A Preliminary Limnological Survey of Swartwater Dam (Qwa-Qwa)

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Abstract

Swartwater Dam is the major impoundment in Qwa-Qwa and its altitude (1 868 m), montane situation and importance to Qwa-Qwa make it a water body of particular limnological interest. During this preliminary limnological survey the following were found: a distinct oxycline in the absence of a distinct thermocline; chemical stratification; a generally low ionic content, which increased markedly, particularly in the case of iron, in the anaerobic hypolimnion; a deeper penetration of light with long wavelengths in the humically stained water; primary production rates, chlorophyll *a* concentrations and phytoplankton populations associated with mesotrophic conditions; and zooplankton and zoobenthos counts indicating a low secondary production level. Since the high iron and manganese concentrations in the hypolimnion are unacceptable for potable purposes, withdrawal of water from the hypolimnion should be avoided; the temperature regime is suitable for trout production in cages or otherwise, but the anaerobic hypolimnion during stratification may be hazaroulds for the production of trout or other fish. Should increased recreational use be made of Swartwater Dam, eutrophication should be minimized as far as possible.

Introduction

Swartwater Dam was completed in October 1976 to supply potable water to the townships of Phuthaditjhaba, Namahale and Patricksdale in the Qwa-Qwa National State. The dam represents the largest water body in this National State and is a resource which may be utilized in other ways such as fish production and recreational angling for the benefit of the local people.

The opportunity of studying this impoundment presented itself in March 1978. However the practical limitations permitted the execution of only a preliminary survey at the time. The results of a more complete study will only be available at a much later stage. Some of the findings were thought to be applicable in the utilization and management of this multipurpose impoundment. Because of its altitude (1 868 m) the data obtained from Swartwater Dam may also be valuable for comparative purposes.

Study Area

Swartwater Dam is 18,5 km from Witzieshoek by road on the Swartwater River (Metsi Matsho) at 28°35'25" S and 28°56'25" E. At full supply level the dam has a surface area of 70,25 ha, mean depth of 6,21 m, maximum depth of 18 m and volume of 4,5 x 10^6 m^3.

The catchment of the Swartwater Dam is relatively small (19,2 km^2) with very little of it under cultivation. Geologically it consists mainly of basalt above Cave Sandstone transversed with dolerite dykes of the Stormberg Series (Du Toit, 1954). The vegetation of the upper part is mainly *Themeda-Eragrostis-Heteropogon* grassland which is not heavily grazed. The lower part is *Eragrostis-Heteropogon-Microchloa* grassland which is grazed by cattle, sheep, goats and horses (WLJ van Rensburg, 1980). The basal cover is fairly dense (25—35%) so that very little erosion occurs and the water entering the dam is clear.

The catchment is in the highland zone of the summer rainfall region where the rainfall is about 1 200 mm per annum, 80% of which falls between October and March, December and January being the wetter months. The average annual runoff at Swartwater Dam is 6,16 x 10^6 m^3.

The annual evaporation for the area is in the region of 1 750 mm per year of which approximately 63% occurs in the warmer summer months (W.L.J. van Rensburg 1980).

The mean monthly maxima for the warmest and the coldest months (January and July) for Harrismith are 31,2°C and 20,2°C respectively (Anon, 1954). The predominant wind direction during summer is North-East and in winter West-North-West (W.L.J. van Rensburg, 1980).

The shape of the dam basin is shown in Figure 1. A retention time of 0,73 years has been calculated, based on the volume at full supply level and the average annual runoff from the

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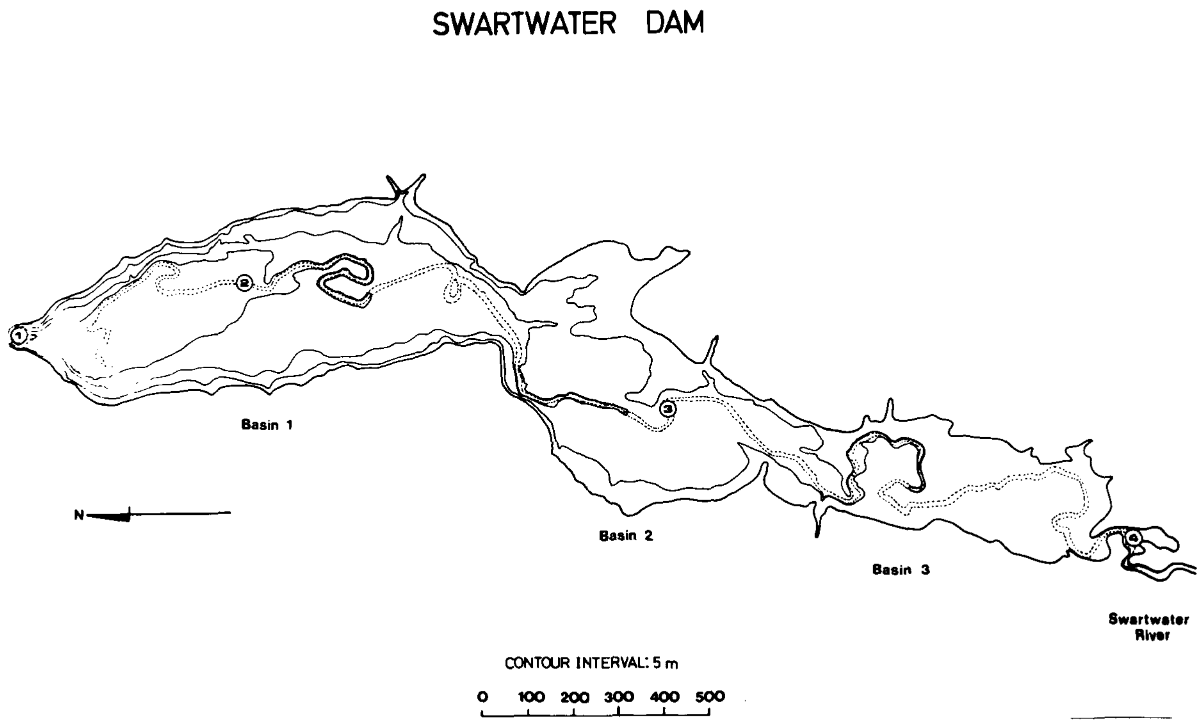

Figure 1
Map of Swartwater Dam indicating sampling stations

catchment area.

The present consumption by the townships is 61,5% of the maximum safe yield of Swartwater Dam (M Roode, 1980).

Methods and Materials

Sampling Locations

Swartwater Dam (Figure 1) is divided into three natural basins: a deeper northern basin (Basin 1), a shallower central basin (Basin 2) and a shallow southern basin (Basin 3). Four sampling stations were chosen. Station 1 (17 m deep) was near the dam wall, Station 2 (13 m deep) in the centre of Basin 1, Station 3 (8 m deep) in Basin 2 and Station 4 in the Swartwater River just above the dam.

Analyses

In situ *measurements*

Oxygen and temperature were measured at 1 m depth intervals (Yellowsprings Oxygen/Temperature meter). Transparency was measured as "photosynthetically active radiation" (PAR) at different depths by means of a "Li-Cor" light meter and compared with Secchi disc readings. Surface radiation was determined by means of a pyranometer sensor at hourly intervals. Planemetric integration was used to determine daily and incubation time radiation totals. The underwater spectral composition was measured with the aid of glass filters (Schott, Mainz, West Germany) as recommended by Vollenweider (1969) in conjunction with the underwater light meter. Turbidity was measured by means of a Hach turbidimeter and expressed as Jackson Turbidity Units (JTU's); pH was measured *in situ* by means of a Beckman pH meter whilst alkalinity was determined titrimetrically with 0,01 N HCl (Golterman, 1969). Specific conductivity was read on a Phillips PR 9501 conductivity meter (K = 20°C).

Chemical Analyses

Samples for chemical analysis were collected in polythene bottles just prior to the departure from the dam by means of a Van Dorn water sampler from 4 depths at Station 1 and from 3 depths at Stations 2 and 3 (see Tables 1 to 5) on 31 March, 30 May and 24 July 1978. After approximately five hours in transit, the samples were stored at 4°C in the laboratory and analysed within three days.

Calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn) were determined by means of atomic absorption spectrophotometry (AAS) (Varian Techtron Model 1000) using lanthanum (La) to eliminate interference.

Chloride (Cl) was measured by conductometric titration

TABLE 5
CONCENTRATION OF CERTAIN TRACE ELEMENTS AT DIFFERENT DEPTHS

	Depth	Fe	Mn	Cu	Zn
	m	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}	mg ℓ^{-1}
Station 1	0,0	0,80	0,10	ND	ND
	7,5	1,40	0,10	ND	ND
	10,0	7,20	1,10	ND	ND
	15,0	17,40	1,65	ND	ND
Station 2	0,0	0,75	ND	ND	ND
	7,5	0,65	ND	ND	ND
	12,0	12,00	1,25	ND	ND
Station 3	0,0	0,20	ND	ND	ND
	3,5	0,35	ND	ND	ND
	7,5	0,40	ND	ND	ND
Inflow	0,0	0,30	ND	ND	ND

ND = Not detectable by the method used

with 0,1 N $AgNO_3$ (Golterman, 1969). Sulphate (SO_4) was determined turbidimetrically after precipitation with barium chloride (Golterman, 1969). Soluble reactive silicon (Si) was determined colorimetrically as a molybdate blue colour after reduction with stannous chloride (Stainton, Capel and Armstrong, 1974). Ammonia nitrogen (NH_3-N) was determined as nitrite after reduction by spongy cadmium (Mackereth, Heron and Talling, 1978). Organic nitrogen was calculated after digestion as total nitrogen minus ammonia-nitrogen. Orthophosphate was determined by the molybdate method with ascorbic acid as a reducing agent and n-hexanol as extractant (Golterman, 1969). Total phosphate was determined after digestion with H_2SO_4 (Golterman, 1969). Organic phosphate was calculated as the difference between total phosphate and orthophosphate. All phosphate results were expressed as μg P ℓ^{-1}. Complete chemical analyses were performed only on water samples collected on 31 March.

Chlorophyll *a* of a 200 ml sample was extracted in a mixture of dimethyl sulfoxide (DMSO) and 90% acetone (1 : 1 v/v) (Shouf and Lium, 1976) and calculated from the equations of Strickland and Parsons (1972). No correction was made for phaeophytin.

Primary production

Phytoplankton primary production in the 0 – 4 m layer at Station 2 on 31 March was estimated by an *in situ* ^{14}C method (Goldman, Steeman-Nielsen, Vollenweider and Wetzel, 1969). 20 μCi of $NaH^{14}CO_3$ was added to 2 ℓ of integrated water-sample from 0 to 2 m and 2 to 4 m depth respectively. This procedure eliminates the necessity of the addition of measured quantities of ^{14}C to each incubation flask thus reducing the time interval between sampling and incubation as well as doing away with an aliquot correction factor. The assimilated ^{14}C was counted in a scintillation counter, the counts converted to absolute disintegrations per min and the primary production calculated according to Goldman *et al.* (1969) and Steeman-Nielsen (1952). Production values for the incubation period were converted to daily rates by multiplying by the ratio of irradiance measured during the day to that during incubation (Vollenweider, 1969).

Phytoplankton

Phytoplankton samples were taken at Stations 1, 2 and 3 on 31 March from the Van Dorn samples for chemical analyses. At each station an integrated (0 to 5 m) water sample was also taken with a 5 m long hosepipe. An aliquot of 100 ml was taken from the integrated sample and fixed immediately with 1 ml acidic Lugol's solution (Vollenweider, 1969). Algal species were identified and counted, either as cells or as colonies depending on the type of alga (Utermöhl, 1958).

Zooplankton

Zooplankton samples were collected by vertical hauls using a 35 cm diameter, 100 μm mesh net. The net was drawn through the entire water column at stations 1, 2 and 3 on 31 March. The samples were fixed in 10% formalin, identified and counted (Edmonson and Winberg, 1971).

Zoobenthos

Zoobenthos samples were taken on 31 March at Stations 1, 2 and 3 with an Ekman grab, (100 cm^2). Subsamples were fixed with 10% formalin. Zoobenthos taxa were identified and total counts were made.

Trout stomach contents

Using rod and line, it was possible to catch only three trout (*Salmo gairdneri* Richardson) weighing 0,7 – 1,3 kg on the 30 and 31 March. The fish were dissected, and the stomach contents fixed in 10% formalin for identification and counting.

Results and Discussion

Temperature and Oxygen

Temperature and oxygen profiles for the three sampling dates representing late summer, autumn and winter conditions are presented in Figure 2. The temperature profiles of 30 March 1978 indicated the presence of thermal stratification. At Stations 1 and 2 the temperature gradient between surface and bottom water was 3°C. At Station 3 the surface water was cooler by about 1,5°C compared to Stations 1 and 2 and a temperature anomaly of about 1,5°C occurred between the 2 and 3 m levels. Below 3 m a gradual decrease in temperature occurred so that the bottom temperature was similar to that of the surface.

At the end of May the temperatures were more uniform with depth and approximately 6°C lower at the surface at Stations 1 and 2 than at the end of March indicating that an overall cooling had occurred. At Station 3 the surface water had cooled by 4,7°C between March and May. A further cooling by about 4°C occurred between May and July at all stations. On the 24th of July the temperature of the surface water was about 2°C warmer than at the 2 m level indicating a water surface heating effect.

Since thermal layering was still evident at Stations 1 and 2 at the end of March, it is strongly suggested that thermal stratification occurs in Swartwater Dam during summer. Overturn occurred between the March and May sampling visits.

TABLE 1
EXTINCTION COEFFICIENTS (ξ) FOR VARIOUS DEPTHS AT DIFFERENT SAMPLING STATIONS ON 30 MARCH AND 24 JULY (COMPARE FIGURE 3)

	30 March		24 July	
	Layer	ξm^{-1}	Layer	ξm^{-1}
Station 1	0 to 1,5 m	1,26	0 to 1 m	1,40
	1,5 to 2,5 m	1,85	1 to 3,5 m	0,71
	2,5 to 5 m	0,47	3,5 to 8 m	0,95
	5 to 7 m	1,27		
Station 2	0 to 1,5 m	1,16	0 to 1 m	1,00
	1,5 to 2 m	2,00	1 to 8 m	0,84
	2 to 3,8 m	0,48		
	3,8 to 6 m	1,31		
Station 3	0 to 1,5 m	1,14	0 to 1,5 m	1,10
	1,5 to 4,4 m	0,78	1,5 to 8 m	0,82
	4,4 to 6,5 mj	1,10		

TABLE 3
pH AND TOTAL ALKALINITY VALUES AT DIFFERENT DEPTHS

	Depth m	pH	Total Alk m eq ℓ^{-1}
Station 1	0,0	6,60	0,9
	7,5	6,00	0,8
	10,0	6,00	0,8
	15,0	6,00	3,4
Station 2	0,0	6,50	0,8
	7,5	6,00	0,6
	12,0	6,00	3,4
Station 3	0,0	6,55	0,9
	3,5	6,70	1,1
	7,5	6,70	0,8
Inflow	0,0	6,55	0,6

TABLE 2
CONDUCTIVITY AND THE CONCENTRATION OF SOME ANIONS AND CATIONS AT DIFFERENT DEPTHS

	Depth m	Ca mg ℓ^{-1}	Mg mg ℓ^{-1}	Na mg ℓ^{-1}	K mg ℓ^{-1}	Cl mg ℓ^{-1}	SO_4 mg ℓ^{-1}	Cond. $\mu S\ cm^{-1}$
Station 1	0,0	1,75	0,60	1,00	0,50	Trace	ND	22,5
	7,5	1,90	0,60	1,00	0,50	ND	ND	26,0
	10,0	2,55	0,70	1,35	1,00	ND	ND	59,0
	15,0	4,60	1,15	1,40	1,30	ND	ND	111,0
Station 2	0,0	1,75	0,60	1,20	0,70	ND	ND	21,4
	7,5	1,75	0,60	1,10	0,65	ND	ND	21,6
	12,0	4,90	0,90	1,40	1,25	ND	ND	81,5
Station 3	0,0	1,75	0,60	1,15	0,50	Trace	ND	21,0
	3,5	1,70	0,55	1,10	0,50	ND	ND	21,0
	7,5	1,70	0,50	1,00	0,45	ND	ND	21,0
Inflow	0,0	1,95	0,60	1,50	0,40	Trace	ND	21,25

ND = Not detectable by the method used

TABLE 4
CONCENTRATION OF PHOSPHATE, NITROGEN COMPOUNDS AND REACTIVE SILICATE AT DIFFERENT DEPTHS

	Depth	PO_4-P	NO_3-N	NH_3-N	Org-P	Org-N	SiO_3-Si
	m	$\mu g\ \ell^{-1}$	mg ℓ^{-1}	mg ℓ^{-1}	$\mu g\ \ell^{-1}$	mg ℓ^{-1}	mg ℓ^{-1}
Station 1	0,0	ND	0,09	0,05	3,22	ND	3,13
	7,5	ND	0,07	0,08	ND	ND	3,13
	10,0	1,10	0,07	0,54	ND	0,55	3,05
	15,0	5,51	0,06	1,27	ND	0,54	2,81
Station 2	0,0	ND	0,09	0,003	6,1	ND	3,09
	7,5	ND	0,08	0,03	ND	ND	3,10
	12,0	1,83	0,07	0,95	ND	0,58	3,16
Station 3	0,0	ND	0,06	0,01	ND	ND	3,10
	3,5	ND	0,09	0,02	ND	ND	3,08
	7,5	ND	0,09	0,01	ND	ND	3,05
Inflow	0,0	ND	0,10	ND	ND	ND	3,85

ND = Not detectable by the method used

The oxygen profiles indicated the presence of a distinct oxycline on 30 March at Stations 1 and 2 with anaerobic conditions in the deep water. At the shallow Station 3 a gradual but slight decline in oxygen concentration with depth occurred. The oxycline occurred between the 4 and 7 m levels at Station 1 compared to the thermocline at between 10 and 13 m depths, while at Station 2 the oxycline and thermocline were more or less coincidental at 8 to 11 m. The oxygen concentration on 30 May was approximately 7 mg ℓ^{-1} throughout the water column. From May to July oxygen concentration increased to 9 mg ℓ^{-1}, indicating increased oxygenation through increased oxygen solubility and/or increased mixing and/or reduced oxygen demand in the deeper water.

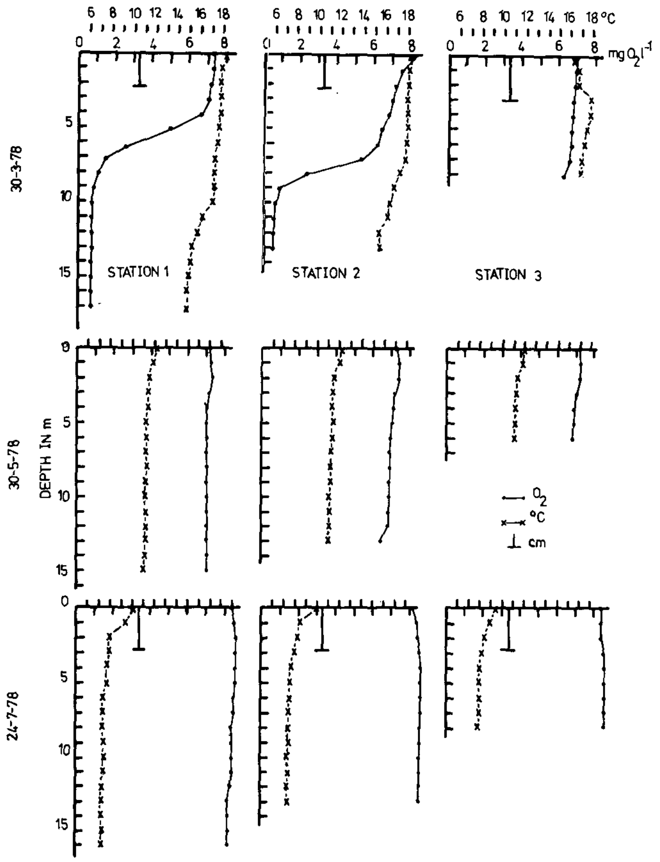

Figure 2
Temperature and oxygen profiles at the three stations at different intervals (Secchi disc measurements in cm)

Light Penetration

Secchi disc readings ranging from 2,0 to 2,8 m were measured at all stations on 30 March and 24 July 1978 (Figure 2), indicating a relatively clear water despite the dark brown tea colour imparted to the water by humic substances. These readings were lower than those recorded at Da Gama and Witklip reservoirs, Eastern Transvaal, (Walmsley and Toerien, 1977) but higher than those at Hartbeespoort Dam (Scott, Seaman, Connell, Kohlmeyer and Toerien, 1977). The presence of humic substances in Swartwater Dam may result in decreased light penetration compared to Da Gama and Witklip reservoirs. Use of the equation of Carlson (1977) to predict the Secchi disc measurements from mean chlorophyll *a* concentrations at the different sampling stations, led to a good agreement. The predicted and actual Secchi disc measurements were respectively 2,2 and 2,0 for Station 1; 1,7 and 2,0 for Station 2 and 3,0 and 2,8 for Station 3. Thus light penetration in Swartwater Dam seems to be restricted more by chlorophyll than by humic substances.

Light intensity at the depth of Secchi disc disappearance varied between 1,3 and 8,6 per cent of the surface light intensity, agreeing with the findings of Walmsley and Toerien (1977) for three Eastern Transvaal reservoirs.

Maximum penetration (0,1 μEinsteins $m^{-2}s^{-1}$) of photosynthetically active radiation (PAR) was 7,1, 6,6 and 7,6 m at Stations 1, 2 and 3 respectively on 30 March. On 24 July it was 9,0, 9,6 and to the bottom (Figure 3) indicating a deep photic zone in the impoundment during late summer to winter conditions. The maximum depth of light penetration was similar to or somewhat lower than in three Eastern Transvaal reservoirs (Walmsley and Toerien, 1977).

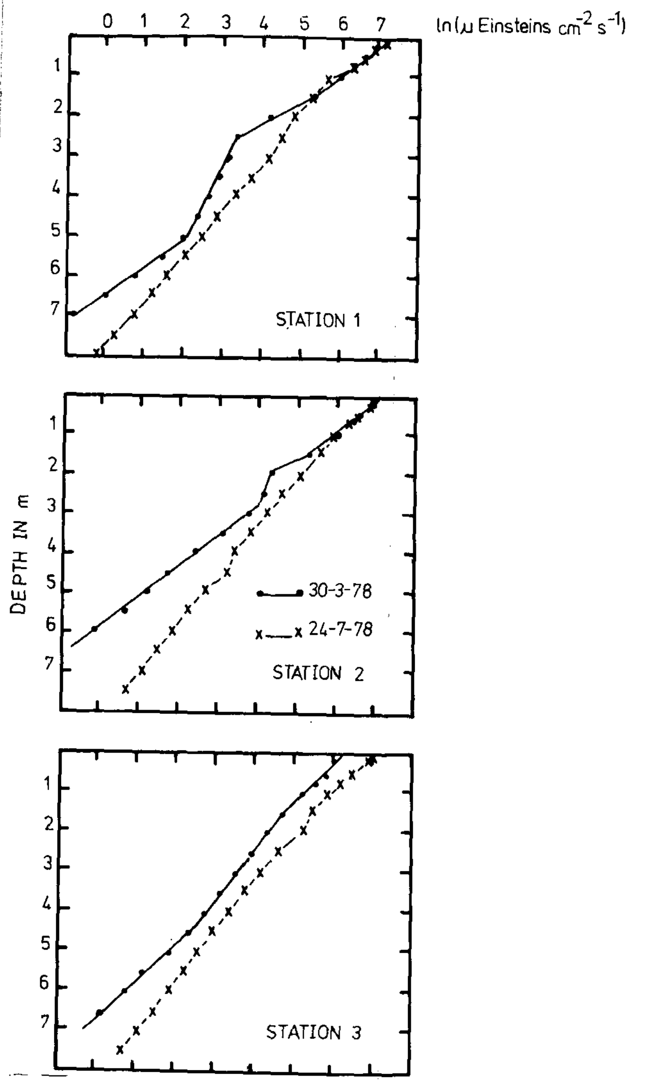

Figure 3
Light extinction coefficients at three sampling points in March and July 1978 at 0,5 m depth intervals

The extinction of PAR, especially on 30 March at Stations 1 and 2, did not take place regularly with depth (Figure 3; Table 1). For instance, the extinction coefficient of the 0 to 1,5 m layer for Station 1 was 1,26 m^{-1} and of the 2,5 to 5,0 layer 0,47 m^{-1} (Table 1). This suggests there were water layers with different optical properties which might be associated with the humic substances in the water of the dam proper and the inflowing waters. On 24 July, after mixing had been taking place for some time, layers with different optical properties were less evident (Table 1). Should further studies be undertaken on the light regime of the impoundment, attention should be paid to this phenomenon.

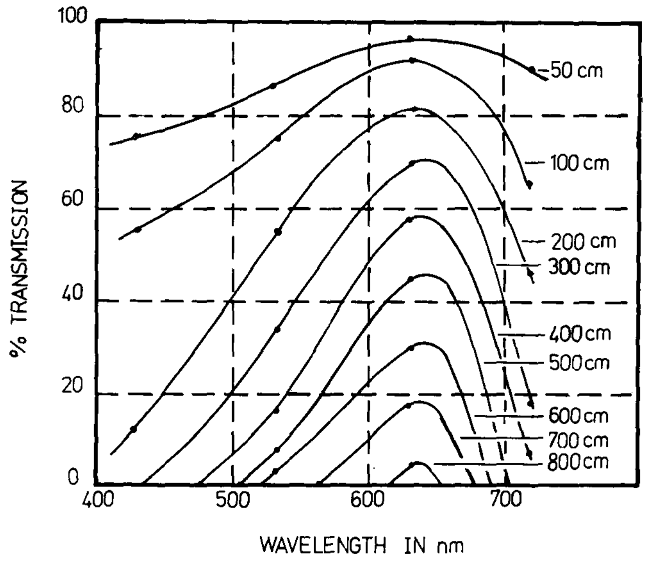

Figure 4
The spectral transmission of Swartwater Dam at different water depths in March 1978 at station 1

A spectral distribution analysis of penetrating light for 31 March at Station 1 (Figure 4) indicated that red light of approximately 630 nm (orange-red) penetrated deeper (>8,0 m) into the water than other wave lengths (compared to a maximum penetration of 7,1 m on 30 March). Blue light of 420 nm was extinguished at about 2,5 m and green light at about 6,5 m. Red light also penetrated the deepest in the turbid Hendrik Verwoerd Dam (to approximately 1,5 m; Grobbelaar and Stegmann, 1976). This is in contrast to clear waters where blue and green light are transmitted deeper than other wave lengths (Wetzel, 1975).

Chemical Characteristics

A summary of the chemical composition of water from the four sampling stations in Swartwater Dam collected on 31 March is presented in Tables 2, 3, 4 and 5. Table 6 compares the specific conductivity values during the visit of 31 March and two subsequent visits to the dam on 30 May and 24 July 1978.

The water entering the dam had a low ionic content (conductivity values ranging from 21,25 μS cm^{-1} in March to 25,6 μS cm^{-1} in July; Table 6). The water was acidic (pH 6,55), with a dark brown colour indicating the presence of organic humic compounds.

TABLE 6
TEMPORAL AND SPATIAL VARIATION OF CONDUCTIVITY

	Depth m	31-3-78 Conductivity μS cm^{-1}	30-5-78 Conductivity μS cm^{-1}	24-7-78 Conductivity μS cm^{-1}
Station 1	0,0	22,5	23,0	23,5
	7,5	26,0	22,6	25,2
	10,0	59,0	23,0	23,5
	15,0	111,0	23,8	22,8
Station 2	0,0	21,4	23,5	23,5
	7,5	21,8	23,5	23,2
	12,0	81,5	22,6	23,3
Station 3	0,0	21,0	23,5	23,5
	7,5	21,0	23,5	23,7
Inflow	0,0	21,25	25,5	25,6

According to the configuration of Gibbs (1970) the chemical composition of the water is influenced by rock dominance of the catchment area and by precipitation. The ionic dominance order in Swartwater Dam is Ca > Na > Si > K > Mg : HCO_3 > Cl which is very similar to rainwater collected at the high altitude bogs of Lesotho (Grobbelaar and Stegmann, in preparation). Thus the influence of precipitation on the water chemistry is presumably greater than the edaphic influence.

In the inflowing water, plant nutrients such as inorganic nitrogen and phosphate, but with the exception of NO_3-N (0,1 mg ℓ^{-1}), were low (being undetectable by the method used). The alkalinity values were also low (0,6 meq ℓ^{-1}). Of the metals, only Fe could be detected at a concentration of about 0,3 mg ℓ^{-1}. No Cl and SO_4 could be detected. The water entering Swartwater Dam thus contained very low concentrations of ionic substances.

In the deep regions of the dam at Stations 1 and 2 in Basin 1, chemical stratification was apparent on 31 March. Below the 7,5 m level at Stations 1 and 2 specific conductivity increased markedly (Table 2) whilst at Station 3 in the shallower Basin 2 no chemical gradient was evident. Chemical stratification in the deeper parts of the dam in late summer is thought to result from a number of causes. Thermal stratification occurred on 31 March and oxygen was depleted in the hypolimnetic water presumably by the decomposition of allochthonous and autochthonous organic matter in the relatively young impoundment. Oxygen depletion was followed by certain chemical changes.

Firstly, Fe was the predominant ion in the bottom water (Table 5); it increased from 0,8 mg ℓ^{-1} at the surface to 17,4 mg ℓ^{-1} at 15 m at Station 1 on 31 March. According to Ruttner (1954) the iron content of anaerobic bottom waters constantly increases during stagnation, reaching very high values in some meromictic lakes, for example 18 mg ℓ^{-1} in Krottensee, and as much as 41 mg ℓ^{-1} in Zellersee. Only a few milligrams per litre are generally found in eutrophic lakes (Ruttner, 1954; Wetzel, 1975). A value of 17,4 mg Fe ℓ^{-1} in the deepwater of Swartwater Dam is therefore notably high, and may indicate a specific chemical characteristic of the water needing further investigation. Many organic bases form strong soluble iron complexes with ferrous and ferric ions (Wetzel, 1975). High concentrations of complex soluble iron are associated with high levels of humic acids

(Shapiro, 1957). The surface water of Swartwater Dam is dark-brown in colour, while the anaerobic deep water is straw coloured *in situ*. This may indicate the presence of iron-humic acid complexes in Swartwater Dam similar to those studied by Shapiro (1964, 1966). Ohle (1955) found that Ca also forms complexes with humic acids under anaerobic and low pH conditions in hypolimnetic waters. These conditions existed in Swartwater Dam, while the concentrations of Ca increased by 62% from the top to the bottom (Table 2). The influence of low pH conditions and the presence of humic substances on calcium dynamics may also need further attention.

Secondly, NH_3-N and Mn concentrations increased by 96 and 94% respectively from the top to the bottom (Tables 4 and 5). The turbidity values of the deeper water were higher (8,5 JTU at the bottom) due to reddish brown precipitate (Fe and Mn) which formed in water samples which had been taken in the anaerobic part of the dam and exposed to the atmosphere. The alkalinity values of the water at Stations 1 and 2 increased despite the low pH values of the deeper water. Organic phosphorus decreased from 3,22 and 6,1 μg P ℓ^{-1} at the surface water of Stations 1 and 2 respectively to undetectably low levels in the anaerobic zone. Organic nitrogen, however, increased from undetectably low levels at the surface to 0,54 and 0,58 mg N ℓ^{-1} in the bottom waters of Stations 1 and 2 (Table 4). Reactive silicate (as Si) was the only nutrient which varied little with locality and depth, although the concentration of the inflowing water was somewhat higher (>1 mg SiO_3-Si ℓ^{-1}).

The existence of a distinct oxycline, resulted in marked vertical chemical gradients (Tables 2, 4 and 5) which could have contributed to the stability of layering thereby retarding total circulation. Indications of chemical gradients were evident from the results of Walmsley and Toerien (1977) for three Eastern Transvaal reservoirs. These impoundments, like Swartwater Dam, are located below the Drakensberg escarpment which may explain some of their similarities. Ruttner (1954), supported by the results of Scott *et al.* (1977) for Hartbeespoort Dam and Walmsley, Toerien and Steÿn (1978) for Roodeplaat Dam, indicated that chemical gradients also occur in eutrophic waters.

The development of chemical gradients in Swartwater Dam appears to follow a certain sequence of events. Thermal stratification develops in the impoundment during summer, effectively isolating the cooler bottom water from the warmer surface water. Oxidation of degradable organic material in the hypolimnion and in or on the sediments results in the development of anaerobic conditions to the depth of a distinct oxycline. The anaerobic conditions result in specific chemical changes, particularly the release of reduced iron and manganese compounds in the anaerobic layer thereby contributing to the stability of layering.

Primary Productivity

Primary productivity estimates, light penetration, solar radiation (total and that of the incubation period for primary productivity estimates), as well as the Secchi disc measurements are presented in Figure 5.

The 1% light intensity level was at a depth of approximately 4 m. Because of Talling's (1971) suggestion that the depth of the photic zone is equal to the depth of the 1% light intensity level, primary productivity incubations were done to a depth of 4 m.

The primary productivity profile followed the normal curve for a relatively clear water-body (Wetzel, 1975) with photo-inhibition at the surface, a maximum photosynthetic activity (95,8 mg C $m^{-3}h^{-1}$) at a depth of 1 m, and decreasing rates of photosynthesis at depths > 1 m. However, the rate of production at the 3 to 4 m depths was still about 20% of that at 1 m, suggesting that the compensation point of photosynthesis of Swartwater Dam may extend to deeper than that of the 1% light intensity level. Grobbelaar and Stegmann (1976) reported a similar phenomenon in the turbid Hendrik Verwoerd Dam.

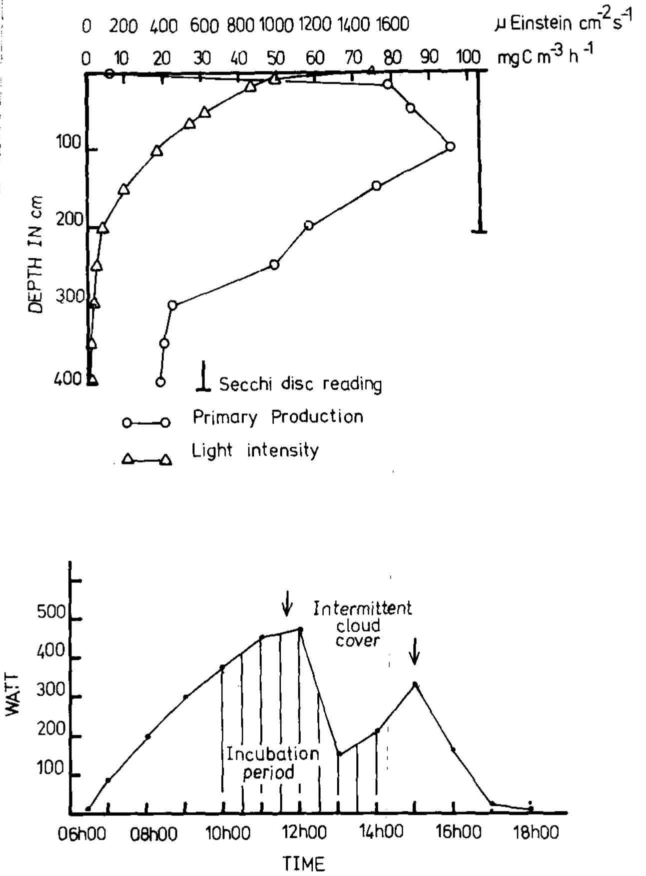

Figure 5

(a) Primary production and light intensity profiles at station 2 in March 1978

(b) Total radiation and radiation for the period of incubation

Light of wavelengths longer than 430 nm penetrated appreciably below 2,5 m, whilst shorter wavelengths did not. Accordingly, dark-light conditions (Golterman, 1975) existed in the deeper water layers, and primary productivity in this region must have been dependent upon algae adapted to low-light conditions.

The total integrated productivity for the incubation period over the 4 m depth was 227 mg C $m^{-2}h^{-1}$ corresponding to 590,2 mg C $m^{-2}d^{-1}$ according to Goldman *et al.* (1969) and 594,4 mg C $m^{-2}d^{-1}$ according to Steeman-Nielsen (1952). The above values might underestimate total primary productivity somewhat because of photosynthesis occurring deeper than 4 m. This single measurement of productivity places the dam in the mesotrophic category according to Wetzel (1975).

The chlorophyll *a* measurements (Table 7) of 3,5 to 16,5 μg ℓ^{-1} in the surface water confirm that there was a low algal standing crop. Based on chlorophyll *a* concentrations in March, Swartwater Dam appears to be mesotrophic (Wetzel 1975). This conclusion is, however, based on only a few measurements and must still be interpreted with caution.

TABLE 7
CHLOROPHYLL *a* AND TURBIDITY VALUES AT DIFFERENT DEPTHS

	Depth m	Chlorophyll *a* $\mu g\ \ell^{-1}$	Turbidity JTU*
Station 1	0,0	5,2	1,8
	7,5	7,2	2,0
	10,0	6,5	5,0
	15,0	ND	8,5
Station 2	0,0	16,5	1,5
	7,5	7,7	1,5
	12,0	4,7	6,1
Station 3	0,0	3,6	1,2
	3,5	3,8	1,2
	7,5	4,7	1,2
Inflow	0,0	8,2	0,8

*JTU = Jackson Turbidity Units

Phytoplankton

The following representatives of five algal groups were found to occur in Swartwater Dam water : Chlorophyceae: *Chlorella* sp, *Sphaerocystis* sp, *Ankistrodesmus* sp, *Scenedesmus* sp, *Eudorina unicocca, Pediastrum duplex, Elakatothrix gelatinosa, Oocystis* sp *Staurastrum paradoxum, Closterium* sp and *Hyalotheca mucosa*; Cryptophyceae: *Cryptomonas* sp 1 and *Cryptomonas* sp 2; Cyanophyceae: ? *Merismopedia* sp, *Microcystis incerta, Oscillatoria subbrevis*; Euglenophyceae: *Phacus* sp, *Trachelomonas* sp as well as a few diatoms (Bacillariophyceae). Only some of the above occurred in numbers large enough to be included in the algal counts (Table 8).

Results presented in Tables 8 and 9 indicate that Chlorophyceae constituted the dominant algal group (average per cent composition 64%) followed by the Cyanophyceae (22%) and the Cryptophyceae (14%) in Swartwater Dam at the time of sampling. Based on the single visit the Chlorophyceae appeared to increase from the inflow towards the dam wall where the community is also more diverse. The Cryptophyceae decreased from the inflow towards the dam wall, while little or no change in the Cyanophyceae occurred. The phytoplankton community was therefore not homogeneously distributed since it appears that the phytoplankton numbers increased toward the inflow.

A comparison of algal counts in the deeper (0,0 to 5,0 m) with the surface (0,0 to 0,5 m) water, (Tables 8 and 9) indicates that the deeper water at the stratified Stations (1 and 2) had higher algal concentrations than the surface water. Tempera-

TABLE 8
CONCENTRATION OF ALGAL CELLS AND COLONIES (col), AND COMPOSITION OF THE PHYTOPLANKTON COMMUNITY IN THE SURFACE (0,0 TO 0,5 m) AND UPPER 5 m (0,0 TO 5,0 m) WATER LAYERS
Sampling date: 31 March

Phytoplankton	0,0 – 0,5 m (surface water)						0,0 – 5,0 m (hosepipe sample)					
	Station 1		Station 2		Station 3		Station 1		Station 2		Station 3	
	$m\ell^{-1}$	%	$m\ell^{-1}$	%	$m\ell^{-1}$	%	$m\ell^{-1}$	%	$m\ell^{-1}$	%	$m\ell^{-1}$	%
CHLOROPHYCEAE												
Chlorella sp	385	7	386	6	142	2	529	8	451	5	372	5
Sphaerocystis sp (col)	901	17	1 381	20	837	12	1 473	22	1 169	15	844	13
Ankistrodesmus sp	0	0	10	0	0	0	0	0	0	0	0	0
Scenedesmus sp	117	2	357	5	538	8	240	3	563	7	373	5
Eudorina unicocca (col)	10	0	10	0	0	0	0	0	0	0	0	0
Pediastrum duplex (col)	0	0	10	0	14	0	0	0	0	0	0	0
Elakotothrix gelatinosa	2 309	43	2 314	33	2 721	39	2 706	38	2 844	34	2 613	37
Total Chlorophyceae	3 722	69	4 468	64	4 252	61	4 948	71	5 027	61	4 202	70
CRYPTOPHYCEAE												
Cryptomonas sp 1	185	3	509	8	1 007	14	461	7	1 366	16	1 474	21
Cryptomonas sp 2	194	4	249	4	156	2	169	2	225	3	43	1
Total Cryptophyceae	379	7	758	12	1 163	16	630	9	1 591	19	1 517	22
CYANOPHYCEAE												
Microcystis incerta (col)	825	15	443	7	284	4	522	7	507	6	144	2
?*Merismopedia* sp (col)	486	9	1 141	17	1 305	19	928	13	1 183	14	1 146	16
Total Cyanophyceae	1 311	24	1 584	24	1 589	23	1 450	20	1 690	20	1 290	18
EUGLENOPHYCEAE												
Phacus sp	10	0	0	0	0	0	0	0	0	0	0	0
Trachelomonas sp	0	0	0	0	0	0	10	0	0	0	0	0
Total Euglenophyceae	10	0	0	0	0	0	10	0	0	0	0	0
TOTAL	5 422	100	6 810	100	7 004	100	7 038	100	8 308	100	7 009	100

TABLE 9
AVERAGE CONCENTRATION OF A CILIOPHORAN (ZOOPLANKTON), ALGAL CELLS AND COLONIES (col), AND AVERAGE COMPOSITION OF THE PHYTOPLANKTON COMMUNITY

Sampling date: 31 March

Phytoplankters and Ciliate	Av. 0,0 – 0,5 m $m\ell^{-1}$	%	Av. 0,0 – 5,0 m $m\ell^{-1}$	%	Average $m\ell^{-1}$	%
CHLOROPHYCEAE						
Chlorella sp.	304	5	450	6	377	6
Sphaerocystis sp. (col)	1 039	17	1 162	16	1 101	16
Ankistrodesmus sp.	3	0	0	0	1	0
Scenedesmus sp.	337	5	392	5	365	5
Eudorina unicocca (col)	7	0	0	0	4	0
Pediastrum duplex (col)	8	0	0	0	4	0
Elakatothix gelatinosa	2 448	38	2 721	37	2 585	37
Total Chlorophyceae	4 146	65	4 725	64	4 437	64
CRYPTOPHYCEAE						
Cryptomonas sp. 1	567	9	1 100	14	834	11
Cryptomonas sp. 2	200	3	146	2	173	3
Total Cryptophyceae	767	12	1 246	16	1 007	14
CYANOPHYCEAE						
Microcystis incerta (col)	517	8	391	5	454	7
?*Merismopedia* sp. (col)	977	15	1 085	15	1 031	15
Total Cyanophyceae	1 494	23	1 476	20	1 485	22
EUGLENOPHYCEAE						
Phacus sp.	3	0	0	0	1	0
Trachelomonas sp.	0	0	3	0	1	0
Total Euglenophyceae	3	0	3	0	2	0
TOTAL	6 410	100	7 450	100	6 931	100
Unidentified Ciliophora sp.	44		73		59	

TABLE 10
CONCENTRATION (INDIVIDUALS m^{-3}) AND COMPOSITION OF THE ZOOPLANKTON COMMUNITIES DISTRIBUTED OVER THE WATER COLUMN AS WELL AS OVER THE OXYGENATED LAYER (O_2 > 3 mg ℓ^{-1}) AT THE THREE SAMPLING STATIONS. THE CONCENTRATION OF THE UNIDENTIFIED CILIOPHORA SP. IS ALSO INCLUDED.

Sampling date: 31 March

Zooplankters	Distributed over entire water column						Distributed over the oxygenated layer: $O_2 > 3$ mgℓ^{-1}					
	Station 1 (17 m) m^{-3}	%	Station 2 (13 m) m^{-3}	%	Station 3 (8 m) m^{-3}	%	Station 1 (6 m) m^{-3}	%	Station 2 (8 m) m^{-3}	%	Station 3 (8 m) m^{-3}	%
Chaoboridae (larvae)	47	11	49	10	60	1	133	11	80	10	60	1
Copepoda												
Calanoida	150	36	98	21	805	19	424	36	159	21	805	19
Cyclopoida	66	15	171	37	428	10	186	15	278	37	428	10
Nauplii	37	9	37	8	1 332	31	106	9	60	8	1 332	31
Total Copepoda	253	60	306	66	2 565	60	710	60	497	66	2 565	60
Branchiopoda												
Daphnia pulex	110	26	89	19	1 064	25	310	26	143	19	1 064	25
Daphnia laevis	12	3	9	2	0	0	34	3	16	2	0	0
Total Branchiopoda	122	29	98	21	1 064	25	344	29	159	21	1 064	25
Rotifera												
Ascomorpha sp	0	0	0	0	587	13	0	0	0	0	587	13
Other Rotifera	0	0	12	3	40	1	0	0	20	3	40	1
Total Rotifera	0	0	12	3	627	14	0	0	20	3	627	14
TOTAL	422	100	465	100	4 316	100	1 187	100	756	100	4 316	100
Ciliophora (unidentified) x 10^6	–	–	–	–	–	–	80	–	70	–	68	–

ture conditions in the upper 5 m layer of the water column at Stations 1 and 2 were similar (Figure 2) while the depth distribution of dissolved nutrients (Tables 2 to 6) suggested that more nutrients might be available for growth in the deeper layers resulting in active growth there. The higher algal numbers might however have been the result of sedimentation of cells from the surface layer.

In contrast to the stratified stations (Table 8) the algal populations at Station 3 appeared to be more evenly distributed with depth. This might be the result of improved mixing at the latter station.

Zooplankton

An unidentified ciliate was sampled and counted together with the phytoplankton (Table 9). This organism was the most numerous zooplankter, and occurred in higher concentrations in the 0,0 to 5,0 m water layer than in the surface waters (0,0 to 0,5 m); i.e. 73 mℓ^{-1} compared to 44 mℓ^{-1}. Therefore it could possibly have been present in higher numbers in an even deeper layer than was sampled.

The concentration and composition of the remainder of the zooplankton community are presented in Table 10. Because one would not expect to sample live zooplankton in appreciable amounts from anaerobic waters, calculations to determine the concentration of the zooplankters were made assuming the organisms occurred only in the oxygenated part of the water column. This was arbitrarily taken as that part of the water column where the oxygen concentration was above 3 mg ℓ^{-1} (Table 10), which was the approximate value at the middle of the oxycline.

The total concentration of the macro-zooplankton (Table 10) was low compared with other South African impoundments. Seaman and Connell (unpublished data) found that zooplankton numbers in vertical haul samples taken in March 1974 at a station near the dam wall in nine Transvaal dams (Bronkhorsspruit, Buffelspoort, Da Gama, Hartbeespoort, Loskop, Nooitgedacht, Premier Mine, Rietvlei and Roodeplaat Dam) were all at least twice as large as those taken at Stations 1 and 2, and all except a sample from the Nooitgedacht Dam were higher than at Station 3 in the present study.

Analysis of monthly samples for periods of over two years from Hartbeespoort Dam (Seaman, 1977), Lindleyspoort, Buffelspoort and Rietvlei Dams (Seaman, unpublished data) showed that the present values were lower than the minima recorded for those dams. Counts from Boskop Dam (Van As 1976) were also higher than those found in Swartwater Dam. The low zooplankton standing stock and, by implication the zooplankton productivity, is probably due to a relatively low phytoplankton concentration, as well as a scarcity of allochthonous suspended matter. The higher zooplankton standing stock at Station 3 might be attributable to one or more of the following: the absence of stratification, the presence of littoral vegetation and (possibly associated) algae, and more readily available suspended particulate matter from this shallower region of the dam.

Four macro-zooplankton groups occurred at Stations 2 and 3, namely the Chaoboridae, Rotifera, Cladocera and Copepoda. The Rotifera was absent from the sample from Station 1 (at the dam wall). The Copepoda were the dominant grazers and by far the most numerous macro-zooplankton group (approximately 60% of the community), followed by the Cladocera (approximately 25%). *Daphnia pulex* Leydig, was the dominant cladoceran. *D. larvis* Birge, a species of irregular occurrence, has also been found in Da Gama Dam (Seaman, unpublished data) soon after the dam's completion. In both cases it appeared in the attenuate form. Da Gama at the time of sampling (September 1973 and March 1974) and Swartwater Dam were similar with respect to depth, low conductivity, low alkalinity and their position below the Drakensberg escarpment.

The Chaoboridae, which are predators, dominated the zooplankton biomass and were more common than is normally the case in South African dams (Seaman, 1977; Botha, 1968; Kruger, Mulder and Van Eeden, 1970). The abundance of chaoborids may be a factor contributing to the low numbers of herbivorous zooplankters.

Zoobenthos

The zoobenthos results are presented in Table 11. It is apparent from these results that no true non-migratory standing water zoobenthos was present in the hypolimnion, i.e. at Stations 1 and 2, due clearly to the low oxygen conditions. The *Cheumatopsyche* sp. individual has no significance and the Chaoborids can move in and out of anaerobic areas. Better oxygenation of the bottom at Station 3 seemed to have a positive influence on benthic faunal composition and numbers.

TABLE 11
COMPOSITION OF THE ZOOBENTHOS COMMUNITIES
Sampling date: 31 March

	Station 1		Station 2		Station 3	
	Count	%	Count	%	Count	%
Trichoptera						
Cheumatopsyche sp. larvae	1	50	0	0	0	0
Chaoboridae:						
larvae	1	50	11	92	11	5
pupae	0	0	1	8	0	0
Nematoda	0	0	0	0	2	1
Oligochaeta	0	0	0	0	215	94
TOTAL	2	100	12	100	228	100

TABLE 12
STOMACH CONTENT OF *SALMO GAIRDNERI*
Sampling date: 31 March

	Count	%
Frog (2,8 cm long)	1	0,2
Odonata larvae	1	0,2
Ephemeroptera larvae (Centroptilidae)	1	0,2
Trichoptera larvae (Leptoceridae cases)	124	22,8
Chironomidae:		
larvae	140	25,7
pupae	80	14,7
Chaoboridae:		
larvae	133	24,5
pupae	34	6,3
Corixidae	26	4,8
Notonectidae	2	0,4
Daphnia pulex	1	0,2
TOTAL	543	100,0

Stomach Contents of *Salmo gairdneri*

The stomach contents of the three *S. gairdneri* had a total wet mass of 796 g (Table 12).

According to Bardach, Ryther and McLarney (1972) *S. gairdneri* inhabits open waters as well as shorelines and weed-beds. The superficial analysis of the stomach contents indicates that the littoral region of Swartwater Dam is of particular importance to the fish. The high percentages of the pupae of Chaoboridae, normally an open-water taxon, and Chironomidae are interesting. These stages are rather immobile and are more common in the water phase than in the benthic phase. Another interesting feature was that almost everything was recognizable as animal except the Leptoceridae cases (? *Athripsodes* sp. near *harrisoni* — KMF Scott, 1980) which were made of leaf detrital material. In this case the fact that they swim about obviously was sufficient to attract the attention of the predator, because the insect itself is not visible. Fairly extensive shallow areas (parts of Basin 1, most of Basin 2 and all of Basin 3) coupled to low water temperatures render the impoundment a natural habitat for trout.

The Utilization of Swartwater Dam

Swartwater Dam is at present the largest water body in Qwa-Qwa and as such represents a natural resource which should be exploited for maximum benefits. Since uses of a water body are dependent on its water quality, the present and possible future uses of the dam may be evaluated in terms of the characteristics observed in this study.

Supply of potable water

The water quality (for those parameters monitored) was compatible with recommended values for potable water (South African Bureau of Standards, 1971) with the exception of Fe and Mn in portions of the water column. Since high Fe and Mn concentrations were measured in March during the stratification period in the anaerobic zone of the dam (below approximately 8 m depth), the withdrawal of potable water from below this depth should be avoided since a substantial floc formation leading to water treatment and/or aesthetic problems could otherwise be encountered.

To minimise the risk of this happening, the release of water from the deoxygenated layer into the river could be considered during the midsummer period if sufficient inflow is available to replace the released water. However, since the deoxygenated water may constitute a hazard to the biota below the dam, such releases should be done under the supervision of suitably qualified persons to minimize negative effects.

Production of trout in the dam

Experiments are currently underway to evaluate the production of trout in cages in the dam (M Roode, 1980). The success of this venture will depend partly on the temperature and oxygen regimes of the water columns. The indications from this study are that possibly with the exception of the midsummer period, the water temperature in the dam will be below 20°C and suitable for raising trout. However, the temperature regime of the shallow littoral zone has not yet been elucidated and care must be exercised in this regard.

Bardach *et al.* (1972) referred to work done in Russia which indicated that *S. gairdneri* does well as long as the dissolved oxygen concentration remains above 5 mg ℓ^{-1} most of the time, at temperatures ranging from 16 to 18°C. At depths less than approximately 8 m from the surface the oxygen concentration in Swartwater Dam is in excess of 5 mg ℓ^{-1} (Figure 2). The surface area of oxygenated water suitable for *S. gairdneri* during summer conditions constitutes approximately 50% of the total bottom surface area of the impoundment, and is situated as indicated above, mainly in Basins 2 and 3. However, the suitability of the temperature regime of this area during summer is not known at present.

The two basins closest to the dam wall developed extensive anaerobic zones in the bottom waters (more than 8 m below the surface) during summer. Should temperature conditions necessitate lowering of the cages in which trout are raised, care must be taken to avoid the anaerobic zone.

The present study has also not yet determined if seiches or other water movements could result in the upwelling of anaerobic waters which could be detrimental to fish production. At present, the positioning of the trout cages should avoid sheltered areas in which upwelling could result in the sudden influx of anaerobic waters with fatal results to the fish.

The production of trout in the dam will contribute to the eutrophication of the dam, directly through food not utilized by the fish or indirectly by the excrement of the fish. Depending on the scale of the operation, this eutrophication could significantly contribute to the development of anaerobic conditions in the bottom water and to a higher primary productivity in the dam. In the latter case, if severe, it could lead to the development of troublesome algal blooms. Since *Microcystis incerta* was found in the dam, it may be possible that other *Microcystis* spp., including toxic strains, may be able to flourish in the water when eutrophied, and in that case a potential health hazard (Toerien, Scott and Pitout, 1976) may be created.

Fish production outside the dam

An alternative approach to the fish rearing currently being investigated in the dam, would be to produce fish in ponds below the dam, utilizing water from the dam. Such an approach may involve trout as well as other species. Under summer stratification conditions in the dam, care will have to be exercised that deoxygenated water from the bottom of the dam is avoided as an input to such a fish production system.

Recreational use of the dam

Swartwater Dam is located in a beautiful setting below the "Amphitheatre" of the Drakensberg range. It is conceivable that the dam and its surroundings may be developed for recreational purposes. Such recreational uses could include boating, angling, picknicking as well as the development of holiday resorts in the catchment of the dam.

Should heavy recreational use be made, it will become necessary to provide toilet facilities, and in the case of holiday resorts even sewage disposal. Depending on the type of system which might be employed, eutrophication of the impoundment could occur. As pointed out earlier this would contribute to algal growth, deoxygenated conditions in the bottom waters and potential health hazards. On the other hand eutrophication would lead to a higher productivity in the impoundment which could result in higher standing crops of fish.

Salmo gairdneri (trout) was encountered in the dam in the present study. It is not known what other fish, if any, occur