PHOSPHORUS LOADING TO MCGRATH AND ELLIS PONDS, KENNEBEC COUNTY, MAINE

By William J. Nichols, Jr., John W. Sowles
and Jeffrey J. Lobao

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below.

Multiply	By	To Obtain
inch (in)	25.40	millimeter (mm)
	2.540	centimeter (cm)
	.0254	meter (m)
foot (ft)	.3048	meter (m)
acre	0.4047	square hectometer (hm^2)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic feet per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cfs-days	2447	cubic meter (m^3)
pounds avoirdupois (lb)	0.4535	kilogram (kg)

Temperatures given in degrees Celsius (°C) can be converted to degrees Fahrenheit by the equation:

$$°F = 1.8°C + 32$$

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By William J. Nichols, Jr[1].,
John W. Sowles[2], and Jeffrey J. Lobao[3]

ABSTRACT

McGrath and Ellis Ponds in south-central Maine have been identified as having nuisance algae blooms. In 1978, a cooperative study between the U.S. Geological Survey and the Maine Department Environmental Protection was begun to evaluate areas in which restoration efforts would best improve water quality of the ponds. Streamflow and phosphorus data were collected from 27 tributaries to the ponds, April 1 through September 30, 1978 and 1979. Phosphorus yields from each tributary watershed were compared to determine their relative importance to the phosphorus budgets of the ponds. Three tributaries that enter the ponds were estimated to contribute 69 percent of the phosphorus load, yet drain only 22 percent of the watershed. Phosphorus input to the ponds would be most easily reduced by instituting phosphorus-control practices in parts of the basin drained by the three tributaries.

INTRODUCTION

McGrath and Ellis Ponds are located in south-central Maine and form the headwaters of the Belgrade Lakes. The quality of water in Ellis Pond has been of local concern for many years because of the nearly annual appearance of nuisance algal blooms which have contributed to the ponds' deteriorating recreational and esthetic values. Numerous complaints led to a reconnaissance study in 1975 by MDEP (Maine Department of Environmental Protection) to determine the cause of the accelerated algal production in the ponds. Results of this study indicated that large concentrations of phosphorus contributed to the ponds were the major cause of the algal blooms (Matthew Scott, oral commun., 1978). Major potential sources of phosphorus loading in the basin identified by the 1975 study included agricultural activities, a logging operation, and the town of Oakland landfill. In 1978 and 1979 the lake and its watershed were studied more intensively by MDEP and the Survey (U.S. Geological Survey).

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Purpose and Scope

This report presents the results of a study to identify phosphorus inputs to McGrath and Ellis Ponds from their common watershed. Phosphorus loadings were estimated for the period April 1 to September 30 during both 1978 and 1979. Phosphorus yields from each tributary watershed were compared to determine their relative importance to the phosphorus budget of the ponds.

Description of Study Area

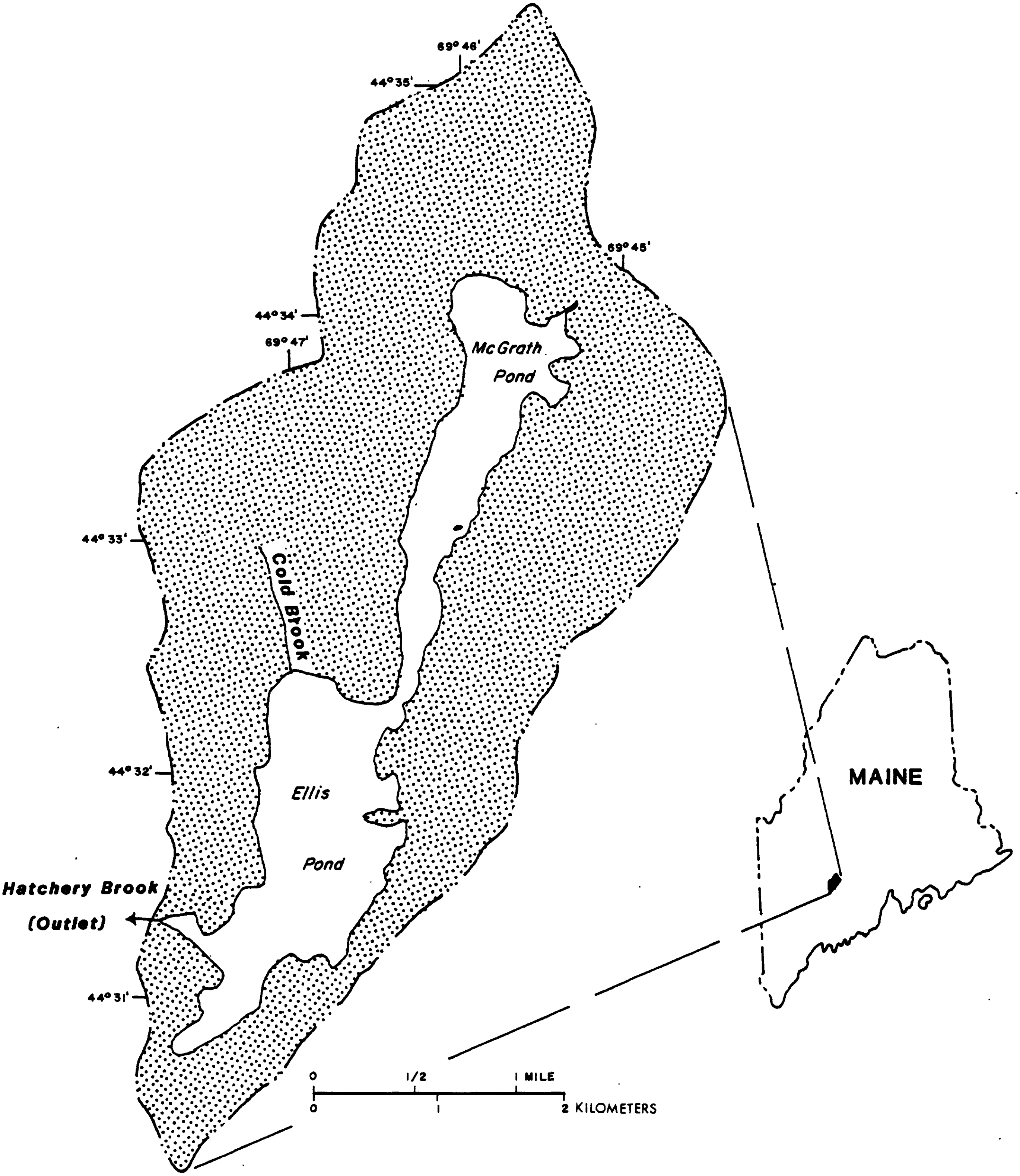
The McGrath and Ellis Ponds watershed drains 5,650 acres in Belgrade and Oakland townships in northern Kennebec County (fig. 1). McGrath Pond, which flows into Ellis, begins a chain of lakes known locally as the Belgrade Lakes. The lakes are temperate and of glacial origin. Their surface area of 1,126 acres constitutes about 20 percent of the total watershed. Physical data for the lake basins (table 1) have been compiled from Cooper (1941).

The climate is humid continental and is characterized by temperature extremes ranging from -30°F to 90°F. The approximately 40 inch annual precipitation is fairly well distributed throughout the year.

As shown in Figure 2, McGrath Pond is shallow with a maximum depth of 27 feet. It mixes throughout the Summer except during hot, calm periods when the upper three feet are temporarily stratified. Ellis Pond, which is as much as 57 feet deep, stratifies in the Spring and remains so until Fall turnover. Algae blooms occur in Ellis Pond, usually in late August and September.

The surficial materials within the McGrath and Ellis Ponds watershed include till, stratified drift, and marine clay. The till, which mantles approximately 99 percent of the watershed, consists of unconsolidated boulders, cobbles, gravel, sand, and silt. Marine clay and stratified drift composed of sand and gravel constitute the remaining 1 percent (fig. 3).

At the south end of Ellis Pond, outcrops exposed by road cuts reveal highly metamorphosed phyllite containing large quartz veins and many schist layers. In the Belgrade Lakes region, biotite-muscovite granite was implaced by an igneous intrusion. The low-lying depression at the contact of these two rock types form the McGrath and Ellis Ponds basin.



BASE FROM U.S. GEOLOGICAL SURVEY 1:62 500
QUADRANGLES: WATERVILLE 1957, AUGUSTA,
NORRIDGEWOCK, VASSALBORO 1956

Figure 1.--Location of study area

Table 1.--Physical data for McGrath and Ellis Ponds

	McGrath Pond	Ellis Pond
Surface area, acres	454	672
Maximum depth, feet	27	57
Mean depth, feet	14.4	23.7
Volume, acre feet	6,556	15,935
Drainage area, acres	2,800	5,650
Average annual flushing rate	0.78	0.63

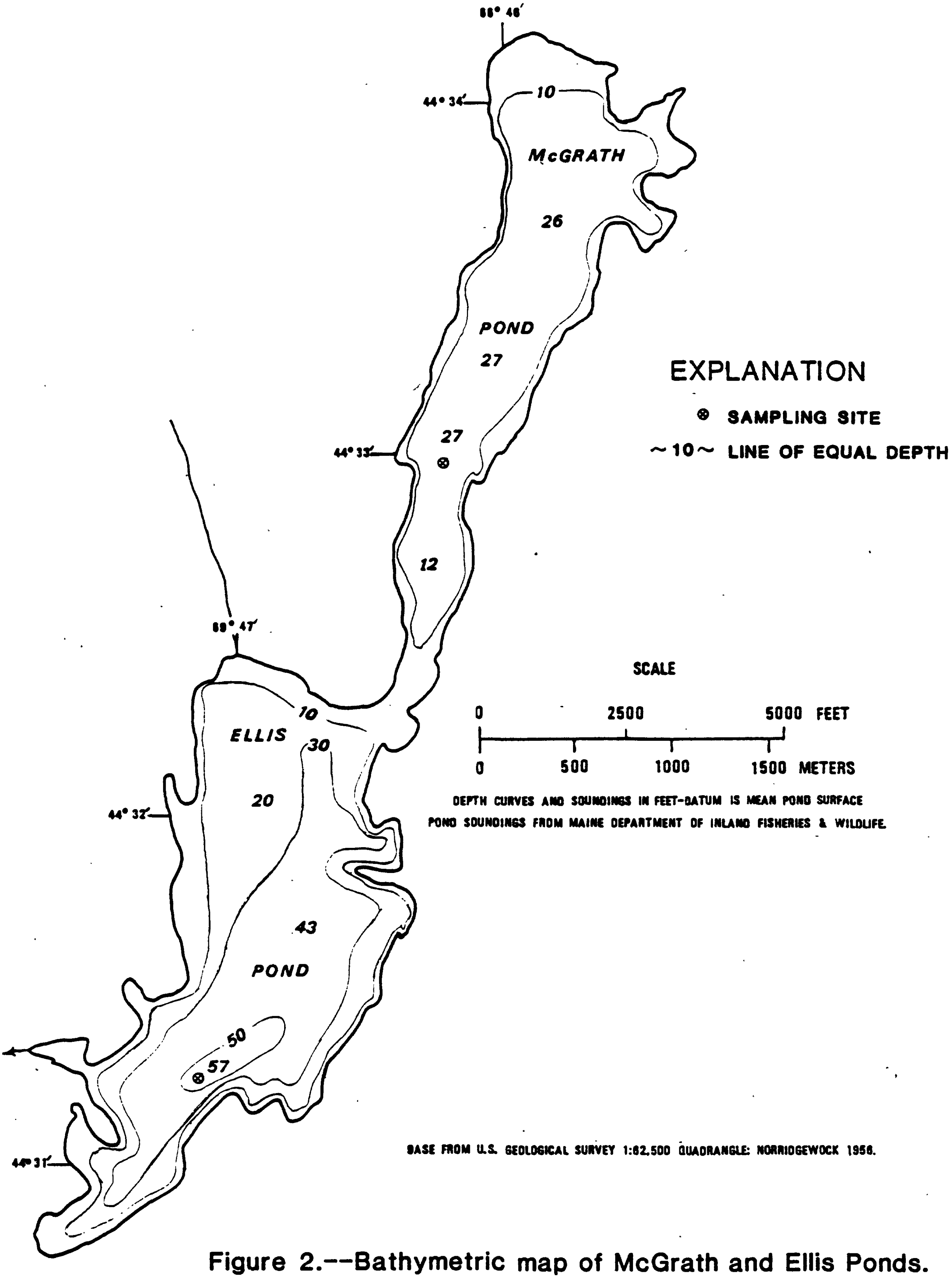
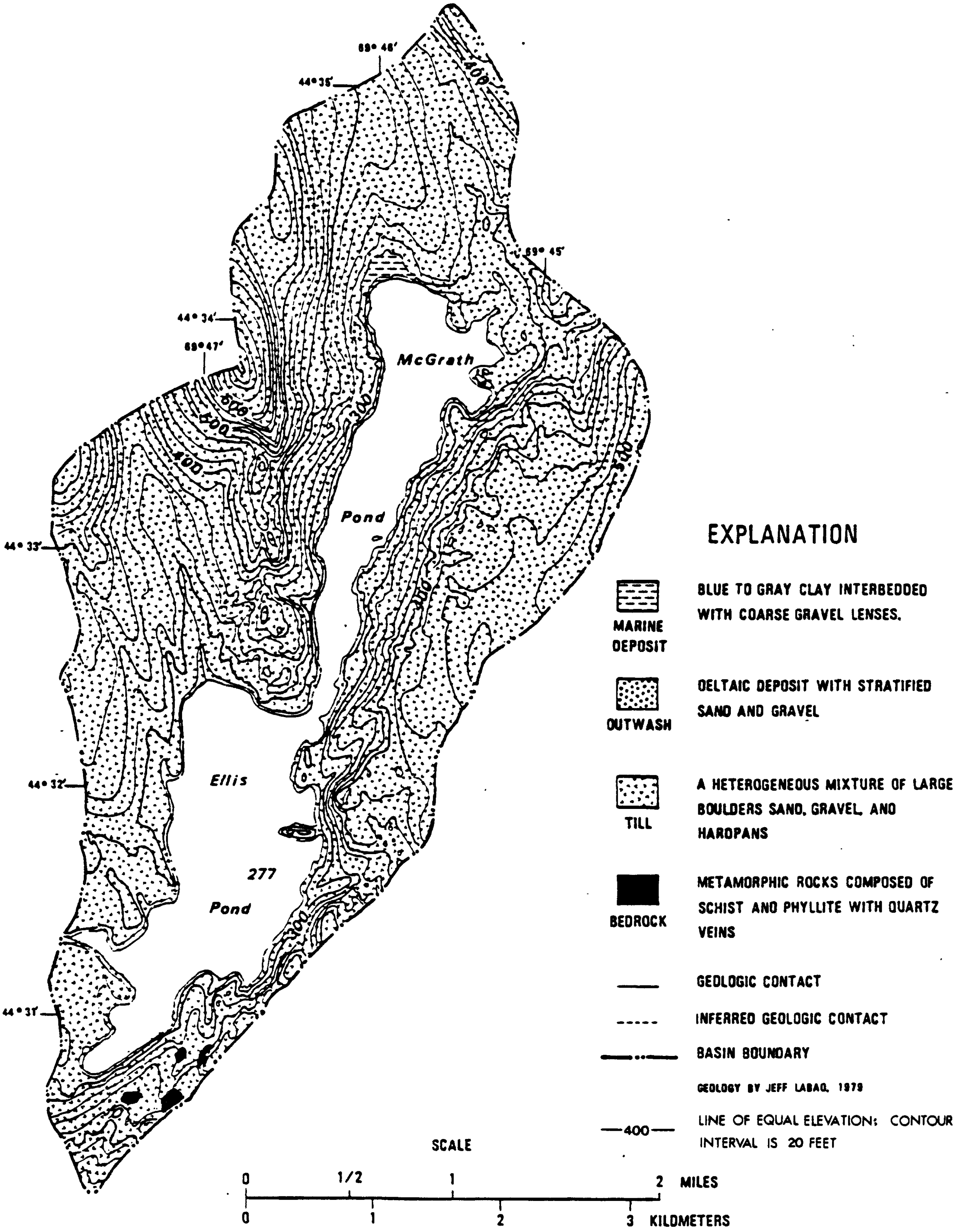


Figure 2.--Bathymetric map of McGrath and Ellis Ponds.



NATIONAL GEODETIC VERTICAL DATUM OF 1929
BASE FROM U.S. GEOLOGICAL SURVEY 1:62,500 QUADRANGLES: WATERVILLE 1957, NORRIDGEWOCK 1956.

Figure 3.--Surficial geology of McGrath and Ellis Ponds drainage basin.

History and Previous Studies

Water-quality problems in Ellis Pond first appeared as early as 1926 when the landlocked salmon (Salmo salar) hatchery operated by the Maine Department of Inland Fisheries and Wildlife experienced a problem of low dissolved oxygen. This hatchery drew its water supply from the hypolimnion of Ellis Pond (Elmer Bickford, personal commun., 1979). Recurrences of that problem caused the hatchery to close in 1942.

Although depressed levels of dissolved-oxygen occured in the 1920's, algae blooms as they occur today were not known. Land-use has remained essentially unchanged during this period; however, agricultural practices have changed. For example, modern farm machinery has facilitated the spreading of manure year-round on frozen ground. Also, dairy operations have become more intensive, resulting in a higher concentration of animals and animal wastes per unit area.

Dissolved-oxygen profiles made during a survey in late August 1940 (Cooper, 1941) showed a complete depletion of dissolved oxygen at depths greater than 36 feet. In 1948, fishery management at Ellis Pond was changed from a predominantly coldwater fishery to a combination coldwater-warmwater fishery. Brown trout (Salmo trutta), the salmonid most tolerant of low dissolved oxygen and warm temperatures, and largemouth bass (Micropterus salmoides) were introduced to replace the declining landlocked salmon and brook trout (Salvelinus fontinalis) stocks. This mixed fishery continues today.

In the fall of 1971, a local landowner informed the MDEP that an algal bloom had developed on Ellis Pond. After a similar complaint was reported in 1975, the MDEP began limnological studies of the pond. The algal blooms in 1976, 1977, and 1979 were composed of two blue-green algae species, *Aphanizomenon flos-aqua* and *Anabaena planktonica*.

Several surveys by the Division of Environmental Evaluation and Lake Studies of MDEP described qualitative lake conditions and attempted to determine phosphorus input sources during 1976-77. Included in those surveys were observations of physical conditions in the lakes, phosphorus concentrations in lake water, and identification of algae genera.

Acknowledgments

Special acknowledgement is made to local residents John and Ruth Zimba, Donald Mairs, Howard Carroll, and Harold MacDougall for assisting in this study.

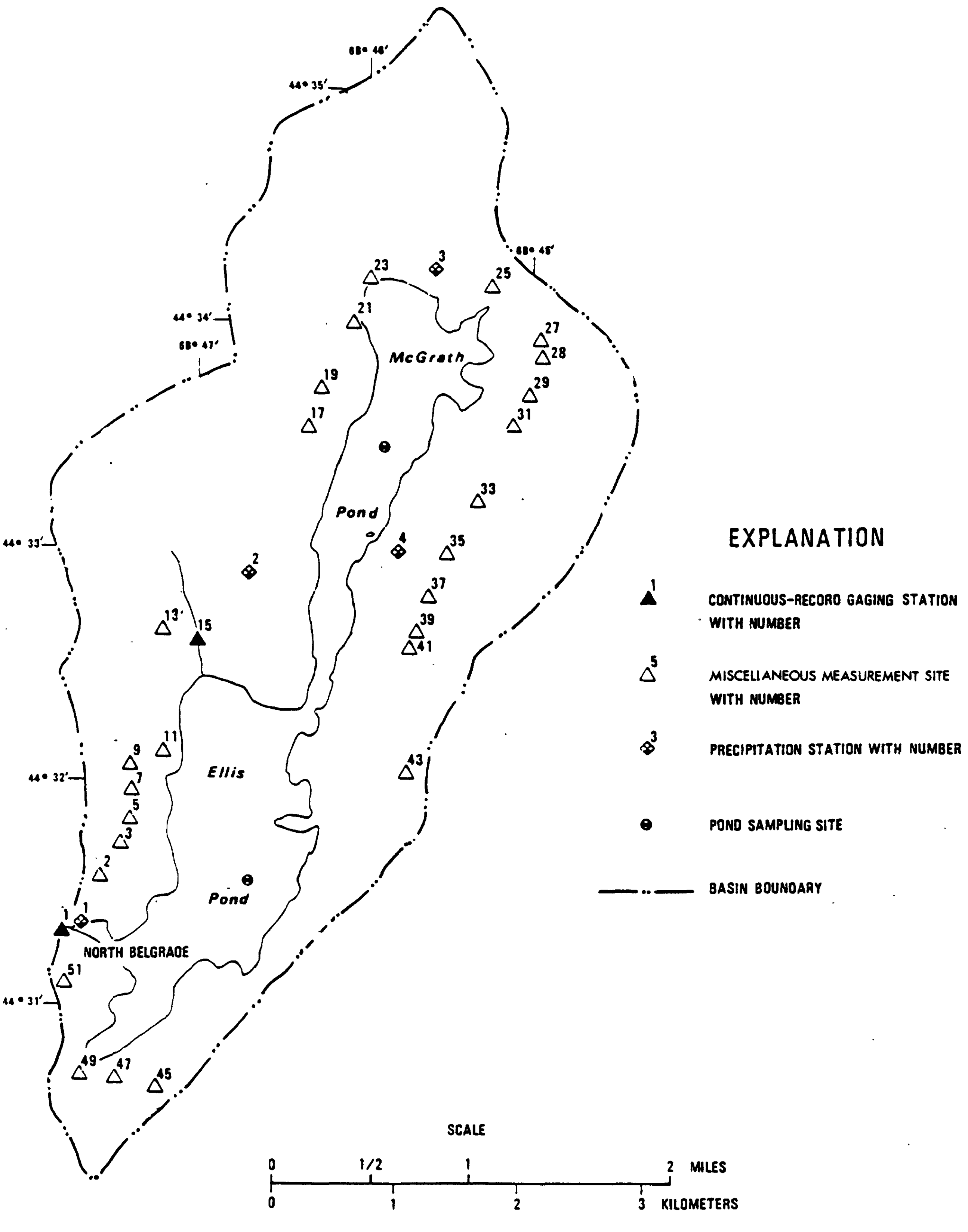
DATA-COLLECTION PROGRAM

Streamflow, water temperature, specific conductance, and total-phosphorus samples were collected every two weeks and more often during selected storms at each of 28 sites within the McGrath and Ellis Ponds watershed (fig. 4). Continuous recording stream gaging stations were established at two of these sites, one on Hatchery Brook, the outlet of Ellis Pond, and another on Cold Brook, the largest stream flowing into Ellis Pond.

In-lake field observations included measurements of pH, color, total alkalinity, and specific conductance. These observations were taken over the deep basin of each pond using the epilimnetic depth-integrated core method. (Cowing and Scott, 1980) Water temperature and dissolved-oxygen concentrations were measured from the top to the bottom of the water column at 3 foot intervals. Samples for laboratory analysis of total phosphorus were also collected at 3-foot intervals.

Samples of lake water were collected with a Kemmerer sampler for analysis of total phosphorus . Fifty milliliters (mL) of the water sample were poured directly into acid-washed 125 mL Erlen-meyer flasks so that storage and digestion could be completed in the same vessel. This method eliminates systematic errors associated with cross-contamination and plating out of phosphorus on plastic sample bottles. Stream samples for total phosphorus were collected directly in acid-washed 125 mL Erlenmeyer flasks. All phosphorus analyses were made by the MDEP laboratory, according to the automated version of the ascorbic acid reduction method (APHA, 1975). Duplicate phosphorus samples were sent periodically to the Survey's laboratory in Doraville, Georgia, for analysis as part of the Survey's water-quality assurance program.

The MDEP laboratory regularly participates in the Survey's Analytical Evaluation Program and the U.S. Enviromental Protection Agency (USEPA) Water Pollution Laboratory Performance Evaluation Program. Results of that participation show that the MDEP results were within 1 to 3 percent of the mean value for total phosphorus reported by the Survey and USEPA. Additionally, standards were run before, during, and after each batch of samples. Accuracy and precision studies were made frequently throughout the year.



BASE FROM U.S. GEOLOGICAL SURVEY 1:62,500 QUADRANGLES: WATERVILLE 1957, NORRIDGEWOCK 1956.

gure 4.--Hydrologic and phosphorus data sites in the McGrath and Ellis Ponds drainage basin.

SURFACE-WATER INFLOW TO MCGRATH AND ELLIS PONDS

Continuous streamflow data was collected on Cold Brook, the largest tributary in the watershed (0.85 mi^2 drainage area), and Hatchery Brook, the basin outflow stream (8.83 mi^2 drainage area). Twenty-six additional miscellaneous sites were measured on the average of seven times during high to low flow to determine the quantity of inflow to the ponds from the area not drained by Cold Brook.

Cold Brook drains till, which constitutes 99 percent of the study watershed. Of the remaining 26 sites, 23 drain till and are ephemeral, whereas the other three drain basins of till, marine deposits, and stratified drift, and flow year round.

Instantaneous flows at each of the 26 miscellaneous sites were compared with the instantaneous flow at the Cold Brook gaging station using linear regressions. The results of these comparisons are summarized in Table 2. Correlation coefficients for the regressions ranged from 0.46 to .99. Figure 5 shows the relationship between flows at site 11 and Cold Brook. The formulas in Table 2 were used to estimate stream discharge for the ungaged tributary streams. An example calculation on table 2 shows the procedure for estimating streamflow. The streamflow records for the Cold Brook gaging station are published in the 1978 and 1979 water resources data reports for Maine (U.S. Geological Survey 1979, 1980).

PHOSPHORUS LOADING TO MCGRATH AND ELLIS PONDS

Phosphorus is generally recognized as the limiting nutrient for primary productivity in most temperate fresh-water lake's (Lee, and others, 1978). This means that, in relation to the quantity of nutrients required for growth, phosphorus is the nutrient least available.

The relative importance of each tributary as a phosphorus contributor in the drainage inflow to McGrath and Ellis Ponds was determined by averaging total phosphorus concentrations of two consecutive sample dates and multiplying this by an estimated discharge (cfs-days) for the interval. The sum of each time-interval phophorus load product is the estimate of total phosphorus load for the study period. Because sampling was biased toward runoff events, loads are not accurate reflections of loading for the period; however, they allow the relative ranking of each tributary according to the total phosphorus balance of McGrath and Ellis Ponds.

Table 2.--Linear regression equations used to compute flows from the small tributaries flowing into McGrath and Ellis Ponds.

(Y = a+bx, where Y is the discharge for the numbered stream, a is a constant, b is a regression coefficient, and x is the flow of Cold Brook.)

Site Number	n (number of measurements)	a	b	r (correlation coefficient)	Drainage area (mi^2)
2	6	0.007	0.029	0.72	.08
3	5	.051	.101	0.86	.05
5	7	.018	.016	0.56	.03
7	8	.020	.008	0.49	.02
9	6	.032	.044	0.53	.03
11	9	-.218	.351	0.99	.31
13	5	-.034	.076	0.98	.08
17	9	.049	.016	0.87	.05
19	5	-.119	.103	0.83	.05
21	11	.117	.174	0.77	.13
23	11	-.025	.490	0.92	.66
25	10	-.375	.772	0.99	.56
27	10	.156	.252	0.95	.32
28	5	.036	.017	0.46	.04
29	6	.023	.091	0.63	.02
31	5	-.542	.464	0.93	.25
33	7	-.033	.052	0.56	.03
35	4	-.075	.164	0.95	.19
37	4	-.005	.022	0.83	.03
39	5	.011	.015	0.99	.05
41	5	-.115	.098	0.82	.08
43	3	-.052	.030	0.94	.05
45	12	-.022	.114	0.97	.12
47	6	.033	.016	0.94	.02
49	9	.011	.032	0.91	.11
51	6	.011	.014	0.73	.03

Example: Site 11-April 1 through May 3, 1978 Cold Brook mean discharge for the period is 6.58 cubic feet per second (ft^3/s)

$$Y = -.218 + (.351 \times 6.58\ ft^3/s) = 2.09\ ft^3/s \quad \text{(Site 11)}$$

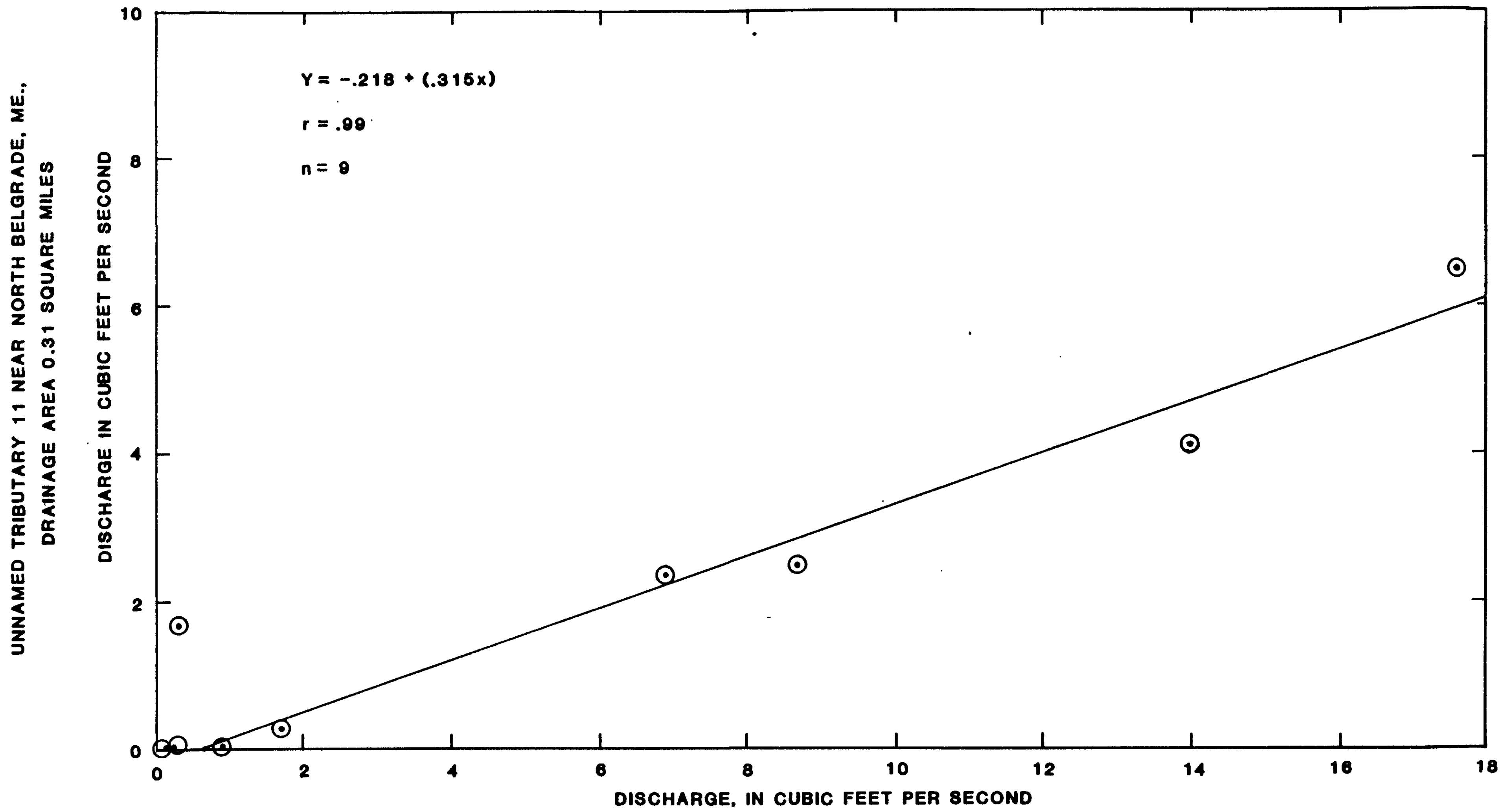


Figure 5.--Correlation of streamflow measurements, Cold Brook and unnamed tributary 11

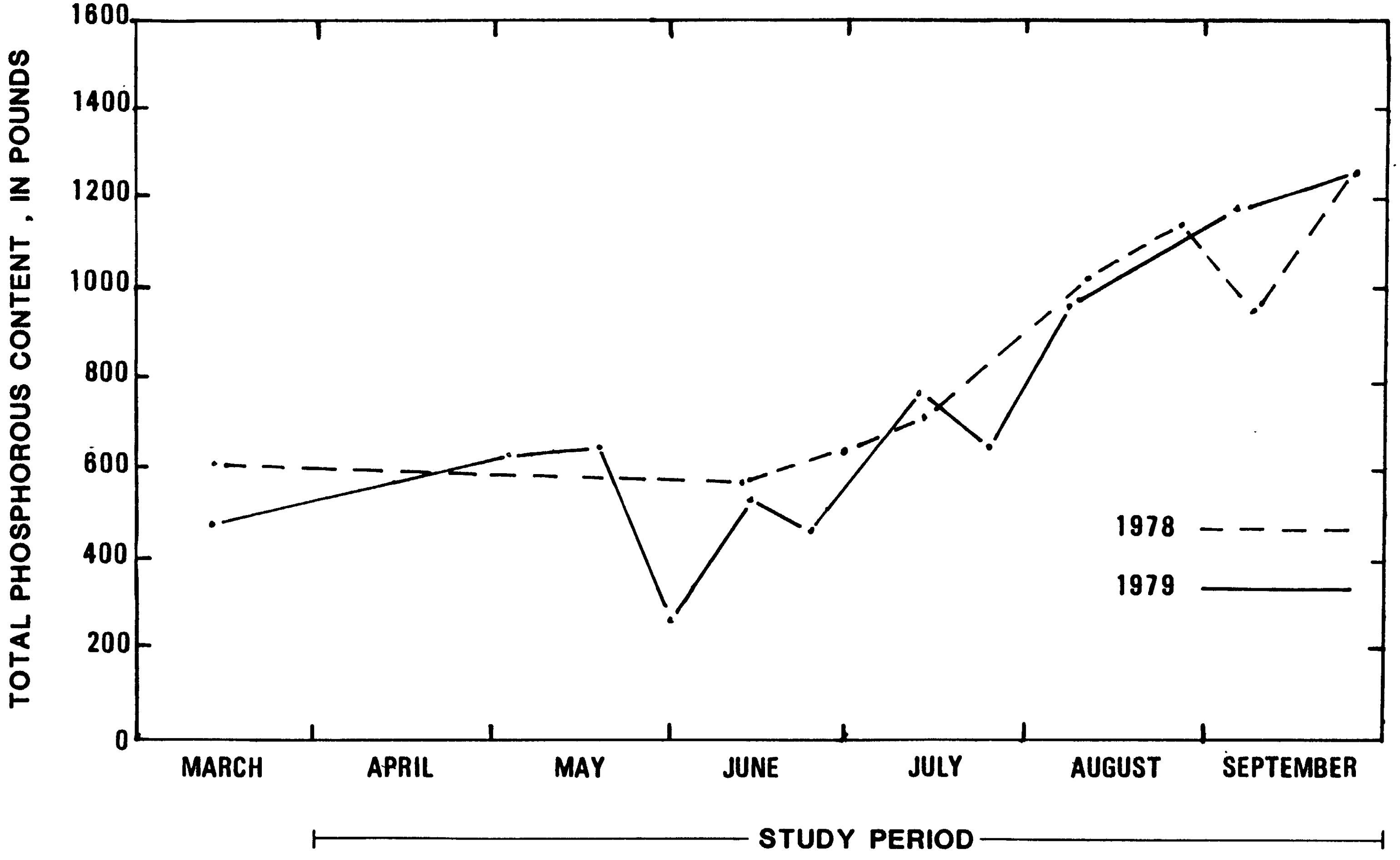
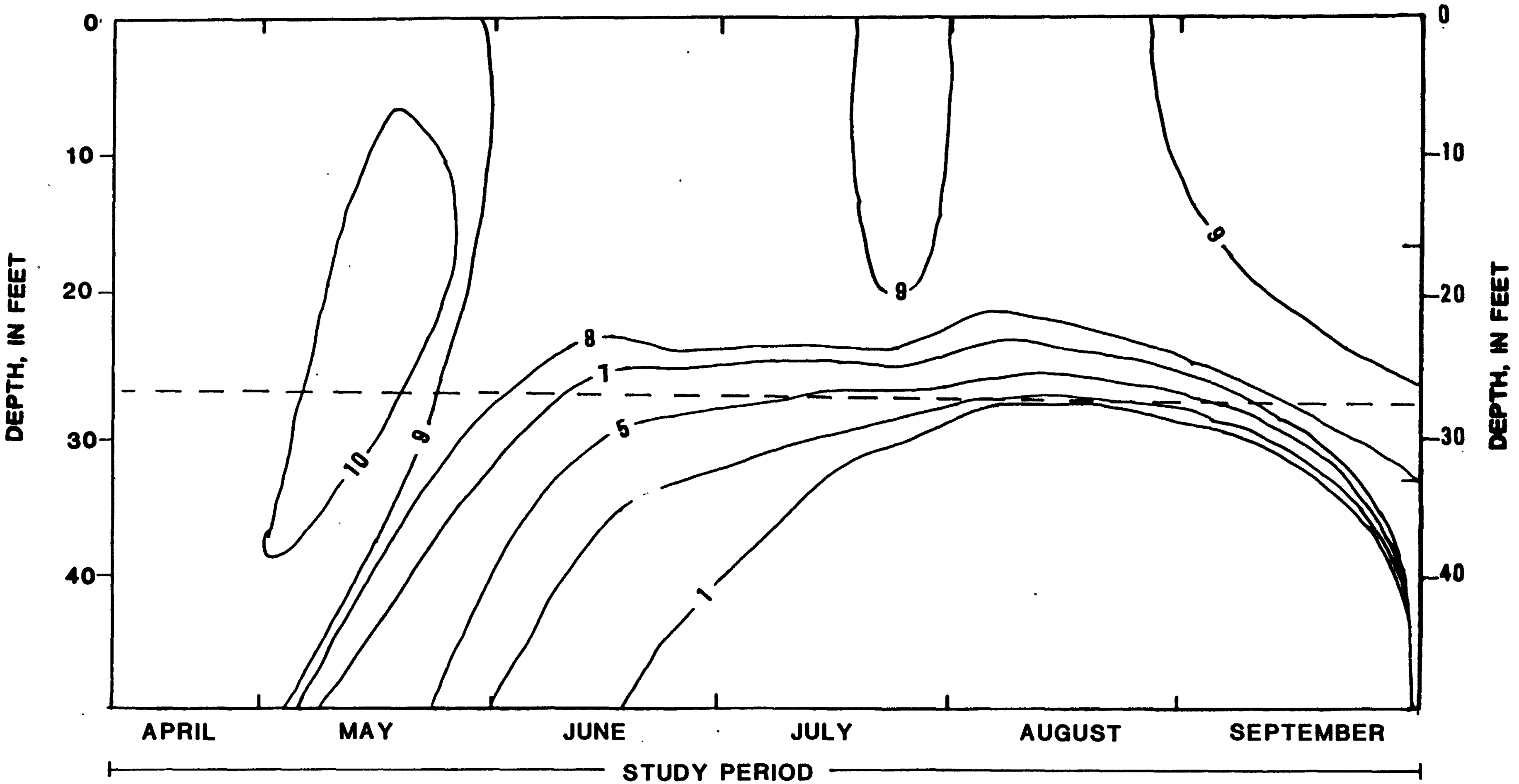


Figure 6.--Total phosphorus in Ellis Pond during 1978 and 1979 study periods



EXPLANATION

—1— ISOPLETH OF DISSOLVED, IN MILLIGRAMS PER LITER

— — — UPPER MARGIN OF THE LATE HYPOLIMNION

Figure 7.--Distribution of dissolved oxygen in Ellis Pond during 1979 study period

Total phosphorus levels in McGrath Pond remain relatively stable throughout the summer, because McGrath does not stratify and remains well mixed and oxygenated. Unlike McGrath, total phosphorus levels in Ellis Pond increased during the summer, as shown in figure 6. The source of this phosphorus is unknown; however, because the the hypolimnion of Ellis Pond becomes anoxic by August (figure 7), total phosphorus is probably released from sediments in the deeper parts of the pond (Mortimer 1941, 1942). Given the limitation of the data, it is not known what fraction of the reservoir increase is due to sediment release or tributary loading.

Regardless of the role of benthic sediments, any reversal of cultural eutrophication must involve a reduction of the ponds' incoming nutrient supply. Total phosphorus was studied for two reasons. First, it is generally regarded as the limiting nutrient of phytoplankton in temperate lakes. Second, of the six macronutrients, phosphorus is the most controllable. Nitrogen and sulfur have gaseous forms which may be biologically fixed, and are water soluble. Common forms of calcium, potassium, and magnesium all are more water soluble and more readily leached from soils than phosphorus. On the other hand, phosphorus is relatively insoluble at circumneutral pH's and under oxidized conditions and has virtually no gaseous form to be biologically fixed.

Observed concentrations and estimated loads of total phosphorus to McGrath and Ellis Ponds by tributary are presented in tables 3,4, and 5. Neither concentration nor load alone are sufficient to have any significant meaning, but together they enable a relative ranking of tributaries for mitigation. For example, tributary 15 shows the fifth highest load for 1979; however, the volume weighted concentration of total phosphorus is only about .008 milligrams per liter (mg/L), a concentration difficult to reduce. Conversely, tributary 37 has total phosphorus concentrations in the upper quartile, yet its load is relatively small. This is due to the small drainage area and correspondingly low discharge values. Although improvement in water quality probably could be made, the net effect in McGrath and Ellis Ponds would be minimal.

Table 3.--Total phosphorus concentrations in McGrath and Ellis Pond tributaries, April 1978 through September 1978.

Local site number	Project Identifier Latitude	Project Identifier Longitude	Apr 5, 1978	Apr 20, 1978	Apr 30, 1978	May 4, 1978	May 9, 1978	Jun 7, 1978	Jun 12, 1978	Jun 29, 1978	Jul 12, 1978	Jul 26, 1978	Aug 14, 1978	Aug 23, 1978	Sept 8, 1978	Sept 15, 1978	Sept 21, 1978
1	44°31'21"	69°47'54"	.024	.017	.013	.019	.017	.021	.012	.021	.045	.023	.021	.022	.039	.047	.021
2	44°31'33"	69°47'22"	.067	.016	.019	.029		.023									
3	44°31'42"	69°47'34"	.044	.032	.043	.028	.044	.059	.046								
5	44°31'50"	69°47'31"	1.3	.15	.047	.039	.31	.14	.056								
7	44°31'56"	69°47'30"	.19	.029	.013	.017	.037	.048	.033								
9	44°32'02"	69°47'31"	.59	.50	2.6	4.6	.60	.92	.53								
11	44°32'07"	69°47'19"	.051	.021	.009	.011	.028	.064	.012	.011		.012	.078				
13	44°32'39"	69°47'19"	.009	.010	.013	.014	.018	.016	.019	.061							
15	44°37'37"	69°47'06"	.009	.007	.006	.008	.016	.016	.008	.017	.013	.020	.022	.022	.017	.130	.016
17	44°33'33"	69°46'23"	.009	.009	.007	.008	.013	.009	.017	.009	.008	.014	.010			.013	
19	44°33'42"	69°46'19"	.011	.008	.007	.023		.011	.006								.017
21	44°33'59"	69°46'07"	.013	.018	.005	.006	.020	.020	.004	.006	.007	.069	.009		.005	.013	
23	44°34'12"	69°46'03"	.046	.011	1.4	.041	.027	.035	.010	.010	.030	.037	.074	.007			
25	44°34'08"	69°45'14"	.013	.010	.01	.012	.026	.017	.015	.021	.021	.027	.033				
27	44°33'54"	69°44'58"	.045	.012	.005	.006	.028	.018	.003	.005	.005	.006	.008		.005	.010	
28	44°33'49"	69°44'58"	.045	.006	.006	.006	.007	.008									
29	44°33'35"	69°45'06"	.035	.008	.003	.005	.012	.008									
31	44°33'30"	69°45'09"	.051	.023	.006	.006	.036	.041	.005	.001							
33	44°33'12"	69°45'21"	.011	.005	.004	.034	.007	.006	.007	.009							
35	44°32'59"	69°45'32"	.024	.015	.024	.024	.043	.028									
37	44°32'47"	69°45'40"	.051	.030	.011	.015	.026	.032	.023								
39	44°32'35"	69°45'45"	.005	.005	.007	.008	.009	.007									
41	44°32'35"	69°45'46"	.026	.010	.015	.008	.015	.014									
43	44°32'00"	69°45'49"		.014	.007	.008	.041										
45	44°30'39"	69°47'22"	.009	.008	.006	.010	.008	.041	.009	.017	.009						
47	44°30'41"	69°47'36"	.005	.004	.006	.007	.009	.007	.006	.009							
49	44°30'42"	69°47'50"	.016	.017	.010	.011	.019	.028	.013	.018		.033	.041				
51	44°31'05"	69°47'55"	.059	.039	.08	.080	.082	.045									

Table 4.--Total phosphorus concentrations in McGrath and Ellis Pond tributaries, April 1979 through September 1979.

Local site number	Apr 1, 1979	Apr 6, 1979	Apr 17, 1979	Apr 27, 1979	Apr 28, 1979	May 2, 1979	May 17, 1979	Jun 1, 1979	Jun 14, 1979	Jun 25, 1979	Jul 13, 1979	Jul 23, 1979	Aug 6, 1979	Sept 4, 1979	Sept 24, 1979
1		.009	.010	.026		.011	.019	.008	.013	.014	.018	.017	.014	.013	.030
2		.009	.012	.026				.031							
3		.012	.016	.039		.021	.036	.026							
5		.120	.062	17.2		.039	.025	.450							
7	.018	.017	.014	.090			.018	.031	.020						
9	1.0	1.5	.530	.480		.570	1.00	1.1							
11		.010	.008	.020		.013	.014	.015	.011	.007					
13			.008	.013				.010	.019						
15		.005	.006	.015	.015	.010	.007	.005	.006	.006	.013	.017	.019	.025	.014
17			.006	.025				.006	.005	.014	.006	.007	.004	.006	.009
19	.009		.006	.012	.013	.014		.009							
21		.003	.004	.015	.005	.005	.003	.004		.010	.005	.010	.011	.010	.004
23			.007	.410		.028	.030	.018	.007	.008	.007	.013		.010	.005
25	.008	.010	.006	.020			.006	.008	.011	.019	.013	.016	.021		.014
27		.018	.004	.270		.006	.013	.005	.005	.007	.003	.004			.001
28	.003	.004	.004	.040		.007									
29		.012	.006	.036				.005	.004						
31		.006	.007	.030		.008	.009	.008	.002						.003
33		.006	.006	.022					.005	.008					
35		.014	.025	.044		.035	.063	.027	.019						
37		.020	.031	.067			.053	.110							
39	.014			.014											
41		.006	.008	.023											
43		.037	.010	.160				.012							
45	.027		.008	.018		.012		.006		.014					
47		.004	.007	.017						.015					
49			.009	.160		.013	.037	.011	.012		.018				
51		.027	.021	.075				.035							

Table 5.--Total phosphorus loads for McGrath and Ellis Ponds tributaries, April through September, 1978 and 1979.

Stream site	1978 Total phos-phorus (grams)	1978 Total phos-phorus (mg/L)*	1979 Total phos-phorus (grams)	1979 Total phos-phorus (mg/L)*
2	731	.032	445	.023
3	3760	.042	1840	.025
5	6370	.393	29400	2.17
7	610	.065	310	.038
9	39000	.957	30900	.905
11	7240	.032	2410	.013
13	676	.013	475	.012
15	8310	.010	5960	.008
17	324	.010	339	.010
19	594	.011	477	.011
21	2970	.016	1050	.006
23	77300	.201	20700	.060
25	8660	.026	4680	.010
27	4860	.018	7960	.031
28	290	.015	173	.015
29	1080	.015	990	.015
31	7580	.030	2000	.010
33	237	.007	320	.012
35	2590	.024	3130	.034
37	498	.031	783	.060
39	82	.006	65	.014
41	923	.015	181	.010
43	268	.014	635	.064
45	998	.012	868	.012
47	126	.006	255	.013
49	493	.017	794	.032
51	867	.056	461	.041

* Volume weighted concentration.

Tributaries with a combination of high phosphorus concentrations and loads are those in which water-quality control efforts would be most effective. Three unnamed tributaries-- 5, 9, and 23--, have this combination. Together, they contribute about 69 percent of the estimated loading yet drain only 22 percent of the pond's gaged watershed. In the watershed drained by tributary 5, there is a small sawmill with a large gravel yarding area. During wet weather, tractors and other vehicles cause erosion of the yard which in turn causes elevated instream total phosphorus levels. On tributary 23, poultry and dairy manure at a small family farm is stored close to an intermittent waterway. The watershed of tributary 9 is entirely within the bounds of a large dairy farm. Both milkroom and feedlot wastes rich in phosphates run into tributary 9 during runoff events. Based on the data, corrective action might best be spent first addressing problems on these three tributaries. At the onset of the study, the Oakland landfill was suspected of being a significant source of phosphorus. Tributary 37 drains the landfill and, as discussed earlier, it has been shown to be a relatively unimportant source.

Because blooms in Ellis Pond are thought to be recent phenomenon, it is implied that if sufficient total phosphorus load reduction were to occur, the pond would revert to nonblooming conditions through hydraulic flushing which would wash out phosphorus accumulations in the pond.

SUMMARY AND CONCLUSIONS

Based on streamflow and water-quality data collected on 28 tributaries to the McGrath and Ellis Pond watershed from April 1st through September 30th in 1978 and 1979, the relative importance of each tributary was determined according to the amount of phosphorus contributed to the pond. Tributaries 5,9, and 23 accounted for 69 percent of the total phosphorus load, but drained only 22 percent of the gaged watershed. Practices that could account for the high loadings including a family farm, a large dairy farm, and a lumber yard with an erosion problem were located within the watersheds of these tributaries. Efforts to restore water quality in Ellis and McGrath Ponds might best be placed on detention of phosphorus within the watersheds of these three tributaries. The Oakland landfill, originally thought to be a major source of phosphorus, was found to contribute relatively small amounts of phosphorus when compared to tributaries 5, 9, and 23.

REFERENCES CITED

American Public Health Association, American Water Works Association and Water Pollution Control Federation, 1975, Standard methods for the examination of water and wastewater: American Public Health Assoc., 874 p.

Cooper, G. P., 1941, A biological survey of lakes and ponds of the Androscoggin and Kennebec River drainage systems in Maine: Dept. of Inland Fish and Game, Augusta, Fish survey report, 238 p.

Cowing, D. J., and Scott, Matthew, 1980, A limnological study of 43 selected Maine lakes. U.S. Geological Survey Water-Resources Investigations, p. 69-80.

Lee, G. F., Rast, Walter, and Jones, R. A., 1978, Eutrophication of water bodies: Insights for an age-old problem: Environmental Science and Technology Vol. 12, Chap. 8, p. 900-908.

Mortimer, C. H., 1941, The exchange of dissolved substances between mud and water in lakes: Journal of Ecology Vol. 29, p. 280-329.

_____, 1942, The exchange of dissolved substances between mud and water in lakes: Journal of Ecology Vol. 30, p. 147-201.

U.S. Geological Survey, 1979, Water resources data for Maine, water year 1978: U.S. Geological Survey Water-Data Report ME-78-1, 230 p.

_____, 1980, Water resources data for Maine, water year 1980: U.S. Geological Survey Water-Data Report ME-79-1, 228 p.