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Limnological characteristics of Lake of the Ozarks, Missouri II: Measurements following formation of a large reservoir upstream[1]

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With 1 figure and 2 tables in the text

Introduction

In this paper, the limnological characteristics of Lake of the Ozarks, Missouri, during summers 1980—1986 are assessed and compared with measurements made during 1976—1979 (JONES & NOVAK 1981) to determine whether changes have resulted from construction of Truman Lake — located on the Osage River immediately above Lake of the Ozarks. Our working hypothesis throughout the study was that creation of this reservoir-series would cause Lake of the Ozarks to become less turbid and, with more light, more productive.

Site description and methods

Although Truman Lake (surface area = 22,510 ha; volume = $1.5 \times 10^9 m^3$) was filled in December 1979, water was impounded at lower elevations starting in summer 1977 (CRUNKILTON et al. 1980). Discharge from Truman Dam is controlled by a weir that directs surface water (average depth = 5 m; in summer 1983 this zone was oxic) over a spillway or through turbines to Lake of the Ozarks (surface area = 24,100 ha; volume = $2.4 \times 10^9 m^3$). The difference in elevation between these two water bodies when both are at pool stage is 14 m.

In this study, data were collected at the same six sites on Lake of the Ozarks as in JONES & NOVAK (1981, Table 1; see that paper for map). During 1984—1986, data were also collected from two additional sites in the former Osage River channel to better describe the gradient of conditions downreservoir. These sites were located four-tenths (Station 2.4) and seven-tenths (Station 2.7) of the distance between the station near the dam (Station 2), and sampling site upreservoir on the Osage Arm (Station 5). Replicate samples were collected from surface waters at each station on three or four sampling dates each summer between late June and early September.

Methods were given in JONES & NOVAK (1981) unless noted otherwise. Total nitrogen was measured by automated block digestion (WALL & GEHRKE 1975) in 1979 and 1980 and by persulfate digestion (D'ELIA et al. 1977) followed by cadmium reduction (USEPA 1979) since 1983. Chlorophyll-a (CHLA) was extracted in acetone/dimethyl sulfoxide (STAUFFER et al. 1979) and estimated by fluorometry (KNOWLTON 1984) during 1982—1985. In 1986, chlorophyll-a was extracted in ethanol (SARTORY & GROBBELAAR 1984) and estimated by fluorometry (KNOWLTON 1984). These methods were found to give comparable results in analyses beforehand. Alkaline phosphatase activity was determined by the spectrophotometric method of HEATH (1986); all activity was attributed to phytoplankton.

Statistical analyses of the variables considered in this study involved construction of linear, additive models to predict the expected value of limnological characteristics in Lake of the Ozarks. These models included the factors: (1) period (two levels, pre- and post-Truman lake), (2) station (six levels), (3) interaction of period and station (12 levels) and (4) hydrology (continuous variable). Inflow data were included as a covariate because JONES & NOVAK (1981) cautioned that water quality varies with inflow; therefore, a simple comparison between data from pre- and post-impoundment periods would not be adequate to interpret whether Truman Lake has affected Lake of the Ozarks.

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Such models were developed from daily measurements of limnological variables combined with 15-, 20-, 25- and 30-day inflow averages as the hydrological covariate and seasonal averages combined with June—July and June—July—August inflow values as the covariate. The resultant models for all data sets were identical in the significant factors included and the ordering of station, period, and period by station means; P-values reported in the text were calculated from the data set of daily values combined with 20-day average inflow as a covariate. These models were appropriate for the data, and statistical assumptions were checked (Milliken & Johnson 1984).

Although the interaction of period and station factors was not a significant component of any model tested ($0.32 \leq P \leq 0.85$ for chlorophyll, phosphorus and Secchi depth models), models which included an interaction term were run to calculate mean values for station-period combinations. These means were examined for consistent patterns of differences.

Interpretation of P-values (the probability that a calculated test statistic is at least as extreme as that actually observed if the null hypothesis is true), is that they provide an inverse measure of the strength of evidence against the null hypothesis. In the text, we use the term significant to reflect a P-value of less than 0.05 in the usual sense. Because the statistical tests we conducted were not independent, we also consider P-values between 0.05 and 0.10 as providing moderate evidence against the null hypothesis, and give attention to consistent patterns in station differences throughout the analysis.

Results and discussion

Seasonal mean values averaged by station for the period before and since filling of Truman Lake are similar (Table 1). Although the Osage River no longer enters the lake directly, the longitudinal gradient of TP concentrations, inorganic suspended solids and water clarity from the headwaters to the dam measured in 1980—1986 is of the same magnitude as in the earlier study (Table 1, Jones & Novak 1981). Values of phosphorus and suspended solids are higher and transparency is lower in the riverine reach of Lake of the Ozarks (Station 6) than in the surface waters of Truman Lake (Table 2). We believe input of water to Lake of the Ozarks via Truman Dam is sufficient to scour unconsolidated materials from the former Osage River channel and results in water quality characterized by high values of inorganic suspended solids and poor water clarity. The CHLA : TP ratio is generally lower here than in Truman Lake or elsewhere in Lake of the Ozarks. But, in contrast to the previous study, CHLA and TP data in all but one season (1981) fit within the confidence of the empirical relation for these variables (Jones & Bachmann 1976) — in the previous study values from this site were usually below the lower confidence limit. The exception is a year of high inflow when CHLA : TP ratios are lower throughout the reservoir. Higher CHLA : TP values ($P < 0.001$) in this reach suggest conditions have changed. Nutrients may be more available and light may be more favorable for algal growth. Also, this reach now receives lake phytoplankton from the upper reservoir, which may bė better adapted to growth while in transit downreservoir than river-born algae (Soballe & Bachmann 1984) that entered the lake during the earlier study.

At the lacustrine sites (all stations except 5 and 6) nutrient values and algal biomass were typical of mesotrophic conditions, and concentrations of inorganic suspended solids were moderate (> 80 % of the daily values were $< 3.6 \text{ mg} \cdot l^{-1}$, the median value found in a broad range of midwestern reservoirs, unpublished data). At these sites, algal biomass largely determined water clarity; the Secchi and CHLA data fit the empirical relation for these variables found in waterbodies with low inorganic turbidity (Jones & Bachmann 1978). The CHLA and TP data also fit that empirical relation (Jones & Bachmann 1976). The Niangua Arm (Station 4) was generally the most fertile and least

Table 1. Mean and standard error of the mean for parameters measured at stations in Lake of the Ozarks during summers 1980–1986. Mean values during 1976–1979 for the same stations (Jones & Novak 1981) are included for comparison. Data from the Osage Arm are arranged by station in order of location from the headwaters to Bagnell Dam to best demonstrate the longitudinal gradient in this reservoir; data from the minor arms follow. Approximate distance between the stations and Bagnell Dam are: Osage Arm Station 6 — 94 km, Station 5 — 62 km, Station 2.7 — 43 km, Station 2.4 — 29 km, Station 2 — 1.6 km, Gravois Arm Station 1 — 14 km; Grand Glaize Arm Station 3 — 34 km; Niangua Arm Station 4 — 54 km. The distance between Bagnell Dam and Truman Dam is about 150 km.

Paramater	Station	1980	1981	1982	1983	1984	1985	1986	1980—1986	1976—1979
Total phosphorus $mg \cdot m^{-3}$	6	49.5 ± 3.9	113.3 ± 17.2	88.3 ± 14.6	68.2 ± 4.1	89.7 ± 14.3	67.0 ± 7.2	61.0 ± 6.7	77.7 ± 5.6	92
	5	28.0 ± 2.5	86.3 ± 7.7	45.0 ± 6.7	36.8 ± 3.2	45.2 ± 9.8	49.1 ± 12.3	45.5 ± 4.1	49.4 ± 4.4	56
	2.7	–	–	–	–	34.6 ± 8.0	35.7 ± 7.0	27.2 ± 0.3	–	–
	2.4	–	–	–	–	28.6 ± 5.5	30.7 ± 3.6	23.0 ± 4.0	–	–
	2	14.6 ± 1.5	47.0 ± 12.8	28.3 ± 7.1	24.8 ± 5.9	22.3 ± 3.1	23.9 ± 3.8	17.7 ± 2.9	25.9 ± 3.0	31
	1	14.3 ± 1.9	31.0 ± 6.4	28.7 ± 8.4	23.3 ± 4.3	17.2 ± 1.1	21.0 ± 2.6	15.9 ± 1.5	21.6 ± 1.8	25
	3	16.5 ± 1.1	49.4 ± 8.8	34.0 ± 8.5	31.2 ± 2.8	22.2 ± 2.9	26.7 ± 4.4	21.9 ± 2.3	29.0 ± 2.7	29.9
	4	18.2 ± 0.8	59.4 ± 6.7	36.6 ± 6.2	31.3 ± 7.0	24.5 ± 0.8	35.8 ± 8.6	27.6 ± 2.4	33.9 ± 3.1	35.7
Total nitrogen $mg \cdot l^{-1}$	6	0.57 ± 0.12	–	–	0.53 ± 0.14	1.07 ± 0.29	0.53 ± 0.10	0.60 ± 0.07	0.67 ± 0.08	0.5
	5	0.63 ± 0.13	–	–	0.65 ± 0.09	0.80 ± 0.13	0.61 ± 0.12	0.55 ± 0.02	0.65 ± 0.05	1.2
	2.7	–	–	–	–	0.82 ± 0.09	0.58 ± 0.09	0.35 ± 0.03	–	–
	2.4	–	–	–	–	0.74 ± 0.12	0.64 ± 0.07	0.29 ± 0.02	–	–
	2	0.70 ± 0.25	–	–	0.41 ± 0.14	0.52 ± 0.08	0.61 ± 0.05	0.24 ± 0.02	0.50 ± 0.06	2.0
	1	0.47 ± 0.07	–	–	0.36 ± 0.08	0.45 ± 0.10	0.46 ± 0.01	0.29 ± 0.02	0.40 ± 0.03	–
	3	0.73 ± 0.20	–	–	0.80 ± 0.09	0.59 ± 0.08	0.53 ± 0.04	0.31 ± 0.02	0.57 ± 0.05	–
	4	0.47 ± 0.12	–	–	0.39 ± 0.06	0.66 ± 0.08	0.58 ± 0.11	0.36 ± 0.07	0.50 ± 0.04	–
Total alkalinity as $mg \cdot l^{-1}$ $CaCO_3$	6	119 ± 5	73 ± 3	105 ± 0	113 ± 3	96 ± 2	92 ± 1	101 ± 2	98 ± 3	102
	5	101 ± 4	78 ± 3	103 ± 2	101 ± 2	99 ± 2	88 ± 2	102 ± 2	95 ± 2	95
	2.7	–	–	–	–	97 ± 2	90 ± 1	104 ± 4	–	–
	2.4	–	–	–	–	99 ± 3	89 ± 1	102 ± 4	–	–
	2	94 ± 1	86 ± 7	90 ± 2	97 ± 2	97 ± 1	87 ± 1	98 ± 5	92 ± 2	94
	1	97 ± 1	94 ± 5	95 ± 1	97 ± 1	93 ± 2	89 ± 1	100 ± 3	95 ± 1	96
	3	101 ± 2	86 ± 5	100 ± 2	102 ± 1	97 ± 2	90 ± 1	103 ± 4	96 ± 2	98
	4	109 ± 3	89 ± 4	106 ± 4	111 ± 5	99 ± 3	94 ± 4	110 ± 4	102 ± 4	104

Table 1. (continued).

Paramater	Station	1980	1981	1982	1983	1984	1985	1986	1980—1986	1976—1979
pH	6	7.8 ± 0.1	7.8± 0.2	8.0± 0.03	7.9 ± 0.1	7.9 ± 0.1	8.1 ± 0.1	7.3 ± 0	7.9 ± 0.1	7.8
	5	8.2 ± 0.1	8.0± 0.2	8.2± 0.1	8.3 ± 0.2	8.4 ± 0.2	8.5 ± 0.1	7.8 ± 0.2	8.2 ± 0.1	8.1
	2.7	–	–	–	–	8.4 ± 0.2	8.5 ± 0.2	8.1 ± 0.2	–	–
	2.4	–	–	–	–	8.2 ± 0.1	8.3 ± 0.1	7.8 ± 0.2	–	–
	2	8.2 ± 0.1	8.4± 0.2	8.6± 0.2	8.6 ± 0.1	8.4 ± 0.1	8.2 ± 0.1	7.6 ± 0.1	8.3 ± 0.1	8.3
	1	8.2 ± 0.1	8.4± 0.2	8.5± 0.2	8.3 ± 0.1	8.6 ± 0.1	8.7 ± 0.1	7.8 ± 0	8.3 ± 0.1	8.2
	3	8.2 ± 0.1	8.5± 0.2	8.5± 0.2	8.5 ± 0.1	8.4 ± 0.1	8.5 ± 0.1	7.8 ± 0.3	8.3 ± 0.1	8.4
	4	8.2 ± 0.1	8.4± 0.2	8.4± 0.1	8.4 ± 0.1	8.5 ± 0.1	8.5 ± 0.1	7.8 ± 0.2	8.3 ± 0.1	8.3
Specific Conductance micromhos/cm 25 C	6	373 ±11	200 ± 7	–	326 ±10	250 ±11	251 ± 6	294 ±12	274 ±13	290
	5	321 ±15	224 ±12	–	310 ± 8	253 ± 2	238 ± 1	296 ±11	268 ± 9	266
	2.7	–	–	–	–	254 ± 2	235 ± 2	308 ± 6	–	–
	2.4	–	–	–	–	259 ± 2	235 ± 6	308 ± 6	–	–
	2	307 ± 6	220 ±15	–	290 ±10	255 ± 4	230 ± 6	293 ±10	261 ± 8	261
	1	308 ±10	247 ±12	–	289 ±11	245 ± 5	231 ± 2	299 ± 7	266 ± 7	268
	3	311 ±10	227 ±14	–	302 ±13	250 ± 9	231 ± 4	300 ± 7	265 ± 8	263
	4	325 ± 8	224 ±10	–	304 ±11	246 ± 6	241 ± 4	305 ± 9	269 ± 9	268
SECCHI disk transparency m	6	0.6 ± 0.1	0.3± 0.1	0.5± 0.03	0.6 ± 0.1	0.3 ± 0.02	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.03	0.5
	5	1.3 ± 0.2	0.5± 0.1	0.9± 0.2	1.4 ± 0.1	0.9 ± 0.2	1.0 ± 0.2	1.0 ± 0.2	1.0 ± 0.1	1.2
	2.7	–	–	–	–	1.3 ± 0.2	1.2 ± 0.3	1.8 ± 0.2	–	–
	2.4	–	–	–	–	1.7 ± 0.3	1.3 ± 0.2	2.3 ± 0.2	–	–
	2	2.1 ± 0.3	1.1± 0.2	1.5± 0.3	2.0 ± 0.3	2.5 ± 0.02	1.7 ± 0.1	2.8 ± 0.2	2.0 ± 0.1	2.0
	1	2.0 ± 0.2	1.3± 0.1	1.5± 0.3	2.1 ± 0.2	2.5 ± 0.5	1.6 ± 0.1	2.9 ± 0.2	2.0 ± 0.1	2.2
	3	1.9 ± 0.2	1.0± 0.1	1.3± 0.2	2.1 ± 0.2	2.0 ± 0.2	1.4 ± 0.2	2.4 ± 0.2	1.7 ± 0.1	1.7
	4	1.7 ± 0.1	0.7± 0.1	1.4± 0.2	1.7 ± 0.3	1.4 ± 0.1	1.2 ± 0.2	1.8 ± 0.2	1.4 ± 0.1	1.4
Inorganic suspended solids mg · l^{-1}	6	8.2 ± 2.2	25.3± 9.1	18.1± 4.1	12.3 ± 3.6	19.7 ± 1.7	11.0 ± 2.0	9.0 ± 3.6	14.8 ± 2.0	–
	5	1.8 ± 0.3	13.8± 6.1	4.7± 0.9	3.1 ± 0.8	6.3 ± 2.1	4.3 ± 1.3	4.8 ± 1.2	5.8 ± 1.2	–
	2.7	–	–	–	–	2.8 ± 0.8	2.8 ± 0.8	1.7 ± 0.4	–	–
	2.4	–	–	–	–	2.5 ± 0.4	2.3 ± 0.6	1.0 ± 0.2	–	–
	2	0.8 ± 0.3	2.3± 0.4	3.1± 0.9	1.6 ± 0.7	2.3 ± 0.5	1.8 ± 0.5	1.0 ± 0.2	1.8 ± 0.2	–
	1	0.9 ± 0.5	1.9± 0.5	2.4± 1.1	1.2 ± 0.2	5.1 ± 0.4	1.2 ± 0.2	0.9 ± 0.1	1.9 ± 0.3	–
	3	1.4 ± 0.5	3.4± 0.5	2.9± 1.0	1.9 ± 0.5	2.9 ± 0.1	2.2 ± 0.7	1.1 ± 0.1	2.2 ± 0.2	–
	4	1.0 ± 0.4	4.5± 1.0	2.9± 0.7	2.0 ± 0.6	3.0 ± 0.7	2.9 ± 1.2	2.4 ± 0.7	2.8 ± 0.3	–

Table 1. (continued).

Paramater	Station	1980	1981	1982	1983	1984	1985	1986	1980—1986	1976—1979
Organic suspended solids mg · l^{-1}	6	3.6 ± 0.6	5.0± 1.4	4.3± 1.1	3.5 ± 0.3	5.5 ± 1.0	2.7 ± 0.2	5.2 ± 2.2	4.3 ± 0.5	–
	5	2.8 ± 0.3	4.1± 1.3	1.5± 0.1	2.2 ± 0.6	2.9 ± 0.3	2.1 ± 0.5	1.8 ± 0.3	2.5 ± 0.3	–
	2.7	–	–	–	–	1.8 ± 0.5	1.8 ± 0.3	1.5 ± 0.1	–	–
	2.4	–	–	–	–	1.3 ± 0.2	1.5 ± 0.2	1.7 ± 0.3	–	–
	2	2.0 ± 0.3	2.6± 0.4	2.4± 0.5	2.0 ± 0.3	1.3 ± 0.1	1.2 ± 0.2	1.0 ± 0.2	1.8 ± 0.2	–
	1	2.1 ± 0.1	2.6± 0.3	2.2± 0.5	1.9 ± 0.2	2.6 ± 0.1	2.0 ± 0.2	1.1 ± 0.1	2.1 ± 0.1	–
	3	2.3 ± 0.1	2.8± 0.5	2.4± 0.3	2.6 ± 0.7	1.7 ± 0.2	1.9 ± 0.4	1.3 ± 0.3	2.1 ± 0.2	–
	4	2.3 ± 0.3	2.8± 0.5	1.5± 0.1	1.5 ± 0.2	2.0 ± 0.3	2.3 ± 0.3	1.8 ± 0.2	2.1 ± 0.1	–
Chlorophyll-a mg · m^{-3}	6	21.7 ± 3.6	11.8± 2.3	35.5±10.9	24.0 ± 7.4	22.2 ± 4.8	19.0 ± 1.5	18.1 ± 3.0	21.1 ± 2.1	14.2
	5	13.2 ± 2.5	16.7± 2.1	17.0± 1.6	14.0 ± 4.7	19.5 ± 3.0	20.2 ± 5.8	20.7 ± 3.3	17.6 ± 1.3	12.6
	2.7	–	–	–	–	15.0 ± 2.8	21.2 ± 5.0	12.8 ± 0.9	–	–
	2.4	–	–	–	–	15.7 ± 0.8	19.1 ± 2.4	11.2 ± 1.9	–	–
	2	9.1 ± 1.2	11.3± 2.7	29.1± 6.3	13.9 ± 1.8	13.4 ± 1.0	17.5 ± 2.4	6.7 ± 0.7	14.1 ± 1.6	10.5
	1	7.2 ± 0.3	10.6± 2.5	25.8± 4.2	16.7 ± 2.8	11.9 ± 1.7	15.0 ± 0.8	6.3 ± 0.5	13.0 ± 1.4	11.8
	3	9.6 ± 0.8	14.6± 2.2	30.5± 5.8	12.7 ± 2.4	17.0 ± 1.8	20.8 ± 4.4	10.7 ± 1.9	16.4 ± 1.6	14.0
	4	10.6 ± 0.9	18.0± 3.0	22.1± 1.7	15.5 ± 2.9	18.7 ± 2.7	25.9 ± 6.5	15.3 ± 2.6	18.2 ± 1.5	15.8

Table 2. Mean values of limnological parameters in the surface waters of Truman Lake near Truman Dam during summers 1982 and 1983.

Parameter	1982	1983
Total phosphorus $mg \cdot m^{-3}$	50	28
Total nitrogen $mg \cdot l^{-1}$	0.72	0.74
Inorganic suspended solids $mg \cdot l^{-1}$	3.4	2.7
Organic suspended solids $mg \cdot l^{-1}$	1.8	1.6
SECCHI transparency m	1.2	1.6
Chlorophyll-a $mg \cdot m^{-3}$	21	13

transparent of the lacustrine sites, in part because this arm receives the greatest inflow of domestic wastewater. Water quality at Station 5 (Table 1) was intermediate between the riverine area (Station 6) and lacustrine sites.

While the downreservoir gradient was similar from summer to summer, values at all sites varied in relation to inflow. Coefficients of correlation from 0.63 to 0.88 were calculated for relations between inflow and various water quality variables. Concentrations of TP and inorganic suspended solids were lower and transparency measurements were greater in dry years (1980, 1984 and 1986) than years of high inflow (1981, 1982 and 1985). Conservative parameters like alkalinity and specific conductance were inversely related to inflow, but showed only a slight downreservoir gradient (Table 1).

After adjusting for differences in seasonal inflow, we found a 25% increase in CHLA (from 13.4 to 16.7 $mg \cdot m^{-3}$) and a 26% decrease in TP (from 49.7 to 38.9 $mg \cdot m^{-3}$) between the two study periods. These changes were most pronounced at stations along the Osage channel, which were most directly affected by the new flow regime. The evidence was significant upreservoir (stations 5 and 6), moderate near the dam (Station 2) and minimal in the minor arms (stations 1, 3 and 4). These changes resulted in an overall increase of 46% in the CHLA:TP ratio (from 0.36 to 0.53, $P < 0.001$) during the new flow regime. We also have examined the CHLA:TP ratio in several Missouri reservoirs with water quality similar to Lake of the Ozarks, using these same methods over the same study period, and found no change in the CHLA:TP ratio in them (unpublished data). From our analyses, we concluded that the increase in CHLA:TP is not an artifact of the methods and that Lake of the Ozarks is now more productive.

Inorganic suspended solids were not routinely measured in the earlier study, so we could not directly test for a change. Indirect evidence, however, suggests values have decreased. There is a negative relation between CHLA:TP and the concentration of inorganic suspended solids in this water body ($r = -0.59$, $N = 54$ seasonal means during 1979—1986, $P < 0.001$) and others in the midwest (HOYER & JONES 1983). High concentrations of inorganic suspended solids decrease the expected CHLA values per unit of TP. The measured increase in CHLA:TP in this reservoir, therefore, indicates a possible reduction in inorganic suspended solids. Also, while SECCHI transparency has not changed ($P > 0.7$), the SECCHI:CHLA ratio has decreased significantly (from 0.20 to 0.12, $P < 0.001$). Both algal biomass and inorganic suspended solids are inversely related to water clarity, but factors controlling this relation are complicated (EDMONDSON 1980, PREISENDORFER 1986). Simply stated, attenuation of light depends on the number of particles and their surface area. In this lake, an increase in algal biomass (based on CHLA data) with no change in transparency suggests a concurrent decrease in inorganic suspended solids. We do not have data to test this hypothesis directly and recognize that changes other than a reduction in the mass of suspended solids could also explain our measurements. When taken together, however, the CHLA : TP and Secchi : CHLA data point toward an overall decrease in inorganic suspended solids in Lake of the Ozarks.

Our data set for nitrogen was incomplete, so we could not test for a change between periods. In 1979 the reservoir was nitrogen-rich. Seasonal mean values ranged from 1.2 to 3.1 mg $\cdot$ l^{-1} and ratios of TN : TP indicated the reservoir was P limited. Data collected in the later study, however, indicate this element may limit algal biomass at some sites. There is a general trend for seasonal mean TN : TP ratios to increase downstream. Values were usually > 17 at the lacustrine sites, suggesting that P limits algal biomass (Forsberg & Ryding 1980). Alkaline phosphatase data, used to assess the P status of phytoplankton, also supported this hypothesis (Fig. 1 a). In 1984 and 1985 alkaline phosphatase values, normalized for chlorophyll-a, increased downreservoir. Elser & Kimmel (1985) found a similar within-reservoir transition in P deficiency. Inflow to the reservoir, and presumably nutrient supply, during summer 1985 was over twice that during 1984. Alkaline phosphatase values reflect this differences — values indicate phytoplankton at all sites was more P deficient in 1984. In addition, TN : TP values were higher in 1984 indicating a greater potential for P limitation. Temporally, values were inversely related to inflow during both summers (Fig. 1 b).

In the earlier study low CHLA : TP values at the riverine site (Station 6) were attributed to high turbidity, low light and short residence time (Jones & Novak 1981). But low values measured during the later study may, in part, result from N limitation. Seasonal mean TN : TP values at this site ranged between 8 and 12, and the CHLA : TN ratio was near or exceeded the upper limit for these variables measured in lakes with a broad range of TN values (Forsberg & Ryding 1980). Both of these ratios suggest N

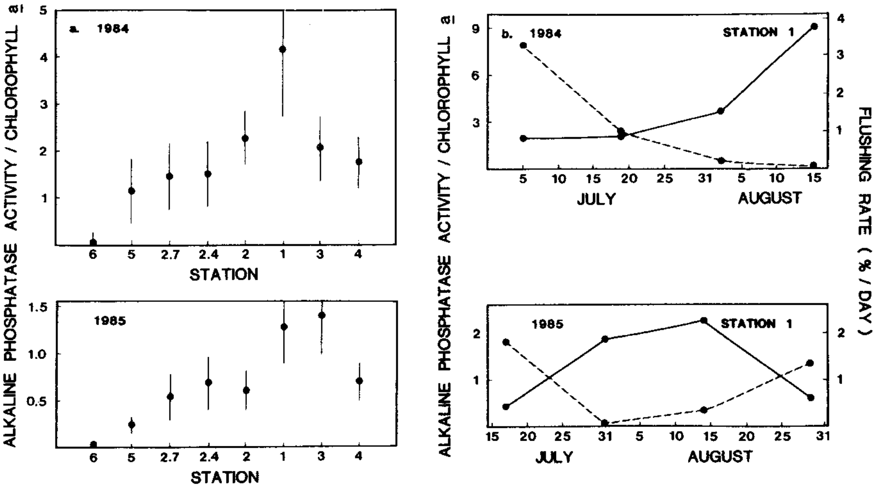

Fig. 1. Left panels: Mean and standard error of alkaline phosphatase activity values normalized for chlorophyll-a (relative units) in surface water algae at stations in Lake of the Ozarks during summer 1984 and 1985. Right panels: Alkaline phosphatase activity values normalized for chlorophyll-a (relative units) in surface water algae at Station 1 on sampling dates in 1984 and 1985 (solid line). Also plotted is the daily hydrologic flushing rate (dashed line) averaged over the 15 days prior to sample collection. Values averaged over 5, 10 and 20 days prior to sample collection show a similar pattern.

deficiency. The CHLA : TN ratio was also high at the lacustrine sites when the seasonal TN : TP ratio was < 17. Among all sites relation between CHLA : TP and TN : TP was positive ($r = 0.49$, $n = 36$, $P < 0.01$) which was consistent with the findings of SMITH (1982).

Conclusions

Based on input-output models (VOLLENWEIDER 1975) and studies in other reservoirs (GLOSS et al. 1980) the external loading of nutrient and inorganic materials to Lake of the Ozarks should be lower with Truman Lake upstream. Processes acting on impounded Osage River water — such as nutrient uptake by algae and sedimentation of particulate materials — now take place in Truman Lake before surface water from that reservoir enters Lake of the Ozarks. Lower TP concentrations in the post-construction survey, especially at sites along the Osage Arm, suggest decreased loading of that element. Higher CHLA values suggest the lake is more productive despite the reduction in TP, the limiting element at most sites. Indirect evidence suggests that conditions are more favorable for algal growth because inorganic suspended solids are lower. A downresevoir gradient in water quality dominates the limnological characteristics of this reservoir, as in the earlier study and in other mainstream reservoirs (SOBALLE & BACHMANN 1984, ELSER & KIMMEL 1985). This gradient is now caused by scouring processes in the former river channel after water passes from Truman Lake.

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