WATER AND NUTRIENT BUDGETS FOR CENTER HILL LAKE

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ABSTRACT--Biweekly instantaneous flows and water samples were collected from Center Hill Lake's inflows and from several wastewater treatment plants that discharge into the inflows over an 11-month period from March 1988 through 1989. The nutrient concentrations and stream discharge data were used to estimate the lake's water and nutrient budgets. Analysis indicates correlation between watershed size, stream discharge, and nutrient loads; similar nutrient loads from inflows receiving effluent from wastewater treatment plants and from inflows receiving primarily non-point pollution; and a significant capture of nitrogen and phosphorus within the lake.

Center Hill Lake has evolved over the past 10 years from a hydropower-flood control impoundment in a drainage basin subject to mining and agriculture to a multipurpose lake that supports a variety of recreational activities in a drainage basin maintained by silviculture and small communities. This report presents the estimated nutrient loads of Center Hill Lake's inflows and tailwater for 1988. Also presented are the lake's water, nitrogen, and phosphorus budgets estimated from data collected from March 1988 through January 1989.

MATERIALS AND METHODS

Field Collection--Water samples and instantaneous flow measurements were collected from the following locations: 1) five wastewater treatment plants (WWTPs) that discharge to the inflows of Center Hill Lake; 2) seven inflows (approximately 85% of the lake's total inflow) at a location of obvious current, and, in the case of an inflow that receives WWTP effluent, a significant distance downstream of the WWTP discharge point to ensure mixing between the stream and effluent; 3) seven embayments at a station influenced primarily by the inflow; 4) four main-channel stations; 5) the tailwater during hydropower generation. At the lake stations, water samples were pumped from three to six depths in relation to the thermocline monthly from June 1988 through October 1988. Physical parameters were measured at each lake station every 2 to 5 m using a Hydrolab Surveyor II (Model SVR2-SU). Inflow, WWTP, and tailwater samples as well as water quality measurements were collected beweekly from March 1988 through January 1989. All water samples were collected in sterile plastic containers, preserved with sulfuric acid and stored at 4°C until analysis. At each inflow, velocities were measured with a portable water current meter (Marsh McBirney Model 201D). Discharges at Great Falls Dam and Center Hill Dam were obtained from the United States Army Corps of Engineers, Nashville District. Precipitation and nutrient data were obtained from a monitoring station of the Tennessee Division of Air Pollution Control located near Caney Fork River Mile 49.0.

Laboratory Analyses--All water samples were chemically analyzed by staff at the Tennessee Technological University Water Center using methods approved by the United States Army Corps of Engineers or the Environmental Protection Agency. Total and ortho-phosphate phosphorus concentrations were measured by a persulfate digesting-ascorbic acid colorimetric technique. Nitrite and nitrate-nitrogen concentrations were measured using a Technicon Auto Analyzer II cadmium-reduction procedure. Total nitrogen analyses followed the same procedure as that for nitrite-nitrate, but water samples were first digested with persulfate. Ammonia concentrations were also measured on the Technicon Auto Analyzer II. Organic nitrogen concentrations were calculated by subtracting inorganic nitrogen from total nitrogen. Blands, spikes, and standards were run on >5% of the samples for quality assurance.

Mathematical Analyses--With only discrete measurements of flow and nutrient concentrations available, nutrient loads for the inflows, tailwater, and WWTPs were best estimated by summing the three-point-running-mean products of discharge and nutrient concentration over time (Cooke et al., 1986). The annual load may then be defined by the equation annual load = sum[avg(N_i + [N_{i+1}] + [N_{i+2}]) x avg[Q_i + Q_{i+1} + Q_{i+2})] x T_i x K, where [N] is the nutrient concentration, Q is the stream discharge, T is the time interval, and K is a conversion constant.

Nutrient loads introduced to the lake by precipitation were estimated from cumulative rainfall and nutrient data, reported by the Global Geochemistry Corporation in 1988, by summing the products of rainfall volume over the lake's surface area and nutrient (total phosphorus, total nitrogen, and ammonia) concentration. Nitrite-nitrogen concentrations were reported as "below detection limits;" therefore, that loading was not calculated. Orthophosphorus concentrations were not reported, and loadings were not calculated.

Center Hill Lake's basic water and nutrient budgets for the period of March 1988 through January 1989 were estimated from the equations inflows + precipitation = outflow + evaporation + change in storage and inflow load = outflow load + net sedimentation + change in storage. The Tennessee Valley Authority operates an evaporation station at Carthage, Tennessee, from April to October each year. The evaporation at Carthage for the period from April to October 1988 was reported by W. Hamburger (Tennessee Valley Authority, pers. comm.) to be 1.10 m. Precipitation for the study period was measured at a centrally located basin station and amounted to 1.33 m for the study period (Cookeville Sewage Treatment Plant). Approximately 0.51 m of the total precipitation was accumulated in December 1988 and January 1989.

RESULTS

Loading Estimates--Nutrient loads were estimated for Center Hill Lake's precipitation, inflows, tailwater, and WWTPs. The precipitation loads for total phosphorus, total nitrogen, nitrate, and ammonia-nitrogen from March 1988 through January 1989 were estimated to be 2,050; 141,000; 120,000; and 21,700 kg, respectively.

Nutrient loads for Center Hill Lake's inflows and tailwater for the period of March 2988 through January 1989 are listed in Table 1. Table 2 lists the nutrient loads from each WWTP. The five WWTPs discharge into Center Hill Lake's inflows as follows: the Baxter WWTP into Mine Lick Creek; the Cookeville WWTP into a tributary of Falling Water River; the McMinnville and Sparta WWTPs into tributaries of the Great Falls inflow; the Smithville WWTP into Fall Creek. Figure 1 shows the inflow (in downstream order) and tailwater nutrient loads to and from Center Hill Lake.

Budget Estimates--Table 3 lists Center Hill Lake's water budget for the period of March 1988 through January 1989. The two largest inflows to Center Hill Lake are the Caney Fork River at Great Falls and Falling Water River. Center Hill Lake's nitrogen and phosphorus budgets are listed in Tables 4 and 5, respectively. Nutrient loads for ungaged direct runoff and lake storage were estimated from the average nutrient concentrations of the lake's inflows and main channel stations, respectively.

DISCUSSION

The present study indicates that nutrient loads into Center Hill Lake from direct precipitation are significant. The volume of direct precipitation was observed to be as large as the contribution from the lake's second largest inflow. With the exception of nutrient loads from Great Falls Dam and Falling Water River, precipitation nutrient loads to Center Hill Lake were significantly larger than stream-inflow nutrient loads.

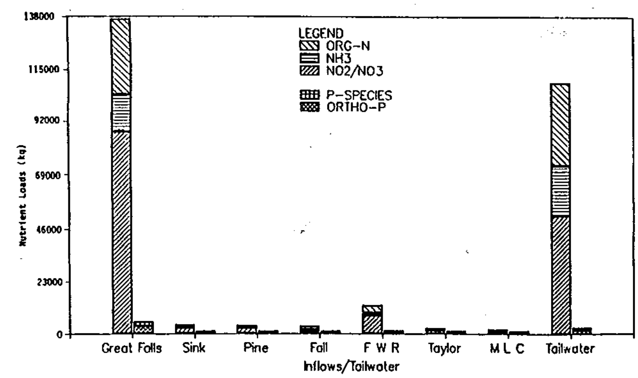

FIG. 1--Nutrient loads for Center Hill Lake's inflows and tailwater. FWR = Falling Water River; MLC = Mine Lick Creek.

The most significant loads introduced to Center Hill Lake were from Great Falls Lake and Falling Water River which, when combined, account for approximately 80% of the lake's drainage basin. The comparison of nutrient loads from inflows receiving WWTP effluent and from inflows receiving primarily non-point pollution indicates that, except for the City of Cookeville, WWTP effluent discharges within Center Hill Lake's watershed do not significantly increase the nutrient load to the lake.

TABLE 1. Inflow and precipitation nutrient loading estimates (in kilograms) from March 1988 through January 1989.

Inflow or outflow	Nitrite-nitrate	Ammonia	Total nitrogen	Organic nitrogen	Total phosphorus	Orthophosphorus
Precipitation	120,000	21,700	141,000		2,050	
Fall Creek	9,300	8,070	31,500	14,200	3,310	1,970
Pine Creek	23,700	2,010	30,800	5,170	658	321
Falling Water River	78,000	11,900	121,000	31,700	11,400	7,260
Sink Creek	24,500	2,030	34,500	8,160	649	246
Taylor Creek	12,300	1,530	18,800	5,030	739	445
Mine Lick Creek	7,570	916	12,300	3,900	1,390	975
Great Falls Lake	857,000	165,000	1,340,000	324,000	51,200	32,100
Tailwater	508,000	208,000	1,070,000	361,000	26,000	13,500

TABLE 2. Loading estimates (in kilograms) at wastewater treatment plants (WWTPs) from March 1988 through January 1989.

WWTP	Nitrite-nitrate	Ammonia	Total nitrogen	Organic nitrogen	Total Phosphorus	Orthophosphorus
Baxter	621	1,510	3,170	1,200	912	626
Cookeville	27,800	23,900	89,300	39,300	16,500	11,100
McMinnville	5,260	8,440	20,400	7,480	2,720	1,710
Smithville	1,900	7,030	20,400	11,500	2,970	1,860
Sparta	807	10,500	15,500	5,310	4,170	2,950

TABLE 3. Water budget for Center Hill Lake from March 1988 through January 1989.

Item	Drainage area (ha)	Mean flow (m^3 x 10^6/ year)	Runoff (m)	Water inflow (%)
Mine Lick Creek	4,999	13.0	0.259	0.636
Falling Water River	32,376	96.5	0.299	4.740
Pine Creek	6,009	20.2	0.335	0.994
Sink Creek	9,635	23.8	0.247	1.170
Fall Creek	3,238	8.1	0.250	0.399
Taylor Creek	8,806	16.0	0.183	0.788
Great Falls Lake	434,356	1,450.0	0.366	71.200
Precipitation[1]	7,374	97.4	1.340	4.790
Ungaged direct runoff[2]	61,730	312.0	0.975	15.300
Total inflow	568,523	2,037.0	0.366	100.000
Evaporation[3]	7,374	81.1	1.100	1.000
Outflow	568,523	1,644.0		80.800
Change in storage		311.9		

[1]Precipitation of 1.33 m at Cookeville wastewater treatment plant.
[2]Calculated value includes seepage, change in storage, and errors.
[3]Measured evaporation of 1.1 m at Carthage, Tennessee.

TABLE 5. Phosphorus budgets (loadings in kilograms, inflows in percentages) for Center Hill Lake from March 1988 through January 1989.

Item	Total phosphorus loading	Phosphorus inflow	Ortho-phosphate	
			Loading	Inflow
Mine Lick Creek	2,450	2.60	1,860	3.30
Falling Water River	19,300	20.10	12,800	23.00
Pine Creek	599	0.64	384	0.69
Sink Creek	726	0.76	257	0.46
Fall Creek	268	0.30	139	0.25
Taylor Creek	1,410	1.50	1,150	2.00
Great Falls Lake	58,000	60.60	33,000	59.00
Precipitation	2,050	2.10		
Ungaged direct runoff[1]	10,900	11.40	6,260	11.20
Total inflow	95,700	100.00	55,900	100.00
Outflow	23,000	24.00	16,400	29.40
Increase in storage[2]	7,030	7.30	3,910	7.00
Captured phosphorus	79,700	83.30	43,400	77.60

[1]Loadings based on average inflow phosphorus concentration of 35 µg/l and ortho-phosphate concentration of 20 µg/l, respectively.
[2]Loadings based on average in-lake phosphorus concentration of 18 µg/l and ortho-phosphate concentration of 10 µg/l, respectively.

Center Hill Lake's water budget from March 1988 through January 1989 indicates that 71 and 5% of the lake's total inflow were from the Great Falls Lake and Falling Water River inflows, respectively. Approximately 15% of the lake's inflow, consisting primarily of direct runoff and seepage, was ungaged during this study. The percentages of nitrogen and phosphorus entering Center Hill Lake through its inflows corresponds to basin size and stream discharge. Sixty percent of the total phosphorus concentration entering the lake was from Great Falls Lake followed by 20% from Falling Water River. Combined, these two inflows contributed 63% of the lake's inflowing total nitrogen concentration. Twenty-three percent of the inflowing total nitrogen was attributed to ungaged runoff and seepage. Approximately 83 and 52% of the inflowing orthophosphorus and total nitrogen concentrations were captured within the lake, respectively.

Based upon this study's 1988 database and the previous studied of Center Hill Lake by Gordon (1976), Morris (1978), and Hunter (1987),

TABLE 4. Nitrogen budgets (loadings in kilograms, inflow in percentages) for Center Hill Lake from March 1988 through January 1989.

Item	Total nitrogen		Nitrate		Ammonia		Organic nitrogen	
	Loading	Inflow	Loading	Inflow	Loading	Inflow	Loading	Inflow
Mine Lick Creek	12,600	0.60	25,800	0.50	6,310	0.37	3,110	0.72
Falling Water River	140,000	7.20	82,100	7.60	15,400	4.50	42,400	9.90
Pine Creek	36,400	1.90	30,300	2.80	1,820	0.53	4,450	1.00
Sink Creek	30,500	1.60	4,760	0.40	2,140	0.62	5,490	1.30
Fall Creek	9,660	0.50	6,260	0.60	1,060	0.31	2,360	0.54
Taylor Creek	22,600	1.20	16,400	1.50	1,760	0.51	3,690	0.85
Great Falls Lake	1,080,000	56.00	581,000	53.60	261,000	75.70	290,000	66.80
Rain	142,000	7.30	120,000	11.00	21,700	6.30		
Ungaged direct runoff[1]	454,000	23.00	237,000	21.90	38,400	11.10	82,500	19.00
Inflow	1,930,000	100.00	1,080,000	100.00	344,000	100.00	434,000	100.00
Outflow	1,180,000	61.20	676,000	62.40	230,000	66.90	279,000	64.40
Storage	254,000	13.10	129,000	11.90	39,100	11.30	89,800	20.70
Captured	1,000,000	51.90	536,000	49.50	153,000	44.40	244,000	56.30

[1]Loadings based on average in-lake total nitrogen concentration of 1.46 mg/l, nitrate concentration of 0.76 mg/l, ammonia concentration of 0.123 mg/l, and organic nitrogen concentration of 0.264 mg/l, respectively.

the following may be concluded. The Caney Fork River inflow from Great Falls Lake contributed an estimated 71.0% of flow, 59.0% of orthophosphorus, and 56.0% of the total nitrogen to Center Hill Lake. The McMinnville and Sparta WWTPs contributed 15.0% of this orthophosphorus (8.8% of total) but only 3.0% of the total nitrogen. Falling Water River contributed an estimated 4.7% of flow, 23.0% of orthophosphorus, and 7.2% of total nitrogen to Center Hill Lake. The Cookeville WWTP contributed most of the orthophosphorus and half of the nitrogen. Overall, the five WWTPs contributed an estimated 18,200 kg of orthophosphorus to the lake over the study period. This is approximately 33.0% of the inflowing orthophosphorus. Direct precipitation contributed an estimated 4.8% of flow, 2.0% of total phosphorus, and 7.3% of total nitrogen to the lake. Ungaged, unmeasured runoff contributed an extimated 15.0% of flow during the study period. Center Hill Lake trapped an estimated 78.0% of incoming ortho-phosphate phosphorus and 52.0% of total nitrogen during the study period.

LITERATURE CITED

COOKE, G. D., E. B. WELCH, S. A. PETERSON, AND P. R. NEWROTH. 1986. Lake and reservoir restoration. Butterworth Publishers, Stoneham, Massachusetts.

GORDON, J. A. 1976. Water quality conditions in Center Hill Reservoir. Nashville District, US Army Corps Eng., Nashville, Tennessee.

HUNTER, M. A. 1987. Effects of stage fluctuations on water quality of Center Hill reservoir. MS thesis, Tennessee Tech. Univ., Cookeville.

MORRIS, J. W. 1978. Dissolved oxygen depletion mechanisms operating in the metalimnion of a deep impoundment. MS thesis, Tennessee Tech. Univ., Cookeville.