The physical and chemical limnology of Sterkfontein Dam, Eastern Orange Free State, South Africa

WG Dörgeloh[1]*, MT Seaman[2] and IG Gaigher[3]
[1]*Technikon RSA, Private Bag X6, Florida 1710, South Africa*
[2]*Dept. of Zoology and Entomology, University of the Orange Free State, PO Box 339, Bloemfontein 9300, South Africa*
[3]*Dept. of Zoology, University of Venda, Thohoyandou, Venda*

Abstract

The great depth and high altitude of Sterkfontein Dam relative to other large reservoirs in Southern Africa make this an unusual water body. It is also characterised by an almost entirely artificial inflow. As Sterkfontein Dam is the main storage reservoir in the Tugela-Vaal interbasin transfer scheme, the water quality needs to be monitored. This is the first limnological study of this reservoir, where the physical and chemical quality of the water body was examined.

The reservoir was stratified during summer, although not very strong. The stratification was easily destroyed by wind. Mixing was such that aerobic conditions prevailed in the profundal zone. Nutrient concentrations were low, suggesting that this system is oligotrophic. The relatively low mean temperatures, low turbidity and distribution of well-oxygenated water to large depths make this a good potential habitat for fish, especially trout.

Introduction

In South Africa water resources are limited and river systems are naturally turbid (Day, et al., 1986). This can be attributed to highly erodible soils and man-induced soil erosion. Reservoirs, usually part of river systems are directly affected by high silt loads in rivers. In addition to this form of pollution, chemical pollution from mines, industries and urban areas further increases the problem of deteriorating water quality. Managing water systems to improve and maintain a high water quality is therefore important.

Sterkfontein Dam is an important supplier of water to the Vaal Dam, the main water reservoir to the PWV area, during periods of drought. Vaal Dam is eutrophic so the inflow of high quality water from Sterkfontein Dam is valuable. Any changes in the limnological environment of Sterkfontein Dam may therefore have large ecological and economic consequences. A knowledge of the limnology of deep high-altitude reservoirs in the Drakensberg is important in predicting how the proposed reservoirs of the Lesotho Highlands Water Scheme might function.

This is the first study on the limnology of Sterkfontein Dam. The objective of this study was to compile a data base to serve as a reference for future monitoring programmes and for further limnological studies.

Study area

Sterkfontein Dam is situated in the E. Orange Free State (RSA) between 28° 23' and 28° 35'S; and 28° 58' and 29° 04'E, at an altitude of 1 620 m (Fig. 1). The location of Sterkfontein Dam along the edge of the lower Drakensberg escarpment, allows only a small natural catchment area of 193 km^2. The relevant morphometric characteristics of Sterkfontein Dam (Table 1) show it to be deeper than any other South African reservoir and to hold more water than all but HF Verwoerd and PK le Roux Dams (Dept. of Water Affairs, 1986).

The Tugela-Vaal project was started in 1969. Regular pumping of water into Sterkfontein Dam began in November 1974 and construction was completed in 1985. The main water source of Sterkfontein Dam is the Tugela River in Natal, rising in the high rainfall area of the Drakensberg. Water is pumped on a weekly basis from the Tugela River into the Driekloof Dam from where it flows over a spillway into Sterkfontein Dam. The present average inflow from Driekloof Dam is 6,8 x 10^6 m^3 per week on a constant basis. Water was released in 1983 for a short period at a flow rate of approximately 45 m^3/s, which resulted in a total withdrawal of 294 x 10^6 m^3. This volume represented 34,6% of the initial water volume in Sterkfontein Dam at that time. Water was released again during 1985 at an average flow rate of 40 m^3/s. A volume of 539,22 x 10^6 m^3 of water was released during these 4,5 months (Dept. of Water Affairs, 1986). Other than the occasional release of water, there is no outflow of water from Sterkfontein Dam. Water is being pumped continuously into this reservoir until it reaches full capacity. The hydrological regime is therefore very stable.

Geological formations of the area are of the Tarkastad Subgroup of the Beaufort Group and form a part of the Karoo Sequence (Johnson and Keyser, 1980; Truswell, 1977). The surrounding hills and mountains are composed of cave sandstone, with occasional top layers of basaltic lava (Lurie, 1981; Truswell, 1977). The same geological composition accounts for the nearby Tugela catchment.

TABLE 1
RELEVANT MORPHOMETRIC CHARACTERISTICS OF STERKFONTEIN DAM

Capacity at full supply level (FSL)	2 656 x 10^{6}m^3
Surface area at FSL	6 940 ha
Maximum depth	82 m
Mean depth at FSL	38 m
Maximum width	6,0 km
Maximum length	19,0 km

*To whom all correspondence should be addressed.
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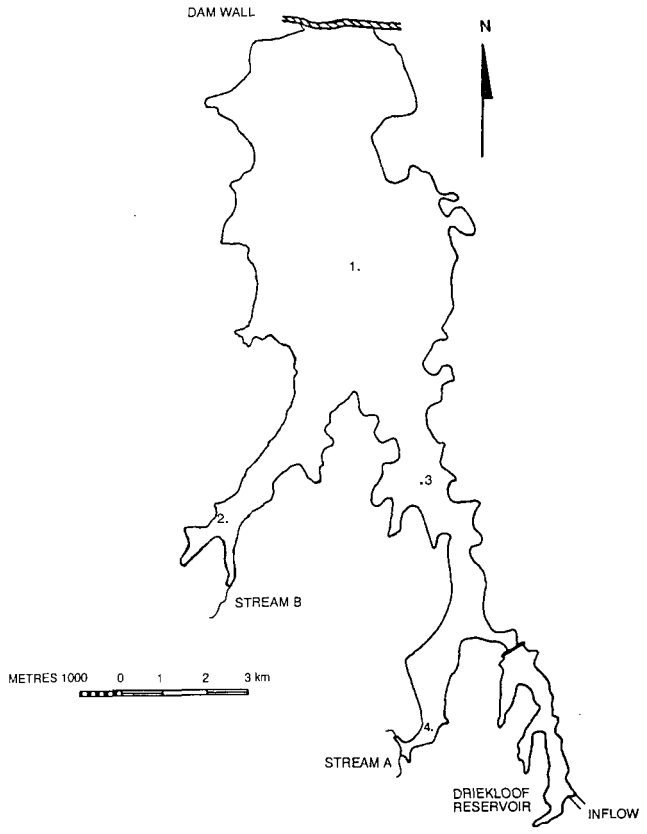

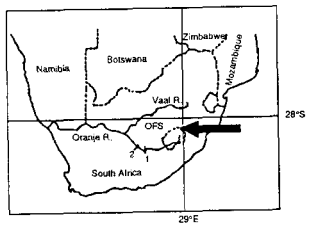

Figure 1
Map of Sterkfontein Dam indicating the sampling points for physical/chemial analysis (Localities 1 to 4). Insert map of Southern Africa indicates the positions of Sterkfontein Dam (↖), Verwoerd Dam (1) and PK Le Roux Dam (2)

The surrounding veld type is classified as a transition zone between Highland Sourveld and *Cymbopogon-Themeda* Veld (Acocks, 1988). Sterkfontein Dam is situated in a high summer rainfall area with an annual mean of 624 mm (Weather Bureau, 1980-1984). Winters are severe with occasional snowfall. Frost occurs during 8 months of the year (Weather Bureau, 1984).

Methods

Sampling localities and monthly readings

The study was conducted from May 1983 to October 1985. Four sampling localities were selected (Fig. 1). They comprised 2 deep water sites (Localities 1 and 3) and 2 shallow sites in the littoral zone (Localities 2 and 4). In September 1983, Localities 2 and 4 were shifted into deeper water as the water level dropped. The sampling sites were shifted back to the original positions in May 1984.

Physical and chemical determinations

In situ determinations

Monthly water samples were taken at the surface at each locality and near the bottom at the deep localities (1 and 3). Integrated surface water samples were taken with a 5 m plastic pipe, whereas bottom water samples were taken with a modified Friedinger water sampler, made of plexiglass. Two sets of samples were collected. One for the analysis of turbidity, electrical conductivity and pH, while the other water samples (250 mℓ) were preserved with approximately 1 mℓ of a 20 mg/ℓ mercuric chloride solution and stored at 4°C for further chemical analysis.

Readings of temperature, dissolved oxygen (DO) and water transparency were taken at each locality. Temperature and DO concentrations were determined by means of an YSI oxygen-temperature meter. Water transparency was estimated with a standard Secchi disc (20 cm dia. and divided into alternate black and white quadrants).

At the shallow localities (Localities 2 and 4), temperature and DO readings were taken at each successive metre. At the deep localities (Localities 1 and 3), temperature and DO readings were taken at the surface and at each successive 2 m to a depth of 20 m, whereafter readings were taken every 5 m to the bottom.

Laboratory analyses

Turbidity was measured in NTU (Nephelometric Turbidity Units), using a Hellige turbidity meter. Electrical conductivity and pH were measured electrometrically with the aid of a CON 602 conductivity meter and a metrohm pH meter respectively.

Water samples marked for chemical analysis were analysed by the Hydrological Research Institute, Roodeplaat, using standard analytical methods (*Standard Methods*, 1971), for the following variables:

Element	expressed as
Ca^{2+}	mg/ℓ calcium
Na^{+}	mg/ℓ sodium
Mg^{2+}	mg/ℓ magnesium
K^{+}	mg/ℓ potassium
SO_4^{2-}	mg/ℓ sulphate
Cl^{-}	mg/ℓ chloride
Kj-N	mg/ℓ Kjeldahl-N (total N; NO_3-N)
NO_3-N	mg/ℓ NO_3-N + NO_2-N
NH_4-N	mg/ℓ NH_4-N
TP	µg/ℓ total phosphates (PO_4-P)
P	µg/ℓ dissolved PO_4-P
Si	mg/ℓ silica

TDS mg/ℓ total dissolved solids
TAL mg/ℓ $CaCO_3$

Results

Physical

Temperature

The lowest water temperatures occurred from July to August after which they increased rapidly. Water remained mixed until November. A weak stratification developed during summer and lasted from December to March during summer 1983/1984 (maximum vertical temperature difference of approximately 2°C) and from October to March during summer 1984/1985 (maximum vertical difference of approximately 7°C) (Fig. 2). No significant stratification could be detected during summer at Localities 2 and 4 (Fig. 3). This was probably due to the shallowness in these areas.

The general breakdown of the stratification in April of each year was followed by a rapid decrease in temperature during May. No temperature differences between surface and bottom water existed during winter and water remained completely mixed until spring.

Turbidity

The mean turbidity of the surface water at Locality 1 was 7,17 NTU and remained fairly constant throughout the year. Values above 10 NTU were recorded only during 3 months. A significant difference ($p < 0,05$) in turbidity was found between surface and bottom water at Locality 1 (Table 2). Turbidity levels at Locality 2 ($\bar{x} = 7,61$) generally remained under 10 NTU (Table 2). The seasonal turbidity pattern at Locality 2 was similar to that of Locality 1.

Higher levels and more considerable fluctuations in turbidity, as a result of the inflow of more turbid water from Driekloof Dam, were found at Locality 3 ($\bar{x} = 10, 81$; Table 2). A turbidity of up to 23 NTU was measured. Turbidity of the bottom water was generally higher and differed significantly ($p < 0,05$) from that of the surface water. The largest fluctuations in turbidity occurred at Locality 4. Turbidity levels ranged between 6 and 99 NTU ($\bar{x} = 28, 32$; Table 2).

Secchi disc readings

Secchi disc readings showed an inverse relationship with the corresponding turbidity and were lower at localities nearer to the inflow (Table 2). Readings at Locality 1 exceeded 2 m for most months, except during summer. Secchi disc readings at Locality 2 ranged between 1,4 and 2,3 m, whereas at Locality 3 readings exceeded 1,5 m only during 4 months. Secchi disc readings at Locality 4 exceeded 1,0 m only during 2 months.

Chemical

Dissolved oxygen

Mixing of the water started during April. Well-oxygenated water (≥7 mg/ℓ) was found throughout the water column during the colder months (May to October) when water temperatures remained below or at 15°C (Fig. 4 and Fig. 5). Water with DO levels of ≥ 7mg/ℓ was periodically found at greater depths during

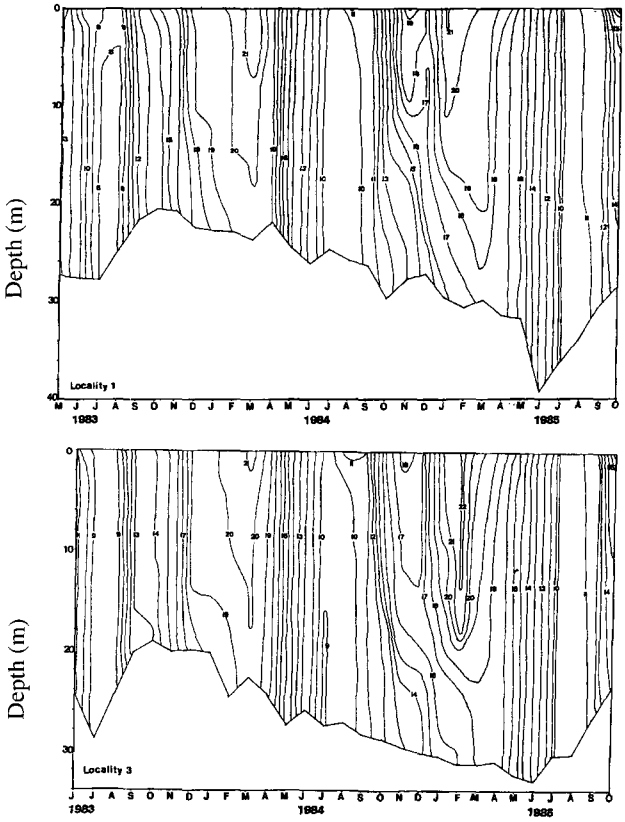

Figure 2
The thermal regime at Localities 1 and 3 showing typical monomixis

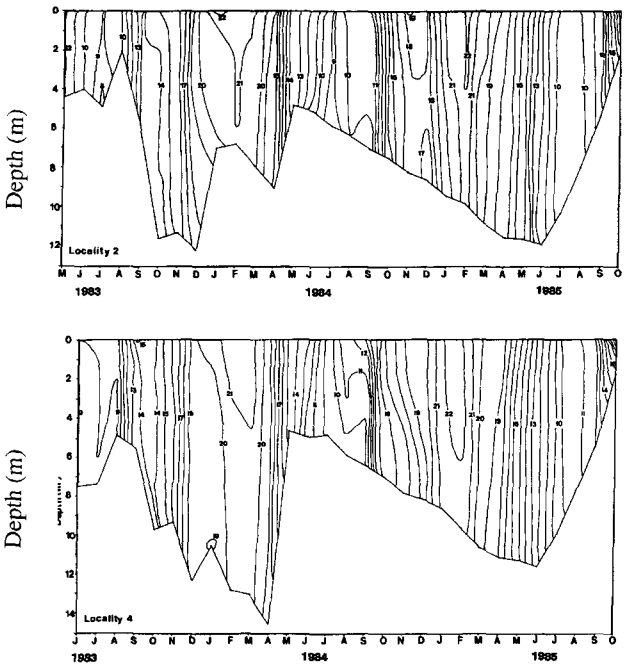

Figure 3
The thermal regime at Localities 2 and 4

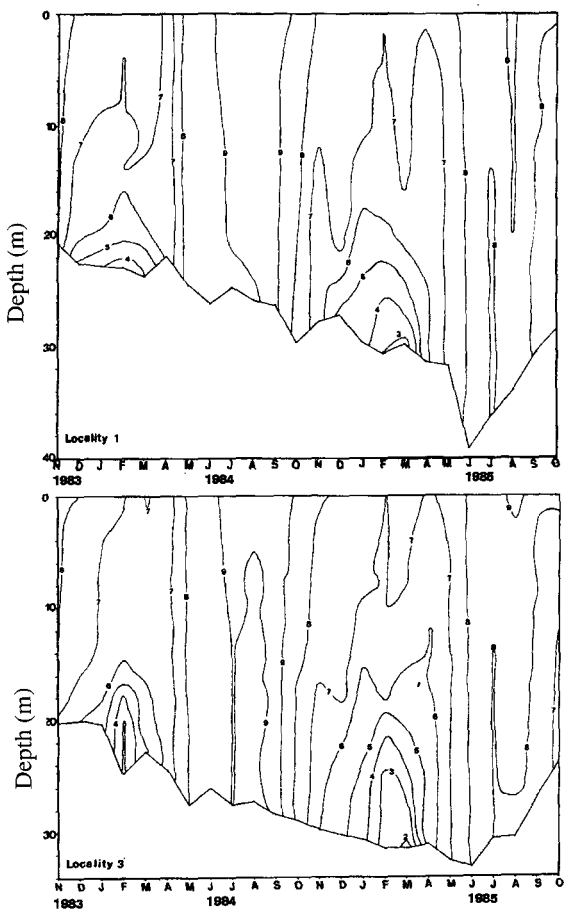

Figure 4
Dissolved oxygen pattern at Localities 1 and 3 showing an absence of anaerobic conditions

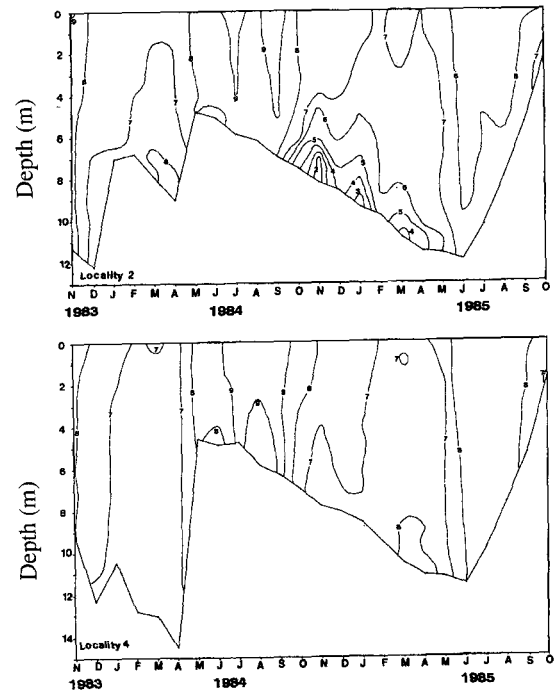

Figure 5
Dissolved oxygen pattern at Localities 2 and 4

summer. This oxygenating and mixing of the upper layers of water was caused by strong winds, generally blowing from a NW or less frequent from a SE direction.

Oxygen stratification generally occurred in deep water from November to April (Fig. 4). Maximum vertical differences in DO concentrations of 5 mg/ℓ and 6 mg/ℓ, occurred during summer 1983/1984 and summer 1984/1985 respectively. Low DO concentrations of up to 2 mg/ℓ were measured at the bottom during summer. These conditions were more pronounced at Locality 2 (Fig. 5). At no time did anaerobic conditions develop.

Major cations

Calcium (Ca^{2+}) was the dominant cation, and was found in the highest concentrations at all 4 localities. Little difference in concentration, ranging from 8 mg/ℓ to 12 mg/ℓ, was found amongst the four localities (Table 2). Sodium (Na^+) was found in lower concentrations than Ca^{2+} and showed some variations in concentration amongst the four localities (Table 2). Magnesium (Mg^{2+}) concentrations were generally less than those of Na^+, ranging between 3 mg/ℓ and 5 mg/ℓ, but exceeded the latter during September 1984. Smaller fluctuations in the Mg^{2+} concentrations were measured at the 2 deep localities, than at the 2 shallow localities (Table 2). Potassium (K^+) was found in the lowest concentrations and showed little seasonal fluctuation ranging between 1,0 mg/ℓ and 2,0 mg/ℓ. There appeared to be a slight increase in concentration during late summer. No marked differences in K^+ were found between localities (Table 2).

Major anions

The reservoir water was analysed for 2 anions, sulphate (SO_4^{2-}) and chloride (Cl^-). The SO_4^{2-} concentrations were higher for most of the year than the Cl^- levels (Table 2). Fluctuations in the SO_4^{2-} content followed a similar pattern at the 4 localities. Chloride concentrations followed similar seasonal fluctuations at the four localities.

Other chemical parameters

Seasonal fluctuations of Kjeldahl-nitrogen (Kj-N) concentrations were found throughout the study period at each locality. It appeared that Kj-N concentrations gradually increased over time. Significant differences ($p < 0,05$) in Kj-N concentrations between surface and bottom water were found only at Locality 1 (Table 2). The lower Kj-N concentrations in the bottom water remained fairly constant.

Total alkalinity (TAL) and total dissolved solids (TDS) (defined as the sum of the major cations, Ca^{2+}, Mg^{2+}, Na^+, K^+ and the major anions, HCO_3^-, CO_3^{2-}, SO_4^{2-} and Cl^-; Faust and Aly, 1981) showed slight seasonal changes. Total alkalinity fluctuated between 23 mg/ℓ and 46 mg/ℓ, while values of TDS were slightly higher during winter than in the other seasons. Little difference in TAL and TDS was measured between localities (Table 2).

Parameters that remained relatively constant throughout the year and showed little variation between localities were nitrate-nitrogen (NO_3-N), ammonia-nitrogen (NH_4-N), total phosphate-P (TP), silica (Si), pH and electrical conductivity (Table 2). Measurements between surface and bottom waters at Localities 1 and 3 indicated no significant differences in NO_3-N concentrations, but a significant difference ($p < 0,05$) in NH_4-N concentrations was found only at Locality 1 with the bottom concentration being slightly lower. Water of Sterkfontein Dam

TABLE 2
MEAN VALUES, GIVEN AS mg/ℓ (EXCEPT FOR TP AND P WHICH ARE GIVEN AS µg/ℓ) OR WHERE OTHERWISE INDICATED AND STANDARD DEVIATION OF SOME PHYSICAL AND CHEMICAL PARAMETERS IN STERKFONTEIN DAM

	Locality 1				Locality 2		Locality 3				Locality 4	
	Surface		Bottom		Surface		Surface		Bottom		Surface	
Parameter	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
Turbidity (NTU)	7,17	2,38	8,84	3,37	7,61	3,31	10,81	5,23	17,05	8,63	28,32	20,19
Secchi (m)	2,08	37,75			1,84	29,87	1,29	40,98			0,66	29,37
Ca^{2+}	9,69	0,86	9,91	0,54	10,08	0,79	9,75	0,87	10,0	0,63	9,5	1,0
Na^{+}	5,54	0,66	5,36	0,67	5,33	0,89	5,5	0,91	5,18	0,87	4,83	1,40
Mg^{2+}	3,92	0,28	3,91	0,30	4,0	0,43	4,0	0,43	4,0	0,0	3,5	0,52
K^{+}	1,56	0,23	1,45	0,19	1,57	0,20	1,46	0,25	1,39	0,21	1,4	0,32
SO_4^{2-}	7,46	1,61	7,18	1,72	7,0	1,48	7,08	1,62	7,27	1,42	6,82	2,27
Cl^{-}	5,62	2,06	5,27	1,97	5,25	1,76	5,17	1,70	4,64	2,20	4,58	1,98
Kj-N	0,21	0,09	0,14	0,05	0,20	0,09	0,20	0,11	0,17	0,05	0,27	0,13
NO_3-N	0,13	0,04	0,17	0,15	0,11	0,03	0,13	0,04	0,13	0,05	0,14	0,04
NH_4-N	0,04	0,03	0,04	0,031	0,04	0,03	0,04	0,03	0,04	0,03	0,04	0,03
TP	10,08	3,75	19,8	20,8	15,3	6,18	19,1	10,8	14,6	5,37	24,8	14,8
P	4,0	7,64	7,28	9,41	7,14	9,49	7,86	9,14	9,17	9,24	10,14	7,69
Si	5,54	0,31	5,69	0,26	5,63	0,21	5,83	0,27	5,79	0,20	5,93	0,49
pH	7,34	0,44	7,44	0,27	7,31	0,43	7,49	0,26	7,43	0,16	7,31	0,33
TAL	35,08	5,66	35,36	6,10	37,0	6,06	35,42	5,84	36,64	6,74	34,5	5,11
TDS	81,7	7,48	81,67	8,03	82,56	6,67	80,9	5,38	82,78	6,28	78,22	6,32
Conductivity (mS/m)	9,84	0,74	9,83	0,84	10,0	0,75	9,60	0,86	9,78	0,78	9,02	1,04

was slightly alkaline with pH values varying between 7,0 and 7,8 (Table 2).

Discussion

Physical

Temperature

Sterkfontein Dam was completely mixed from autumn to spring, with minimum water temperatures of 8°C and weakly stratified during summer. It can therefore be classified as warm monomictic. Temperature stratification generally started developing during October and reached a peak during February. A temperature difference of 10°C to 15°C between surface and bottom water is common in Southern Hemisphere lakes. Maximum temperature differences of approximately 7°C were measured in Sterkfontein Dam during summer 1984/1985. This stratification was unstable and cold spells, with the attending strong winds could easily re-circulate the surface waters to depths of approximately 16 m. The unstable stratification pattern was related to altitude, basin geometry and surface wind stress. The stratification broke down again during April, which is standard for water bodies in the region (Allanson et al., 1990; Beadle, 1974; Fischer et al., 1979; Moss, 1982). Temperatures were generally slightly colder than Verwoerd Dam (Stegmann, 1975) and PK le Roux Dam (Allanson et al., 1983).

Turbidity

The highest concentrations and fluctuations of suspended solids occurred at the upper end of the reservoir (Locality 4), ranging from 6,1 to 99,8 NTU (Secchi readings 0,20 to 1,30 m) due to the inflow of turbid water from Driekloof Dam. Turbid water extended approximately 8 km into the reservoir.

Most siltation took place in Driekloof Dam and in the upper reaches of Sterkfontein Dam resulting in clear water in the main body of the reservoir (Fig.1). Approximately 80% of the total surface area of the reservoir had a turbidity of less than 10 NTU or mean Secchi disc reading of about 2,00 cm. In this respect, Sterkfontein Dam differs considerably from the majority of other South African reservoirs. These are generally more turbid with 81% of the reservoirs (n = 57) having mean Secchi disc readings of < 2 m (Walmsley and Bruwer, 1980).

Chemical

Dissolved oxygen

The entire water column was well-oxygenated (≥ 8 mg/ℓ DO) during the colder months. The weak oxygen stratification found during summer was easily broken down by periodical strong winds during this time. This resulted in mixing and oxygenation (≥7 mg/ℓ DO) of the upper layers of water to depths of 16 m (Fig. 4). Wind, blowing predominantly from NW and SE directions, had the greatest effect on the main body of the reservoir due to the unsheltered surroundings and the long fetch over the reservoir.

Mixing of water occurred to a lesser extent at the 2 shallow localities, which are more protected by the surroundings. The low DO concentrations (< 5 mg/ℓ below 6 m depth) at Locality 2 during summer, may be a result of the high organic load and decomposition of reeds in this area. The oxygen regime in this

area could therefore pose a problem for fish during summer. Minimum constant DO values of 5 mg/ℓ are necessary to sustain life activities, such as egg hatching, juvenile growth and migration in the life cycle of fish, particularly trout (Alabaster and Lloyd, 1982).

An overlap between low DO concentrations (≤ 6 mg/ℓ) and warm temperatures (≥ 20°C) at Locality 2 during summer could force fish, such as rainbow trout into deeper water. However, the general oxygen and turbidity levels in Sterkfontein Dam do not appear to be a limiting factor for rainbow trout.

Major cations

The chemical composition of water in Sterkfontein Dam is mainly determined by the geological formations in the catchment area of the Tugela River. Concentrations of the major cations in Sterkfontein Dam were similar to those in Verwoerd Dam but tended to be lower than in other reservoirs (Table 3). The cationic dominance order of the water in Sterkfontein Dam was $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$, which is different from that found in Verwoerd Dam where $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ (Allanson et al., 1990). Calcium was the dominant cation in Bloemhof Dam and Roodeplaat Dam (Walmsley and Butty, 1980), whereas Na^{+} was dominant in Hartbeespoort Dam (Scott et al., 1977) and Loskop Dam (Walmsley and Butty, 1980) (Table 3). However, the cationic order of the latter 2 reservoirs differed from those usually found globally. The tendency of the cationic order in global waters is $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ (Wetzel, 1975).

Calcium is the most abundant cation in natural freshwaters and the concentrations depend on the geological formations in the catchment area. The Tugela River rises in the Drakensberg range which consists of a cave sandstone base, overlain by basaltic lava which may be a reason for the relatively high Ca^{2+} content (Lurie, 1981; Macintosh, 1983; Truswell, 1977) found in Sterkfontein Dam.

The relatively high Na^{+} content in comparison to Mg^{2+}, differs from the normal freshwater situation, where Na^{+} concentrations are lower than both Ca^{2+} and Mg^{2+}. In saline and brackish waters, the reverse is found (Faust and Aly, 1981). Basalt is composed of plagioclase feldspar (Macintosh, 1983), which is a good source of Na^{+} when weathered (Faust and Aly, 1981) and may be a reason for the higher Na^{+} content in Sterkfontein Dam.

Magnesium is rarely the dominant cation, but occurs mostly with Ca^{2+} (Faust and Aly, 1981). Sedimentary rocks, such as dolomite and magnesite, are some of the major sources of Mg^{2+} (Faust and Aly, 1981). Dolomite and magnesite does not occur in the Drakensberg mountains (Coetzee, 1976) which is possibly the reason for the relatively low concentrations of Mg^{2+} in Sterkfontein Dam.

Potassium was present in low concentrations, which is usual for natural freshwaters (Faust and Aly, 1981). Potassium concentrations in Sterkfontein Dam were slightly lower than those in other reservoirs.

Major anions

The major anion relationship in world waters is $CO_3^{2-} > SO_4^{2-} > Cl^{-}$ (Faust and Aly, 1981; Wetzel, 1975). Of the 2 anions analysed in Sterkfontein Dam, concentrations of SO_4^{2-} were generally higher than Cl^{-} for most of the year, but decreased below Cl^{-} concentrations during summer. Low Cl^{-} values are characteristic of catchments on Stormberg, Beaufort and Ecca strata (Kemp et al., 1976). A similar anion relationship was

TABLE 3

MEAN PHYSICAL AND CHEMICAL CONCENTRATIONS (AS mg/ℓ, EXCEPT WHERE OTHERWISE INDICATED) OF SURFACE WATER IN A RANGE OF SOUTH AFRICAN RESERVOIRS. VALUES FOR HF VERWOERD DAM (STEGMANN, 1975) AND PK LE ROUX DAM (ALLANSON ET AL., 1983) ARE GIVEN FROM BASIN 4 AND STATION 3 RESPECTIVELY, FOR HARTBEESPOORT DAM (SCOTT ET AL., 1977) FROM 6 STATIONS AND FOR THE OTHER RESERVOIRS (WALMSLEY AND BUTTY, 1980) FROM SINGLE DEEP WATER STATIONS. THE DATA FOR STERKFONTEIN DAM WERE OBTAINED DURING THIS STUDY.

	Sterkfontein Dam	HF Verwoerd Dam	PK le Roux Dam	Hartbeespoort Dam	Bloemhof Dam	Loskop Dam	Roodeplaat Dam	Midmar Dam
Temperature (°C)	7,9					21,63	20,8	18,0
Turbidity (NTU)	2,08					15,2		8
Secchi (m)					0,66	0,8	3,49	1,31
DO						7,31	7,61	7,9
Ca^{2+}	9,75	7,63		35,52	27,6	11,9	19,49	4,0
Mg^{2+}	3,86	5,74		19,0	14,9	6,8	15,69	2,3
Na^{+}	5,39	5,53		41,86	22,1	13,2	16,24	
K^{+}	1,56	1,81		7,34	4,3	3,0	2,21	
SO_4^{2-}	7,40	3,06		64,24	47,8	28,5	16,84	
Cl^{-}	5,05	3,85		42,34	18,4	9,0	19,95	
Dis. Kj-N	0,21					0,390	0,465	0,160
NO_3-N	0,13	2,86	0,401	2,09	0,82	0,196	0,444	0,203
NH_4-N	0,044			0,69	0,13	0,070	0,242	0,015
Total P	0,01		0,092	0,64		0,044	0,075	0,015
Si	5,51			3,85	2,64		3,81	3,2
pH (Bronsted)	7,34	8,25	8,0	8,15	7,7	8,11	8,0	7,4
TAL	35		7,0	128,69	113,6	46	115	21
TDS	81,7							
Conductivity (mS/m)	9,84	13,13	0,15	54,04	36,0	17,3	30,9	5,6

found in Bloemhof Dam, Loskop Dam (Walmsley and Butty, 1980) and Hartbeespoort Dam (Scott et al., 1977) (Table 3). In Verwoerd Dam (Stegmann, 1975) and Roodeplaat Dam (Walmsley and Butty, 1980) Cl^- was present in higher concentrations than SO_4^{2-} (Table 3). The anion concentrations in Sterkfontein Dam were generally lower compared with those in other reservoirs (Table 3).

Other chemical parameters

Concentrations of Kj-N, NO_3-N, NH_4-N and TP were generally low compared to other reservoirs (Table 3). The closeness of Sterkfontein Dam to the headstream and the scarcity of organic matter in the reservoir contributed to the low levels of nutrients. Organic matter is a source of ammonia during decomposition (Wetzel, 1975). Oxygen is used during the oxidisation of NH_4-N to NO_3 and NO_2 by bacterial nitrification. The low organic matter content in Sterkfontein Dam and the well-oxygenated water probably prevented the build-up of NH_4-N.

The particularly low P:N ratio of 1:21 strongly suggests that P might be a limiting nutrient in Sterkfontein Dam. Low P:N ratios affirm the oligotrophic status of waters (Allanson et al., 1990) which applies to Sterkfontein Dam. The Si content in Sterkfontein Dam was relatively high in comparison with that of other reservoirs (Table 3). Grains of sandstone and feldspars, which are found in great quantities in the Tugela catchment area (Lurie, 1981; Macintosh, 1983; Truswell, 1977) are some of the main sources of Si (Faust and Aly, 1981). The Si content of drainage water stays fairly constant (Wetzel, 1975) as was also found in Sterkfontein Dam.

The water of Sterkfontein Dam was less alkaline than that of the other reservoirs (Table 3) but was well within the pH tolerance limits of fish. Fish generally have a pH tolerance limit between 5 and 9 (Alabaster and Lloyd, 1982). Total alkalinity was considerably lower than in most other reservoirs (Table 3).

Total dissolved solids were present at concentrations less than 95 mg/ℓ, which compares with that of Verwoerd Dam (Table 3). Electrical conductivity was low in comparison with other reservoirs surveyed (Table 3). The low electrical conductivity reflects the general low levels of major ions such as Ca^{2+}, Mg^{2+}, Na^+, K^+ and Cl^-. This can be ascribed to the low ionic uptake of the Tugela River during its fairly short flow, before the water is pumped into Sterkfontein Dam.

Conclusion

The low nutrient status and high water quality of Sterkfontein Dam is a reflection of its close proximity to the headwaters, the small natural catchment area and the surrounding geology. The oligotrophic status of this reservoir is unlikely to change in the short to medium term due to the limited recreational development along its shores, the protection of the headwaters of the Tugela River in the Royal National Park and the relatively pristine state of the remainder of the upper Tugela catchment area. The water released from Sterkfontein Dam during times of drought would improve the water quality of the Vaal Dam which is ecologically and economically advantageous.

The relatively low temperatures, low turbidity and well-oxygenated water during all seasons make this an excellent habitat for cold water fish such as trout. At present trout has to be stocked, notwithstanding the rich availability of food. Zooplankton was dominated numerically by *Daphnia pulex*, a species not common where predation by fish is intense (Zaret, 1980), and *Metadiaptomus meridianus* at a mean biomass of 1,1 mg (dry weight) m^{-2} (Dörgeloh, 1986).

The information gathered from this study should be useful to an understanding of the proposed reservoirs of the Lesotho Highlands Water Scheme, some of which are expected to be at least as deep as Sterkfontein Dam and of low turbidity, cool, well-oxygenated and populated with rainbow trout.

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References

ACOCKS, JPH (1988) Veld types of South Africa. *Mem. Bot. Surv.* SA No. 57. Botanical Research Institute, Pretoria.

ALABASTER, JS and LLOYD, R (1982) *Water Quality Criteria for Freshwater Fish.* Butterworth Scientific, London.

ALLANSON, BR, BEUTHIN, CL, JANSEN, CJ and SELKIRK, WT (1983) The physical and chemical background in relation to biological production. In: ALLANSON, BR and JACKSON, PBN (eds.) *Limnology and Fisheries Potential of Lake Le Roux.* South. Afr. Nat. Sci. Programmes Report No. 77. CSIR, Pretoria.

ALLANSON, BR, HART, RC, O'KEEFFE, JH and ROBARTS, RD (1990) *Inland Waters of Southern Africa: An Ecological Perspective.* Kluwer Academic Publishers, Dordrecht.

BEADLE, LC (1974) *The Inland Waters of Tropical Africa.* Longman, London.

COETZEE, CB (1976) *Delfstowwe van die Republiek van Suid-Afrika.* (5th edn.) Handbook 7. Government Printer, Pretoria.

DAY, JA, DAVIES, BR and KING, JM (1986) Riverine ecosystems. In: O'Keeffe, JH (ed.) *The Conservation of South African Rivers.* South. Afr. Nat. Programmes Report No. 131. CSIR, Pretoria.

DEPT. OF WATER AFFAIRS (1986) *Management of the Water Resources of the Republic of South Africa.* Dept. of Water Affairs, Pretoria.

DÖRGELOH, WG (1986) A study on ecological aspects of the rainbow trout (*Salmo gairdneri*) in Sterkfontein Dam. M.Sc. Thesis, UOFS, Bloemfontein.

FAUST, SD and ALY, OM (1981) *Chemistry of Natural Waters.* Ann Arbor Science, Ann Arbor.

FISCHER, HB, LIST, EJ, KOH, RCY, IMBERGER, J and BROOKS, NH (1979) *Mixing in Inland and Coastal Waters.* Academic Press, New York.

JOHNSON, MR and KEYSER, AW (1980) Tarkastad Subgroup. In: *Handbook 8. Geological Survey.* South African Committee for Stratigraphy (SACS) RSA, 1.

KEMP, PH, CHUTTER, FM and COETZEE, DJ (1976) Water Quality and Abatement of Pollution in Natal Rivers. Part V. The Rivers of Southern Natal. Report by National Institute for Water Research. CSIR and Natal Town and Regional Planning Commission, Pietermaritzburg.

LURIE, J (1981) *South African Geology.* McGraw-Hill, Johannesburg.

MACINTOSH, EK (1983) *Rocks, Minerals and Gemstones of Southern Africa.* Struik Publishers, Cape Town.

MOSS, B (1982) *Ecology of Fresh Waters.* Blackwell Scientific Publications, London.

SCOTT, WE, SEAMAN, MT, CONNELL, AD, KOHLMEYER, SI and TOERIEN, DF (1977). The limnology of some South African impoundments. I. The physico-chemical limnology of Hartbeespoort Dam. *J. Limnol. Soc. South. Afr.* **3**(2) 43-58.

STANDARD METHODS (1971) *Standard Methods for the Examination of Water and Waste Water* (13th edn.) American Public Health Association, Washington DC.

STEGMANN, P (1975) Preliminary physico-chemical and primary productivity studies of the Hendrik Verwoerd Dam. M.Sc. Thesis. University of the Orange Free State, Bloemfontein.

TRUSWELL, JF (1977) *The Geological Evolution of South Africa.* Purnell, Cape Town.

WALMSLEY, RD and BRUWER, CA (1980) Water transparency characteristics of South African impoundments. *J. Limnol. Soc. South. Afr.* **6**(2) 69-76.

WALMSLEY, RD and BUTTY, M (eds.) (1980) *The Limnology of Some Selected South African Impoundments*. Water Research Commission, National Institute for Water Research and CSIR Report, Pretoria.

WEATHER BUREAU (January 1980 - December 1984) Monthly Weather Reports. Dept. of Environment Affairs. Government Printer, Pretoria.

WETZEL, RG (1975) *Limnology*. Saunders Company, Philadelphia.

ZARET, TM (1980). *Predation and Freshwater Communities*. Yale University Press, London.

Page 181, Table 2
The standard deviations of the Secchi disc readings (m) should read:

Locality	Secchi (m)	S.D.
1	2,08	0,3775
2	1,84	0,2987
3	1,29	0,4098
4	0,66	0,2937

Page 182, Table 3
Chemical concentrations, originally given in mg/ℓ were recalculated and are presented in me ℓ^{-1}

The cationic dominance order of the water in Sterkfontein Dam should read $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ which is "standard" for global waters.

The major anion relationship in Sterkfontein Dam remains $SO_4^{2-} > Cl^{-}$ which corresponds to that of world waters.

TABLE 3
MEAN PHYSICAL AND CHEMICAL CONCENTRATIONS (AS me ℓ^{-1} EXCEPT WHERE OTHERWISE INDICATED) OF SURFACE WATER IN A RANGE OF SOUTH AFRICAN RESERVOIRS. VALUES FOR HF VERWOERD DAM (STEGMANN, 1975) AND PK LE ROUX DAM (ALLANSON ET AL., 1983) ARE GIVEN FROM BASIN 4 AND STATION 3 RESPECTIVELY, FOR HARTBEESPOORT DAM (SCOTT ET AL., 1977) FROM 6 STATIONS AND FOR THE OTHER RESERVOIRS (WALMSLEY & BUTTY, 1980) FROM SINGLE DEEP WATER STATIONS. THE DATA FOR STERKFONTEIN DAM WERE OBTAINED DURING THIS STUDY.

	Sterkfontein Dam	HF Verwoerd Dam	PK le Roux Dam	Hartbeespoort Dam	Bloemhof Dam	Loskop Dam	Roodeplaat Dam	Midmar Dam
Temperature (°C)						21,63	20,8	18,0
Turbidity (NTU)	7,9					15,2		8
Secchi (m)	2,08				0,66	0,8	3,49	1,31
DO						7,31	7,61	7,9
Ca^{2+}	0,486	0,38		1,772	1,378	0,594	0,972	0,200
Mg^{2+}	0,318	0,472		1,564	1,226	0,560	1,29	0,190
Na^{+}	0,234	0,241		1,821	0,961	0,574	0,706	
K^{+}	0,040	0,046		0,188	0,110	0,077	0,057	
SO_4^{2-}	0,154	0,064		1,337	0,996	0,594	0,35	
Cl^{-}	0,142	0,109		1,194	0,519	0,254	0,563	
Dis. Kj-N	0,015					0,028	0,033	0,011
NO_3-N	0,002	0,038	0,005	0,027	0,011	0,003	0,006	0,003
NH_4-N	0,001				0,004	0,002	0,008	0,0005
Total P	0,0003		0,003			0,001	0,002	0,0005
Si	0,196			0,137	0,094		0,136	0,114
pH (Brönsted)	7,34	8,25	7,96	8,15	7,7	8,11	8,0	7,4
TAL	35				113,6	46	115	21
TDS	81,7							
Electr. conduct. (mS/m)	9,84	13,13	0,15		36,0	17,3	30,9	5,6