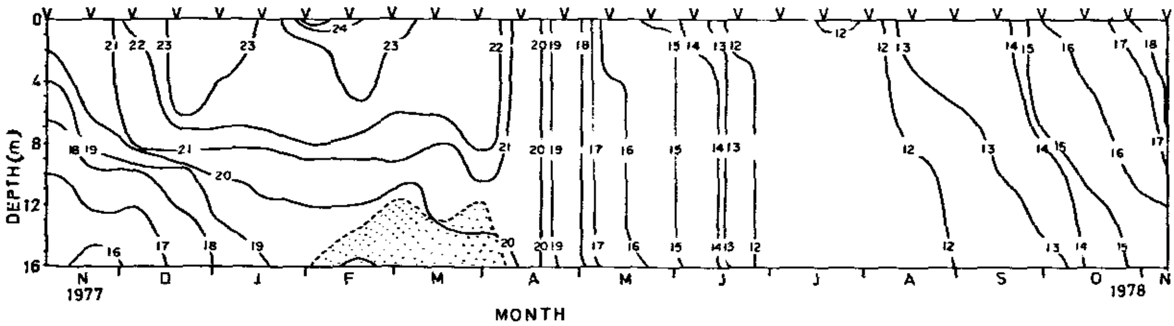

FIGURE 6. Temperature distribution in Midmar Dam (Nov. 1977 – Oct. 1978)

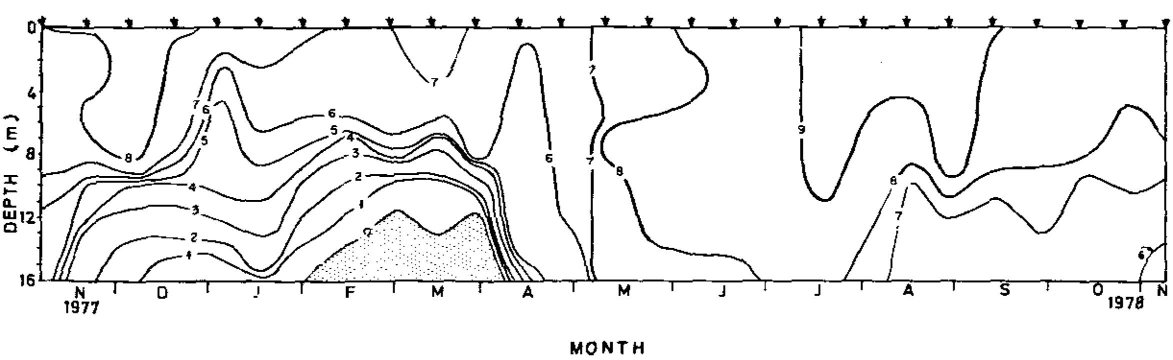

FIGURE 7. The distribution of dissolved oxygen in Midmar Dam (Nov. 1977 – Oct. 1978)

NAGLE DAM

by

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INTRODUCTION

The municipally-owned Nagle Dam was the first reservoir to be built on the Mgeni River. It was completed in 1950 and initially served as an important supplementary source of water for the post-war expansion of the city of Durban after the Vernon Hooper Dam supply proved inadequate to meet the ever-increasing demand.

Original control of the system was exercised by the construction of a diversion weir and control gates at the head of the dam which is shaped like a horseshoe. This system enabled the authorities to bypass unwanted silt-laden water during floods and thus maintain water of good quality in the reservoir itself. Further control of the regime has been achieved since the construction of the larger Midmar (1964) and Albert Falls dams (1976) upstream of Nagle Dam. Nagle Dam is therefore maintained at full supply level almost all year (despite the rapid draw-off) by compensation water discharge from Albert Falls Dam. Nagle Dam now has a unique hydrological regime because, unlike other Natal systems, it is not subject to great seasonal fluctuations of inflow and nutrient input, but receives a steady input all the year round.

Nagle Dam is a major water resource serving the greater Durban area and because of its unique hydrological condition, the authorities should be able to manage the system to achieve optimal utilization. Nutrient loading patterns and other limnological data will serve as an important guideline for the establishment of effective in-system management strategies. The importance of this system cannot be over-emphasized because it is the "holding" reservoir before transfer to the major water treatment distribution network of the Durban area.

DESCRIPTION OF THE AREA

The dam is situated in the Natal belt of ultrametamorphism and granitization but much of the immediate catchment is dominated by the quartzites and shales of the Table Mountain series of the Cape System, with small wedges of Dwyka tillite and sandstones of the Karoo system.

The major inflow is derived from the Mgeni River which discharged 145,30 x 10^6 m^3 into the dam during the period of study and therefore the river has a large influence on the chemical composition of the water retained in the system. Phosphorus and nitrogen concentrations in the Mgeni River increased after discharge from Albert Falls Dam, indicating a considerable nutrient input from the immediate catchment between the two dams. Very little suspended silt is derived from this reach of the river (mean 15 mg/dm^3) and therefore, together with effective flood control, the system is a clearwater impoundment with low in-system values.

The upper catchment has no industrial development but there are numerous smallholdings, some large farms and two small villages. The remaining area is undeveloped rural tribal trustland (Fig. 1).

the Mposane River is a very small input to the dam and enters from the north after draining a hilly, undeveloped catchment. Although some high nutrient concentrations were measured on occasions (e.g. nitrate maximum 0,964 mg/dm^3) the inflow is relatively small and therefore the load is likely to be insignificant in comparison with the Mgeni River input.

There is no recreational activity on Nagle Dam but fishing from the shoreline is controlled by permits obtained from the authorities. Picnic facilities are provided on the banks near the dam wall while a small game park has been established on the central neck of land between the main wall and the diversion weir.

A map of Nagle Dam indicates the riverine features and the unique horse-shoe shape of the dam, which is free of dendritic margins and smaller inlet legs. Depths exceeding 35,0 m have been measured near the dam wall on the north bank but the dam becomes shallower towards the south shore while nearer the inlet the contours are more evenly distributed between 10 and 15 m (Fig. 2).

RESULTS AND DISCUSSION

The basic morphometric features of the impoundment and its catchment are given in Table 1.

The total inflow of 146,72 x 10^6 m^3 into the dam during the period of investigation gives a retention time of 0,17 years (61 days) and a flushing rate of 6 times/annum. Nagle Dam is a controlled system and received a constant monthly input (mean 12,11 x 10^6 m^3; coefficient of variation 9 %) and therefore there is no marked seasonal fluctuation of inflow or nutrient loading. Although there was a reasonably constant input there was also a correspondingly high draw-off which compensates for the steady nutrient loading of the system by increasing the annual flushing rate. About 49 % of the total nitrogen load and 62 % of the total phosphate load were introduced during the summer months from October 1977 to April 1978, indicating that there was a substantial winter input of nutrients to the dam as well.

In-system concentrations of nutrients such as nitrate, soluble reactive phosphate and soluble silica were never very high during the study period despite the continuous supply from the Mgeni River. Particulate nitrogen and phosphate levels did not show marked increases to match the low nutrient levels. Very low turbidities and suspended solids together with high Secchi depth readings (mean 2,51 m) indicated the clarity of the water during the study period. Over 75 % of the turbidity observations made during the study were less than 5 Jackson Turbidity Units (Figs. 3 to 5).

Nagle Dam can be classified as a warm monomictic system characterized by summer stratification, autumn turnover and a winter period of isothermal conditions. However, the thermocline is weakly defined between 8 and 10 m. The potential for development of a stable, strongly defined thermocline in the very clear sheltered system is counteracted to some degree by the deep riverine nature of the system and the constant flushing rate throughout the year. During summer there often was a 10 °C difference between surface and bottom waters (Fig. 6).

A depth-time oxygen distribution curve of Nagle Dam indicated that the well-oxygenated water was confined to the upper layers above 20 m but winter oxygen isopleths show a uniform distribution of oxygen through the water column. An anaerobic zone is not indicated because the Yellowspring probe has a maximum depth of 30 m. However, using the Winkler method, the bottom waters were found to be anaerobic during the summer stratification period, but the extent of the anaerobic zone was not determined (Fig. 7).

The steeply contoured shoreline of Nagle Dam is not conducive to major development of rooted aquatic macrophytes and there was very little evidence of nuisance growths of water hyacinth in the open water.

Phytoplankton populations were dominated by *Ankistrodesmus Braunii* (Naeg.) Brunnthaler and a small *Cosmarium* species during the summer of 1977/78. *Melosira granulata* (Ehrenb.) Ralfs never reached the same concentrations observed in the Albert Falls Dam but was frequently present for most of 1978. However, the dominant winter diatom was *Melosira distans* (Ehreb.) Kützing which persisted from the end of March until early September before decreasing. *Cyclotella stelligera* C. u. Grun. was also present in large numbers during the summer period but diminished at the end of May. *Anabaena* and *Microcystis* species were recorded during the year on some occasions and the latter species showed an increasing trend during spring. However, no algal developments reached nuisance levels and a maximum chlorophyll *a* concentration of only 6,0 $\mu g/m^3$ was obtained during the study period with a mean concentration of 2,5 mg/m^3.

During the study period *Thermocyclops oblongatus* (Sars.) was the dominant zooplankton species encountered but *Daphnia pulex* Leydig and *Daphnia longispina* O.F. Müller were numerically important during the mid-winter months.

Nutrient loading rates have been estimated for orthophosphate (0,17 $g.m^{-2}.a^{-1}$ P) and inorganic nitrogen (23,02 $g.m^{-2}.a^{-1}$ N) for the study period. These figures indicate that Nagle Dam experienced a much higher gross loading rate than Midmar and Albert Falls dams upstream during the same period. However, Nagle Dam is a very much smaller system in terms of capacity and surface area and it has a high flushing rate, despite the fact that the dam is maintained at full supply level. It is therefore evident that effective nutrient loading rates on a system are given by the net annual load which would provide a more realistic comparison between the three reservoirs.

Nagle Dam is a very important reservoir on the Mgeni River and can be classified as an oligotrophic phosphate limited system. It is a clearwater impoundment with a unique hydrological regime and therefore management strategies can be implemented for optimal utilization and storage.

ACKNOWLEDGEMENTS

The City Engineer's Department of Durban is gratefully acknowledged for providing hydrological data. Messrs W.D. Turner and B.D. Gardner are thanked for computerization of the data.

TABLE 1. Characteristics of Nagle Dam and its catchment

Geographical location	29 ° 35'S; 30 ° 37'E
Magisterial district	Pietermaritzburg
Catchment type	Grasslands, undeveloped smallholdings
Usage of dam	Potable
Catchment area	883 km^2
Inflowing rivers	Mgeni 875 km^2, Mposane 7 km^2
Dam wall completed	1950
*F.S.L. volume	24,67 x 10^6 m^3
F.S.L. area	1,62 km^2
F.S.L. maximum depth	38,1 m
F.S.L. mean depth	15,2 m

*F.S.L. = full supply level

TABLE 2. *A summary of physical and chemical characteristics of water collected from the inflows (Mgeni and Mposane), the outflow and a station D1 on Nagle Dam. Values are based on fortnightly samples collected between November 1977 and October 1978.*

PARAMETER	DAM STATION TOP				DAM STATION BOTTOM				MGENI				MPOSANE				OUTFLOW (MGENI				OUTFLOW			
	Min	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.**	*Min*	*Max*	*Mean*	*C.V.*
Na																								
K																								
Ca	5,2	6,4	5,7	5	5,0	7,7	5,9	11	5,0	6,1	5,5	6	3,9	7,1	5,7	16	5,2	6,2	5,7	5				
Mg	2,9	4,2	3,4	9	2,9	4,8	3,7	15	2,8	4,8	3,5	11	3,2	5,7	4,4	17	2,9	4,3	3,4	8				
SO_4																								
Cl																								
Si	2,2	3,2	2,7	10	2,8	4,1	3,4	14	2,1	4,8	2,8	19	8,4	12,9	10,5	10	2,5	3,4	2,9	8				
Cond	7,1	9,8	8,3	7	7,5	10,7	8,5	10	6,9	11,0	8,2	10	10,5	14,6	12,4	11	7,3	10,2	8,2	8				
Alk	28	34	29	4	28	41	31	12	26	32	29	5	20	48	34	19	26	33	29	4				
Tot Kj – N	0,143	0,492	0,254	30	0,160	1,590	0,391	76	0,174	0,401	0,277	23	0,153	0,671	0,289	49	0,115	0,387	0,204	27				
Dis Kj – N	0,103	0,203	0,160	18	0,112	0,314	0,172	32	0,135	0,267	0,181	20	0,096	0,291	0,160	31	0,111	0,192	0,147	12				
NH_4 – N	0,004	0,029	0,013	42	0,005	0,180	0,034	137	0,003	0,056	0,019	56	0,003	0,021	0,009	40	0,005	0,022	0,011	40				
NO_3 – N	0,098	0,268	0,205	22	0,110	0,307	0,223	24	0,108	0,435	0,240	28	0,086	0,964	0,569	42	0,157	0,276	0,234	13				
NO_2 – N	0,001	0,007	0,002	49	0,001	0,005	0,002	58	0,001	0,008	0,003	63	0,001	0,008	0,002	61	0,001	0,006	0,002	63				
Tot P	0,005	0,033	0,012	49	0,005	0,356	0,059	127	0,006	0,073	0,025	73	0,007	0,129	0,032	79	0,003	0,030	0,012	48				
Tot dis P	0,002	0,016	0,004	61	0,002	0,083	0,007	201	0,002	0,020	0,006	75	0,004	0,071	0,011	109	0,001	0,016	0,004	71				
PO_4 – P	0,001	0,005	0,001	80	0,001	0,006	0,001	71	0,001	0,010	0,002	104	0,001	0,013	0,004	67	0,001	0,007	0,001	92				
Fe																								
Mn																								
Temp	15,0	28,5	22,4	19	13,0	24,0	17,7	20																
DO	6,0	9,9	8,4	11	1,7	9,2	5,3	45																
Tu	1	4	3	79	2	140	26	121	1	80	17	125	2	58	10	140	1	20	5	95				
pH	7,4	8,4	7,8	3	6,9	7,5	7,2	3	7,3	7,8	7,5	2	7,3	7,9	7,5	2	7,2	7,9	7,6	2				
SS	1	11	3	66	1	330	42	154	1	91	15	137	1	133	18	174	1	14	4	80				

*C.V. = coefficient of variation

TABLE 3. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Nagle Dam (Nov. 1977 – Oct. 1978)

Mean depth m		15,2	
Retention time a		0,17	
Hydraulic load m/a		89,4	
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P		0,17	
Total P		2,11	
Inorganic nitrogen		23,02	
Total nitrogen		46,75	
	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	6,0	1,2	2,6
Secchi depth m	4,37	0,9	2,5

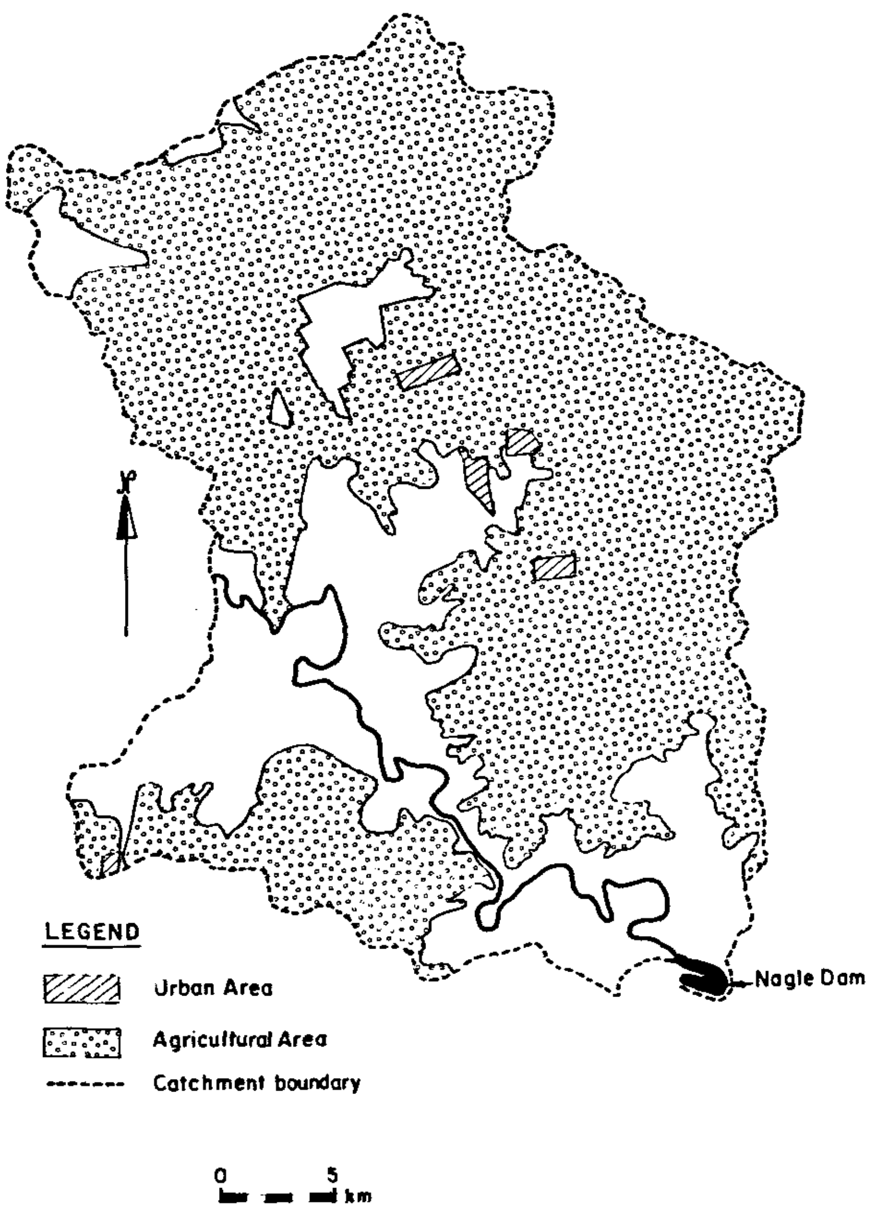

FIGURE 1. Nagle Dam catchment.

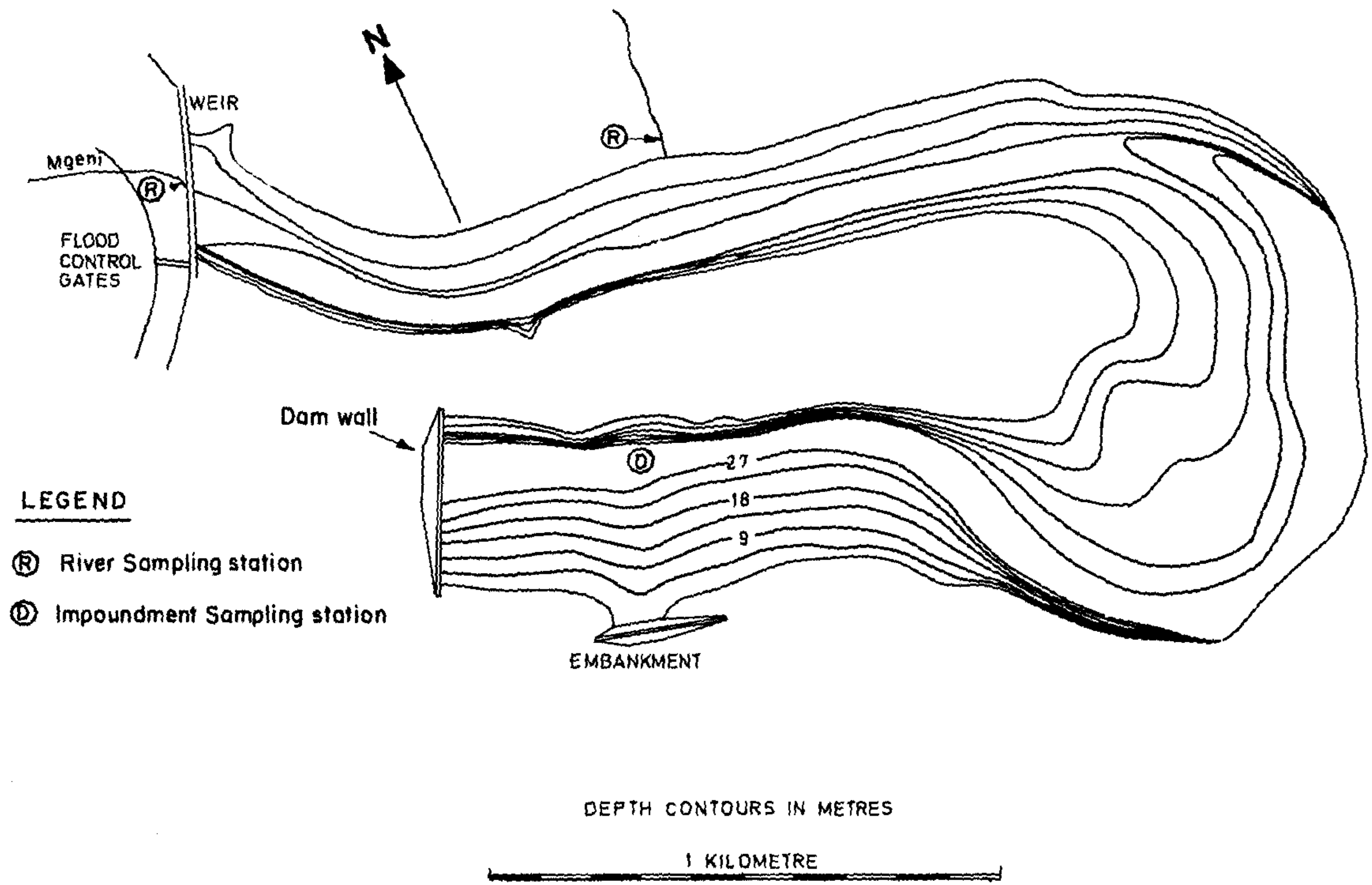

FIGURE 2. Map of Nagle Dam showing sampling stations.

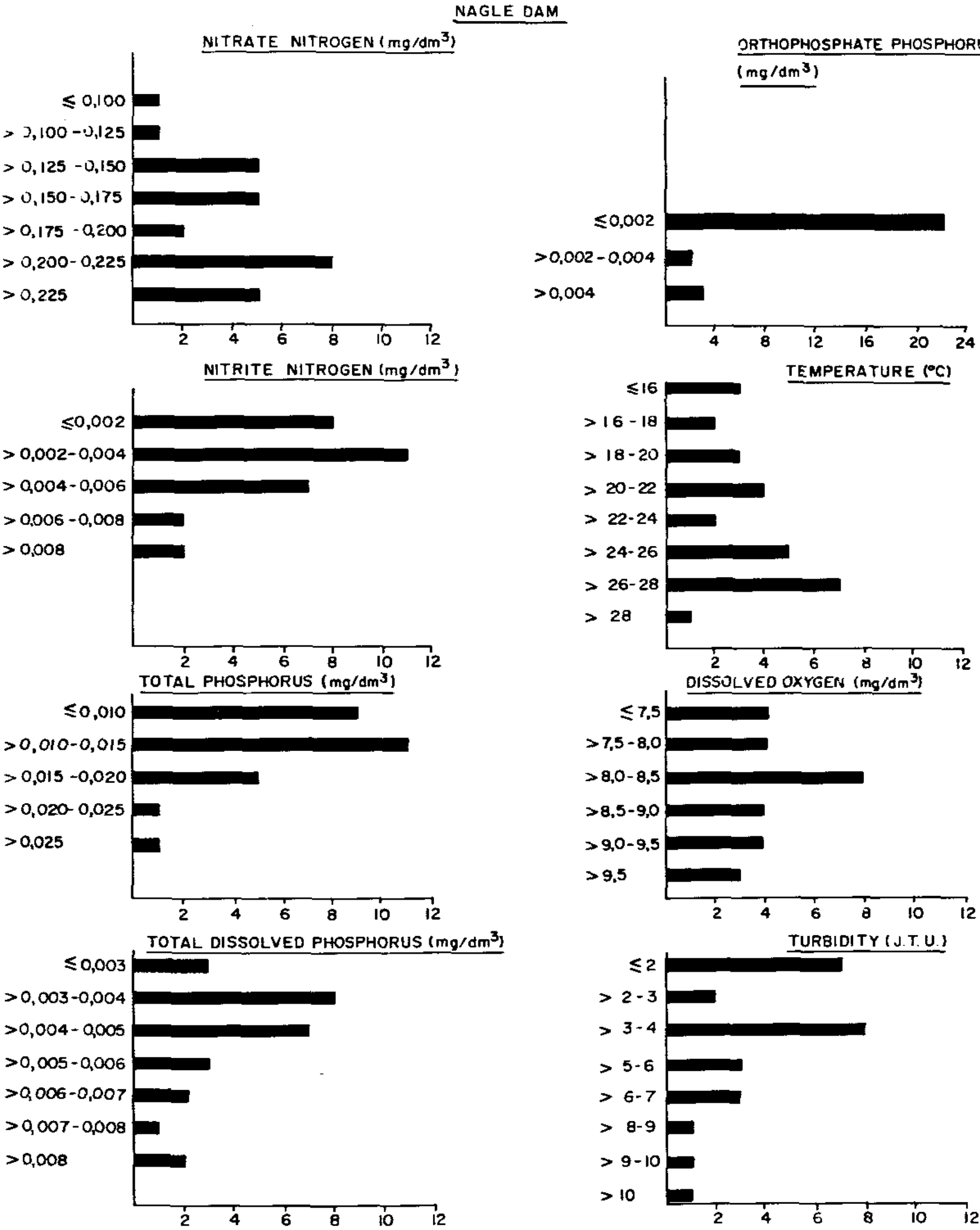

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Nagle Dam.

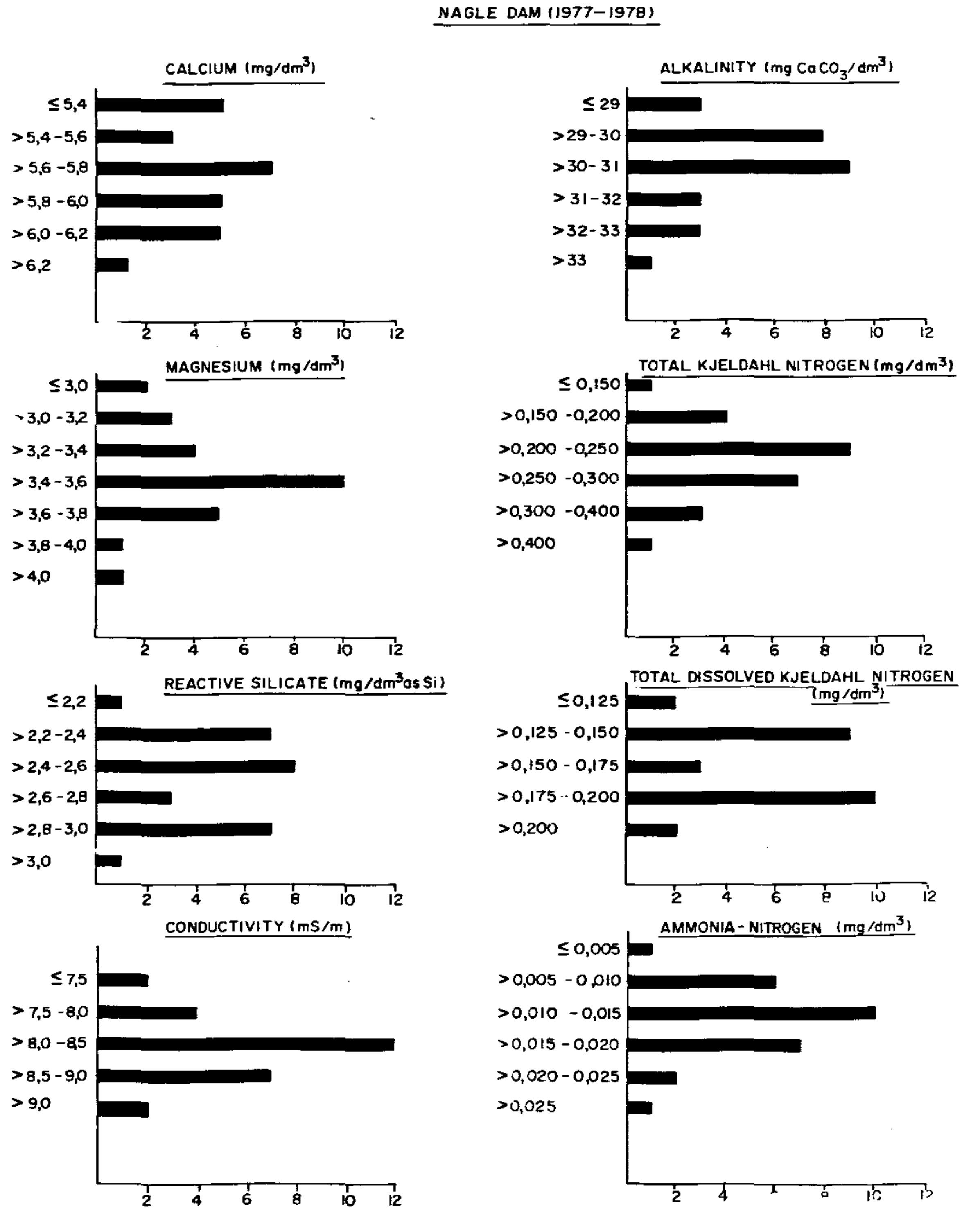

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Nagle Dam.

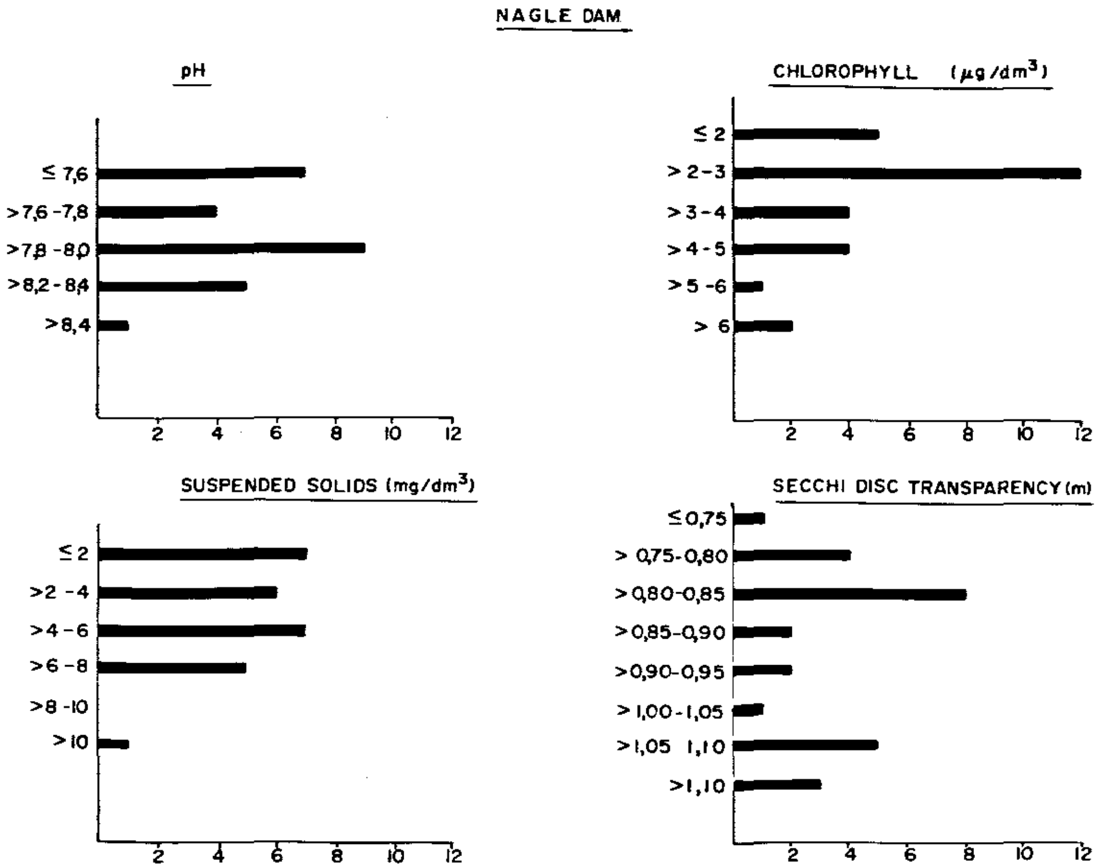

FIGURE 5. Frequency histograms for selected parameters pertinent to the surface waters of Nagle Dam.

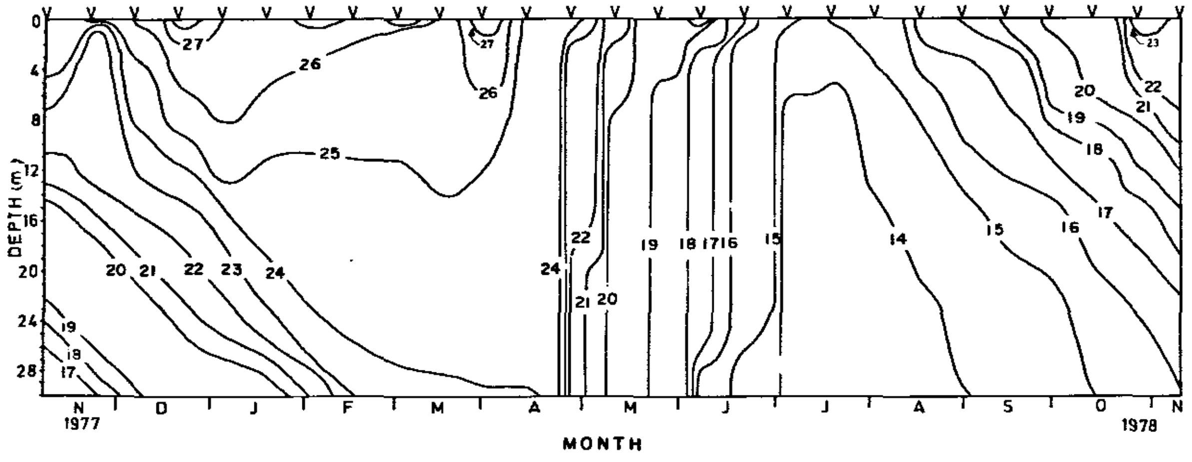

FIGURE 6. **Temperature distribution in Nagle Dam** (Nov. 1977 — Oct. 1978)

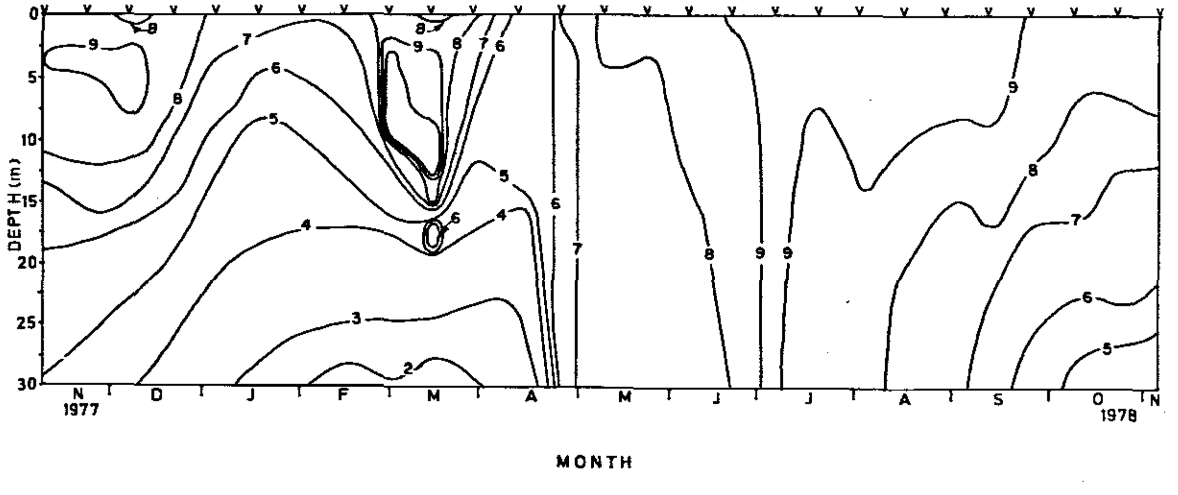

FIGURE 7. **The distribution of dissolved oxygen in Nagle Dam** (Nov. 1977 — Oct. 1978).

VERNON HOOPER DAM

by

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INTRODUCTION

The Vernon Hooper Dam at Ntshongweni was completed in 1927 and is the oldest dam in Natal. It has been an important water supply for the city of Durban for many years but its continuation as a water resource is seriously threatened by a waste disposal problem as a result of effluent discharges from an industrial complex and a domestic sewage works in the catchment. A history of the development in the catchment area and a record of changes in the water quality and subsequent action by the Durban City Engineers Department are given by Howes (1976). The enrichment of the system has continued with little opportunity for effluent diversion. In 1976 a study was made to assess the extent of the problem and the impact of the nutrient load, by describing the limnological behaviour of the impoundment (Archibald and Warwick, 1976).

The future of the impoundment as a water supply should be judged against the background of predictions of a shortfall in water resources by the turn of the century. It is therefore essential to implement external preventive measures to reduce, if not eliminate, the abnormal allocthonous load reaching the system. The success of such measures will depend on the urgency with which the situation is viewed by all concerned, the future rate of expansion in the catchment and the efficiency of the control measures. Furthermore the excessive enrichment of the system has led to the accumulation of phosphate in the sediments and therefore the development of effective control measures requires an accurate prediction of sediment phosphate release as a function of changing limnological conditions.

DESCRIPTION OF THE AREA

The dam wall was built in a deep rocky gorge below the original confluence of the Mlazi, Sterkspruit and Wekeweke rivers, and is situated in an area dominated by quartzite and shales of the Table Mountain series of the Cape system. The upper catchment is interspersed with small outcrops of Dwyka tillite and shales of the Ecca series of the Karoo system.

The Mlazi River which enters the system from the west drains 81 % of the catchment and delivered 124,43 x 10^6 m^3 during the study period. The water entering the dam via the Mlazi River is frequently rich in nutrients with soluble reactive phosphate concentrations reaching 0,355 mg/dm^3 P and nitrate levels often exceeding 1,0 mg/dm^3 N. Although the suspended solids levels are high during periods of flow maxima in summer, the input from the river can be controlled by diversion gates and the operation of a bypass tunnel which discharges the excess turbid water below the dam wall.

The upper Mlazi catchment is dominated by agricultural activities such as sugar-cane cultivation, large dairy and poultry farms and some smaller vegetable holdings. There is a large African township nearer the dam itself and the domestic sewage works serving the township discharges effluent directly into the Mlazi River after conventional treatment (Fig. 1).

The Sterkspruit River enters the system from the north-west and drains only 15 % of the catchment but it receives effluent from an industrial waste plant and therefore the river water is also rich in nutrients, particularly nitrogen. Very high nitrogen values were measured during the study and reached a maximum of 4,751 mg/dm^3 during the winter period of flow minima, but soluble reactive phosphate concentrations were relatively low (annual mean 0,032 mg/dm^3 P. An intensive battery system of poultry production and processing and the development of textile industries in 1963 has led to the construction of a wastewater plant, the effluent of which is discharged into the Sterkspruit River after treatment. Very high conductivity levels in the river indicate the extent of mineralization which has also occurred in this reach of the river (Fig. 1).

The small Wekeweke stream enters the system from the north and drains a small catchment in which sugar-cane cultivation is the main agricultural activity. The nutrient concentrations emanating from this catchment were never in excess of those from the Sterkspruit, although a maximum nitrate concentration of 3,714 mg dm^3 N was measured during the study.

There are no organized recreational facilities available at the Vernon Hooper Dam because it is a municipally-owned water resource. However, casual angling from the shoreline is permitted and picnic facilities are provided below the dam wall.

A bathymetric map of the system indicates that there are three shallow inlet areas converging on a deeper central region which is steeply sided and U-shaped in the gorge near the dam wall. The positions of the sampling stations on the rivers and of the station near the dam wall are indicated on the bathymetric map of Vernon Hooper Dam (Fig. 2).

RESULTS AND DISCUSSION

The basic morphometric characteristics of the impoundment and its catchment are shown in Table 1. Table 3 gives a summary of the monthly hydrological behaviour of the system during the study period.

The total inflow into the dam during 1976 was 144,51 x 10^6 m^3 which is more than three standard deviations in excess of the mean of the total annual inflow of 53,90 x 10^6 m^3. This therefore represents a unique hydrological condition for the Vernon Hooper Dam and thus, by discarding this observation from the average term data over the period 1968/78 the adjusted mean annual inflow is calculated as 46,04 x 10^6 m^3 which gives a mean retention period of 0,16 years (57 days). However, based on the total inflow during the study period, the retention period was calculated as 0,05 years (18 days) and therefore the flushing rate was 20 times/annum. A major flood at the end of March contributed to the abnormally high inflows and during this event sufficient water entered the dam to replace the entire volume in less than one day. The influence of the Sterkspruit, in terms of total water input per month, increased from an average of 6 % during summer to 42 % during the dry winter period. During this period conductivity values in the dam rose steadily because of the highly mineralized water being brought in by the Sterkspruit. During winter the average retention period increased to 73 days and extended over a period from July to the end of September when an extensive diatom bloom occurred.

The Umlaas River input was the dominant external source of phosphate and nitrogen, and contributed 87 % and 72 % respectively of the total annual load during the study period. Although there is a seasonal fluctuation in the river flows the nutrient load is subject to less variation (the summer input is only 69 % of the total nutrient load) because of the continuous discharge of effluents from two sewage works in the catchment. Frequency histograms for surface water data are presented in Figures 3 and 4.

Soluble reactive phosphorus concentrations in the surface waters were changed by seasonal inflow from the rivers and by algal blooms. A maximum value of 0,051 mg/dm^3 was measured during the year and more than 70 % of the observations exceeded 0,015 mg/dm^3. Concentrations decreased rapidly in spring and early summer during periods of intense algal activity. Total phosphate phosphorus concentrations increased sharply after periods of high flow and reached a maximum of 0,203 mg/dm^3 P in March during floods. However, the excessive phosphate load was equally rapidly exported from the system (Table 4).

Nitrate-nitrogen concentrations were maximal in spring (2,054 mg/dm^3) at the surface after a winter build-up by nitrification and following a period of algal inactivity. The water column exhibited a classic dichotomic distribution pattern in summer with maximum nitrate concentrations at intermediate depths, and low concentrations in both the surface waters (algal immobilization) and bottom waters (denitrification). For more than 70 % of the study period nitrate levels exceeded 1,250 mg/dm^3. The concentrations of ammonium nitrogen in surface waters increased during winter rather than at autumn turnover. The high levels of ammonium nitrogen in the surface waters may be due to the proximity of the dam to the sewage works which often may have operated inefficiently. Bottom concentrations were maximal during summer stagnation periods (0,764 mg/dm^3) and developed from a combination of bacterial decomposition of settled seston and possible release from the sediments.

Fluctuations of soluble silicon concentrations in surface waters were attributable to the proliferation of diatom populations in September, October and December. Replenishment of silicon was rapidly effected with water rich in silicate via the inflows following good catchment rains. In February the soluble silicon concentrations did not decrease markedly despite the diatom bloom, probably because the high inflow rates were able to sustain the existing levels. Soluble silicon levels in the surface waters decreased rapidly during a *Melosira* bloom in September. In less than one month the surface concentrations decreased from 5,1 mg/dm^3 Si to 0,4 mg/dm^3 Si to 0,4 mg/dm^3 Si which represents a very large immobilization of soluble silica. However, for more than 70 % of the study period surface concentrations exceeded 5,5 mg/dm^3 Si.

Chlorophyll *a* concentrations were the highest levels measured in all Natal reservoirs and reached a maximum of 56,7 $\mu g/m^3$ during the study period. Nearly half the observations made during the year exceeded the annual mean of 15,9 $\mu g/m^3$.

The investigation commenced during a period of stratification in the summer of 1975/76. Surface temperatures ranged from a maximum of 27,5 °C in mid-February to a winter minimum of 13,1 °C in July. Typical isothermal conditions developed in the water column at the end of May and persisted throughout winter. Rapid heating of the surface water from the end of August to mid-September increased the surface temperatures from 15,8 °C to 21,5 °C and a strongly defined stable thermocline developed at a depth of 6 to 8 m. A relatively high thermal gradient (6 — 8 °C) existed between surface and bottom waters during reformation of summer stratification in 1967/77. The rapidity with which stratification took place may be attributed to the morphometric features of the system, the wind protected locality, low surface area to volume ratio and its hydrological characteristics. Marked changes in the surface water temperature (heating) occurred in September following a long period of low inflow. Water movement was confined to the epilimnion during the windy months of August and September (Fig. 5).

A depth-time oxygen distribution curve of the Vernon Hooper system indicated that the mid-summer (1975/76) stratification was well established. Supersaturation values were obtained in the surface waters but anaerobic conditions prevailed in the hypolimnion near the bottom (Fig. 6).

Floods in March introduced well-oxygenated waters to all parts of the dam and subsequently isothermal conditions ensured adequate vertical circulation and therefore replenishment in the deeper regions of the dam. The development of a thermocline in mid-September and the consequent density gradient greatly influenced the vertical distribution of oxygen in summer. A large anaerobic zone developed in the hypolimnion and this increased in volume with the progress of summer stratification. The surface waters, however, were frequently supersaturated (maximum 158 %) by photosynthetic activity of the algal blooms.

Changes in the suspended solids were often attributable to an increase or decrease in suspended silt input from the three main rivers. Secchi depth values therefore more often than not indicate turbidity of the water due to suspended silt particles rather than being a reflection of algal proliferation or depletion. Man-made lakes are often characterized by a large ratio of drainage basin to lake area so that the volume of water in the impoundment is frequently less than 10 % of the mean annual runoff from the catchment. Therefore the introduction of silt-laden water following good catchment rains will have a marked impact on the turbidity within the system. The situation is further aggravated in many parts of Natal by the primitive agricultural erosional practices of the indigenous population in the catchment.

Secchi depth readings reached a maximum of 303 cm during the long winter period which was characterized by flow minima, low suspended silt loads (<10 mg/dm^3) and algal inactivity. During the summer months Secchi depth readings rarely exceeded 70 cm due to high silt loads but a marked decrease at the end of September prior to the first summer rains was entirely due to prolific growth of *Melosira granulata*. A minimum value of 12 cm was recorded two days after the March flood waters had subsided.

In-system conductivity values were generally lower in the summer months as a result of the rapid flushing rate of the dam during flow maxima. Conductivity values reached a peak in late September because the influence of the highly mineralized water emanating from the Sterkspruit River input (82,8 mS/m) is greatly accentuated during the dry period. The first rains in October were sufficient to reduce the conductivity values in the surface waters only (4—6 m), and flushed out the algal bloom which had developed without disrupting the thermocline or disturbing the hypolimnetic water.

During the warmer months surface pH values and carbon dioxide concentrations fluctuated markedly as a result of disturbance of the CO_2/bicarbonate equilibrium by algal activity. A maximum pH value of 0,5 was recorded in the surface waters during periods of intensive photosynthesis in September while free carbon dioxide concentrations dropped to less than 9,1 mg/dm^3. Bottom pH values ranged from 7,0 to 7,8 through the year while the free carbon dioxide concentrations varied from 1,9 mg/dm^3 in winter to 8,6 mg/dm^3 during mid-summer when microbial activity was greatly increased.

Heavy infestations of water hyacinth have occurred from time to time in Vernon Hooper Dam, and during the study period larger quantities were confined to the major inlet legs. Smaller aggregations of the plants were wind-blown at random across the dam.

The phytoplankton population was dominated by an extensive diatom bloom in February 1976, and again in September and October of the same year. *Melosira granulata* (Ehrenb.) Ralfs and *Melosira granulata* var. *angustissima* Müll together with *Thalassiosira fluviatilis* Hustedt were the main constituents of the bloom. *Cyclotella Meneghiniana* Kützing and *Cyclotella Kützingiana* Thwaites were also frequently present amongst the diatom population.

Although three forms of *Microcystis* were observed together with *Anabaena flos-acquae* (Lyngb.) during summer months, no major bloom of blue-green algae occurred. In previous years extensive *Microcystis* blooms have been responsible for major water treatment problems, particularly during the drier periods after the industrial development had occurred.

Zooplankton populations were not analysed in sufficient detail but the *Daphnia pulex* Leydig/*Daphnia longispina* O.F. Müller group of *Cladocera* were apparently dominant during the winter months.

Nutrient loading rates for orthophosphate (9,66 $g.m^{-2}.a^{-1}$ P) and inorganic nitrogen (215 $g.m^{-2}.a^{-1}$ N) indicated that large quantities of nutrients entered the dam, in a readily available form for algal growth. It was evident that the effluent which emanated from point source discharges below the two sewage works in the catchment was largely responsible for the high nutrient input to the dam. The Sterkspruit contributed a greater percentage of the nitrogen load (25 %) than the total phosphate load (12 %) during the study.

The total N:P ratios indicate that nitrogen may be the limiting nutrient but the ratios of external sources do not necessarily produce similar in-system ratios of available nutrients. The ratio of N:P in the system was approximately 25,5 and therefore phosphate may have been limiting on many occasions although this is a eutrophic system.

Vernon Hooper Dam is a small eutrophic system which is frequently phosphate-limited. The loading rates were extremely high throughout the year but the high summer inflows and consequent rapid flushing rate (20/annum) allow a rapid export of nutrients from the system. Although diatom blooms dominated during the study period, nuisance species of blue-green algae may well reappear during warm, dry periods.

ACKNOWLEDGEMENTS

The City Engineer's Department of Durban is gratefully acknowledged for providing the hydrological data. The Natal Town and Regional Planning Commission is also thanked for permission to use data obtained under their auspices. Messrs W.D. Turner and B.D. Gardner are thanked for computerization of data.

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TABLE 1. Characteristics of Vernon Hooper Dam and its catchment

Geographical location	29 ° 52'S; 30 ° 43'E
Magisterial district	Pinetown
Catchment type	Mixed agricultural (poultry, vegetable, sugar-cane, timber) undeveloped grassland
Usage of dam	Potable
Catchment area	786 km^2
Inflowing rivers	Umlaas 639 km^2, Sterkspruit 120 km^2, Wekeweke 26 km^2
Dam wall completed	1927
*F.S.L. volume	7,16 x 10^6 m^3
F.S.L. area	0,81 km^2
F.S.L. maximum depth	16,2 m
F.S.L. mean depth	8,8 m

*F.S.L. = full supply level

TABLE 2. A summary of monthly hydrological characteristics for Vernon Hooper Dam (Jan. — Dec. 1976)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	7,16	6,98	7,12	10	
Area km^2	0,81	0,79	0,80		
Mean depth m	8,84	8,84	8,84		
Monthly inflow x 10^6 m^3	32,01	2,36	12,04	90	
Monthly outflow x 10^6 m^3					

*C.V. = coefficient of variation

TABLE 3. A summary of physical and chemical characteristics of water collected from the inflows (Umlaas, Sterkspruit and Wekeweke), the outflow and a station D1 on Vernon Hooper Dam. Values are based on fortnightly samples collected between January and December 1976.

PARAMETER	DAM STATION								MLAZI				STERKSPRUIT				WEKEWEKE				OUTFLOW (UMLAAS)			
	TOP				BOTTOM																			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na																								
K																								
Ca																								
Mg																								
SO_4																								
Cl																								
Si	0,5	8,3	5,4	42	2,6	7,6	6,2	16	3,1	8,5	5,8	28	3,9	8,2	6,6	19	3,7	6,9	4,6	8	2,5	8,3	6,1	19
Cond	15,4	40,4	27,7	24	17,9	40,1	31,1	19	39,4	19,76	27,0	24	20,0	82,9	46,9	59	12,7	17,89	15,5	8	17,9	38,5	29,0	19
Alk	22	72	51	23	17	75	56	25	33	101	67	29	28	81	46	51	8	49	15	44	29	70	54	18
Tot Kj–N	0,479	1,715	0,705	39	0,486	1,306	0,892	25	0,341	1,106	0,521	38	0,745	1,988	1,368	31	0,250	0,686	0,401	29	0,554	0,964	0,711	16
Dis Kj–N	0,357	0,677	0,457	25	0,535	1,202	0,749	27	0,203	0,582	0,341	23	0,324	1,564	0,957	35	0,202	0,627	0,320	27	0,342	0,786	0,529	21
NH_4–N	0,012	0,281	0,092	90	0,036	0,764	0,363	55	0,009	0,076	0,027	61	0,027	0,674	0,211	83	0,006	0,184	0,027	117	0,021	0,571	0,169	63
NO_3–N	0,430	2,054	1,381	33	0,763	2,234	1,505	21	0,519	2,448	1,430	35	1,188	4,761	2,474	57	0,880	3,714	1,440	39	0,527	1,849	1,450	26
NO_2–N	0,001	0,097	0,039	74	0,003	0,087	0,042	64	0,006	0,079	0,020	79	0,010	0,353	0,118	74	0,002	0,032	0,007	80	0,005	0,095	0,046	58
Tot P	0,037	0,203	0,081	40	0,049	0,194	0,078	40	0,115	0,425	0,216	45	0,070	0,611	0,167	65	0,005	0,326	0,045	126	0,048	0,121	0,076	24
Tot dis P	0,013	0,082	0,045	41	0,023	0,087	0,047	28	0,039	0,374	0,169	52	0,018	0,164	0,066	51	0,004	0,062	0,026	59	0,036	0,066	0,049	34
PO_4–P	0,004	0,05	0,024	55	0,009	0,053	0,030	36	0,025	0,355	0,159	60	0,009	0,092	0,032	59	0,001	0,038	0,012	69	0,006	0,052	0,029	39
Fe																								
Mn																								
Temp	13,7	27,6	20,6	21	13,1	21,5	16,7	16	10,6	25,5	18,0	31	11,6	27,5	19,1	27	9,5	22,5	15,5	32	13,9	27,4	18,9	27
DO	6,2	14,0	8,6	22	0,1	7,5	3,8	74																
Tu																								
pH	7,3	9,5	8,1	9	7,0	7,8	7,4	5	7,6	9,1	8,1	5	7,5	8,5	7,8	4	7,0	8,9	7,5	2	7,3	8,9	7,8	5
SS	1	197	21	164	1	203	20	206	3	112	24	114	6	171	54	118	1	190	15	211	1	54	13	98

*C.V. = coefficient of variation

TABLE 4. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Vernon Hooper Dam (Jan. — Dec. 1976)

Mean depth m		8,8	
Retention time a		0,05	
Hydraulic load m/a		176	
Surface loading rates $g/m^2.a^{-1}$			
PO_4-P		9,66	
Total P		26,30	
Inorganic nitrogen		215,14	
Total nitrogen		304,85	

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	56,7	1,21	15,9
Secchi depth m	3,30	0,12	1,18

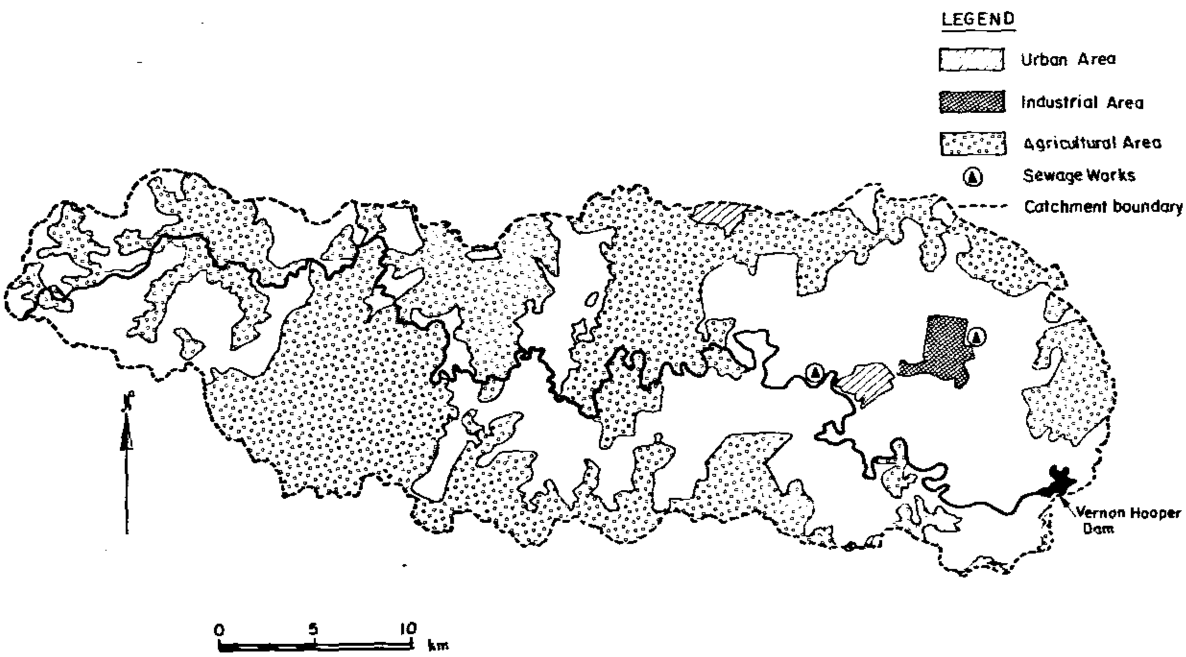

FIGURE 1. Vernon Hooper Dam catchment.

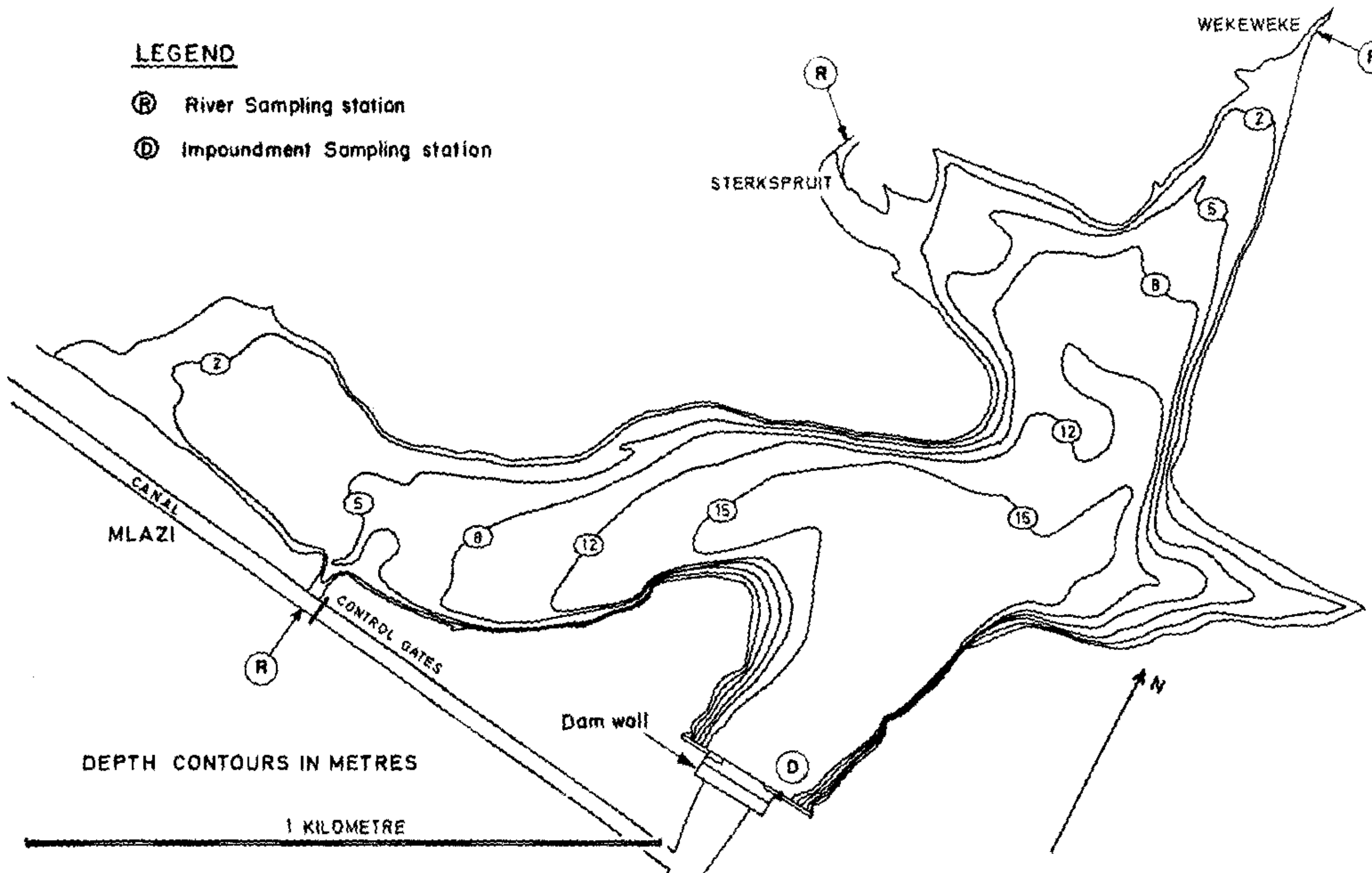

FIGURE 2. Map of Vernon Hooper Dam showing sampling stations.

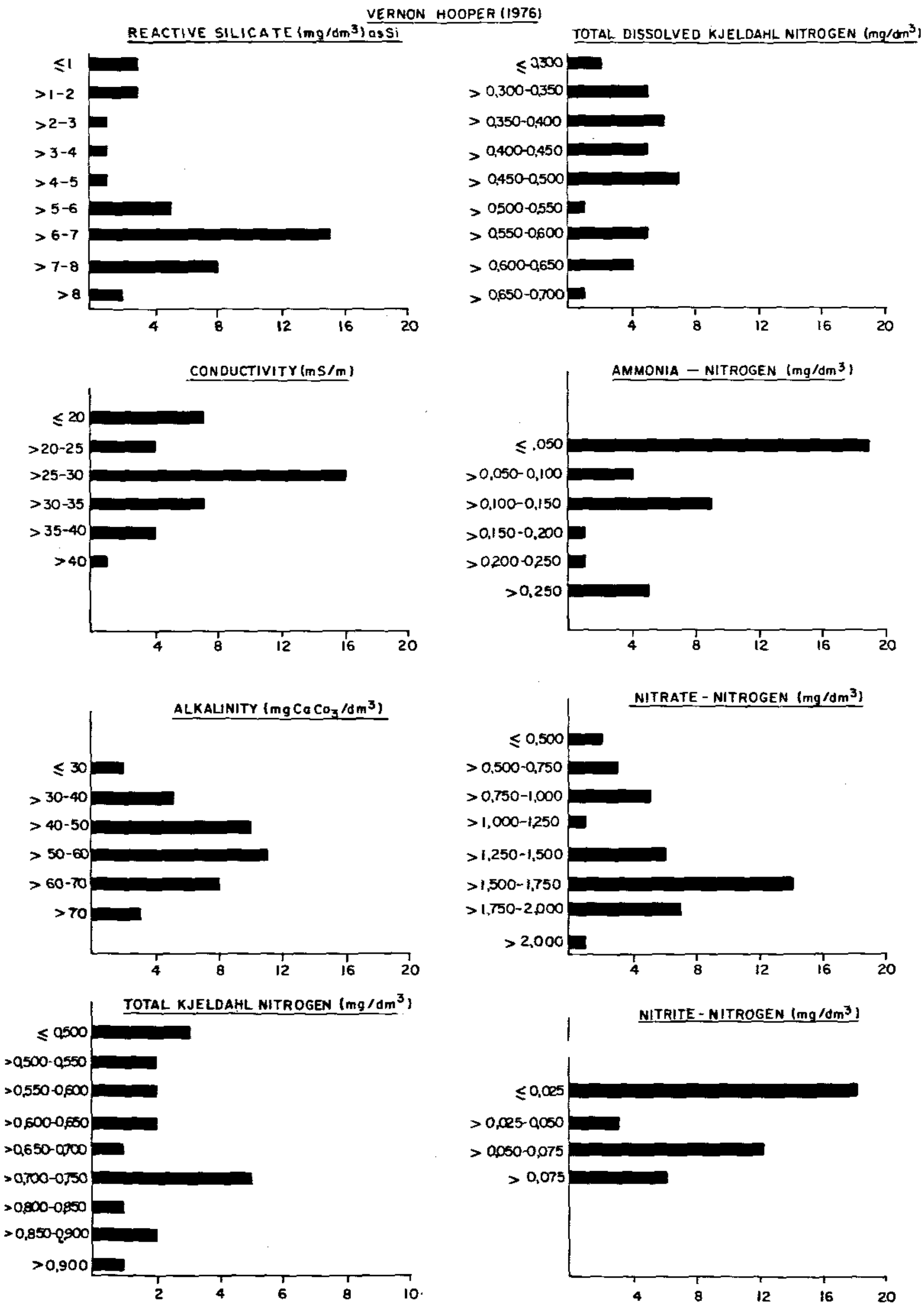

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Vernon Hooper Dam.

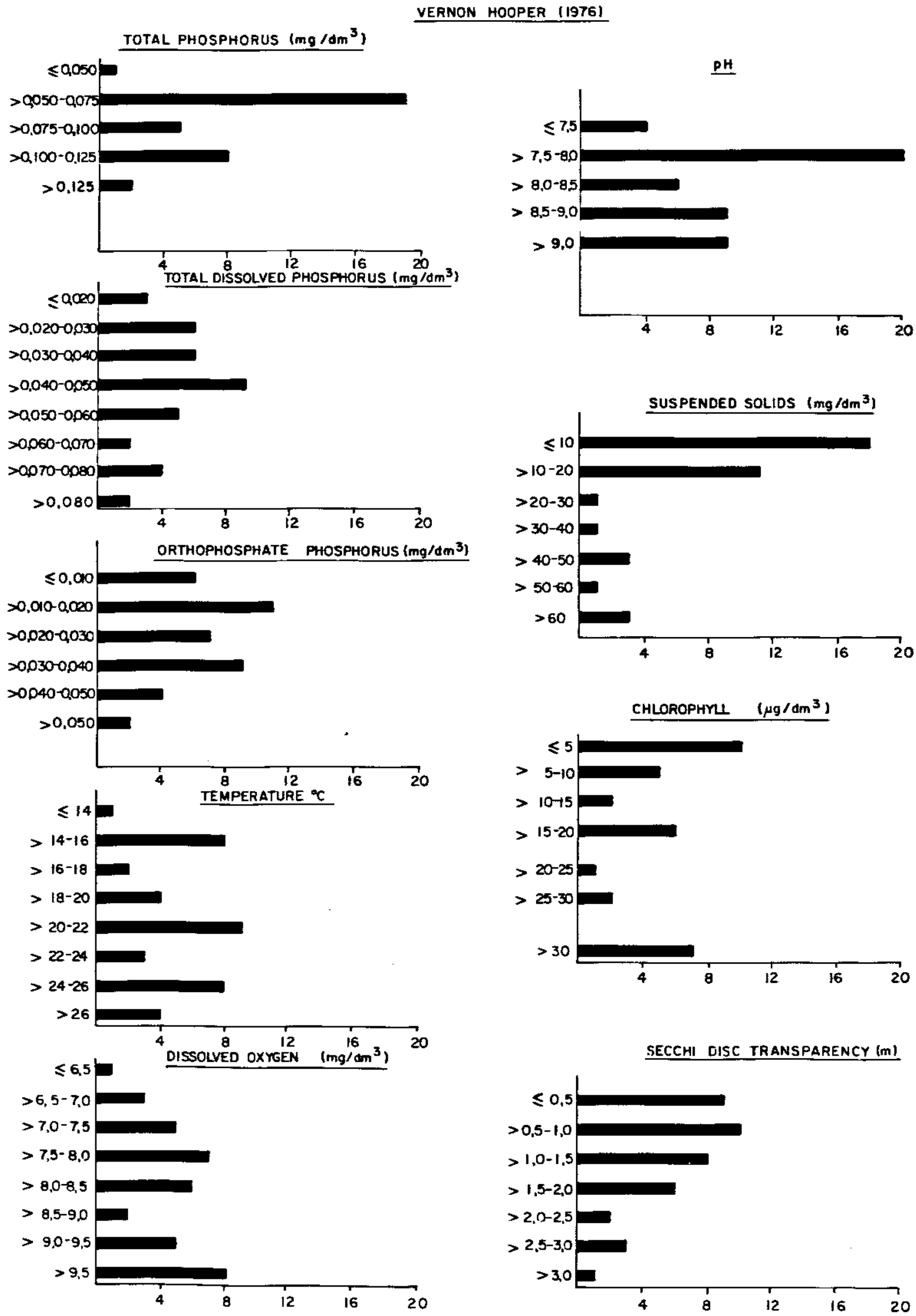

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Vernon Hooper Dam.

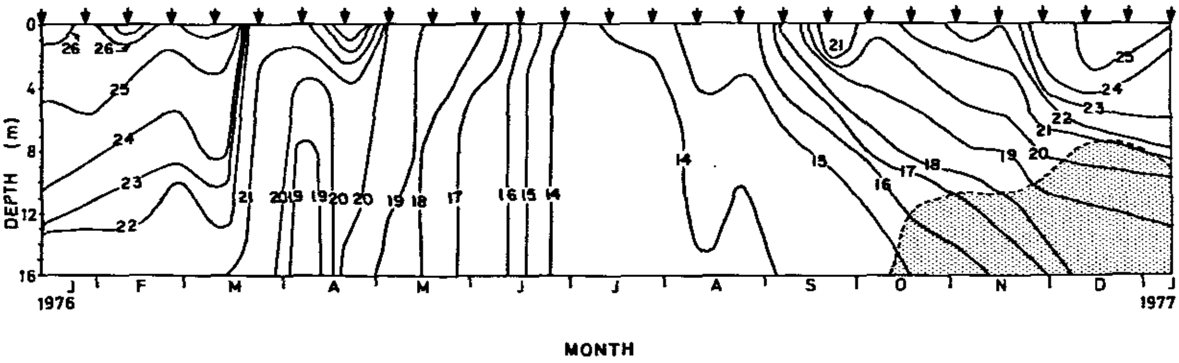

FIGURE 5. **Temperature distribution in Vernon Hooper Dam (Jan. — Dec. 1976).**

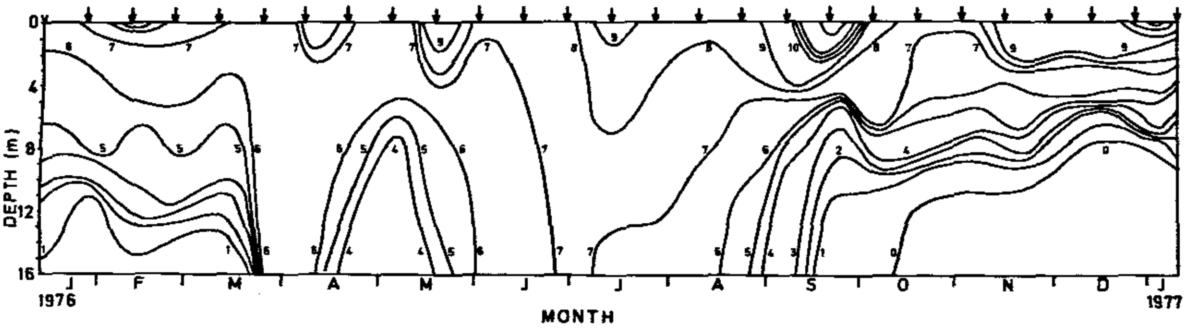

FIGURE 6. **The distribution of dissolved oxygen in Vernon Hooper Dam (Jan. — Dec. 1976).**

BRIDLE DRIFT DAM

by

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INTRODUCTION

Bridle Drift Dam, the largest of four impoundments on the Buffalo River, is situated approximately 18 km west of East London. This impoundment is owned by the Municipality of East London, and is the major water supply for East London and adjoining areas, including the township of Mdantsane. Bridle Drift Dam (Fig. 1) forms part of the Bridle Drift Nature Reserve and serves as an important recreational centre.

Reed and Thornton (1969) drew attention to the vulnerability of Bridle Drift Dam to possible consequences of runoff from Mdantsane and put forward a number of recommendations to minimize pollution and eutrophication effects. From data supplied by the City Engineer's Department of the East London Municipality, Toerien and Walmsley (1974) noted that the impoundment was already eutrophied to some extent and that orthophosphate phosphorus concentrations were increasing. *Microcystis* blooms have occurred in the impoundment since 1973 (Toerien and Tow, 1976). A water hyacinth infestation which appeared in 1973 was successfully eradicated by means of physical removal (G.P.K. Thornton – personal communication). Schutte and Bosman (1973) noted that in February 1972, a thermocline tended to form at 15 m and that there was a low oxygen concentration near the sediments.

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment are given in Table 1. Following floods in August 1970, the crest of the impoundment was raised by 3 m. A further raising of 5 m, to increase the net assured draft, is under consideration. A map showing the catchment area and the sampling stations on the inflowing river systems, is given in Figure 1. The Mdantsane Sewage Purification Works is situated on the banks of the Umdanzani Stream, approximately 2 km from the dam. The maturation pond effluent passes over the Umdanzani Stream by means of a diversion weir, after which the effluent passes through a tunnel and is then discharged via a pipeline into the Buffalo River at a point below the East London Municipality water supply abstraction point. The bathymetry of the impoundment and the sampling station on the impoundment are shown in Figure 2. There is a deep gulley which runs along the length of the impoundment representing the old river bed. This gulley is in excess of 40 m in the vicinity of the dam wall. Bridle Drift Dam has a mean depth (12,3 m) which is high in relation to other South African impoundments (Walmsley and Butty, 1979).

The hydrological characteristics of Bridle Drift Dam from 1969 to 1978 (Table 2) show a wide variation in the mean water retention time (0,88 years – coefficient of variation 97 %). During 1969/70, a year in which heavy floods occurred, the retention time was reduced to 0,19 years, indicating that the water in the impoundment was replaced 5,26 times during that year. The severity of the floods can be gauged by the fact that during August 1970, the water was replaced 4,66 times. After the completion of the dam wall in late 1968 until the floods, the water content of the impoundment was low and the average monthly volume was only 33 % of the full supply capacity. However, with the advent of the floods, the monthly volume was never below 83 % of the full supply capacity. Although the combined catchment areas of the four streams draining Mdantsane form 15 % of the Bridle Drift catchment below Laing Dam, their flow contribution amounted to <1 % of the total inflow for the study period.

RESULTS AND DISCUSSION

A summary of the hydrological characteristics for Bridle Drift Dam from September 1977 to August 1978 is given in Table 3. The inflow during the study period was 2 % higher than the average mean value for 1969/78. This is reflected in the slightly higher mean values of volume, area and mean depth. The reduced retention time (0,56 years) also reflected the higher inflow.

The impounded waters, with a mean turbidity of 68 JTU and a mean Secchi depth of 0,10 m were highly turbid. It has been stated that the high silt content of impounded waters in the Buffalo River catchment can be largely associated with poor farming methods, over-grazing and inadequate erosion control (Reed and Thornton, 1969). The extent of mineralization of the impounded water is indicated by the sodium, chloride, potassium, calcium, magnesium, and sulphate values (Table 4). A mean orthophosphate phosphorus concentration of 0,09 mg/dm³ and a mean nitrate nitrogen concentration of 1,11 mg/dm³ was recorded for the impounded waters for the study period. Frequency histograms for surface water data are given in Figures 3 and 4. Orthophosphate phosphorus was most commonly encountered at concentrations varying between 0,06 mg/dm³ and 0,10 mg/dm³, while nitrate nitrogen was most frequently between 0,51 mg/dm³ and 1,00 mg/dm³. Turbidity usually ranged between 51 JTU and 75 JTU.

The inflowing waters, in particular the streams draining Mdantsane, had high sodium and chloride contents (Table 4). These streams are, under dry weather conditions, largely fed by natural springs. The nutrient concentrations of these four streams varied considerably but were generally high. The mean orthophosphate phosphorus concentrations varied between 0,50 mg/dm³ and 4,09 mg/dm³ and mean nitrate nitrogen concentrations varied between 2,00 mg/dm³ and 3,68 mg/dm³. The respective values for the Buffalo River were 0,08 mg/dm³ and 0,89 mg/dm³. The high values found in the four streams could, on occasion, be directly attributed to sewage contamination from Mdantsane. Evidence of organic pollution is provided by the high Kjeldahl nitrogen and ammonia nitrogen values which were recorded. Of the inflowing systems, the Umdanzani Stream showed the highest phosphate concentrations (mean orthophosphate phosphorus concentration of 4,09 mg/dm³).

The temperature distribution during the study period is shown in Figure 5. The water column stratified in September 1977, but this was briefly disrupted in December 1977 after an increased inflow. Stratification recurred and persisted until March 1978. A maximum temperature gradient of 8 °C through the water column was recorded in January 1978. An orthograde oxygen distribution was present from April 1978 until the end of the study period in August 1978. Stratification of dissolved oxygen occurred from September 1977 until March 1978, after being briefly disrupted in December 1977 (Fig. 6). The hypolimnion showed an oxygen deficit from October 1977. This deficit was reduced in November/December 1977 due to higher inflows, but low oxygen levels were re-established by mid-December 1977. An anaerobic zone was formed during February 1978 at 23 m. This layer represented 10 % of the impoundment's water content. After overturn in April 1978, recirculation resulted in the reoxygenation of this anaerobic zone.

Microcystis colonies were first observed in mid-October 1977 and prominent surface scum was intermittently present between November 1977 and March 1978. During December 1977 and January 1978 scum covered large surface areas of the impoundment. However, the mean chlorophyll *a* concentration over the year was only 0,15 μg/dm³ (Table 5), with a maximum of 1,67 μg/dm³. It is obvious that the scum was not detected by the chlorophyll *a* determinations. Apart from an aesthetic detraction, the appearance of *Microcystis* did not, at any time, directly affect water purification processes. In January 1978, large scums of *Microcystis* were observed in the upper reaches of the impoundment and were probably growths which had been washed out of Laing Dam (see Laing Dam). A bloom of *Pandorina* developed in the Umdanzani estuary at the beginning of August 1978 and was present for 3 to 4 weeks. This alga, which is known to cause taste and odour problems (Palmer, 1962), was also observed in the upper reaches of the dam. In mid-March 1978, water hyacinth was noticed in the Shangani estuary, the site of a previous infestation. These plants were physically removed before they reached problem proportions.

The orthophosphate phosphorus surface loading rate for the study period was 2,43 $g.m^{-2}.a^{-1}$ (Table 5), of which 9% was contributed by the four streams draining Mdantsane. These streams contributed 3 % of the inorganic nitrogen into the impoundment (inorganic nitrogen surface loading rate 19,30 $g.m^{-2}.a^{-1}$).

The total phosphate phosphorus surface loading rate into the impoundment was 18,72 $g.m^{-2}.a^{-1}$, of which the Buffalo River contribution amounted to 18,36 $g.m^{-2}.a^{-1}$. These values suggest that most of the incoming phosphate was associated with suspended material. The mean suspended solids value in the Buffalo River was 133 mg/dm³ whilst mean values in the four streams varied between 11 mg/dm³ and 40 mg/dm³.

The nutrient surface loading rates and nutrient concentrations of the impounded waters indicate that Bridle Drift Dam can be classified as eutrophic. It appears however, that the severity of the symptoms of eutrophication were moderated, to a large extent, by the high turbidity. With a mean Secchi depth of 0,10 m and a mean surface turbidity of 68 JTU, Bridle Drift Dam probably represents one of the most turbid impoundments in the country. Thus, although the impoundment displayed low phytoplankton productivity during the study period, it obviously has a high potential to develop severe eutrophication problems.

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I acknowledge the Department of Water Affairs for supplying the hydrological data and Mr M. Butty for processing these data. Values for potassium, calcium, magnesium, sulphate and alkalinity were supplied by the City Engineer's Department, East London Municipality.

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TABLE 1. Characteristics of Bridle Drift Dam and its catchment

Geographical location	32 ° 59'S; 27 ° 44'E
Magisterial district	East London
Catchment type	Urban, cultivated, uncultivated
Usage of dam	Urban and industrial water supply
Catchment area	1 176 km²
Inflowing rivers	Buffalo, Shangani, Sitotana, Tindelli, Umdanzani
Dam wall completed	1968
*F.S.L. volume	76,0 x 10^6 m^3
F.S.L. area	6,16 km^2
F.S.L. maximum depth	40,9 m
F.S.L. mean depth	12,3 m

*F.S.L. = full supply level

TABLE 2. Average-term hydrological characteristics of Bridle Drift Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	68,23	22
Area km^2	5,88	17
Mean depth m	11,4	11
Annual inflow x 10^6 m^3	136,39	59
Annual outflow x 10^6 m^3	138,88	59
Retention time a	0,88	97

*Average mean is based on monthly values and an annual cycle:
Period: September to August (1969 – 1978);
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics of Bridle Drift Dam (Sept. 1977 – Aug. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	76,71	67,80	73,52	4	8
Area km^2	6,29	5,97	6,22	2	6
Mean depth m	12,0	11,3	11,8	2	4
Monthly inflow x 10^6 m^3	38,19	0,91	11,16	112	2
Monthly outflow x 10^6 m^3	35,90	2,17	10,96	106	5

*C.V. = coefficient of variation

TABLE 4 A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Bridle Drift Dam for September 1977 to August 1978

PARAMETER	DAM STATION TOP				DAM STATION BOTTOM				BUFFALO RIVER			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	49	70	56	12	49	66	55	10	23	159	71	45
K	4,6	6,8	5,6	11	5,5	8,9	6,8	13	4,1	21,7	5,9	55
Ca	12,3	20,9	14,7	13	11,6	19,5	14,7	13	9,3	41,2	18,8	40
Mg	11,3	14,5	12,5	9	11,4	13,8	12,5	8	6,7	44,0	17,1	51
SO_4	11,4	25,8	18,8	20	12,0	21,4	17,2	16	6,8	39,9	21,4	38
Cl	60	86	71	11	60	78	69	10	36	280	101	58
Si												
Cond	36	45	39	7	35	44	38	7	12	111	48	44
Alk	61	86	73	10	59	84	72	9	21	161	86	33
Tot Kj–N	ND*	2,24	0,83	72	ND	3,42	1,10	71	0,22	7,00	1,16	107
Dis Kj–N	ND	1,33	0,56	78	ND	0,85	0,51	65	ND	1,73	0,65	68
NH_4-N	ND	0,27	0,07	110	ND	0,27	0,08	107	ND	6,08	0,32	357
NO_3-N	0,44	2,88	1,11	52	0,18	2,52	0,98	51	ND	6,08	0,89	122
NO_2-N	ND	0,04	0,003	274	ND	0,02	0,001	452	ND	0,01	0,001	294
Tot P	0,44	5,40	1,14	96	0,49	9,28	1,73	115	0,15	3,28	1,03	66
Tot dis P	0,18	0,74	0,50	31	0,20	0,88	0,55	32	0,05	1,20	0,50	53
PO_4-P	0,04	0,15	0,09	39	0,02	0,15	0,09	34	0,03	0,26	0,08	70
Fe												
Mn												
Temp	12,1	26,8	18,5	26	11,3	18,9	14,9	18	12,1	26,6	20,7	21
DO	6,4	11,0	8,3	13	0,2	8,8	4,5	67				
Tu	42	148	68	32	62	248	109	41	9	392	75	92
pH	7,6	8,1	7,9	2	7,0	7,8	7,5	4	7,2	8,1	7,7	4
SS	8	76	46	43	55	282	140	40	9	1955	133	286

PARAMETER	SHANGANI				SITOTANA				TINDELLI				UMDANZANI				OUTFLOW			
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	46	195	130	29	88	254	206	19	68	325	150	41	88	174	133	19	49	75	55	12
K																	5,8	8,9	7,1	11
Ca																	9,9	28,6	14,6	22
Mg																	9,8	20,0	12,7	15
SO_4																	13,2	27,4	18,4	21
Cl	66	376	202	38	124	474	354	22	88	626	201	51	108	246	184	23	710	110	80	14
Si																				
Cond	30	148	91	31	56	187	136	21	48	161	89	29	45	137	90	23	37	59	43	11
Alk																	63	109	75	12
Tot Kj–N	0,06	44,40	4,27	207	ND	7,56	1,59	143	0,06	11,28	2,45	107	ND	10,30	1,93	145	ND	2,94	1,02	69
Dis Kj–N	ND	30,80	3,02	211	ND	4,75	0,91	130	ND	9,35	1,86	122	ND	10,12	1,52	171	ND	1,68	0,52	89
NH_4-N	ND	37,00	2,44	311	ND	5,90	0,47	280	ND	5,74	0,94	178	ND	6,16	0,73	221	ND	0,23	0,07	101
NO_3-N	ND	6,32	2,00	78	0,44	5,13	2,04	70	0,01	9,20	3,68	60	ND	11,56	2,73	111	0,57	2,48	1,11	46
NO_2-N	ND	0,85	0,15	155	ND	0,50	0,07	208	ND	0,75	0,11	172	ND	2,30	0,18	262	ND	0,02	0,001	389
Tot P	0,45	9,60	1,92	118	0,33	2,90	0,92	69	0,55	9,56	2,80	84	1,77	12,30	4,74	47	0,36	5,40	1,47	72
Tot dis P	0,25	9,04	1,63	135	0,13	2,71	0,80	76	0,44	9,52	2,51	93	1,76	9,70	4,44	52	0,28	0,90	0,59	24
PO_4-P	0,06	9,42	1,28	172	0,04	2,71	0,50	131	0,20	9,52	2,23	109	1,76	8,95	4,09	49	0,03	0,28	0,12	48
Fe																				
Mn																				
Temp	9,9	24,2	18,3	24	10,5	25,2	19,0	23	8,2	24,8	18,6	26	9,5	25,8	19,2	27	13,5	21,4	17,8	15
DO																				
Tu	1	186	25	196	0,40	140	10	268	0,4	70	8	208	0,4	100	8	259	54	186	107	33
pH	7,0	8,2	7,6	3	7,6	8,4	8,1	2	7,0	8,1	7,6	4	7,4	8,1	7,7	3	7,3	8,1	7,8	2
SS	0	311	40	194	0	188	19	193	0	65	11	127	0	101	12	173	6	177	94	63

*ND = not detected
C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Bridle Drift Dam (Sept. 1977 – Aug. 1978)

Mean depth m		11,8	
Retention time a		0,56	
Hydraulic load m/a		21,07	
Surface loading rates g/m^2.a^{-1}			
PO_4-P		2,43	
Total P		18,72	
Inorganic nitrogen		19,30	
Total nitrogen		44,24	

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	1,67	ND*	0,15
Secchi depth m	0,15	0,07	0,10

*ND = not detected

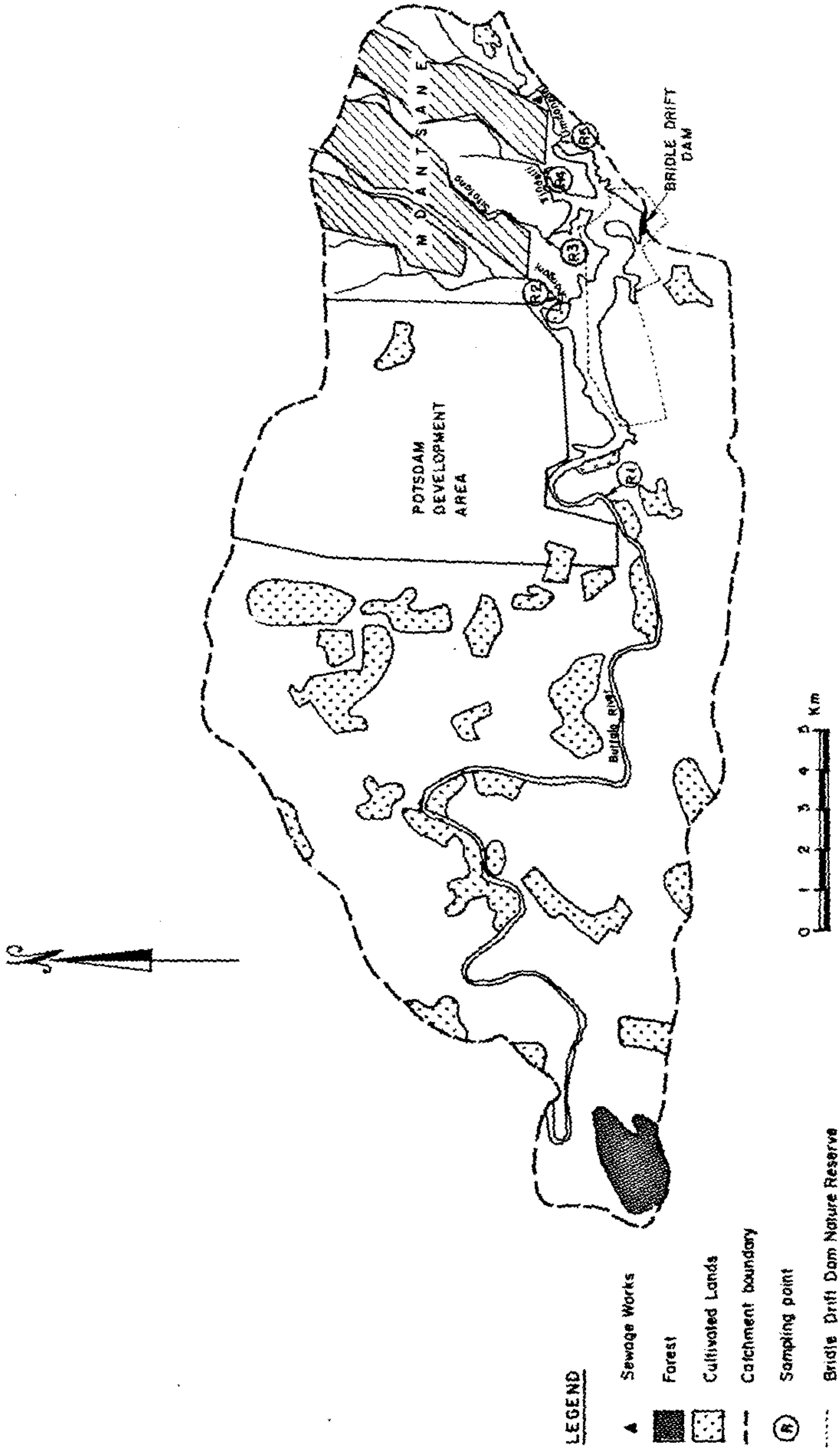

FIGURE 1. Bridle Drift Dam catchment.

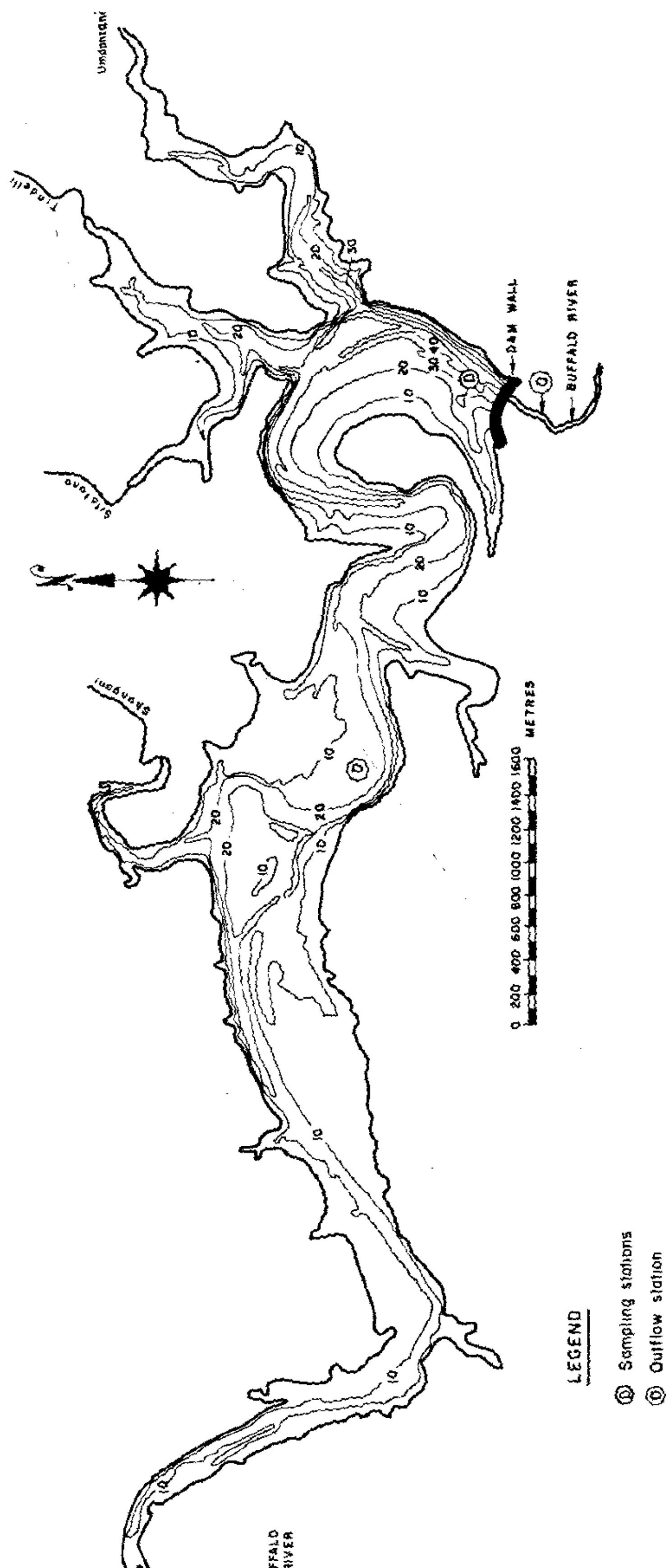

FIGURE 2. **Map of Bridle Drift Dam showing sampling station.**

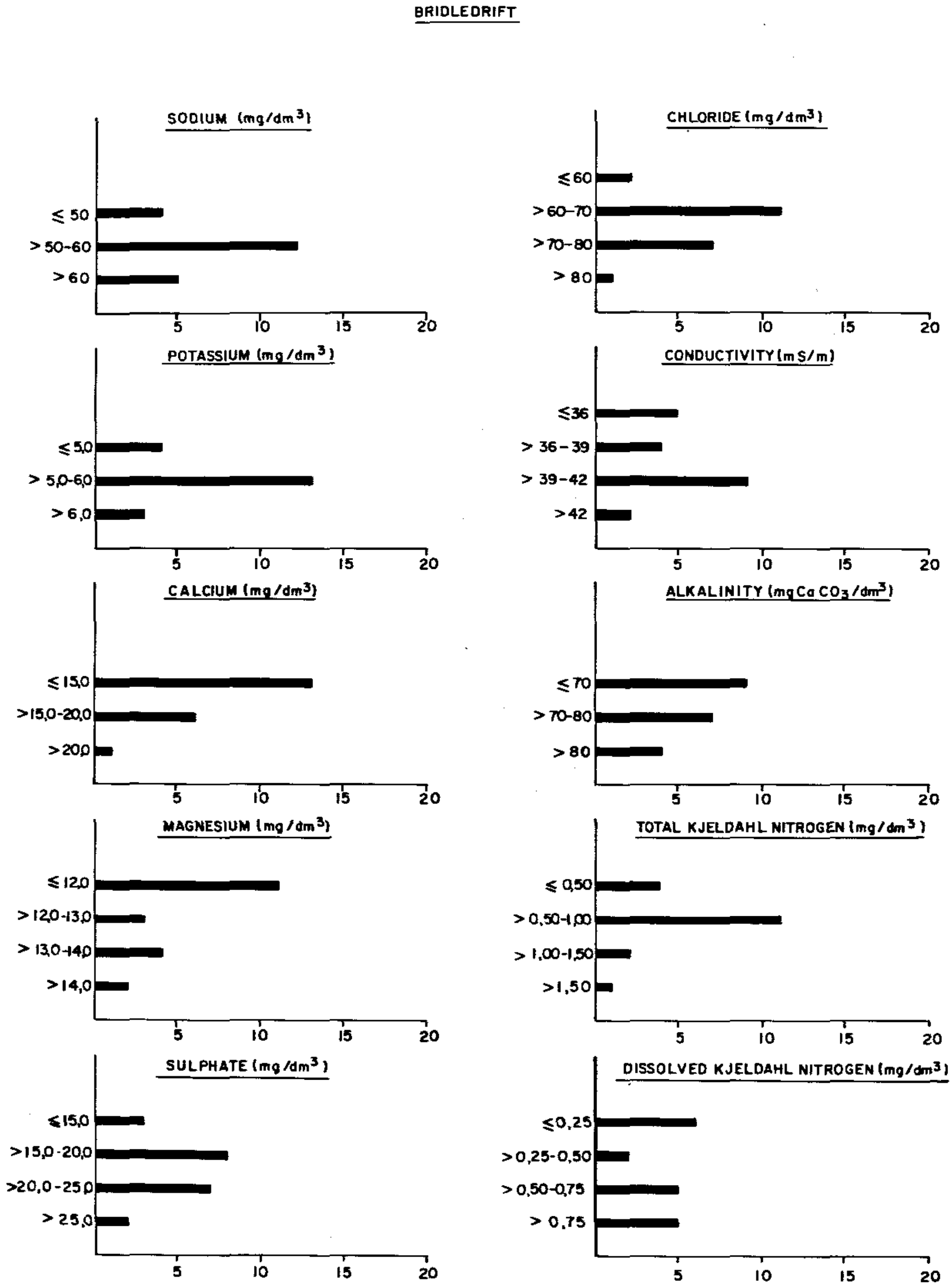

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Bridle Drift Dam.

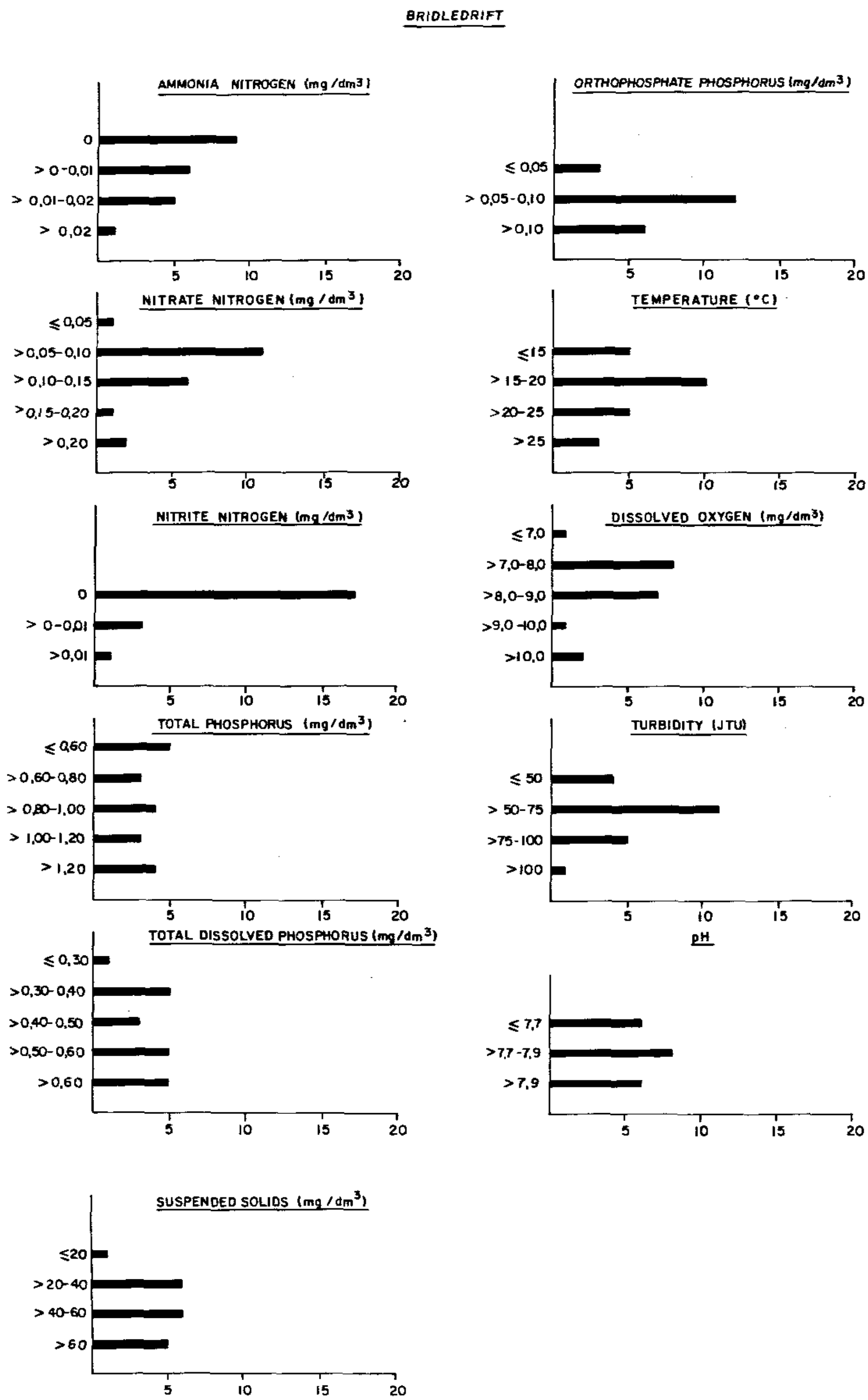

FIGURE 4. Frequency histograms for selected parameters pertinent to the surface waters of Bridle Drift Dam.

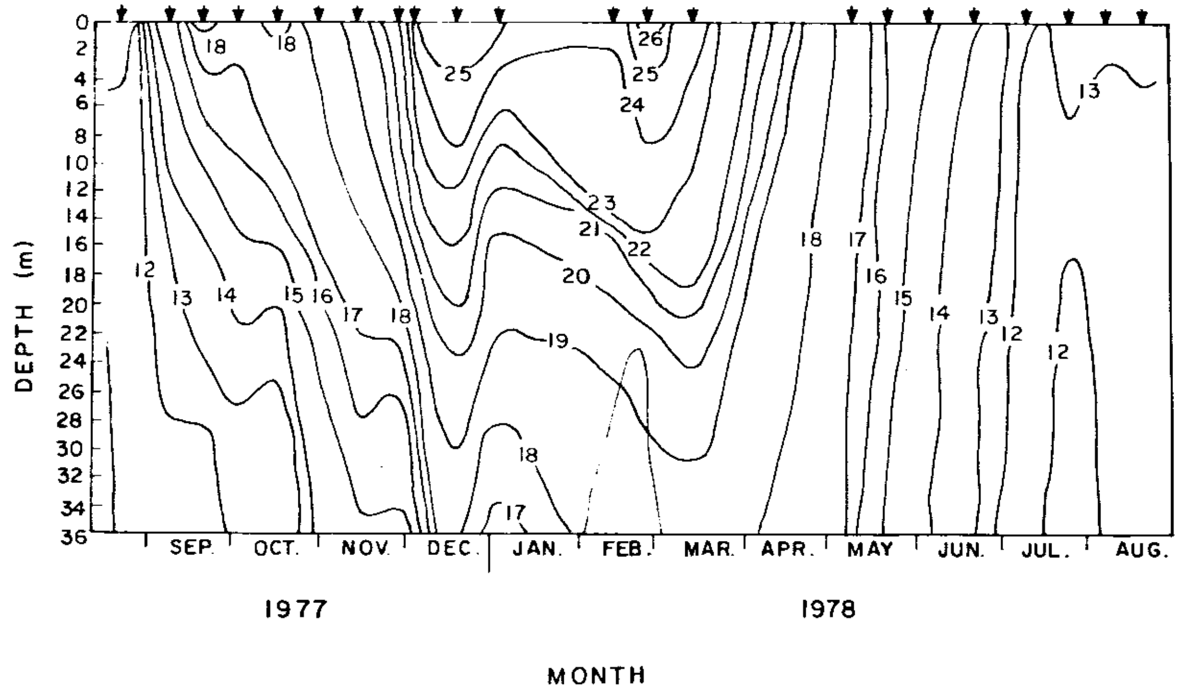

FIGURE 5. Temperature distribution pattern in Bridle Drift Dam (Aug. 1977 — Aug. 1978). (Arrows indicate sampling dates, shaded area represents anaerobic zone.)

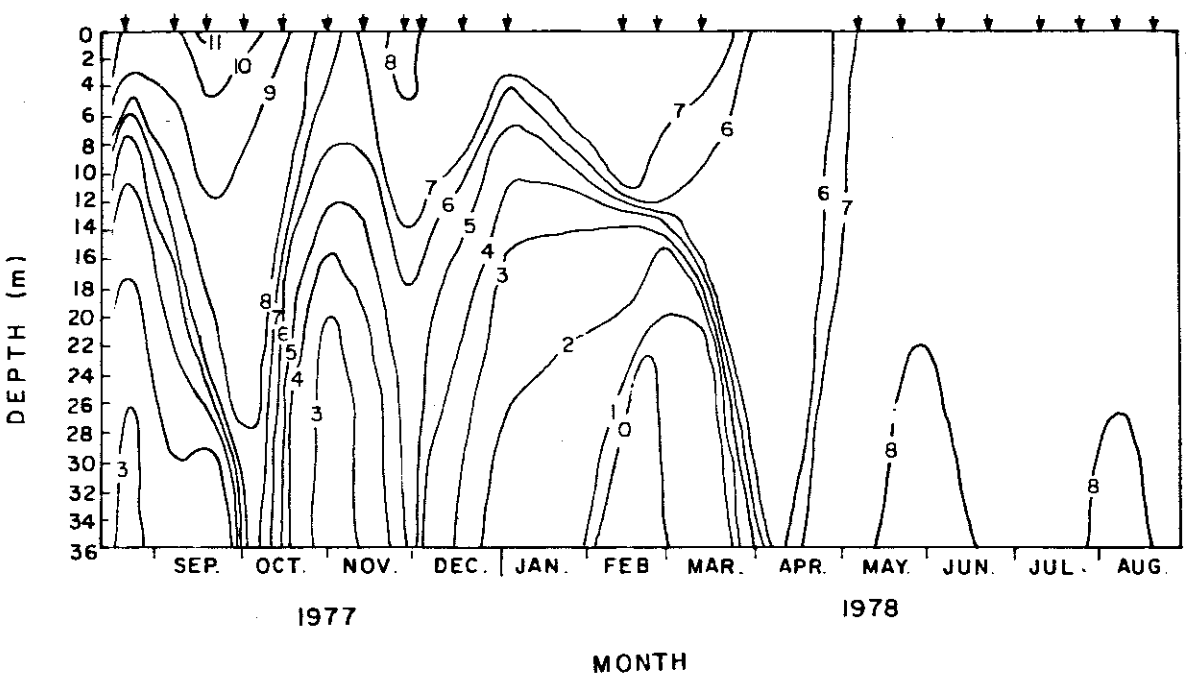

FIGURE 6. Oxygen distribution pattern in Bridle Drift Dam (Aug. 1977 — Aug. 1978). (Arrows indicate sampling dates, shaded area represents anaerobic zone).

LAING DAM

by

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INTRODUCTION

Laing Dam is situated in the middle reaches of the Buffalo River, 14 km south-east of King William's Town and 40 km west of East London. Ownership of the impoundment was transferred from the East London Municipality to the Department of Water Affairs in 1976. It is currently being used as a domestic and industrial water supply. The supply areas include Berlin, Zwelitsha township, Mount Coke Hospital and a number of rural settlements.

An algal bioassay of a number of South African impoundments (Toerien *et al.*, 1975) indicated that Laing Dam has the 17th highest algal growth potential of the 98 impoundments surveyed. Algal blooms were first noted in the impoundment during 1975 (Toerien and Tow, 1976), a period of reduced turbidity. Schutte and Bosman (1973) found that oxygen depletion occurred in the hypolimnion of Laing Dam during the summer of 1968/1969. A well-defined thermocline was also present during the same period, although this was not permanent.

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment are listed in Table 1. After the August 1970 floods in the East London-King William's Town region, the dam wall had to be strengthened and the spillway capacity increased in view of present-day standards. These modifications were completed in 1977. Laing Dam has two major inflowing rivers, the Buffalo and the Yellowwoods (Fig. 1). King William's Town and Zwelitsha are situated in the catchment of the Buffalo River. The main nutrient point sources are the sewage purification works of the respective towns and a textile factory. The Yellowwoods River has, in its catchment, the developing Breidbach township, which is at present unsewered. The Tshaba River also enters Laing Dam, but its contribution is insignificant when compared with that of the Buffalo and Yellowwoods rivers. It was therefore not included in this study. The results given in this report represent the sampling stations R1 and R6 as indicated in Figure 1. The bathymetry of the impoundment and the sampling station are shown in Figure 2. There is a deep gorge behind the dam wall (37 m), but areas near the inflows are relatively shallow (<10 m). Islands are present in these shallow areas.

The hydrological characteristics of the impoundment from 1968 to 1978 are given in Table 2. The average mean retention time (1,20 years) indicates that the impoundment has a slow rate of replenishment compared with many other South African impoundments (Walmsley, *et al.*, 1978). However, considerable variation is evident since the lowest value for the mean retention time was 0,17 years (1969/70) whilst the highest was 4,77 years (1972/73). Based on catchment area ratios, it has been estimated that the Yellowwoods River contributes approximately 30 % of the total inflow into Laing Dam. This report presents data obtained during a limnological survey between November 1977 and October 1978.

RESULTS AND DISCUSSION

The basic hydrological characteristics of the impoundment are shown in Table 3. There was a greater than average inflow into the impoundment during the study period with the result that the mean volume of the impoundment was only slightly below the full supply capacity. The increased inflow also resulted in a relatively low retention time (0,42 years).

The results of chemical analysis of water from the two inflowing rivers, the impoundment and outflow during the study period are presented in Table 4. The impounded waters showed high nutrient levels. The mean values for nitrate nitrogen and orthophosphate phosphorus were 1,29 mg/dm^3 and 0,16 mg/dm^3 respectively. Based on the sodium and chloride content, the impoundment can be regarded as relatively highly mineralized. A mean surface turbidity value of 51 JTU and a mean Secchi depth of 0,17 m showed the impoundment to be highly turbid. The frequency of occurrence of different concentrations of the surface water parameters are shown in Figures 3 and 4. Orthophosphate phosphorus concentrations varied most frequently between 0,10 mg/dm^3 and 0,20 mg/dm^3. The most frequent concentrations of nitrate nitrogen were between 0,50 mg/dm^3 and 1,00 mg/dm^3. Surface water turbidity values of between 20 JTU and 40 JTU were most common.

The temperature distribution in the water column for the study period is shown in Figure 5. Stratified conditions were encountered at the commencement of the study in November 1977. These conditions persisted until the end of March 1978, when cooling of the water temperatures resulted in overturn. During winter, a temperature gradient was always present.

Stratification occurred in August/September 1978. Oxygen isopleths for the study period are presented in Figure 6, and these show that a clinograde oxygen distribution was present from December 1977 until March 1978. During this period, an extensive anaerobic zone was present, with the limit of the upper layer varying between 12 m and 23 m. This zone represented between 3 and 27 % of the water capacity of the impoundment. Overturn occurred in early April 1978 and resulted in the reoxygenation of the anaerobic waters. The winter temperature gradient caused an oxygen gradient to be present during the greater part of winter.

During the study period by far the greater proportion of nutrients entered Laing Dam via the Buffalo River. This is an indication of the high degree of industrialization and urbanization in this catchment by comparison with the Yellowwoods River catchment. The orthophosphate phsophorus surface loading rate of 13,82 $g.m^{-2}.a^{-1}$ (Table 5) is extremely high as is the total nitrogen surface loading rate of 63,61 $g.m^{-2}.a^{-1}$ (Vollenweider, 1968). This represents 31,57 t of phosphate phosphorus and 113,08 t of nitrogen which entered Laing Dam during the study period. The mean orthophosphate phosphorus and total nitrogen concentrations for the Buffalo River were 1,35 mg/dm^3 and 5,70 mg/dm^3 respectively. By contrast the mean orthophosphate phosphorus and mean total nitrogen concentrations for the Yellowwoods River were 0,09 mg/dm^3 and 1,76 mg/dm^3 respectively. Loading estimates reveal that the Yellowwoods River contributes 4 % of the orthophosphate load and 9 % of the inorganic nitrogen load into Laing Dam.

The results show that, with regard to nutrient status, Laing Dam can be classified as eutrophic. However, in terms of algal growth, this impoundment cannot be classified as such. Although *Microcystis* growths occurred in late December 1977, these were washed out after heavy rains and did not reappear. This impoundment has not reached its full potential with regard to algal growth. The chlorophyll *a* values during the study period were extremely low (Table 5) and it appears likely that the high turbidity played an important role in suppressing algal growth. The possible inhibitory influence of textile effluents on phytoplankton growth can also not be discounted.

ACKNOWLEDGEMENTS

I am grateful to Mr G.B. Keppie, Chief City Engineer, Mr R.B. Reed, past City Engineer and Mr G.P.K. Thornton, past Chief Chemist, East London Municipality, for advice and assistance throughout this programme; Mr R.E. Bartel for useful discussions and co-operation at all times; Mrs E. Coltman for invaluable assistance in the analysis of samples; Mr R.D. Walmsley for his interest and assistance and Mr C.J. Alexander for help in dataprocessing.

I acknowledge the Department of Water Affairs for supplying the hydrological data and Mr M. Butty for processing these data.

I also wish to express my gratitude to Mr G.P. Beyleveld, Laing Dam Purification Works Supervisor, for all his assistance.

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TABLE 1. Characteristics of Laing Dam and its catchment

Geographical location	32 ° 58'S; 27 ° 30'E
Magisterial district	King William's Town
Catchment type	Urban, cultivated, uncultivated, forest
Usage of dam	Urban and industrial water supply
Catchment area	913 km^2
Inflowing rivers	Buffalo, Yellowwoods, Tshaba
Dam wall completed	1951
*F.S.L. volume	22,0 x 10^6 m^3
F.S.L. area	2,11 km^2
F.S.L. maximum depth	37,5 m
F.S.L. mean depth	10,4 m

*F.S.L. = full supply level

TABLE 2. Average-term hydrological characteristics of Laing Dam

	*Average mean	*C.V.
Volume x 10^6 m^3	20,04	19
Area km^2	1,97	17
Mean depth m	10,1	3
Annual inflow x 10^6 m^3	49,72	82
Annual outflow x 10^6 m^3	49,74	79
Retention time a	1,20	138

*Average mean is based on monthly values and an annual cycle:
Period: November to October (1968 — 1978)
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics of Laing Dam (Nov. 1977 — Oct. 1978)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	22,19	20,28	21,91	2	9
Area km^2	2,18	1,93	2,14	3	9
Mean depth m	10,4	10,2	10,2	1	1
Monthly inflow x 10^6 m^3	16,75	0,15	4,73	130	14
Monthly outflow x 10^6 m^3	16,79	0,13	4,45	134	7

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Laing Dam for November 1977 to October 1978.

PARAMETER	DAM STATION								BUFFALO RIVER				YELLOWWOODS RIVER				OUTFLOW			
	TOP				BOTTOM															
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.
Na	33	82	58	28	40	97	65	25	48	417	156	57	30	216	108	53	33	82	58	29
K																	4,5	7,2	5,6	15
Ca																	8,0	22,3	16,5	23
Mg																	8,1	16,6	12,6	23
SO_4																	11,3	28,2	21,5	26
Cl	40	102	73	29	42	108	78	24	60	324	164	45	44	368	168	56	38	106	73	30
Si																				
Cond	21	62	42	29	31	69	47	24	32	194	89	49	29	153	81	50	13	68	43	33
Alk																	38	103	77	21
Tot Kj – N	0,30	2.70	0,97	56	0,68	2,86	1,18	55	0,85	9,55	2,91	72	0,58	2,64	1,15	40	0,15	3,40	1,08	63
Dis Kj – N	0,03	2,01	0,69	69	0,13	1,54	0,75	53	ND	8,44	1,82	97	0,28	1,48	0,73	42	ND	1.18	0,66	50
NH_4 – N	ND*	1,21	0,15	163	ND	1,59	0.21	173	ND	4,52	1,02	125	ND	0,37	0,13	78	ND	1,25	0,15	165
NO_3 – N	0,66	2.61	1,29	36	0,19	2,21	1,20	44	0,94	5,74	2,80	51	ND	1,91	0,59	75	0,54	2,03	1.17	31
NO_2 – N	ND	0,02	0,001	351	ND	0,09	0.01	240	ND	0,45	0,12	117	ND	0,50	0,06	239	ND	0,05	0,01	244
Tot P	0.40	2.56	1,05	52	0,51	2,23	1,19	38	0,71	6,36	2,89	41	0,18	2,60	0,97	81	0,52	3,00	1,13	61
Tot dis P	0,24	0,93	0,58	31	0,26	0,72	0,51	30	0,12	5,80	1,93	75	0,08	0,91	0,43	64	0,28	0,83	0.53	23
PO_4 – P	0,06	0,31	0,16	42	0,06	0,27	0,15	44	0,08	3,30	1,35	71	0.01	0,26	0,09	79	0,02	0,23	0,12	52
Fe																				
Mn																				
Temp	12,8	26,9	19,0	25	10,8	17,5	14,0	18	10,9	26.6	19,0	28	10,6	26,2	16,8	28	12,1	24,8	18,9	22
DO	6,4	9,5	7,4	11	0,1	8,3	3,1	93												
Tu	19	122	53	55	35	95	58	32	3	120	24	128	3	150	46	88	26	280	72	86
pH	7,1	8,1	7,7	3	6,7	8,0	7,4	5	7,1	9.0	7,7	5	7,2	8,6	8,0	5	7,7	8,8	8,1	4
SS	5	90	33	76	16	160	66	66	3	257	49	136	3	188	61	77	9	1 784	157	238

*ND = *not detected*

C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Laing Dam (Nov. 1977 – Oct. 1978)

Mean depth m	10,2
Retention time a	0,42
Hydraulic load m/a	24,29
Surface loading rates g/m^2.a^{-1}	
PO_4-P	13,82
Total P	33,94
Inorganic nitrogen	37,55
Total nitrogen	63,61

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	2,22	ND*	0,17
Secchi depth m	0,45	0,04	0,17

*ND = not detected

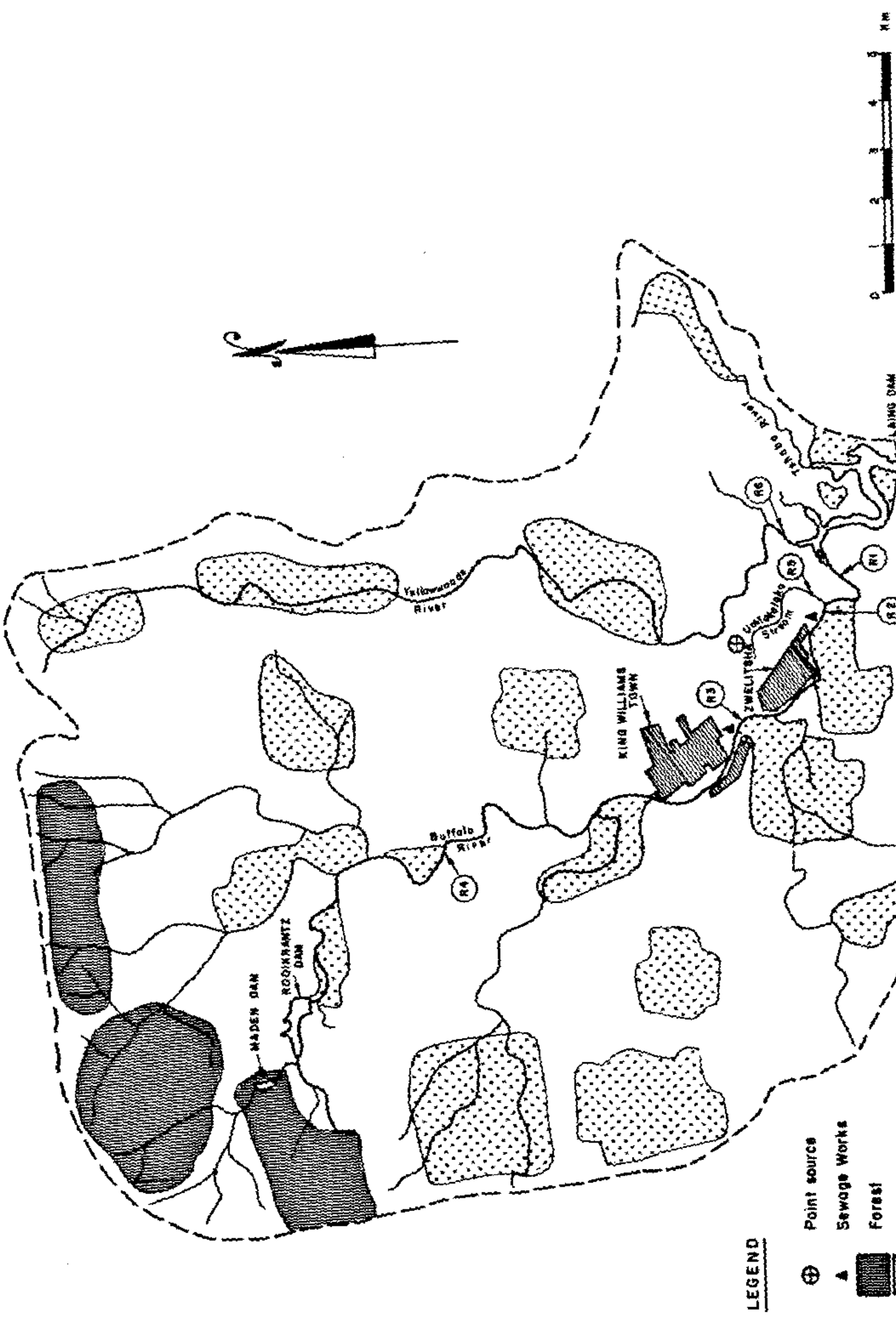

FIGURE 1. Laing Dam catchment.

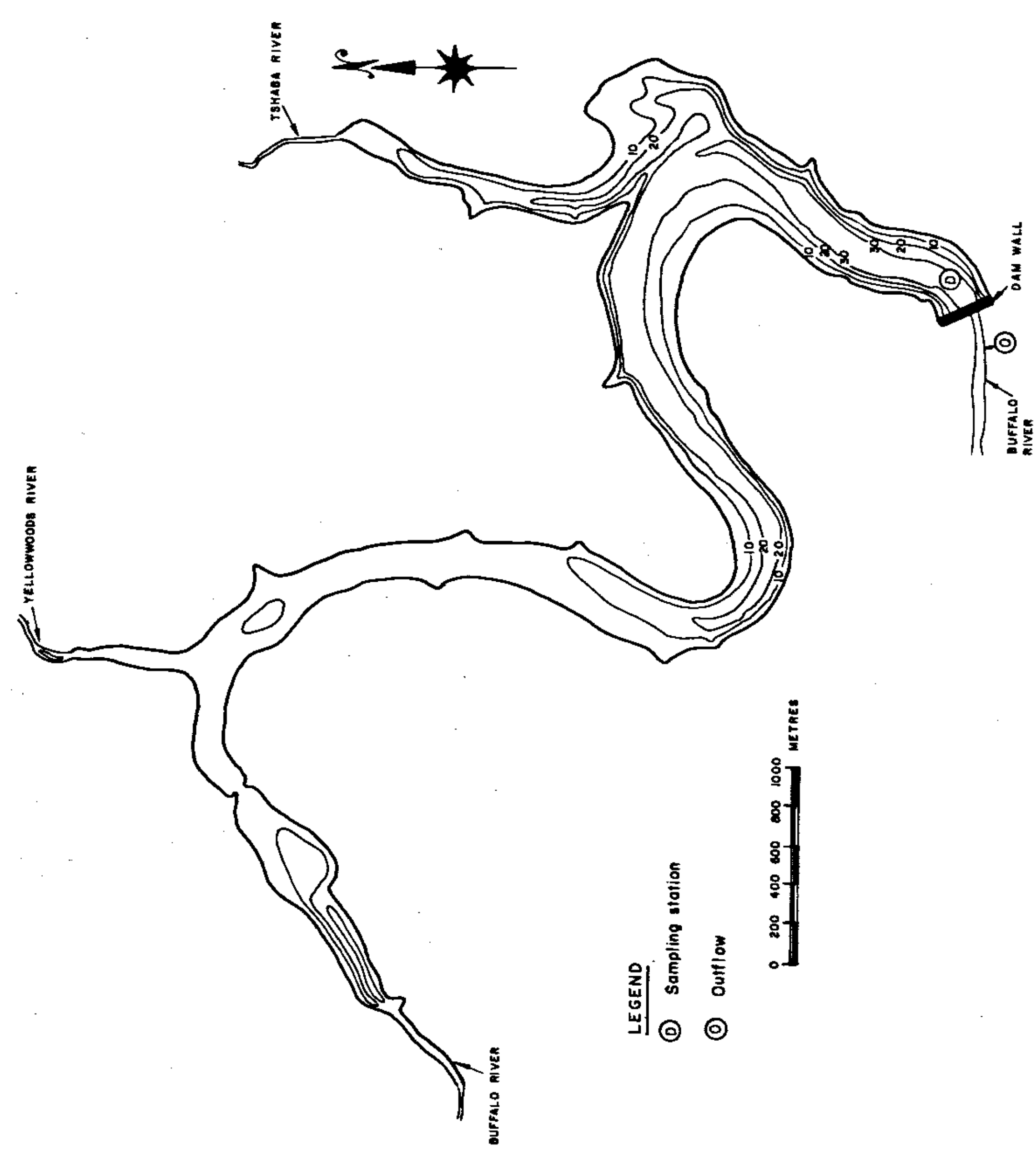

FIGURE 2. Map of Laing Dam showing sampling station.

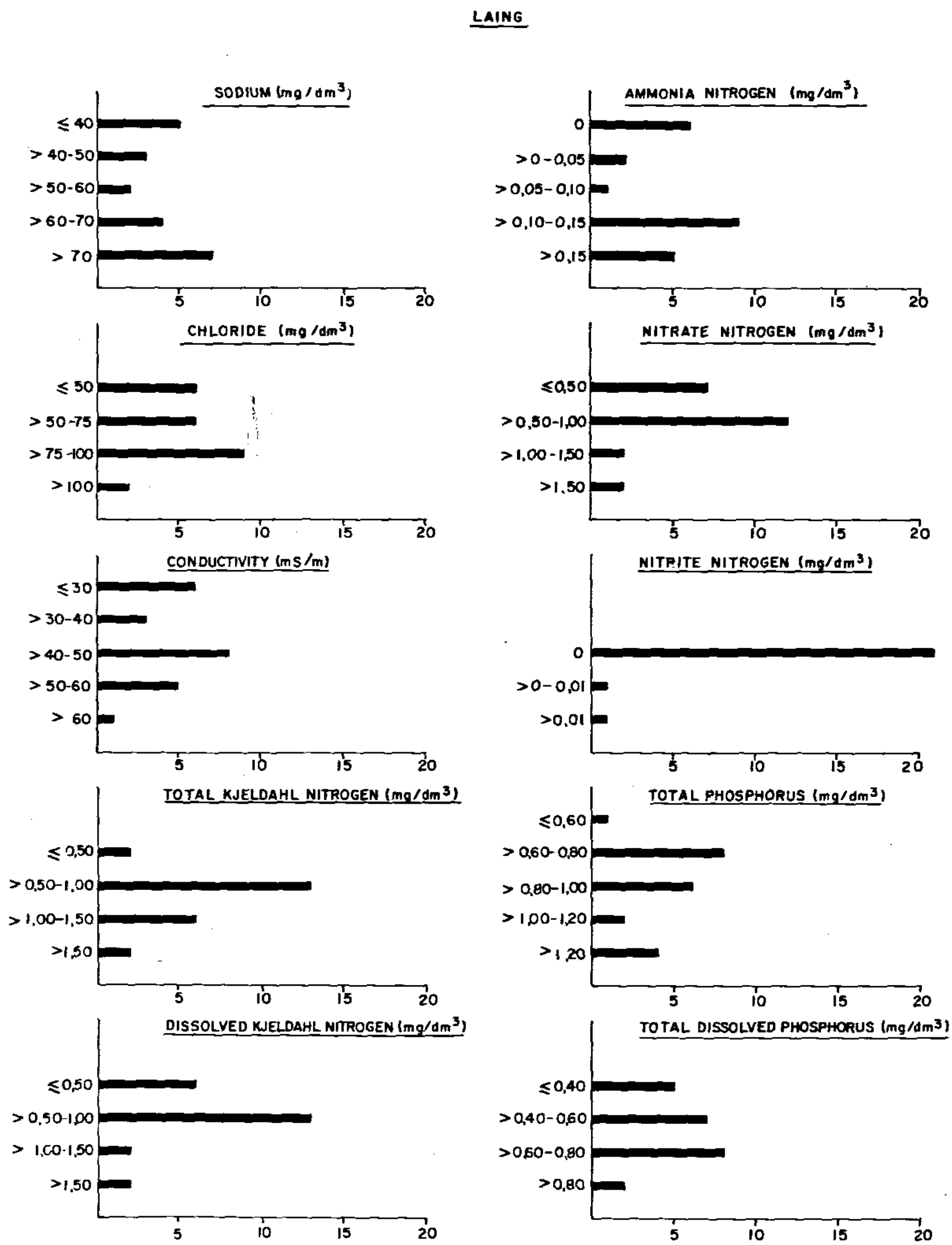

FIGURE 3. Frequency histograms for selected parameters for the surface waters of Laing Dam.

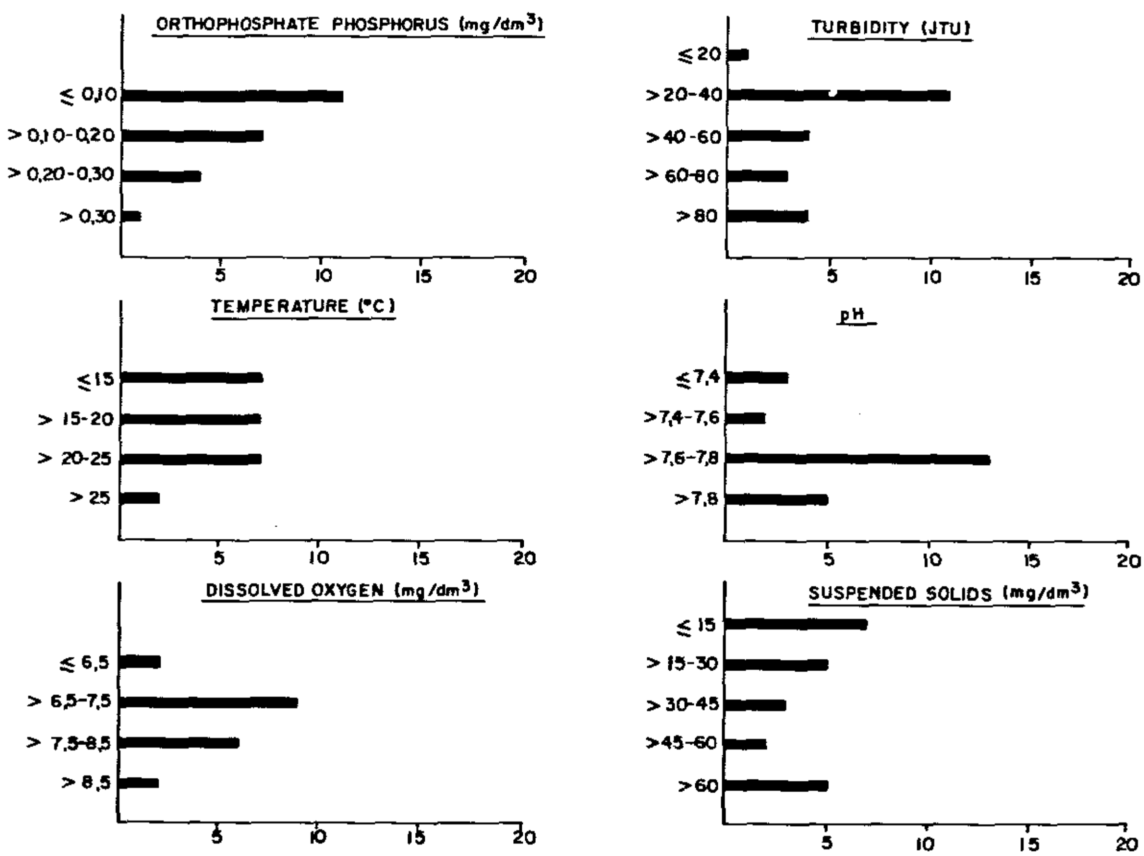

FIGURE 4. Frequency histograms for selected parameters for the surface waters of Laing Dam.

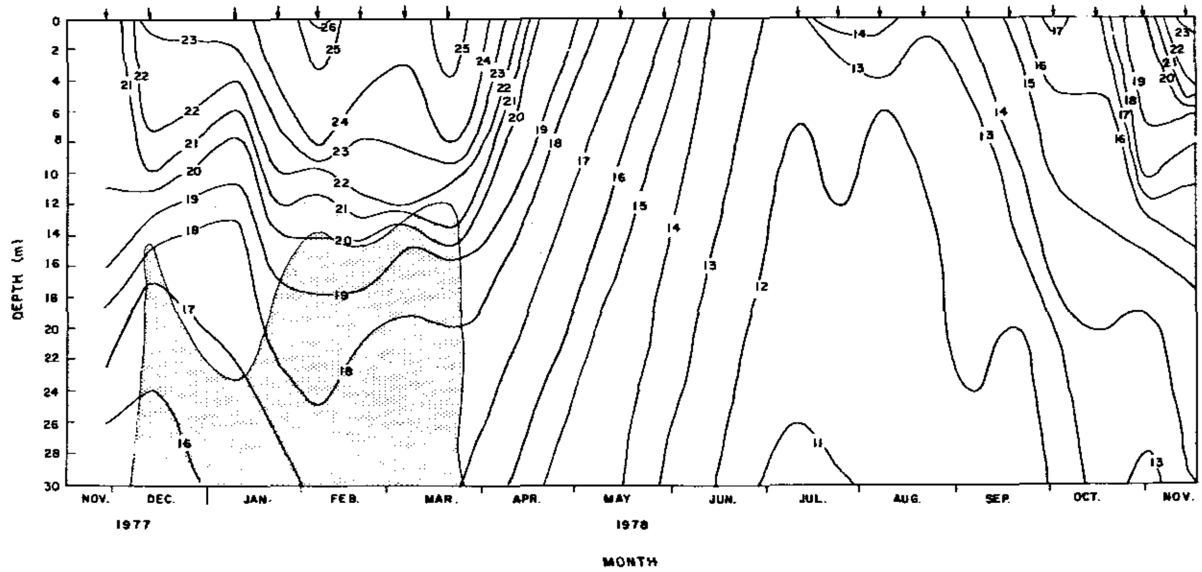

FIGURE 5. **Temperature distribution in Laing Dam (Nov. 1977 — Nov. 1978).** (Arrows indicate sampling dates, shaded area represents anaerobic zone.)

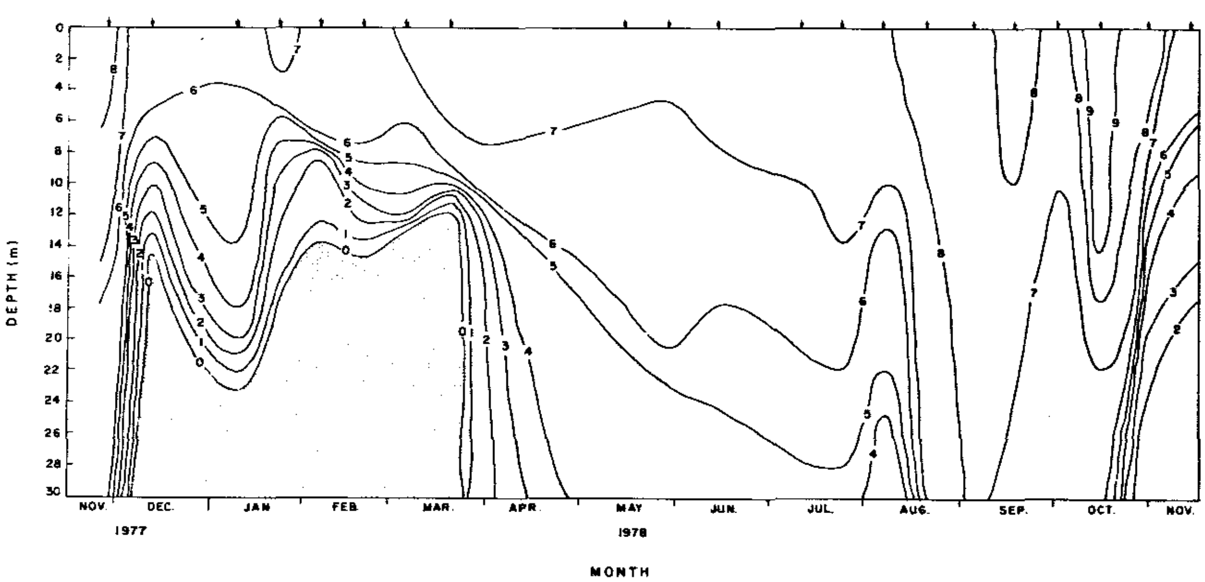

FIGURE 6. **Oxygen distribution in Laing Dam (Nov. 1977 — Nov. 1978).** (Arrows indicate sampling dates, shaded area represents anaerobic zone.)

NAHOON DAM

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INTRODUCTION

Nahoon Dam, an impoundment on the Nahoon River, is situated approximately 15 km north-west of East London. This State-owned impoundment is used as an industrial water supply and for irrigation. It is envisaged that water from Nahoon Dam will, in the near future, augment the supply to the densely populated Mdantsane township and the developing township of Potsdam.

In a trophic status classification of 98 South African impoundments, Toerien *et al.* (1975) showed Nahoon Dam to have an algal growth potential of 14,5 mg/dm^3. This is relatively low when compared with the other impoundments which were investigated, where the range varied between 4,3 mg/dm^3 (Gubu Dam) and 660,4 mg/dm^3 (Rietvlei Dam). Schutte and Bosman (1973), in their survey of physical and chemical parameters of South African impoundments, indicated that thermal stratification occurred in Nahoon Dam and that an oxygen deficit occurred in the hypolimnion during the summer months from 1969 to 1972. This report presents data obtained during a limnological survey between September 1976 and August 1977.

DESCRIPTION OF THE AREA

The basic characteristics of the impoundment and its catchment are given in Table 1. In view of the expected increase in demand for water in the East London — King William's Town region, the Nahoon Dam wall was raised by 10,6 m in 1978. In order to fully exploit the potential of the river, a further raising of 3 m has been proposed (Department of Water Affairs, 1976 — this report is in the process of being updated). Figure 1 shows the position of Nahoon Dam in relation to its catchment. The catchment is made up of cultivated and uncultivated lands. The settlements of MacLeantown and Kei Road are situated on the northern and north-western edge of the catchment. These areas are not expected to develop to any significant extent in the near future (Water Research Commission, 1976). Although the Berlin Industrial Area falls within the Nahoon Dam catchment, this region has not yet been fully developed, and as such, no effluent is being discharged into the Nahoon River. There are, at present, no nutrient point sources in the catchment. The sampling stations on the inflowing streams are indicated in Figure 1. The bathymetry of the impoundment and the impoundment sampling station are shown in Figure 2. The impoundment consists essentially of a narrow valley which runs along the length of the impoundment, the deepest portion (18 m) being in the vicinity of the dam wall.

The hydrological characteristics of the impoundment (Table 2) show that there is a considerable variation in the annual inflowing volumes. The Rwantsa River (Fig. 1), a tributary of the Nahoon River, is estimated to contribute 12 %, by volume, of the total inflow. The mean retention time for the period 1968/77 was 0,5 years which indicates that the waters of the impoundment were replaced twice per annum.

RESULTS AND DISCUSSION

Table 3 shows a summary of the monthly hydrological characteristics for Nahoon Dam from September 1976 to August 1977. It can be seen that the mean values for the morphological features were considerably lower than the average mean for the period 1968/77 (Table 2). This resulted from the unusually low inflow, as well as the fact that the water level was kept at a reduced level due to construction activities on the dam wall. The reduced inflow was also reflected in the increased retention time of 1,66 years.

The results of chemical analysis of the inflowing, impounded and outflowing waters for September 1976 to August 1977 are presented in Table 4. The impounded water was turbid (mean turbidity value 51 JTU) and a mean Secchi depth of 0,37 m was recorded for the study period. A high dissolved solids content was indicated by a mean conductivity value of 58 mS/m. The Nahoon catchment falls within the area described by Bond (1946) as having highly mineralized chloride-sulphate waters. This can be seen in the high sodium and chloride values for the impoundment, as well as for the inflowing waters. The impounded waters had a mean orthophosphate phosphorus concentration of 0,07 mg/dm^3. Frequency histograms for the physical and chemical parameters measured are shown in Figures 3 and 4. Orthophosphate phosphorus concentrations were generally below 0,05 mg/dm^3, while nitrate nitrogen concentrations varied between 0,51 mg/dm^3 and 0,75 mg/dm^3. Sodium was most frequently in the 81 mg/dm^3 to 90 mg/dm^3 range while chloride was most often in the 126 mg/dm^3 to 150 mg/dm^3 range.

Temperature isotherms for the dam station for the study period are given in Figure 5. The impoundment developed thermal stratification in October/November 1976. However, this pattern was disrupted during December 1976. Thereafter stratification redeveloped and persisted until the end of February 1977. Throughout the summer of 1976/77, no distinct thermocline was evident. The water temperature decreased gradually from February 1977 until the end of the study period in August 1977. The oxygen distribution pattern for the study period is shown in Figure 6. From the beginning of the study period until the end of February 1977, the water column showed dissolved oxygen stratification. This pattern was briefly disrupted in November 1976 by increased inflows. During the summer months, an anaerobic zone developed and the upper layer of this zone fluctuated between 7 and 11 m. This anaerobic layer represented between 17 and 50 % of the water volume during the study period.

The impoundment had an orthophosphate phosphorus surface loading rate of 0,99 g.m^{-2}.a^{-1} (Table 5), whilst the total phosphate phosphorus surface loading rate was 6,18 g.m^{-2}.a^{-1}. These values suggest that a high proportion of the phosphate which entered the impoundment was associated with incoming silt and suspended material. This pattern was also exhibited by nitrogen loading figures for the impoundment.

Growth of *Microcystis* was frequently present during the summer of 1976/77. However, because of the gas-vacuolate characteristic of this alga, colonies were generally localized at the surface, and because of the sampling method employed and the sampling station chosen, low chlorophyll concentrations were recorded (Table 5). It should be noted that whilst these growths did not represent nuisance proportions with respect to water treatment, they must be considered undesirable. This impoundment can be classified as eutrophic with regard to its nutrient status. However, its full potential has not been reached and as with the other impoundments investigated (Bridle Drift and Laing dams), it appears likely that high turbidity is important in retarding the growth of nuisance algae.

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TABLE 1. Characteristics of Nahoon Dam and its catchment

Geographical location	32 ° 54'S; 27 ° 49'E
Magisterial district	East London
Catchment type	Cultivated and uncultivated
Usage of dam	Urban and industrial water supply, irrigation
Catchment area	450 km^2
Inflowing river	Nahoon
Dam wall completed	1966
*F.S.L. volume	5,9 x 10^6 m^3
F.S.L. area	0,82 km^2
F.S.L. maximum depth	18,4 m
F.S.L. mean depth	7,2 m

*F.S.L. = full supply level

TABLE 2. Average-term hydrological characteristics of Nahoon Dam

	*Average mean	*C.V. %
Volume x 10^6 m^3	5,18	16
Area km^2	0,75	11
Mean depth m	6,8	6
Annual inflow x 10^6 m^3	27,74	85
Annual outflow x 10^6 m^3	26,92	89
Retention time a	0,50	105

*Average mean is based on monthly values and an annual cycle:
Period: September to August (1968 – 1977)
C.V. = coefficient of variation.

TABLE 3. A summary of monthly hydrological characteristics of Nahoon Dam (Sept. 1976 – Aug. 1977)

	Maximum	Minimum	Mean	*C.V.	Deviation of mean from average %
Volume x 10^6 m^3	4,34	2,79	3,58	17	– 31
Area km^2	0,66	0,53	0,59	9	– 21
Mean depth m	6,6	5,2	5,9	9	– 13
Monthly inflow x 10^6 m^3	1,91	0	0,50	141	– 98
Monthly outflow x 10^6 m^3	0,84	0,06	0,18	116	– 99

*C.V. = coefficient of variation

TABLE 4. A summary of physical and chemical characteristics of inflowing, outflowing and impounded waters of Nahoon Dam for September 1976 to August 1977.

PARAMETER	DAM STATION								RWANTSA				NAHOON				OUTFLOW			
	TOP				BOTTOM															
	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*	Min	Max	Mean	C.V.*
Na	38	97	79	19	24	95	76	22	34	306	152	50	38	236	158	30	36	95	77	20
K																				
Ca																				
Mg																				
SO_4																				
Cl	51	268	118	30	29	202	111	30	43	386	208	49	51	578	251	39	48	234	113	30
Si																				
Cond	25	69	58	20	14	67	53	25	22	177	95	46	28	139	97	29	23	68	55	23
Alk																				
Tot Kj – N	ND*	2,28	1,01	65	ND	2,98	1,12	64	ND	1,98	0,78	61	ND	1,90	0,79	69	ND	1,90	0,78	63
Dis Kj – N	ND	1,90	0,69	75	ND	1,54	0,55	77	ND	1,74	0,51	87	ND	3,30	0,57	107	ND	1,38	0,51	71
NH_4 – N	ND	0,16	0,02	175	ND	0,55	0,09	154	ND	0,19	0,03	174	ND	0,16	0,02	179	ND	0,19	0,02	213
NO_3 – N	0,13	1,28	0,69	36	0,19	1,05	0,55	42	ND	1,03	0,34	75	0,16	1,28	0,47	54	0,15	1,00	0,57	37
NO_2 – N	ND	0,05	0,01	159	ND	0,05	0,01	151	ND	0,01	0,01	169	ND	0,05	0,01	175	ND	0,07	0,01	229
Tot P	0,16	1,37	0,56	54	0,18	1,50	0,69	51	0,10	1,08	0,53	55	0,15	1,20	0,51	51	0,15	1,27	0,62	50
Tot dis P	0,10	0,90	0,37	57	0,09	1,04	0,40	55	0,10	0,75	0,31	55	0,09	0,68	0,32	55	0,09	0,93	0,40	58
PO_4 – P	ND	0,21	0,07	87	ND	0,22	0,08	76	ND	0,28	0,08	86	ND	0,23	0,09	77	ND	0,34	0,09	91
Fe																				
Mn																				
Temp	12,0	26,7	19,4	25	10,4	24,2	17,0	23	12,0	26,8	19,2	24	12,7	27,4	19,8	24	12,4	28,2	19,3	24
DO	4,9	9,7	6,9	19	0	7,6	3,2	84												
Tu	12	240	51	100	14	978	125	149	2	170	33	129	4	170	31	144	12	780	87	166
pH	7,2	8,2	7,8	3	7,1	8,1	7,6	3	7.6	8,5	8,0	3	7,2	8,4	8,0	3	7,2	8,5	7,8	4
SS	0	314	33	156	1	1 804	200	181	0	283	42	155	4	329	37	161	0	834	68	201

*ND = not detected
C.V. = coefficient of variation

TABLE 5. Hydrological characteristics, nutrient loading rates, chlorophyll *a* and water transparency characteristics of Nahoon Dam (Sept. 1976 – Aug. 1977)

Mean depth m	5,9
Retention time a	1,66
Hydraulic load m/a	3,55
Surface loading rates $g/m^2.a^{-1}$	
PO_4-P	0,99
Total P	6,18
Inorganic nitrogen	5,33
Total nitrogen	17,07

	Maximum	Minimum	Mean
Chlorophyll *a* $\mu g/dm^3$	8,63	ND*	0,75
Secchi depth m	0,05	0,78	0,37

*ND = not detected

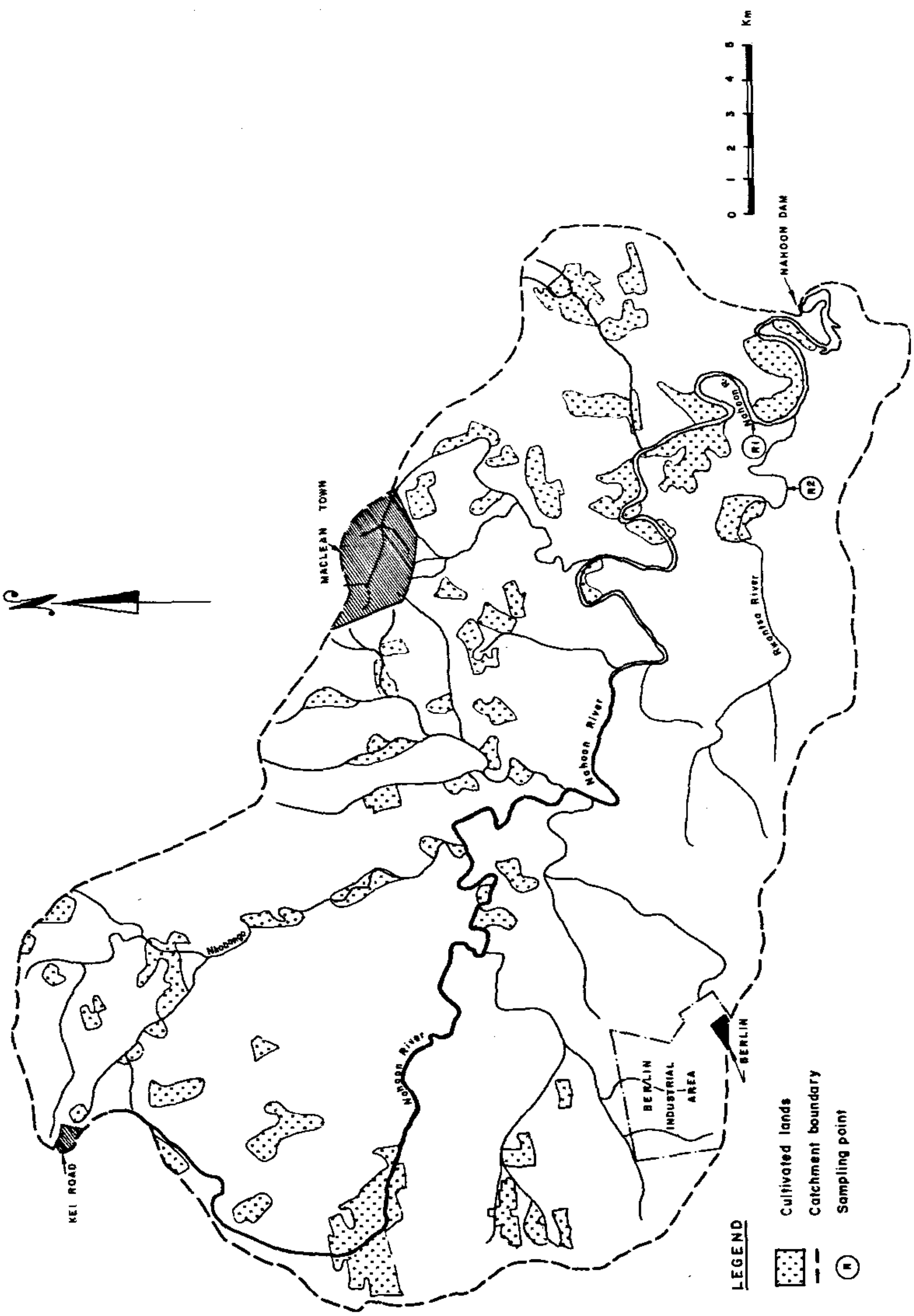

FIGURE 1. Nahoon Dam catchment.

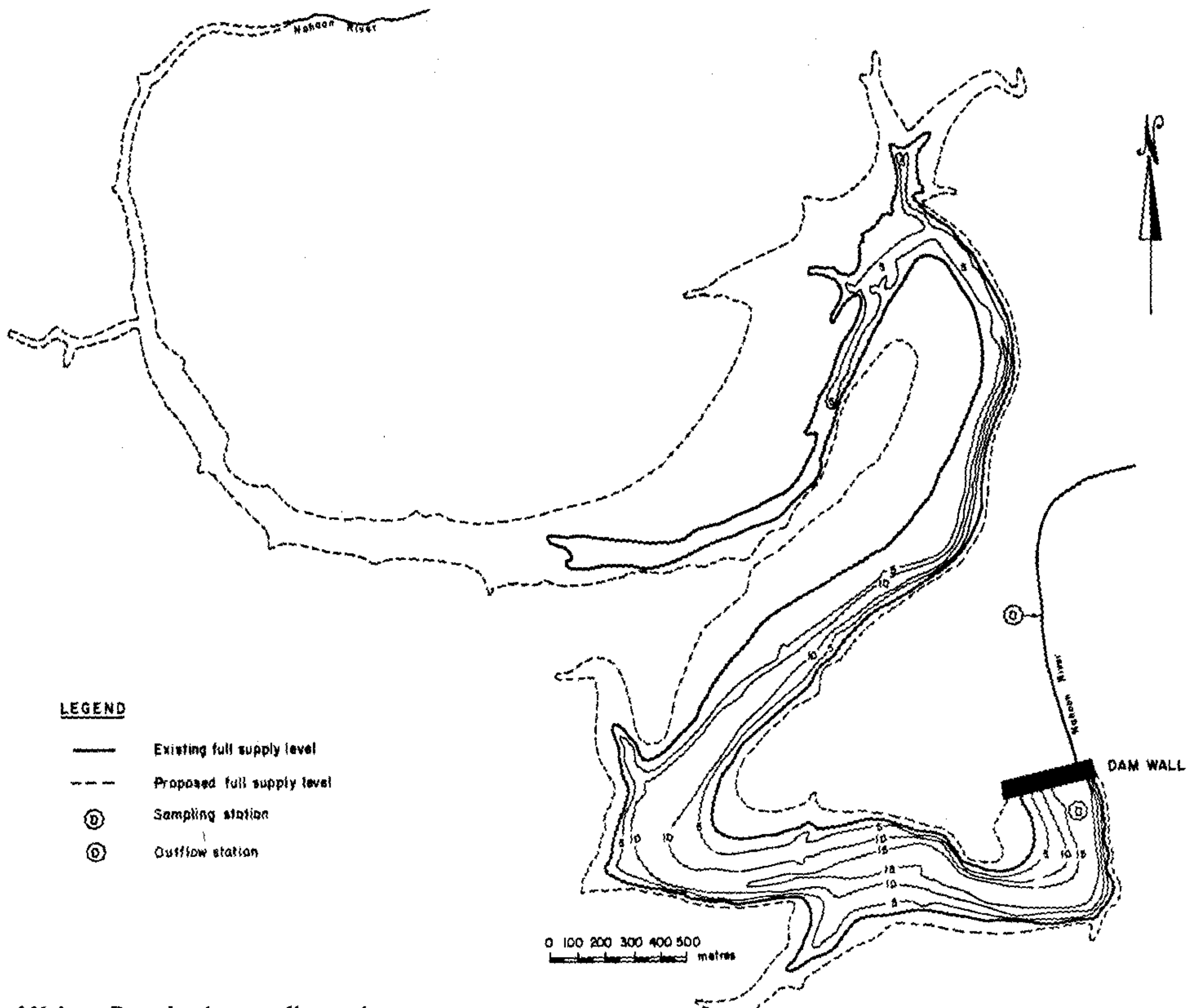

FIGURE 2. Map of Nahoon Dam showing sampling station.

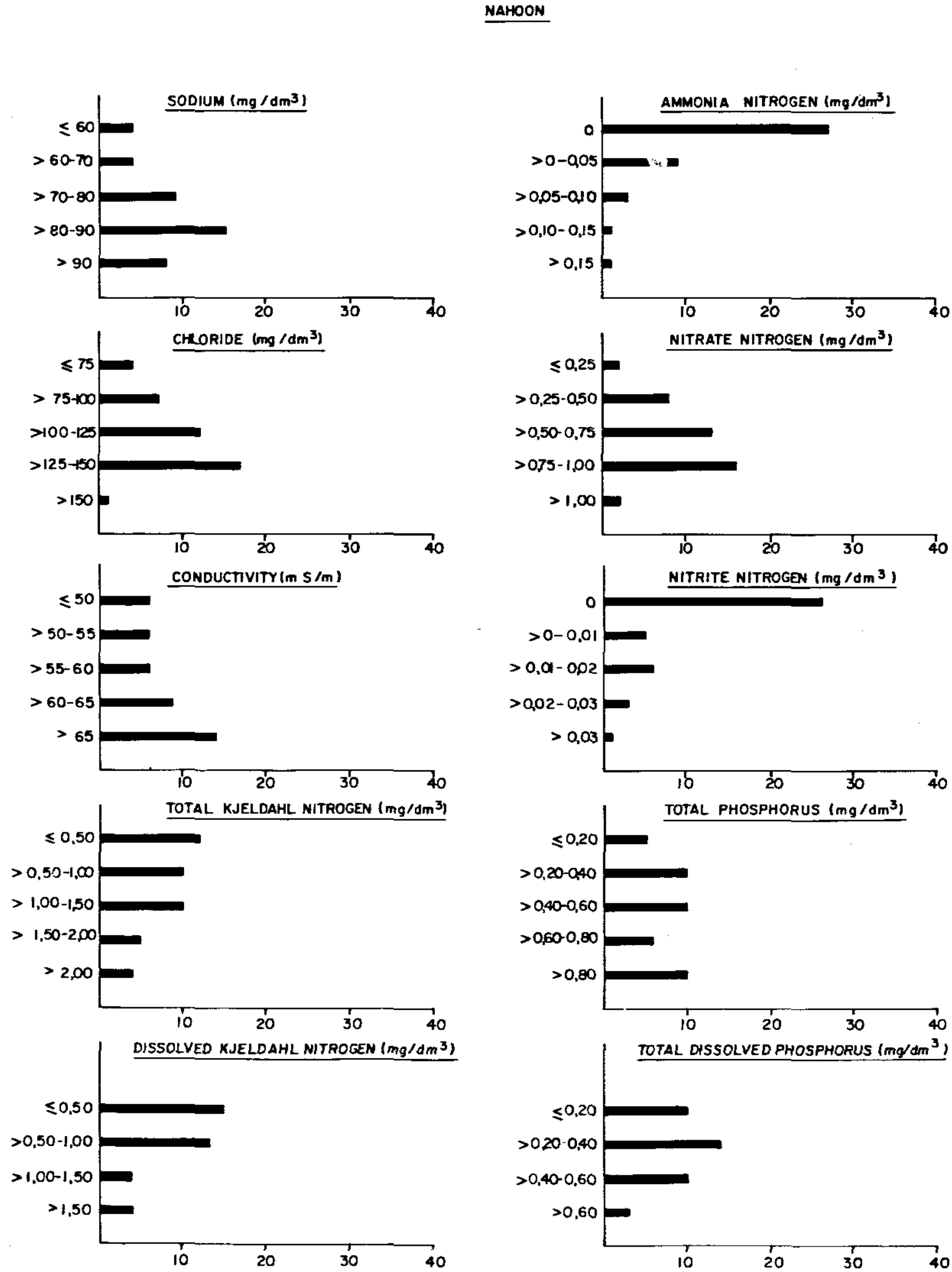

FIGURE 3. Frequency histograms for selected parameters pertinent to the surface waters of Nahoon Dam.

NAHOON

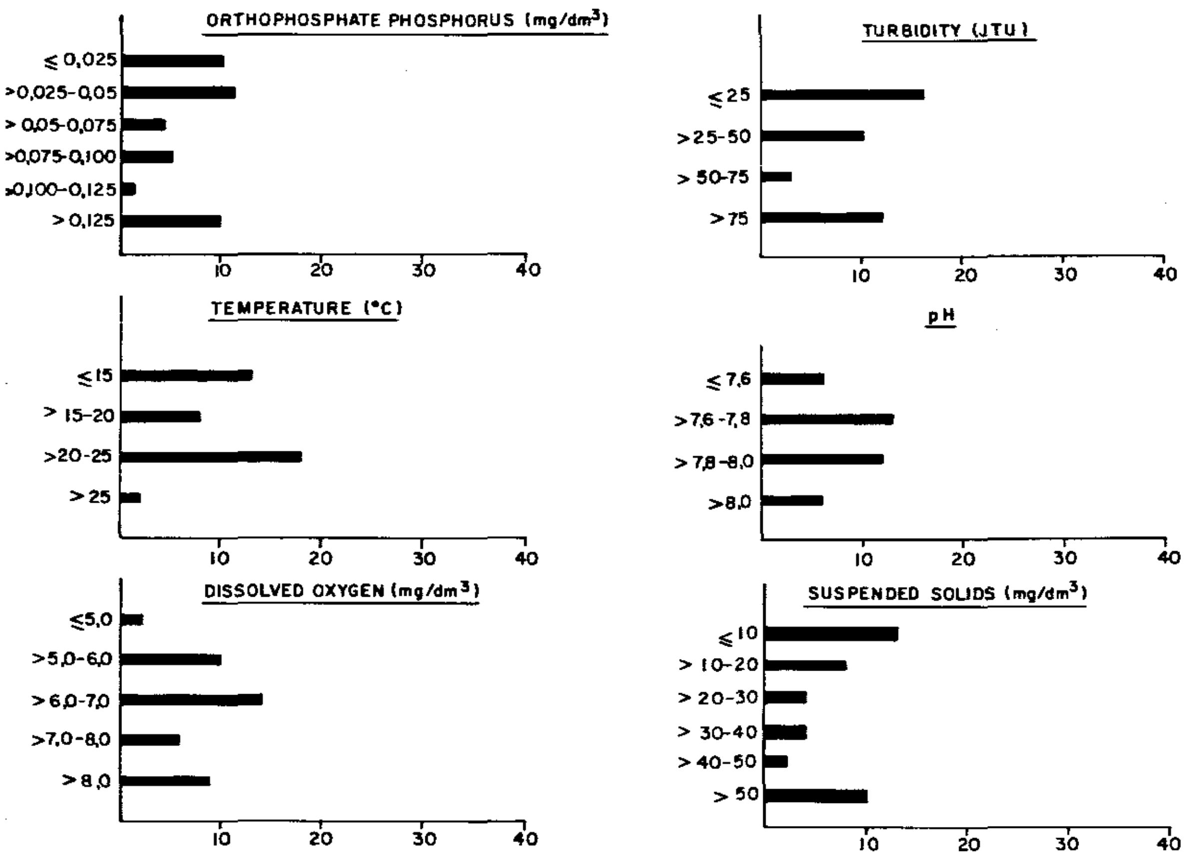

FIGURE 4. **Frequency histograms for selected parameters pertinent to the surface waters of Nahoon Dam.**

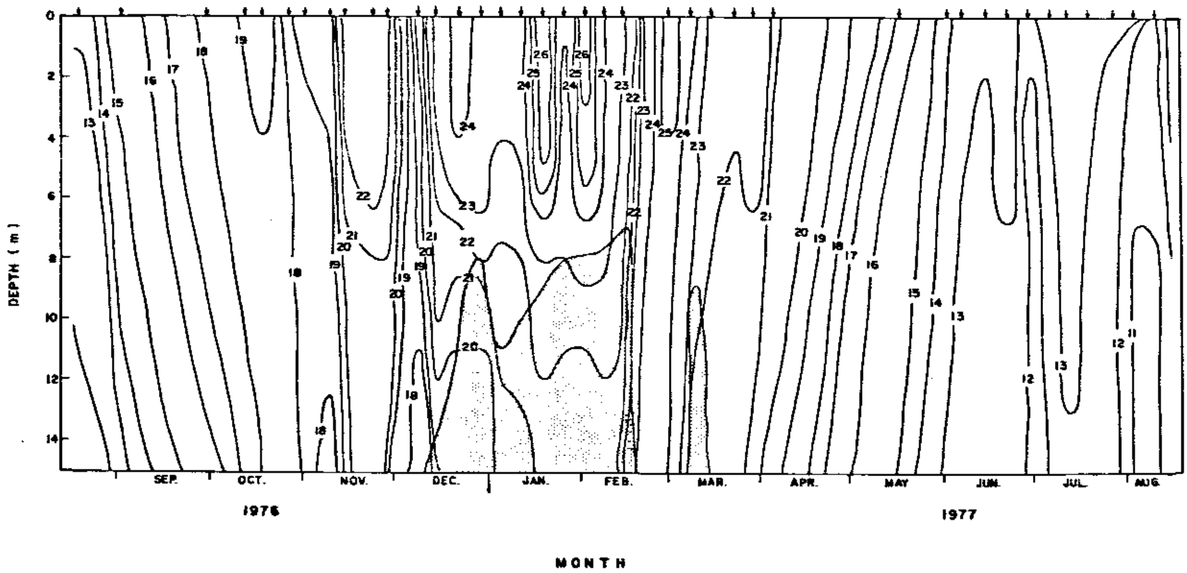

FIGURE 5. Temperature distribution in Nahoon Dam (August 1976 – August 1977). (Arrows indicate sampling dates, shaded areas represent anaerobic zones.)

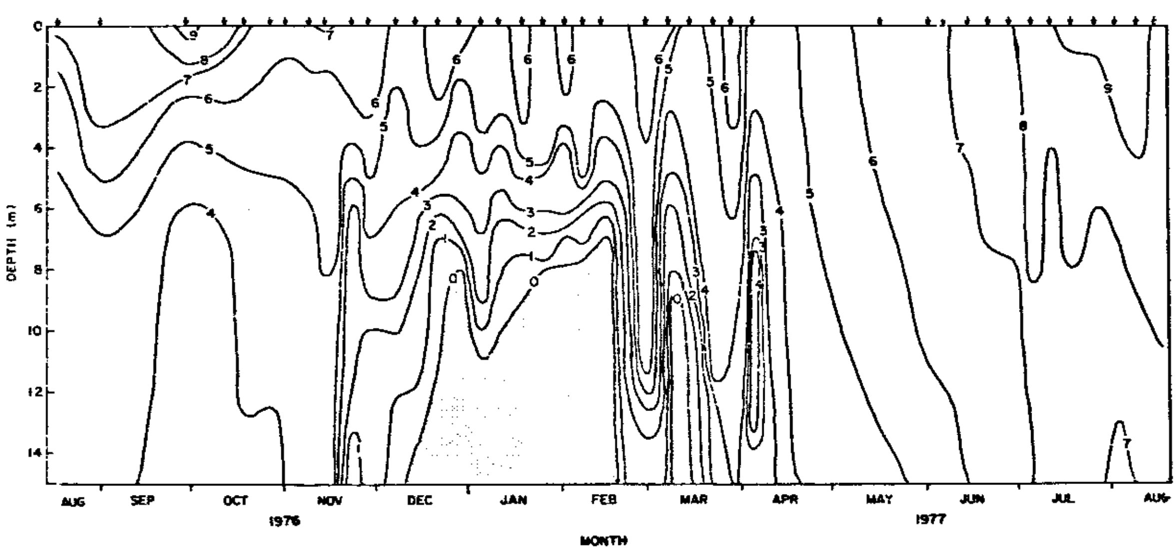

FIGURE 6. Oxygen distribution in Nahoon Dam (August 1976 – August 1977). (Arrows indicate sampling dates, shaded areas represent anaerobic zones.)