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[1] Botany Department, Kenyatta University, Nairobi, Kenya;
[2] SPARVS Agency, Limuru, Kenya.;
[3] Institute of Freshwater Ecology and Inland Fisheries, Neuglobsow, Germany

The Physico-chemical Conditions of Turkwel Gorge Reservoir, a New Man Made Lake in Northern Kenya

KIPLAGAT KOTUT[1], STEPHEN G. NJUGUNA[2], FRANCIS M. MUTHURI[1] & LOTHAR KRIENITZ[3]

With 6 Figures and 2 Tables

Key words: Reservoir, seasonality, physico-chemical conditions, nutrients, loading

Abstract

Variations in some physical, chemical, and nutrient conditions were investigated at Turkwel Gorge Reservoir and its inflowing river, Suam between 1994 and 1995. Seasonal changes in inflow volume had the greatest impact on the reservoir and river conditions investigated. A wide fluctuation in inflow volume combined with a regulated outflow independent of season resulted in a draw down of over 10 m in each year. Flood inflows during the wet season resulted in the lowest values of Secchi depth (range, 0.09–2.16 m), electrical conductivity (EC, range = 140–200 mS cm^{-1}) and total alkalinity (TA, range = 75–111 mg l^{-1}) while the highest values were measured during the dry season. A functional relation between EC and TA (TA = 0.529 mg l^{-1}, EC: $R^2 = 0.876$) suggests a predominance of carbonates among the anions. Vertical profiles of temperature and dissolved oxygen (DO) revealed that the reservoir is monomictic with a wide variation in the depth of the daily mixed layer. High values of pH (range = 6.7–8.9) and DO (range = 4.9–9.2 mg l^{-1}) were associated with periods of peak phytoplankton photosynthesis while the lowest values followed reservoir mixing. Peak total nitrogen (TN, range = 119–526 µg l^{-1}) and total phosphorus (TP, range = 8.9–71.6 µg l^{-1}) levels during the wet season resulted from increased river loading. Values of dissolved reactive silica (DRS, range = 0.41–9.77 mg l^{-1}) showed a wet season decline which was related to diatom depletion during the wet season. Annual reservoir areal loading rates of 27.38, 10.90 and 408.5 mg m^{-2} were computed for TN, TP and DRS respectively based on estimates of inflowing river loads in 1994.

At the inflowing river Suam, low levels of EC (range =107–210 µS cm^{-1}) and TA (range = 62–125 mg l^{-1}) occurred during the wet season while the highest levels occurred shortly before the river dried up. The first flood water at the resumption of river inflow in March was characterized by very low levels of DO (range = 1.8–8.2 mg l^{-1}) and high levels of TN (range = 205–3354 µg l^{-1}) and TP (102–1259 µg l^{-1}). River pH (6.9–7.7) and DRS (range = 9.01–19.93 mg l^{-1}) varied irregularly throughout the year.

Introduction

Closed in May 1990, Turkwel Gorge Reservoir is the sixth hydropower reservoir to be built in Kenya. The first five reservoirs form a cascade on the country's longest river, the Tana. Compared to the natural lakes, very limited limnological information has been documented for Kenya's reservoirs. The limited attention can be attributed to their much smaller size as compared to the giant projects of Africa that have drawn a lot of international attention. Kenya is a relatively dry country with limited and unevenly distributed water resources. A sound management of the available water resources is therefore necessary for a sustainable social and economic development. The construction of multiple use reservoirs has been seen as a way of stimulating rapid economic growth. However, without a clear picture of the ecological interactions in these systems, an optimum and sustainable exploitation of their resources may not be realized. The Turkwel Gorge Reservoir is an example of a reservoir built with multiple use objectives, e.g. electricity generation, irrigation and domestic water supply, an increased fishery and promotion of the region's development. This paper presents parts of an investigation carried out to establish the ecological conditions of the new reservoir prior to the initiation of multiple use operation. Findings on the phytoplankton properties form the subject of a separate publication (KOTUT et al. 1998). The phytoplankton investigation by KOTUT et al. (1998) revealed that the seasonal changes in phytoplankton biomass, diversity, composition and primary production were mainly influenced by seasonal changes in inflow volume. A lower inflow volume in 1995 as compared to 1994 resulted in a muted seasonality in phytoplankton properties in 1995 as compared to 1994. Diatoms were found to dominate periods of high discharge while periods of relative calm were dominated by the blue green algae. Prior to the present study, no previous limnological investigation had been carried out at the reservoir and its principle tributary.

Advances in the understanding of the physical and chemical dynamics of reservoirs, especially in the temperate region, have contributed to the appreciation of the relations between natural lakes and reservoirs (THORNTON et al. 1982; RYDER 1978; KENNEDY et al. 1982). Recognition of the difference between the two systems has been made and attributed to a difference in the forcing functions acting on similar processes (THORNTON 1990). Typically, reservoirs have been shown to exhibit a longitudinal profile in their physical and chemical structure. This feature is attributable to the usually elongated basin structure combined with inflows entering mostly at a point furthest away from the dam structure (THORNTON 1990). Because this gradient constitutes a shift from lotic to lentic conditions, reservoirs have often been described as river-lake hybrids (BRUCE et al. 1990; THORNTON et al. 1982 etc.). On the basis of this spatial heterogeneity, a heuristic model (THORNTON et al. 1982) that divides reservoirs into three ecologically different zones has been advanced. Although this model has been shown to work in many reservoirs in the tropical and temperate region, its applicability to a tropical impoundment with very irregular inflow patterns remains to be established. Reservoir project operation design also imparts some influence on the seasonal changes in its environmental conditions by affecting water level changes, stratification patterns and nutrient dynamics.

Study area

Turkwel Gorge Reservoir is located in the north of Kenya, some 500 km from the capital city, Nairobi. The geology of the surrounding area is one of a marine deposition in a geosyncline during the Precambrian, followed by a major orogeny accompanied by metamorphosis. The major earth movements that were accompanied by rifting and volcanism, which affected most parts of the East African region during the Mid Tertiary appear to have been restricted in this area. A greater part of the exposed rocks consists of gneisses and shists of the basement system. Ingenious rocks are scarce

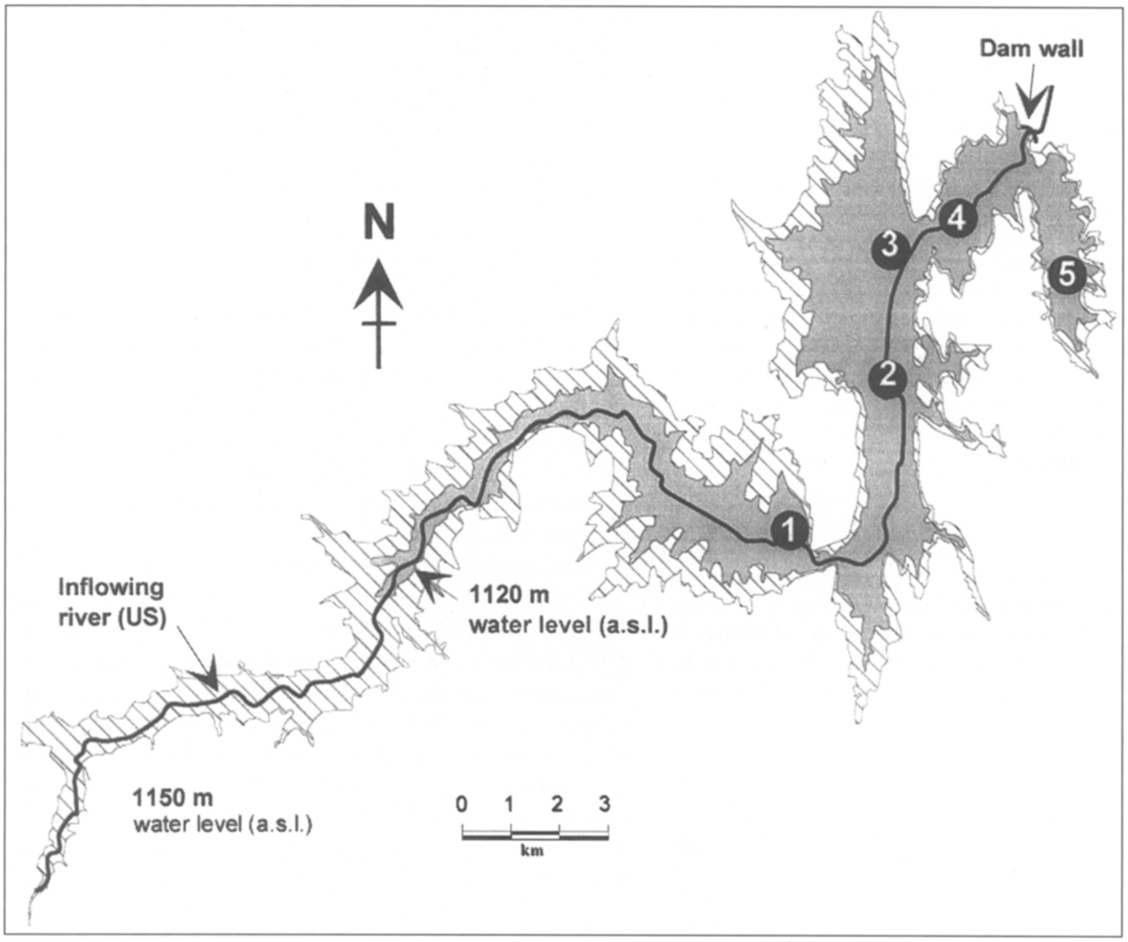

Fig. 1. Turkwel Gorge Reservoir, the sampling stations (1–5; US). Map obtained from KOTUT et al. (1998).

occurring in some places as intrusions into the basement system, e.g. the foliated granites on the Gorge area. The reservoir is located on the Suam Plains, an erosional surface formed during the end Tertiary Era. The soils are a shallow skeletal type dominated by stony, silty and sandy gravel. Bush clad hills dot the plain and are dominated by *Acacia reficiens* var. *misera* community. The principle river draining into the reservoir is the Suam which rises from a crater in Mt. Elgon. Its principle tributaries are the Kanyangereng and Kunyao rivers, which drain the Karamoja Hills of Uganda.

During the study period, the reservoir had an average surface area of between 13.1 km^2 (1995) and 16.8 km^2 (1994) and a mean depth of between 16.1 m (1995) and 17.4 m (1994). Mean water depth at the deepest part of the reservoir (dam wall area) was 63.8 m and 59.3 m in 1994 and 1995, respectively.

The area around the reservoir is chiefly the seasonal grazing land for the Pokot and Turkana communities. Some increase in settlements around the reservoir appear to have resulted from the creation of the reservoir, which now serves as a perennial source of water for livestock watering. Small scale alluvial gold prospecting occurs along the river valley and in some neighboring hills. Some small-scale fishing also occurs at the reservoir. However the landings which comprise riverine fish species are low.

Materials and Methods

Sampling stations

A total of 6 stations, 1 upstream (inflowing river) and 5 at the reservoir were investigated during the first year (1994). To establish the extent of the spatial differentiation that is common to such elongated reservoirs, a preliminary transect study was carried out along the main axis of the reservoir. A total of 11 transects running perpendicular to the long axis of the reservoir were investigated for a number of parameters. An analysis of the results revealed the existence of some small differences between transects. Based on these findings, five representative stations distributed along the main axis of the reservoir were selected (Fig. 1). The inflowing river is not very accessible. Consequently only 1 station (US) was selected at some 50 meters upstream of the river mouth. Because of the wide seasonal fluctuation in reservoir water level, the position of this station was not fixed. The sampling frequency during the first year of investigation (1994) was monthly and concentrated on the spatial changes in the selected parameters. During the second year (1995), it was bimonthly and devoted to the vertical structure of these parameters at a central reservoir station.

Analytical procedures

The Kerio Valley Development Authority made available rainfall, river discharge, and daily water level data. Air and surface water temperatures were determined in the field with an ordinary glass mercury thermometer calibrated to tens of a degree centigrade. Reservoir Secchi depth measurements were made with a Secchi disc with a diameter of 21 cm (LIND 1979). Water pH readings were made in the field with an Aquamate Water Quality Checker (WQA, Type SM-5). Electrical conductivity (K_{25}) measurements were made in the field with a Markson Model 10 conductivity meter with automatic temperature compensation to 25 °C. Equipment calibration was done with KCl standard solutions (APHA 1975). Levels of dissolved oxygen (DO) were determined by unmodified Winkler titration method (APHA 1975). DO fixation was done in the field in 300 ml BOD (biological oxygen demand) bottles. Acidification and titration were accomplished at the field laboratory. Total alkalinity (TA) determination was done in the laboratory by titrating a known volume of water sample with standard H_2SO_4 and using a mixed methyl red and bromcresol indicator to establish the titration end point (APHA 1975). Glassware for phosphorus determination was cleaned following the procedure outlined in LIND (1979). Sample oxidation for total phosphorus (TP) determination was carried out with ammonium persulphate oxidation technique (APHA 1975). Samples for orthophosphate phosphorus (PO_4-P) were filtered in pre-washed 4.7 cm diameter glass fiber filters (GF/C). The amounts of the two forms of phosphorus were determined by the colorimetric ascorbic acid reduction procedure (APHA 1975). Nitrite nitrogen (NO_2-N) was determined by the colorimetric diazotization technique (GOLTERMAN et al. 1978). Nitrate nitrogen (NO_3-N) and total nitrogen (TN) were determined by the modified sodium salicylate colorimetric procedure (SCHEINER 1974) on filtered and oxidized samples respectively. The oxidation of all forms of nitrogen to nitrates was carried out using the ammonium persulphate oxidation technique. Soluble reactive silica was determined on filtered samples by the colorimetric molybdosilicate method (APHA 1975). For all colorimetric procedures, standard solutions were subjected to similar treatments as the samples.

Results

Hydrological conditions

The available rainfall information from the Kerio Valley Development Authority (KVDA) was for the period 1990 to 1996. The total amount of rainfall given in each month of this period varied widely (Fig. 2a). The total rainfall received in each year ranged from 330.7 mm in 1995 to 1332.4 mm in 1992 (Fig. 2b). Total rainfall for each month of 1994 and 1995 is presented in Fig. 2c. Tables 1 and 2 provide the mean levels of all parameters investigated during the study.

Total monthly discharge data of the river for the period 1957–1985 varied widely from year to year (Fig. 2d). Using this data, an average discharge rate of 18.2 m^{-3} s^{-1} was computed for the Suam River. Estimates of river discharge into the reservoir during the period 1991 to 1995 ranged from 7.62 m^{-3} s^{-1} to 14.6 m^{-3} s^{-1}. Hence river discharge from the time the reservoir was created has been lower than the mean river discharge. Fig. 2e presents an estimate of the yearly discharge into the reservoir between 1991 and 1995 while Fig. 2f presents the total discharge for each month of 1994 and 1995. A positive correlation between total inflow and TP ($R = 0.577$, $P = 0.03$) and a negative correlation to DRS ($R = -0.820$, $P < 0.001$) and Secchi depth ($R = -0.550$, $P = 0.04$) were established in 1994. In 1995, positive correlation with DO (R = 0.829, P < 0.001) and TN (R = 0.808, P < 0.001) was noted.

The closure of the low-level outlet (LLO) on the dam wall of Turkwel Gorge Reservoir in May 1990 resulted in a rapid rise in reservoir water level to the highest level at 1122 m a.s.l. in 1991 (Fig. 2g). Between 1992 and 1995, mean monthly reservoir water levels were lower with a wide amplitude of fluctuation (Fig. 2g). Maximum water level changes of 12.49 m and 10.59 m were observed in 1994 and 1995 respectively.

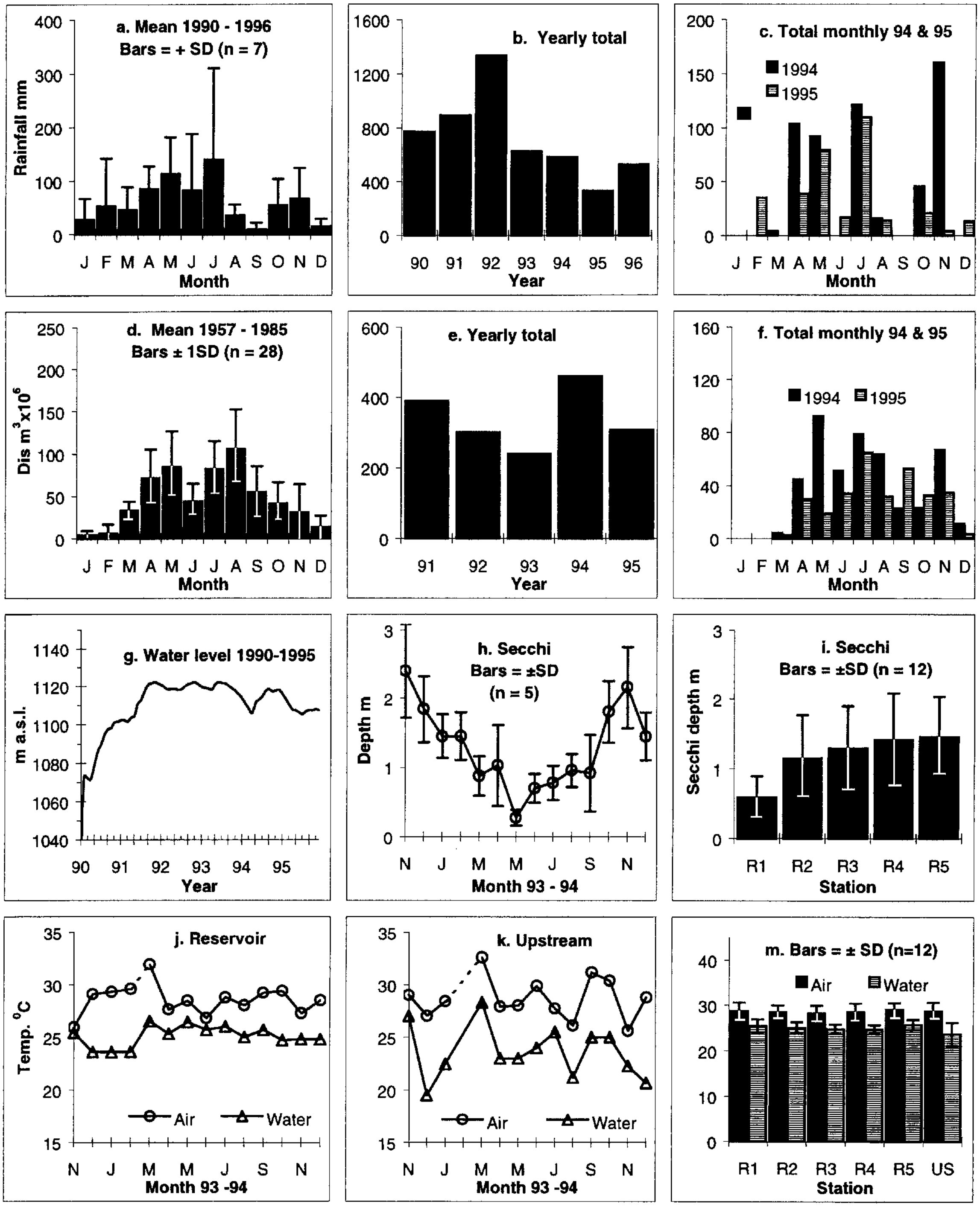

Fig. 2. Rainfall (a–c), discharge (d–f), water level (g), Secchi depth (h–i) and temperature (j–m) changes at the Turkwel Gorge area, reservoir, and the inflowing river. A dashed line at the inflowing river represents a period with no river flow.

Table 1. Results of the mean levels of the physical, chemical and biological parameters investigated at the Turkwel Gorge Reservoir and the inflowing (US) river during the period November 1993 to December 1994. The values given for the reservoir (Res) are means for the five sampling stations while those of the inflowing river (US) are values for each sampling trip.
Abbreviations: Dis – Discharge; W Temp – Water Temperature; PP – Primary production; Div – Diversity.

Parameter	Site	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain mm	Tot	135.1	0	0	0	4	103.6	92.3	0	121.3	15.5	0	45.7	160.6	0
Dis 10^6 m^3	Tot	14.4	6.9	0.0	0.0	4.4	44.8	92.5	51.3	78.7	63.0	22.5	23.3	66.9	11.3
Level m	Res	1117.6	1115.9	1113.7	1110.8	1108.1	1106.1	1111.1	1112.9	1114.7	1117.5	1118.5	1117.4	1117.6	1118.2
Air Temp °C	Res	25.9	29.1	29.3	29.6	31.9	27.6	28.4	26.8	28.8	28.0	29.2	29.4	27.3	28.5
	US	29.0	27.0	28.4	dry	32.6	27.9	28.0	29.9	27.7	26.1	31.2	30.4	25.6	28.8
W Temp °C	Res	25.4	23.6	23.6	23.6	26.5	25.3	26.4	25.7	26.0	25.0	25.7	24.7	24.8	24.8
	US	27.0	19.5	22.5	dry	28.3	23.0	23.0	24.0	25.5	21.2	25.0	25.0	22.3	20.7
Median pH	Res	7.5	7.7	7.9	7.8	7.6	8.0	8.0	8.7	8.4	7.5	7.1	7.2	7.1	–
	US	7.0	7.0	6.9	dry	7.4	6.9	7.0	7.3	7.0	7.7	7.5	7.2	7.0	–
Secchi depth m	Res	2.18	1.45	1.43	1.29	0.90	1.06	0.25	0.50	0.67	0.85	1.06	1.61	1.82	1.45
DO mg l^{-1}	Res	7.1	8.2	6.8	6.8	7.3	6.6	8.2	8.3	7.8	6.0	5.6	6.4	6.6	5.6
	US	7.6	8.2	6.6	dry	1.8	4.4	5.5	7.0	6.8	7.1	7.4	6.9	7.0	
EC µS cm^{-1}	Res	177.4	186.4	190.6	181.2	198.4	200.0	184.0	168.0	167.4	170.0	166.0	168.2	166.6	164.2
	US	180.0	200.0	200.0	dry	210.0	135.0	137.0	140.0	145.0	140.0	150.0	110.0	107.0	165.0
TA mg l^{-1}	Res	94.2	99.6	101.6	99.2	108.0	105.8	100.6	81.6	86.8	85.2	88.0	90.2	88.8	86.2
	US	100.0	125.0	117.0	dry	114.0	76.0	76.0	75.0	62.0	60.0	81.0	55.0	59.0	86.0
NO_2-N µg l^{-1}	Res	0.3	1.0	0.2	0.2	0.3	6.3	1.3	0.8	0.5	1.1	0.8	0.2	0.2	0.1
	US	26.7	2.7	7.6	0.0	49.3	15.6	8.6	1.7	2.8	3.9	1.2	3.1	1.6	0.8
NO_3-N µg l^{-1}	Res	30.7	55.6	33.3	41.5	19.1	57.8	44.0	52.5	31.5	30.7	25.8	16.0	36.0	43.1
	US	177.8	93.3	53.3	dry	471.0	482.2	320.0	153.3	166.6	186.6	95.5	124.5	126.7	95.5
TN µg l^{-1}	Res	239.9	163.1	171.4	193.1	246.1	376.6	425.9	283.5	254.3	204.0	165.0	161.2	126.3	203.9
	US	512.2	438.8	–	dry	1913.0	3354.0	1805.2	401.7	501.7	737.1	210.6	308.5	204.8	237.9
PO_4-Pµg l^{-1}	Res	4.0	2.0	1.6	0.4	0.0	2.0	1.2	2.0	2.2	2.8	4.2	2.4	1.0	0.8
	US	16.0	13.9	5.0	dry	2.0	19.8	18.8	17.8	14.9	69.0	1.0	36.6	36.6	17.8
TP µg l^{-1}	Res	15.	8.7	16.8	15.2	24.1	26.6	33.5	22.8	22.1	19.3	17.5	14.1	14.3	18.8
	US	289.2	196.8	152.1	0.0	1259.4	904.9	452.5	250.0	321.0	608.5	116.4	172.3	166.6	101.8
Silica mg l^{-1}	Res	8.5	10.1	9.6	9.2	7.7	4.1	2.7	0.9	1.6	2.4	3.8	5.2	5.5	7.0
	US	8.1	14.8	9.8	dry	13.2	19.9	16.2	12.5	9.0	18.6	16.1	14.3	15.2	15.8
Chl a µg l^{-1}	Res	8.0	6.9	7.7	6.7	10.5	18.8	28.3	12.6	15.1	8.5	7.0	5.6	6.4	7.2
Biomass mg l^{-1}	Res	0.68	0.75	1.09	1.37	4.97	5.36	9.33	11.17	9.45	4.99	0.55	0.51	0.61	0.44
PP g O_2 m^{-2} d^{-1}	Res	–	3.7	4.9	3.1	–	7.1	9.7	7.7	5.7	4.0	1.8	2.4	3.7	3.7
Div Index H′	Res	2.40	2.73	2.43	1.42	0. 52	0.38	0.38	0.18	0.55	0.29	1.39	2.34	1.88	2.32

Physical and chemical conditions

- **Secchi depth**

Mean Secchi depth at the reservoir ranged from 0.25 to 1.82 m (Fig. 2h) with a minimum of 0.09 m and a maximum of 2.16 m in 1994. The lowest measurements were taken in the month of May following a large inflow of floodwater (Fig. 2h). The overall impact of the wet season flood inflow was an upreservoir decline in mean station Secchi depth (Fig. 2i). Secchi depth measurements in 1995 varied from 0.80 to 1.88 m (Table 2).

- **Temperature**

Mean monthly air temperature at the reservoir in 1994 ranged from 25.9 to 31.9 °C (Fig. 2j) with no distinct seasonal trend. A greater range from 25.6 to 32.6 °C was established at the inflowing river (upstream, Fig. 2k). Mean reservoir and upstream surface water temperatures in 1994 ranged from 23.6 to 26.5°C (Fig. 2j) and from 19.5 to 28.3 °C (Fig. 2k) respectively, with a wider fluctuation upstream. In general, seasonal changes in water temperature were irregular with no distinct seasonal trend. Depth-time plots of the vertical profiles of temperature in 1995 are presented in Fig. 5a.

Table 2. Monthly results for the physical, chemical and biological parameters investigated at the Turkwel Gorge Reservoir (Res) in 1995 and the yearly mean (except for pH whose median is given) levels for all parameters at Turkwel Gorge Reservoir and the inflowing river.
Abbreviations: Dis – Discharge; W Temp – Water Temperature; PP – Primary production; Div – Diversity.

Month 1995	Rain-fall mm	Dis × 10^6 m^3	Level. m	Air Temp °C	W Temp °C	Secchi m	DO mg l^{-1}	EC µS cm^{-1}	TA mg l^{-1}	NO_2-N µg l^{-1}	NO_3-N µg l^{-1}	TN µg l^{-1}	PO_4-P g l^{-1}	TP µg l^{-1}	DRS mg l^{-1}	Chl a µg l^{-1}	Biomass mg l^{-1}	PP. g O_2 m^{-2} d^{-1}	Div Index H′
Feb	35.6	0.0	1113.0	28.5	25.3	1.9	0.0	167	98	0.13	22.3	221.2	0.0	13.4	7.6	5.8	0.49	3.1	2.4
Apr	38.6	29.5	1107.9	28.5	25.8	1.2	6.1	175	95	0.27	44.4	274.3	1.0	16.8	7.6	7.7	0.84	3.3	1.3
Jun	16.5	33.9	1106.3	27.2	25.6	1.1	6.3	180	100	0.27	66.7	336.0	3.0	24.6	8.8	11.5	1.35	5.1	0.7
Aug	14.0	31.7	1106.7	27.5	25.7	0.9	6.9	170	94	1.34	111.1	281.6	1.0	17.9	8.4	7.1	0.59	3.2	2.2
Oct	20.2	33.0	1107.5	25.2	25.0	0.9	6.5	155	88	0.67	46.7	303.9	0.0	19.0	10.3	10.6	0.43	5.4	2.2
Dec	13.3	3.7	1107.8	25	24.1	0.8	6.6	140	82	0.53	84.4	266.8	8.9	69.3	11.8	4.9	0.53	3.0	1.9
Res Mean 1994	45.3	38.2	1113.9	28.7	25.2	1.07	6.1	177.1	93.5	1.00	35.9	234.3	1.72	20.4	5.0	11.2	4.15	4.9	1.17
US Mean 1994	–	–	–	28.8	23.7	–	6.8	149.0	78.3	8.0	206.8	967.5	21.8	375.5	14.6	–	–	–	–
Res Mean 1995	23.0	22.0	1108.2	27.0	25.3	1.13	5.4	164.5	92.8	0.54	62.6	280.6	2.32	26.8	9.1	7.9	0.71	3.9	1.78

Surface water temperatures ranged from 24.8 to 27.6 °C depending on the season and the time of measurement. The bottom water temperatures were more uniform, ranging from 23.1 to 24.6 °C. Annual variation in the depth of the uppermost stable isotherm suggests that the depth of the daily mixed zone changes constantly during the year. Since the stable isotherms are found at a depth below 10 meters, the Turkwel Gorge Reservoir therefore has a daily mixed layer of about 10 meters deep.

- **Conductivity (EC)**

Mean reservoir conductivity ranged from 160 to 200 µS cm^{-1} (Fig. 3a) with a minimum and maximum of 150 and 200 µS cm^{-1} respectively in 1994. Reservoir conductivity in 1995 ranged from 140 to 180 µS cm^{-1} (Table 2). Vertical profiles of conductivity during 1995 (Fig. 5c–h) showed some small and irregular variations. Conductivity at the upstream station (inflowing river) ranged from 107 to 210 µS cm^{-1} in 1994 (Fig. 3b). Overall, the inflowing river had a slightly lower mean conductivity as compared to the reservoir stations (Fig. 3c). In general, high conductivity values were common towards the end of the dry season during a period characterized by little or no inflow. Low records were made at the end of the wet season.

- **Total alkalinity (TA)**

Mean reservoir TA ranged from 82 to 108 mg l^{-1} (Fig. 3d) with a minimum and maximum of 75 and 111 mg l^{-1} respectively in 1994. In 1995, reservoir TA ranged from 82 to 100 mg l^{-1}. Vertical profiles of TA during 1995 (Fig. 5c–h) lacked a distinct vertical gradient. Upstream (inflowing river) TA ranged from 55 to 125 mg l^{-1} (Fig. 3e). High TA levels were recorded around the end of the dry season while low levels were noted in the middle of the rain season. Based on the 1994 reservoir results, a positive correlation between TA and electrical conductivity ($R = 0.922$, $P < 0.001$) was established. Assuming a linear relationship passing through the origin, reservoir TA can be predicted as a function of conductivity (Cond.) by the following equation:

$$\text{TA (mg l}^{-1}\text{)} = 0.5293\ \text{Cond.}\ (R^2 = 0.8761,\ n = 12).$$

- **pH value**

Median pH values at the reservoir during 1994 varied from 7.1 to 8.7 (Fig. 3g) with maximum and minimum pH of 6.7 and 8.9, respectively. Slightly higher pH values were recorded during the wet season. Inflowing river pH ranged from of 6.9 to 7.7 (Fig. 3h). Overall median pH at the inflowing river was slightly lower than that of most reservoir stations (Fig. 3i).

- **Dissolved oxygen (DO)**

Mean reservoir DO levels during 1994 ranged from 5.6 to 8.3 mg l^{-1} (Fig. 3j) with minimum and maximum values of 4.9 and 9.2 mg l^{-1} representing a saturation range of 70 to 123 % respectively. Oxygen supersaturation occurred at the lower sections of the reservoir during the wet season. River flood inflows depressed DO levels at the upreservoir section resulting in a downreservoir decline in mean station DO (Fig. 3l). Mid reservoir DO in 1995 ranged from 5.5 to 6.9 mg l^{-1} representing a saturation range of 75 to 97 %. With

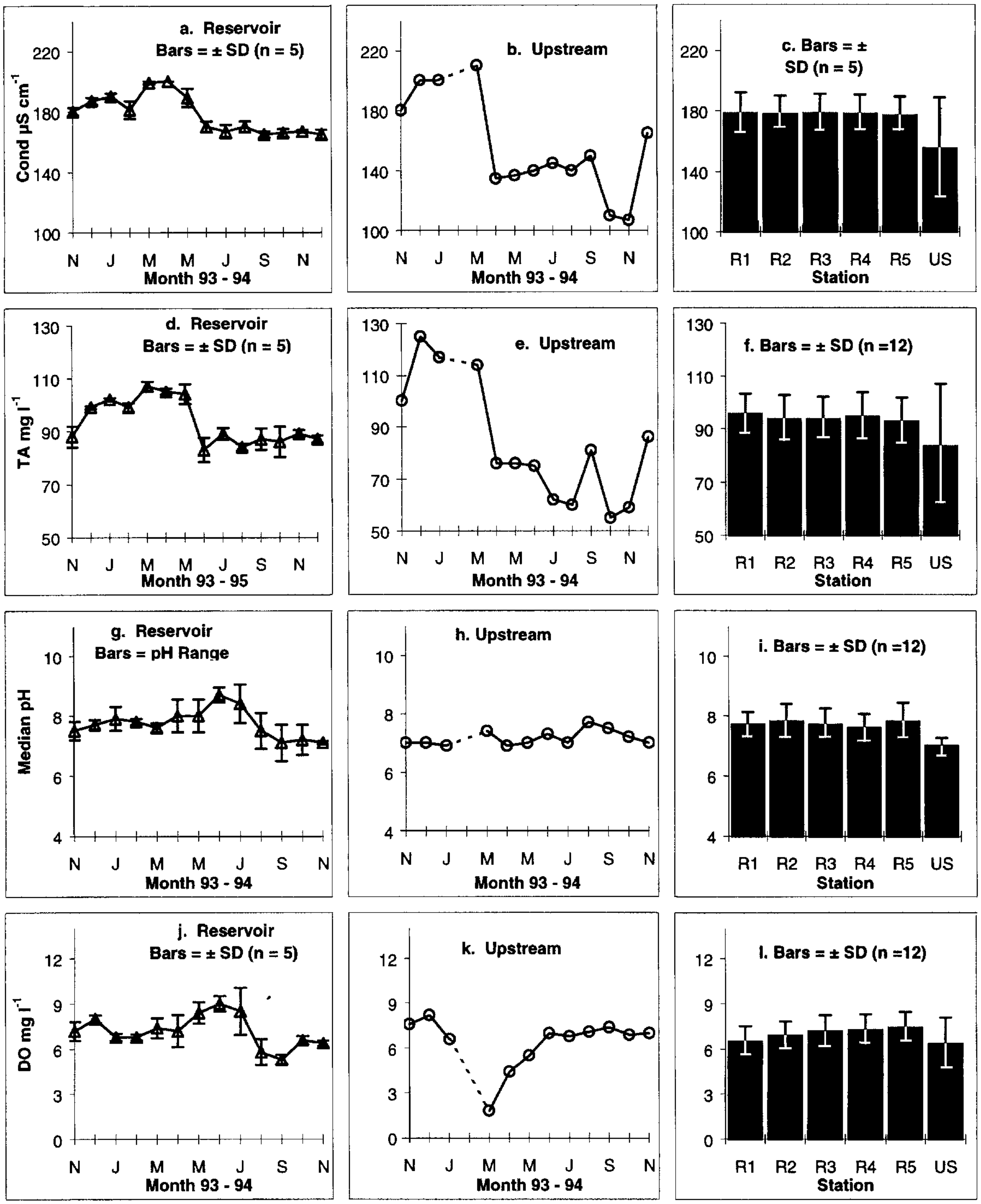

Fig. 3. Variation in conductivity (a–c), total alkalinity (d–f), median pH (g–i) and dissolved oxygen (j–l) at Turkwel Gorge Reservoir and the inflowing river. A dashed line at the inflowing river represents a period with no river flow.

the exception of December, a distinct DO stratification was characteristic of the reservoir during most of 1995 (Fig. 5b). During this period, DO concentration below a depth of 20 m ranged from 0 to 0.7 mg l^{-1}. The presence of a distinct oxycline at between 12 to 16 m was in contrast to the temperature profile that lacked a thermocline. The most severe bottom water deoxygenation occurred in August coinciding with the period with the most developed temperature stratification (Fig. 5b). Relatively low and nearly uniform levels of dissolved oxygen down the water column in December 1995 confirmed that some overturn did occur some time before the December sampling. Upstream (inflowing river) DO levels ranged from 1.8 to 8.2 mg l^{-1} (Fig. 3k) representing a saturation of 26 to 109 %. Low levels of dissolved oxygen were recorded in the first flood water following a period with no discharge.

- **Nitrite nitrogen (NO_2-N)**

Levels of NO_2-N ranged from above the acceptable minimum limit of detection (> 1 l^{-1}; APHA 1975) through spectrophotometrically detectable but below the acceptable minimum limit of detection (between 0.1 to 1.0 l^{-1}) to spectrophotometrically undetectable levels (< 0.1 l^{-1}). Reservoir NO_2-N levels were in most occasions below the limit of detection with the highest concentration of 26.9 µg l^{-1} being measured at the upreservoir section following a large inflow of flood water. During both 1994 and 1995, reservoir NO_2-N levels were comparatively higher during the wet season. Upstream NO_2-N levels ranged from above the limit of detection to a high of 49.3 µg l^{-1} measured following the resumption of river flow.

- **Nitrate nitrogen (NO_3-N)**

Mean reservoir NO_3-N ranged from 16.0 to 57.8 µg l^{-1} (Fig. 4a) with maximum and minimum concentrations of 6.7 and 153.3 µg l^{-1} respectively. In general, NO_3-N results varied irregularly among the stations and within stations. Elevated levels of NO_3-N at the upreservoir section during the wet season resulted in a noticeable downreservoir decline in mean station NO_3-N concentration (Fig. 4c). Levels of NO_3-N in 1995 ranged from 22.3 to 111.1 µg l^{-1}. Vertical profiles of NO_3-N in 1995 varied from a distinct vertical gradient to a nearly uniform depth profile (Fig. 6a–f). Upstream river NO_3-N in 1994 ranged from 53.3 to 482.2 µg l^{-1} (Fig. 4b). The highest concentration was recorded at the beginning of the wet season.

- **Total nitrogen (TN)**

Mean reservoir TN in 1994 ranged from 126 to 426 µg l^{-1} (Fig. 4d) with a maximum and minimum concentration of 119 and 526 µg l^{-1} respectively. In 1995, TN varied from 221 to 336 µg l^{-1}. Slightly higher measurements were made during wet season when inflow volumes were high. Vertical profiles of total nitrogen (Fig. 6 a–f) at the reservoir in 1995 varied from a nearly uniform change with depth to a distinct increase with depth. The upstream station recorded the highest total nitrogen values with a range from 205 to 3354 µg l^{-1} (Fig. 4e). The highest concentration was recorded following the resumption of river flow.

- **Phosphate phosphorus (PO_4-P)**

Measurements of PO_4-P ranged from levels above the acceptable minimum level of detection (> 10 µg l^{-1}, APHA 1975) through levels that were spectrophotometrically detectable but below the acceptable minimum level of detection (1 to 10 µg l^{-1}) to levels that were spectrophotometrically undetectable (< 1 µg l^{-1}). Mean reservoir PO_4-P levels in 1994 and 1995 ranged from undetectable to 5.3 µg l^{-1} with a maximum of 8.9 µg l^{-1}. Slightly higher values were noted during the wet season. Levels of PO_4-P in 1995 ranged from undetectable levels to 8.9 µg l^{-1}. Upstream PO_4-P concentration ranged from undetectable to 69.0 µg l^{-1} with no clear temporal trend.

- **Total phosphorus (TP)**

Elevated levels of TP were noted during the wet season with the highest increase occurring at the inflowing river and upreservoir stations. Mean reservoir TP concentration in 1994 ranged from 14.1 to 33.5 µg l^{-1} (Fig. 4g) with maximum and minimum levels of 8.9 and 71.6 µg l^{-1} respectively. Higher levels received at the upreservoir stations resulted in downreservoir decline in mean station TP (Fig. 4i). Mid reservoir TP concentration in 1995 ranged from 22.3 to 69.3 µg l^{-1}. Depth profiles of TP in 1995 were generally uniform (Fig. 6 g–l) with the exception of the profiles for April and December, which showed some noticeable vertical increase at lower depths. December 1995 had the highest and greatest vertical range of TP (Fig. 6l). Upstream levels of TP ranged from 101.8 to 1259.4 µg l^{-1} (Fig. 4h). The peak level of TP was recorded at the beginning of the wet season in first flood water.

- **Dissolved reactive silica (DRS)**

Levels of DRS at the reservoir in 1994 showed a progressive decline to the lowest concentration in June followed by a steady increase that was maintained to the end of 1995. Mean reservoir DRS concentration in 1994 ranged from 0.87 to 9.59 mg l^{-1} (Fig. 4j) with minimum and maximum levels of 0.41 and 9.77 mg l^{-1}, respectively. Levels of DRS in 1995 ranged from 7.59 to 11.82 mg l^{-1}. Vertical profiles of DRS in 1995 were generally uniform throughout the year (Fig. 6g–l). Temporal changes in levels of DRS upstream in 1994 were less regular than at the reservoir (Fig. 4k) with a range from 9.01 to 19.93 mg l^{-1}.

- **Nutrient budgets estimates**

The maximum monthly loads of TN (Fig. 4m), TP (Fig. 4n) and DRS (Fig. 4o) into the Turkwel Gorge Reservoir in 1994 were 167.0, 41.9 and 1498.8 tons per month respectively. The highest input of most nutrients was recorded in May when the highest volume of inflow was also recorded. Total

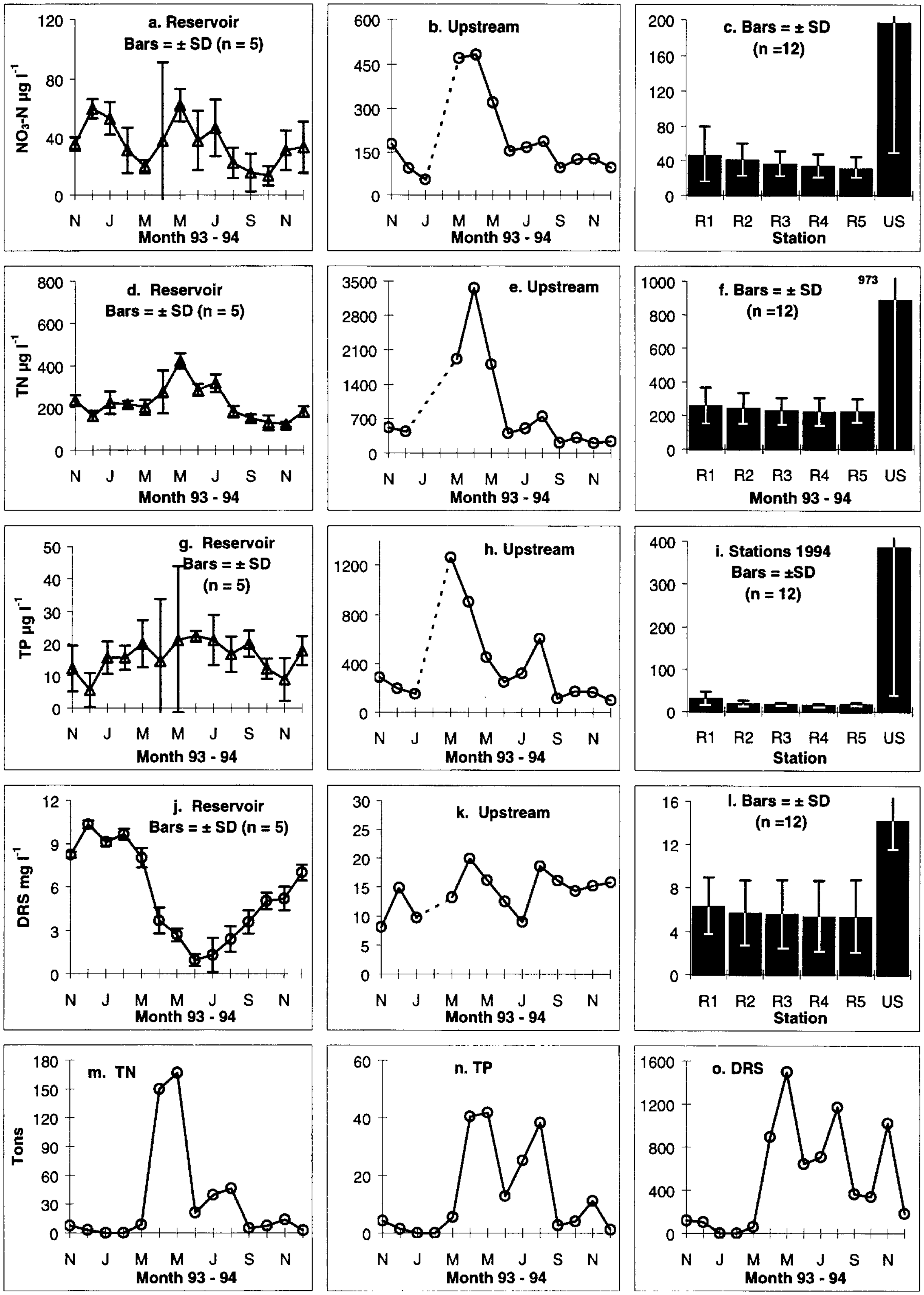

Fig. 4. Changes in nitrate nitrogen (a–c), total nitrogen (d–f), total phosphorus (g–i) and dissolved reactive silica (j–l) at Turkwel Gorge Reservoir and the inflowing river and monthly loading rates of total nitrogen (m), total phosphorus (n) and dissolved reactive silica (o) into Turkwel Gorge Reservoir. A dashed line at the inflowing river represents a period with no river flow.

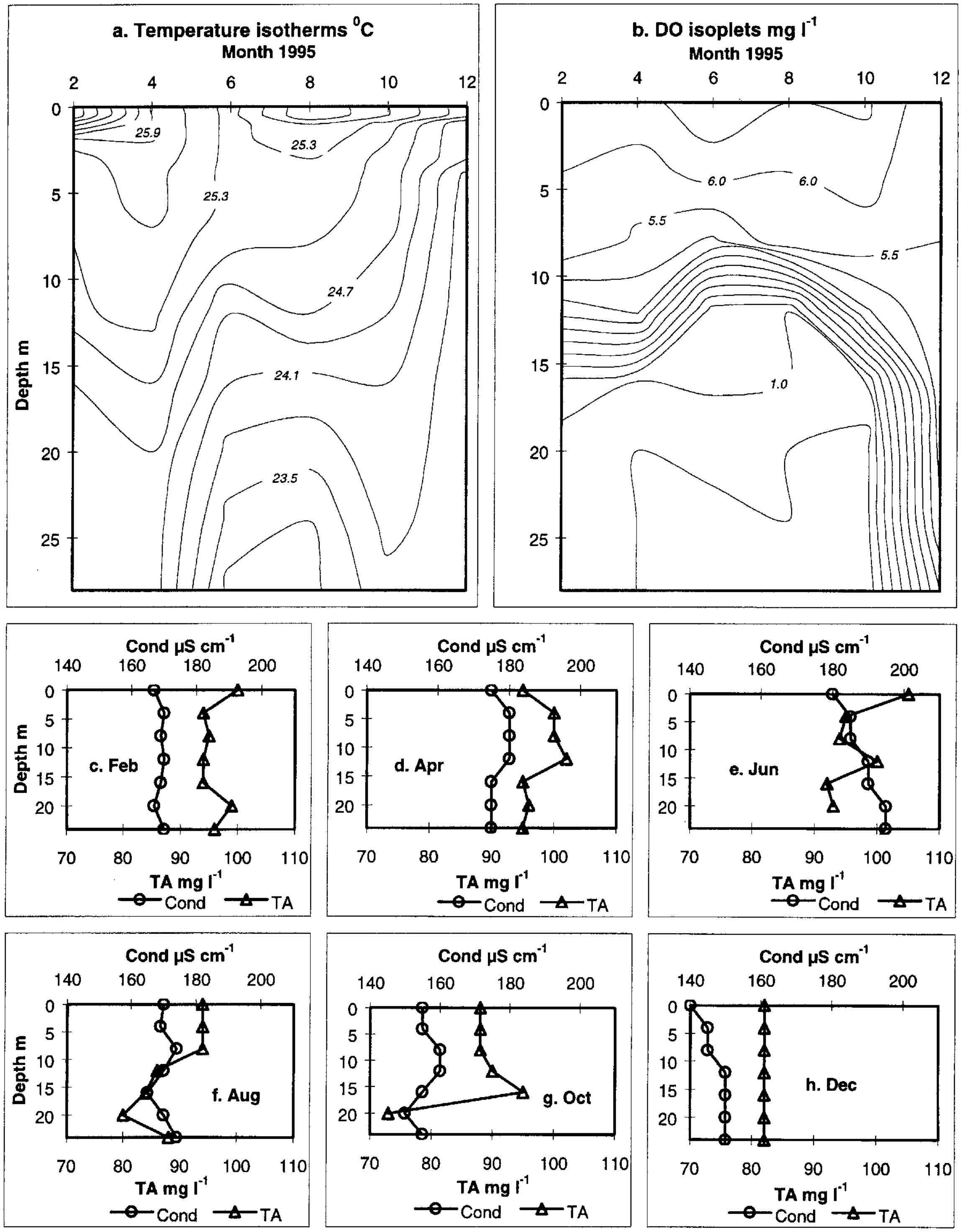

Fig. 5. Temporal changes in vertical profiles of temperature (a) and dissolved oxygen (b) and the vertical profiles of electrical conductivity and total alkalinity (c–h) at Turkwel Gorge Reservoir.

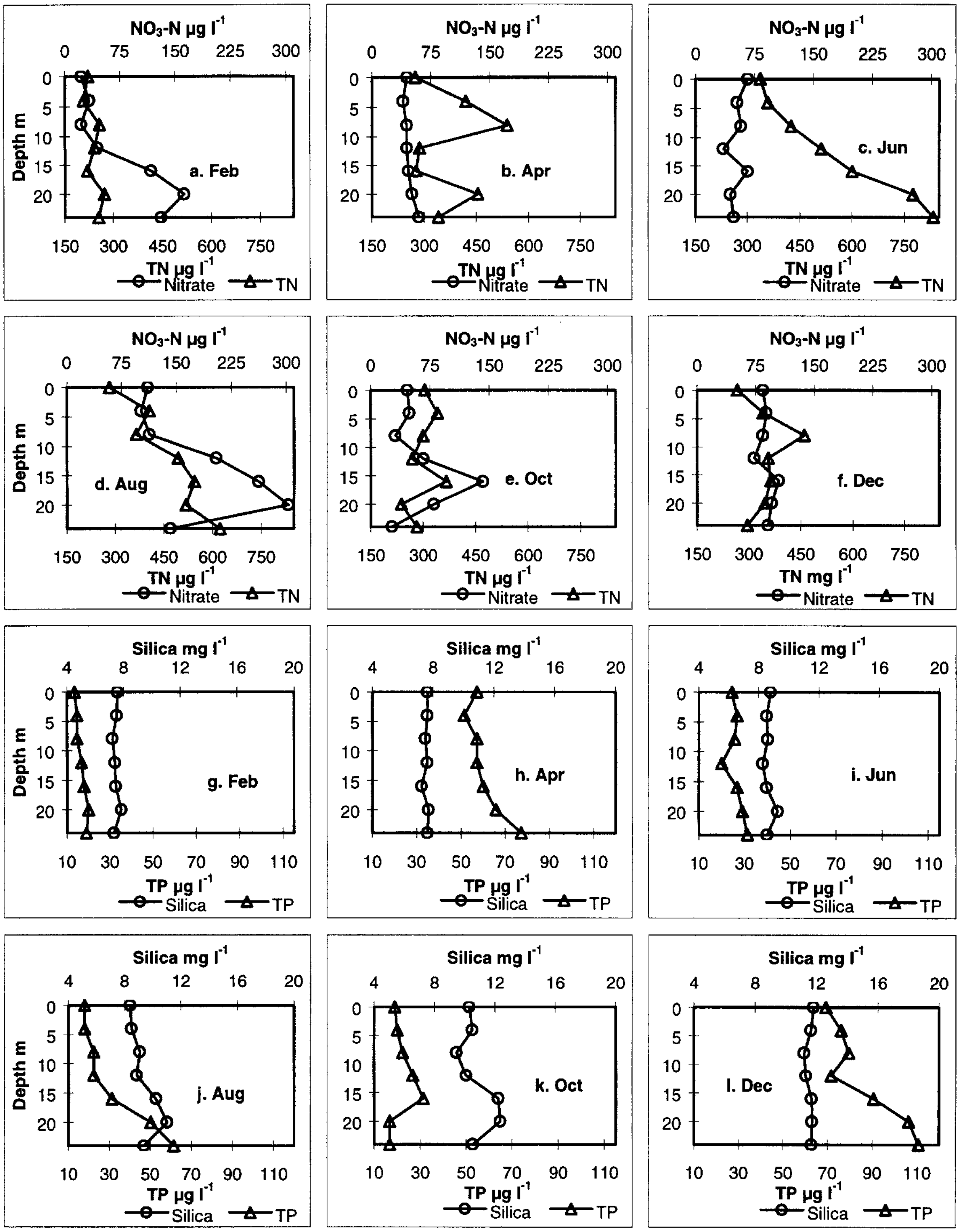

Fig. 6. Vertical profiles of nitrate nitrogen, total nitrogen (a–f), total phosphorus and dissolved reactive silica (g–l) at Turkwel Gorge Reservoir.

monthly nutrient loads showed a positive correlation to total monthly inflow volume (R values = 0.64, 0.81 and 0.94 for TN, TP and DRS; $P < 0.01$). The total loads for TN, TP and DRS in 1994 were 460.4, 183.3 and 6867.5 tons respectively. This represents mean input rates of 0.81 mg m^{-3} (TN), 0.36 mg m^{-3} (TP), and 12.68 mg m^{-3} (DRS) of river inflow, which converts to annual areal loading rates of 27.38 mg m^{-2} (TN), 10.90 mg m^{-2} (TP) and 408.5 mg m^{-2} (DRS).

Discussion

• Rainfall

The wide variation in total yearly and monthly rainfall as observed during the study is a common feature of semiarid regions. In general, the rainfall amount is very important for determining the amounts of ions that are transported from catchments into lakes (HENRIKSEN et al. 1998). However, absence of a significant relationship between rainfall at the study site and water level suggests that the rainfall over the reservoir area only contributes a small proportion of the water entering the reservoir.

• River discharge

A positive correlation between total inflow volume and a number of physico-chemical conditions in the reservoir established at Turkwel Gorge Reservoir confirms the important role of inflow dynamics in influencing reservoir conditions. Positive correlation between inflow volume and a number of phytoplankton properties of the reservoir has also been demonstrated (KOTUT et al. 1998) suggesting that inflows similarly play an important role in reservoir primary production dynamics. The dominant influence of inflow dynamics on the physical limnology of reservoirs has been demonstrated in a number of reservoirs, e.g. Solomon Dam in Australia (HAWKINS 1985), Guma Dam in Sierra-Leone (MTADA 1986) and Lake Kutubu in Papua-New Guinea (OSBORNE & TOTOME 1992). Compared to the Tana River cascade of reservoirs with inflow rates of between 107.1 $m^3 s^{-1}$ to 141.1 $m^3 s^{-1}$ (NIPPON KOEI 1995), a mean discharge rate into Turkwel Gorge Reservoir of 18.2 $m^3 s^{-1}$ is low. A lower inflow volume into the reservoir in 1995 as compared to 1994 explains the lower amplitude of fluctuation in reservoir physico-chemical and biological conditions (Tables 1 and 2). Considering the total annual inflow volume to be an index of expected magnitude of yearly variation in physico-chemical and biological conditions, a wider range of variation can be expected at the reservoir. This is because the total inflow volumes of 458.65 and 306.20 million cubic meters for 1994 and 1995 respectively are still lower than the expected mean annual inflow volume of 568 million cubic meters. However, it is possible that the intensity and frequency of flooding episodes play an equally important role. Intense floods can mobilize large quantities of nutrients along with suspended and dissolved solids as compared to a uniformly distributed rainfall pattern.

• Water level

High and irregular water level fluctuation at Turkwel Gorge Reservoir is a combined result of an irregular inflow variation and the reservoir use patterns. A wide fluctuation in water level is a common feature of reservoir limnology and has some influence on its ecology (RYDER 1978; KIMMEL & GROEGER 1984) through, for example, an enhanced nutrient exchange between pelagic and littoral zones of the reservoir (KENNEDY & WALKER 1990). Yearly water level changes ranging from 10.6 to 12.5 m show that the reservoir has a draw down greater than 12.5 m. This is the highest record for Kenya's hydropower reservoirs. Kenya's largest reservoir, Masinga has a maximum draw down of 10 m (PACINI 1993). Draw downs in Africa's large reservoirs range from 3 m in Lakes Volta, Kariba and Kossou to 10 m in Lake Kainji (ADENIJI et al. 1981). A combination of a wide draw down and a mostly rocky shoreline has resulted in bare shoreline deficient of littoral vegetation. Hence BERNACSEK's (1984) conclusion that a draw down of 3 meters and above limits macrophyte development holds true for Turkwel Gorge Reservoir.

• Temperature

Absence of a distinct seasonal trend in temperature at Turkwel Gorge Reservoir area can be attributed to a wide variation in diel temperature coupled with a difference in the time of sampling. Compared to other African reservoirs, a mean surface water range of 23.6 to 26.5 °C puts Turkwel Gorge Reservoir within about the same range as Lakes Volta and Kainji with ranges of between 27.5 to 30.0 °C and 23 to 31 °C respectively (LATIF 1984). This range is higher than 15 to 24 °C at Lake Nasser Nubia (LATIF 1984). A greater range of fluctuation in surface water temperature upstream (19.5 to 28.3 °C) as compared to the reservoir stations suggests a stronger influence of ambient conditions at the river. Surface water temperatures of rivers have been reported to follow the ambient air temperatures fairly closely (BREEN et al. 1981).

The temperature isoplet diagram for 1995 clearly demonstrates that some overturn did occur in December 1995. It is suspected that the depressed levels of dissolved oxygen, low levels of chlorophyll *a* and low biomass observed at the reservoir in September 1994 (Table 2) were the result of an overturn. It can therefore be tentatively concluded that the reservoir is typically monomictic with an irregular mixing time. A monomictic mixing pattern resulting from a drop in temperature has been reported for Masinga Reservoir (PACINI 1994).

Below the depth of the daily mixed surface layer, the temperature drop at the Turkwel Gorge Reservoir is so gradual that it cannot to be defined as a thermocline. This gradual drop in temperature appears to be sufficiently stable to be an effective barrier to mixing. The existence of a stable temperature gradient without a distinct thermocline has been reported for many tropical lakes (EWER 1966; BOND et al. 1978; ROBARTS & WARDS 1978; ARCIFA et al. 1981; VAN DER HEIDE 1982; PACINI 1994). In such cases, a thermocline can be defined as the temperature discontinuity located below the level of daily warming and nocturnal cooling that is sufficient to constitute an effective barrier to mixing. Excluding the wide diurnal temperature fluctuation at the reservoir, the maximum stable water temperature difference between the surface water and the bottom water was about 2.2 °C which is close to an estimate of 1.5 °C for equatorial lakes (LEWIS 1996).

- **pH value**

As demonstrated by a positive correlation between pH value and all phytoplankton properties in 1994 (KOTUT et al. 1998), a high reservoir pH during the wet season was the result of increased phytoplankton photosynthesis. Depletion of CO_2 as a result of increased photosynthesis brought about a rise in pH to values higher than those recorded at the inflowing river. Photosynthesis in some weakly buffered African lakes such as Lake George and Lake Bangwelu has been shown to result in a wide diurnal change in pH (HOWARD-WILLIAMS & GANF 1981). This is in contrast to other African lakes with a strong chemical buffering such as Lake Naivasha (LITTERICK et al. 1979), Lake Chilwa (KALK et al. 1979) and Lake Baringo (PATTERSON & WILSON 1995) that experience limited shifts in pH.

- **Conductivity**

The Turkwel Gorge Reservoir conductivity with a range from 160 to 200 μS cm^{-1} was close to that of the inflowing river with a range from 107 to 210 μS cm^{-1}. This suggests that most of total dissolved solids (TDS) of the reservoir originate from the inflowing river. The conductivity range of the section of the Suam River draining into Turkwel Gorge Reservoir does not differ appreciably from that of the major rivers that drain into some of Africa's large reservoirs (COCHE 1974; HALL et al. 1977). Its range is roughly equal to that of the Bandama River which drains into Lake Kossou (90 to 200 μS cm^{-1}) and the Zambezi River draining into Lake Cabora Bassa (100 to 150 μS cm^{-1}). The range is slightly higher than that of the section of the Zambezi River draining into Lake Kariba (36 to 121 μS cm^{-1}) and the Niger River draining into the Lake Kainji (34 to 80 μS cm^{-1}).

Evaporative concentration following an increase in the detention time of the river at the reservoir resulted in a slightly higher mean conductivity at the reservoir as compared to that of the inflowing river. Monthly evaporation estimates for the study period ranged from 1.02 to 3.40 million cubic meters. The conductivity range at the Turkwel Gorge Reservoir (160 to 200 μS cm^{-1}) places the reservoir into a group of African reservoirs with a relatively high conductivity (COCHE 1974). Its range is nearly the same as that of Lake Volta (65 to 180 μS cm^{-1}) but is higher than that of Lake Kainji (35 to 54 μS cm^{-1}), Lake Kariba (55 to 81 μS cm^{-1}) and Masinga Reservoir (113 to 140 μS cm^{-1}). Absence of a notable vertical change in conductivity means that the reservoir lacks a chemocline. Chemoclines at the position of the thermocline have been reported for some of Africa's reservoirs such as Lakes Volta (VINER 1970), Cabora Bassa (BOND et al. 1978) and Kariba (COCHE 1974).

- **Dissolved oxygen (DO)**

The depletion of DO by the organic matter that accumulates in the riverbed during the dry season resulted in the low level of DO (1.8 mg l^{-1}) at the inflowing river following the resumption of river flow. This in turn lowered upreservoir levels of DO. Supersaturated levels of DO recorded at the reservoir during the wet season in 1994 have been shown to be the result of increased phytoplankton photosynthesis (KOTUT et al. 1998). Comparatively lower phytoplankton photosynthesis in 1995 (Table 2) and possibly a weaker stratification accounts for a lack of DO supersaturation as in 1994. A weak stratification allows for gaseous exchange between the surface water and the deeper less oxygenated water. The DO profiles at Turkwel Gorge Reservoir indicate that a stable oxycline occurs at a depth of between 10 to 15 m. This confirms that the depth of daily mixing is about 10 m. Reservoir mixing lowers the level of DO at the reservoir surface. Decreasing surface water DO concentration due to the upwelling of DO deficient waters during overturn periods has also been reported for Lake Volta (BISWAS 1966; VINER 1970) and Lake Kariba (BEGG 1970).

- **Total alkalinity**

Alkalinity, definable by the electroneutrality condition as the difference between strong base cations and strong inorganic and organic acid anions (SAMSON et al. 1994), is a useful index of the buffered state of a water body. In areas free from the influence of marine seas salt deposition, the actual concentration of these ions in runoff water is determined by the chemical composition of catchment bedrock and soils (HENRIKSEN et al. 1998). A wide variation in inflow volume explains the wide range of TA at the inflowing river (55 to 125 mg l^{-1}). Dilution under periods of high inflow volume results in low TA levels. Compared to the TA of the inflowing river, a narrow range in reservoir TA (75 to 111 mg l^{-1}) suggests that inflow dilution had a lower effect on TA of the reservoir. A close relationship between TA and conductivity has been described for many of Africa's inland waters (TALLING & TALLING 1965) and is believed to be due to the predominance of carbonates and bicarbonates among the anions. A ratio TA : conductivity of 0.529 established at the Turkwel Gorge Reservoir is in close agreement with a ratio of 0.5 computed by TALLING & TALLING (1965) for a number of African lakes and reservoirs. Vertical gradients in TA are of a less common occurrence as compared to conductivity. A vertical decline in TA, which is possibly maintained by an underflow of river water with a low TA has been reported for the Masinga Reservoir (PACINI 1994).

- **Nitrogen**

Nitrogen entering aquatic systems arises from a variety of sources that include point and non point source pollution, biological fixation of gaseous nitrogen and the deposition of nitrogen oxides and ammonium (STODDARD 1994). Under natural conditions, deposition usually has a limited impact on the nitrogen levels. In any water body, the proportion of different forms of nitrogen is determined by the forms introduced and the balance between assimilation, mineralization, nitrification, denitrification and nitrogen fixation. Thinly populated settlements are found in the area surrounding Turkwel Gorge Reservoir. Hence the direct organic matter input from these settlements is not likely to make a significant impact on the levels of various nitrogen compounds at the reservoir. An important source of nitrogen is the organic matter load of the Suam River and its tributaries. At the inflowing river, high levels of nitrite nitrogen (49.3 $\mu g\ l^{-1}$), NO_3-N (482.2 $\mu g\ l^{-1}$) and TN (3354.0 $\mu g\ l^{-1}$) at the resumption of river flow possibly resulted from a high load of organic matter in the flood water. When the river flow resumes, all the dry season accumulation of portable organic and inorganic matter on the dried river bed and in the catchment area is swept downstream by the first flood water. In general, river inflows influence to a large extent the nutrient status of reservoirs (KENNEDY & WALKER 1990). However, actual nutrient concentration is a function of a complex interaction between hydrodynamic (inflow and outflow regimes) and morphometric (basin morphology and depth) characteristics, and within lake processes such as flow pattern, sedimentation and internal loading.

At Turkwel Gorge Reservoir, changes in the levels of nutrients in the surface water are dominated by the inflows, while vertical profiles may have resulted from the exchange dynamics between the surface water and the bottom water. Progressive increase in NO_3-N concentration with depth as observed in some months is possibly the result of the oxidation of organic nitrogen in the descending seston. In many lakes of East Africa, high levels of NO_3-N in deep layers have been described for situations where thermal stratification is pronounced, provided that deoxygenation is not too extreme (for example Lake Albert, TALLING 1963; Lake Victoria, FISH 1957). Hence the low levels of NO_3-N near the reservoir bottom in some months can be explained by the extreme bottom deoxygenation as evidenced by the low levels of DO near the bottom. The balance between the rate of seston accumulation at the hypolimnion and the rate of mineralization or recirculation to the epilimnion explains the profiles of TN. An irregular depth variation observed in some months can possibly be attributed to patches of descending seston.

- **Phosphorus**

The geology of the drainage basin is the principle factor that determines the phosphorus level in rivers (GOLTERMAN 1973; TALLING & TALLING 1965). In East Africa, VINER (1975) considers rainfall frequency and vegetation type as being important in bringing about variation in phosphorus levels. In general, low river phosphorus loads are characteristic of areas with a good vegetation cover and low intensity rainfall. The high erosive nature of rainfall at Turkwel Gorge Reservoir catchment as shown by the high load of silt in the inflowing river is probably the principle source of phosphorus of the reservoir. A modest increase in the concentration of PO_4-P (maximum concentration, 19.8 $\mu g\ l^{-1}$) in the first flood water of 1994 as compared to a notable increase in TP (maximum concentration, 1129.4 $\mu g\ l^{-1}$) suggests that most of the incoming phosphorus is in a bound form. According to FROEHLICH (1988), only about 5 to 10 % of the phosphorus eroded from continental rocks is carried in a dissolved form. The majority is transported in more or less tightly bound fluvial organic and inorganic sediments. The TP range at the Turkwel Gorge Reservoir (8.9 to 71.6 $\mu g\ l^{-1}$) compares closely to that of Masinga Reservoir with a range from 8.0 to 35.9 $\mu g\ l^{-1}$ (PACINI 1994). Common to both reservoirs is a wet season increase in TP concentration.

High phosphorus content of flood water is related to the transport pattern of fluvial sediments (THORNTON 1990). Usually the fine silt and clay particles that have a high sorptive capacity for phosphorus and other nutrients (PITA & HYNE 1974) normally accumulate at the flood plain under normal flow conditions (VANONI 1975). During storm events, they are washed into the river and transported to standing water bodies. The limited impact of inflowing river TP input on the reservoir surface water levels of TP suggests that most incoming phosphorus is soon lost, possibly through sedimentation. Phosphorus loss through sedimentation has been shown to be more rapid in reservoirs as compared to natural lakes. In the Tennessee Valley Authority reservoirs HIGGINS & KIM (1981) observed a phosphorus settling velocity that was nine times that of natural lakes.

Vertical variation in TP can be attributed to the balance between the rate of seston accumulation at each level and the rate of removal by sedimentation, or recirculation to the epilimnion. However, the unusually high level of phosphorus in the month of December 1995 that was also characterized by a sharp increase with depth may have been a result of the extent of water mixing. It is believed that a vigorous mixing that disturbed the sediment layer occurred in December. This led to the resuspension of sedimented or sorbed forms of phosphorus.

- **Dissolved reactive silica (DRS)**

River DRS is primarily derived from the weathering of silicate rocks under the influence of CO_2 (HUTCHINSON 1957). Actual concentration in rivers depends on the mobility of surrounding soils. Higher levels of DRS at the inflowing river (mean, 14.13 $mg\ l^{-1}$) when compared to the level at the reservoir (mean, 4.96 to 9.1 $mg\ l^{-1}$) confirms that river inflow plays an important role in regulating levels at the Turkwel Gorge Reservoir. In many lakes in Africa, river input has been noted to play a primary role in determining the lake level of DRS (TALLING & TALLING 1965). The mean concentration of DRS at the Turkwel Gorge Reservoir is lower than that of Masinga Reservoir whose mean concentration is 13.3 $mg\ l^{-1}$ (PACINI 1994). A more or less uniform vertical distribution of DRS as observed in 1995 suggests that input and recycling processes are enough to stabilize uptake losses at the surface. Increase in DRS with depth has been reported for Lake Tanganyika where the level of DRS increases from 3.2 mg l^{-1} at the surface to 12.0 mg l^{-1} at a depth of 1500 m (TALLING & TALLING 1965).

A high diatom biomass during the wet season (KOTUT et al. 1998) explains the wet season decline of DRS in 1994. Diatom depletion of DRS is supported by the negative correlation between DRS and diatom biomass at the reservoir (R = –0.777, P = 0.001) in 1994. A common feature of diatom dominated lakes, especially in temperate regions, is the dominant role of diatom dynamics in influencing the seasonal patterns of DRS (SAMPSON et al. 1994). The sensitivity of DRS concentration to diatom biomass increase lies in the slower rate of the regeneration of structural DRS as compared to other elements. It has been shown that the ratio of DRS to phosphorus in sedimenting diatom cells increases with depth (SHAFER & ARMSTRONG 1994). Absence of a diatom bloom in 1995 resulted in a progressive increase in DRS levels.

- **Nutrient input and output relations**

Reservoir water quality and productivity are controlled to a large extent by the quantity and quality of external nutrient loading (KENNEDY & WALKER 1990). Knowledge on the loading rates of commonly limiting nutrients can shed some light on the potential productivity of the reservoir. In each reservoir, the total nutrient load is determined by a complex of factors, e.g. watershed climate, parent soil characteristics, river volume, erosion rates and stream sediment transport properties. A high silt load of the Suam River (estimated at 10 million tons per year) means that erosion plays a major role in the nutrient loading to the Turkwel Gorge Reservoir. A close correlation between discharge volume and the total load of most nutrients into the reservoir suggests that yearly nutrient input is a function of total inflow.

Conclusion

The reservoir is characterized by a wide draw-down. This combined with a mostly rocky shoreline has resulted in a poor development of littoral vegetation. The present water level has been maintained since 1992, hence it is unlikely that the reservoir will attain its maximum capacity in the foreseeable future. This has an implication on the multiple use plans for the reservoir since the volume of water available will remain lower than expected.

River inflows exert the greatest influence on the limnological conditions of the reservoir. Flood inflows lead to a decline in Secchi depth, electrical conductivity and total alkalinity. Peak levels of these parameters characterize periods with no inflows. On average, high nutrient levels and loading occur during periods of increased river inflow. However, seasonal variation in surface water dissolved oxygen and pH appears to be mainly regulated by the photosynthetic activity of the euphotic zone.

Vertical profiles of dissolved oxygen and water temperature suggest that the reservoir is monomictic with an irregular mixing time. However, nearly uniform profiles of the main nutrients in most months mean that the turbulent exchange across the water layers is enough to balance nutrient levels but not dissolved oxygen and temperature.

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Authors' addresses: Kiplagat Kotut, Francis M. Muthuri, Botany Department, Kenyatta University, P.O. Box 43844, Nairobi, Kenya;
Stephen G. Njuguna, SPARVS Agency, P.O. Box 122, Limuru, Kenya;
Lothar Krienitz, Institut für Gewässerökologie und Binnenfischerei, Alte Fischerhütte 2, D-16775 Neuglobsow, Germany.