1987

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RELATION OF SEDIMENT AND NUTRIENT LOADS TO WATERSHED CHARACTERISTICS AND LAND USE IN THE OTISCO LAKE BASIN, ONONDAGA COUNTY, NEW YORK

by James E. Paschal, Jr. and Donald A. Sherwood

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4026

Prepared in cooperation with

ONONDAGA COUNTY ENVIRONMENTAL MANAGEMENT COUNCIL

U.S. DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

Ithaca, New York

1987

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

TABLES (continued)

CONVERSION FACTORS AND ABBREVIATIONS

The inch-pound units used in this report may be converted to metric (International System) units by the following factors:

Multiply Inch-Pound Unit	By	To Obtain SI Units
inch (in.)	25.4	millimeter (mm)
inch per year (in./yr)	2.54	centimeter per year (cm/yr)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic feet per second per day [(ft^3/s)/d]	0.02832	cubic meter per second per day [(m^3/s)/d]
acre	0.4047	hectare (ha)
pound (lb)	0.4536	kilogram (kg)
pound per acre (lb/acre)	0.1833	kilogram per hectare (kg/ha)
ton	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per acre (ton/acre)	2.242	megagram per hectare (Mg/ha)
ton per acre per year [(ton/acre)/yr]	2.242	megagram per hectare per year [(Mg/ha)/yr]
million gallons per day (Mgal/d)	3.785	million liters per day (ML/d)
degrees Fahrenheit (°F)	5/9 (°F-32)	degrees Celsius (°C)

Relation of Sediment and Nutrient Loads to Watershed Characteristics and Land Use in the Otisco Lake Basin, Onondaga County, New York

By James E. Paschal, Jr. and Donald A. Sherwood

ABSTRACT

Otisco Lake, the smallest and easternmost of New York State's Finger Lakes, is the source of water supply for several villages in Onondaga County. In recent years, turbidity and algal blooms have periodically impaired the lake's use for both water supply and recreation.

Otisco Lake is about 6 miles long, averages 0.75 mile wide, and has a mean depth of 33 feet and a maximum depth of 60 feet. The lake occupies a 20-mile-long preglacial valley in the southwest corner of Onondaga County. The drainage area of the watershed, excluding the lake, is 38.8 square miles. Five major tributaries and several small intermittent streams drain into the lake. Watershed altitudes range from 788 feet (lake surface) to 1,900 feet above sea level. The major soils of the basin are formed from alluvial deposits and lacustrine sediment.

Principal land uses within the Otisco Lake basin are woodland (39 percent) and cropland (49 percent). Willow Brook, the third smallest subbasin, has the greatest percentage of cropland (80 percent) and the smallest percentage of woodland (9 percent). Spafford Creek, the largest subbasin, is only 35 percent cropland and 55 percent woodland. Conservation practices such as contour farming, strip cropping, and diversion ditches are applied to about 47 percent of the cropland in the basin.

Runoff and concentrations of sediment and nutrients in the five major tributaries, which together drain about 70 percent of the lake's watershed, were monitored from November 1981 through September 1983, and sediment and nutrient loads from the ungaged areas of the watershed were estimated. Otisco Lake received 10,600 tons of sediment, 20,600 pounds of phosphorus as P, 199,000 pounds of total kjeldahl nitrogen as N, and 236,000 pounds of nitrite plus nitrate as N from the five tributaries and the ungaged area during the 23-month study.

Spafford Creek basin (12.0 square miles) contributed about 72 percent of the annual sediment load and 46 percent of the annual nutrient load; the other four subbasins, which range from 2.6 to 3.7 square miles in area, each contributed 3 to 5 percent of the annual sediment load and 6 to 16 percent of the annual nutrient load. The ungaged part of the watershed contributed 12 percent of the annual sediment load and 28 percent of the annual nutrient load. The largest loads of sediment and nutrients and highest concentrations of total phosphorus were those from Spafford Creek. The highest concentrations of nitrite plus nitrate were in Willow Brook and Rice Brook; the lowest were in Van Benthuysen Brook.

Concentrations of ammonia as N were relatively uniform through the year, although some extremely high concentrations occurred during the summer. Total kjeldahl nitrogen concentrations were highest in the summer and lowest in the

fall. Concentrations of nitrite plus nitrate were significantly lower in winter than in the rest of the year. Total phosphorus concentrations were slightly higher in the spring than at other times, and concentrations of dissolved phosphorus were slightly higher in the summer.

Storms and snowmelt accounted for 70 to 90 percent of the runoff, 90 to 99 percent of the sediment load, and 70 to 98 percent of the nutrient loads from the tributaries. The largest nutrient loads occurred during the spring of each year, when runoff was highest. About 70 percent of the sediment, 60 percent of total kjeldahl nitrogen, 58 percent of total phosphorus, and 53 percent of nitrite plus nitrate were transported during spring high flows.

Stepwise multiple regression analyses of runoff per acre and yield (load per acre) in relation to selected watershed characteristics showed significant relationships for monthly, seasonal, and total values. Total phosphorus loads were lower in subbasins in which the percentage of cropland with contour farming and streambank improvements to reduce erosion is highest.

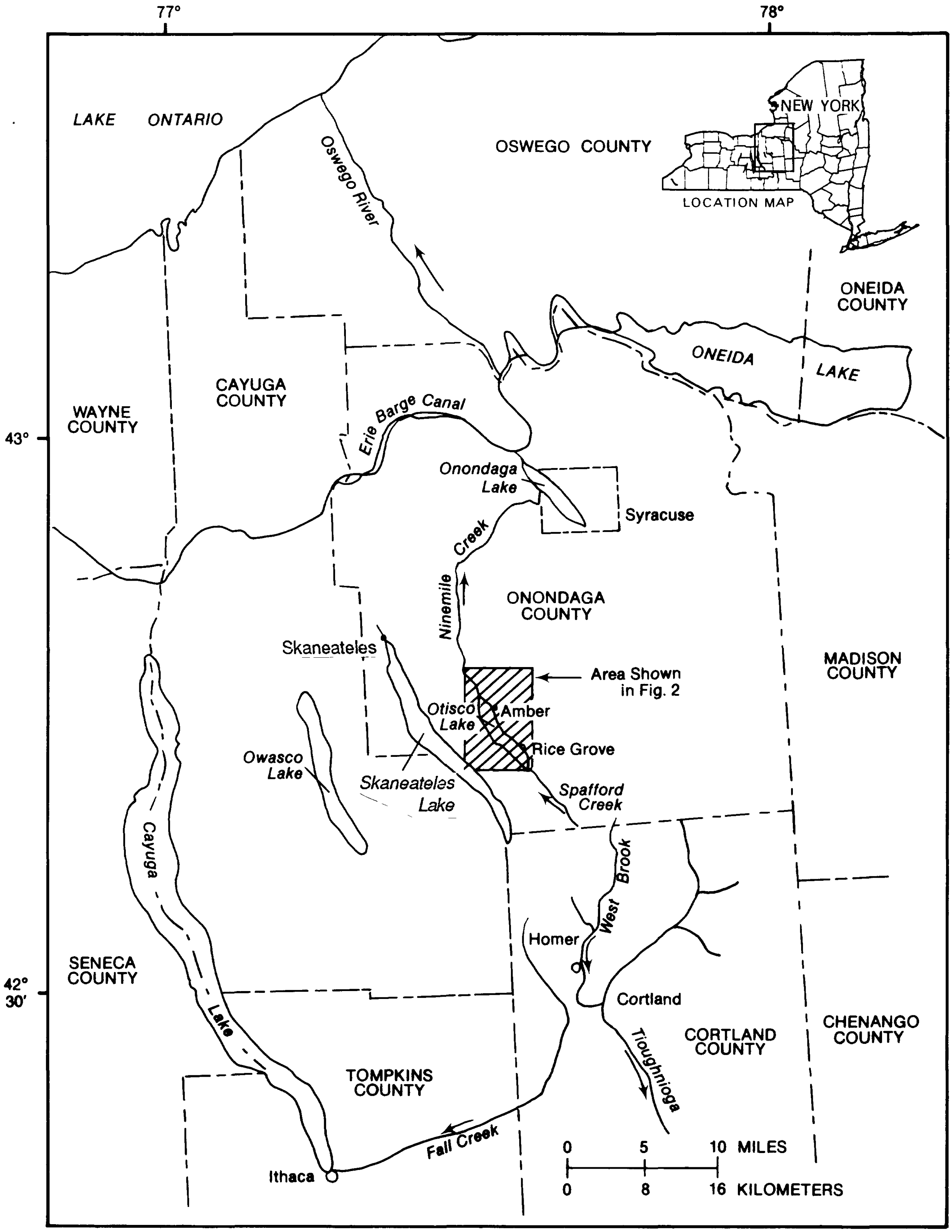
During the 114 years from 1869, when the lake level was first raised, to 1983, approximately 390,000 tons of sediment were deposited in Otisco Lake south of the causeway. This indicates a long-term average deposition rate of 3,420 tons per year, which closely compares with the U.S. Soil Conservation Service's estimate of 3,573 tons per year and the U.S. Geological Survey's calculated load of about 3,820 tons per year. At present, less than 15 percent of the nutrient and sediment load carried by Spafford Creek is retained by the wetland at the south end of the lake. Retention of Spafford Creek flows in the wetland for 8 or 9 hours at an altitude of 792 feet above sea level would inundate about 80 acres and would decrease high-flow sediment and particulate nutrient loads to the lake by 60 to 80 percent and annual loads by 40 to 60 percent.

INTRODUCTION

Otisco Lake, 14 miles (mi) southwest of Syracuse, occupies a narrow 20-mi-long valley in the southwest corner of Onondaga County (fig. 1). It is the smallest and easternmost of New York's glacially scoured "Finger Lakes." Otisco Lake is part of the Onondaga County Water Authority public water-supply system and provides about 20 million gallons per day (Mgal/d) to customers in several towns.

The lake has had a history of high turbidity, and, because the turbidity levels occasionally exceed State drinking-water standards, the water supply has been operating under a variance from the New York State Department of Health. Concern has arisen that excessive algal growth and suspended sediment may hasten eutrophication of the lake. Recreational use of the lake is periodically impaired by turbidity and by summer algal blooms.

Soil erosion is the primary source of suspended-sediment and nutrient loads to the lake, and high concentrations of nutrients contribute to algal growth. Sheet and rill erosion are removing the soil base and depleting the nutrients of the cropland surrounding the lake (U.S. Department of Agriculture, 1983). The U.S. Soil Conservation Service has estimated that 13,240 tons of eroded soil and nearly 14 tons of phosphorus are deposited in



Base from New York State Department of Transportation, 1967, 1:500,000

Figure 1.--Location of Otisco Lake and major geographic features of Onondaga County in central New York.

the lake each year from all tributaries. In 1984, the U.S. Soil Conservation Service allocated funds to plan and implement a watershed-protection project in the Otisco Lake basin to improve water quality by reducing soil erosion and fertilizer runoff.

Effective management of this resource will require that the sources of sediment and nutrients be identified and the rate at which they are entering the lake determined. In 1981, the U.S. Geological Survey, in cooperation with the Onondaga County Environmental Management Council, began a study to measure the amounts of sediment and nutrients entering the lake. The objectives of the study were to (1) estimate annual, seasonal, and monthly sediment and nutrient loads entering the lake from selected tributaries; (2) compare yields of sediment and nutrients from the watershed subbasins, which differ in topography, geology, soil type, and land use; (3) measure the thickness and composition of the lake sediment in the south end of the lake, where most of the sediment is impounded; and (4) evaluate the potential for artificially increasing sediment and nutrient retention in wetland and lowlands that border Spafford Creek at the south end of the lake. Data were collected from November 1981 through September 1983.

Purpose and Scope

This report describes the physical setting, land uses, soil-erosion potential, and fertilizer use in the five gaged subbasins as well as the ungaged areas of the basin. It also gives estimates of sediment and nutrient loads transported to the lake; relates sediment and nutrient loads to land use, geology, and soil type; describes sediment-deposition patterns within the lake; and discusses the potential for sediment and nutrient retention within Spafford Creek wetland.

Maps are included that show watershed boundaries, station locations, sediment thickness at the south end of the lake, and the extent of flooding in the wetland and adjacent lowlands at specified water-surface altitudes. Several tables summarize subbasin characteristics, runoff rates, and sediment and nutrient concentrations and loads for each of the tributaries. Three appendixes give information on statistical methods and quality-assurance practices for chemical analyses that were used in this report and include statistics on the sediment and nutrient samples collected during the study. Daily mean streamflow and daily mean suspended-sediment concentrations and discharges, along with the analyses of all samples collected during the study, are published by the U.S. Geological Survey (1982, 1983).[1]

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[1] Streamflow and suspended-sediment data from Spafford Creek at Bromley Road, Amber Brook, and Van Benthuysen Brook, for November 1981 through March 1982 and Rice Brook for November 1981 to April 1982 are not published but were used for calculations in this study. These data are available from the files of the U.S. Geological Survey's office in Ithaca, N.Y.

Methods

Six stream-gaging stations were established on the five major tributaries to Otisco Lake (fig. 2); two were on Spafford Creek, the largest tributary. The upstream station monitors flow from the upper 25 percent of the basin (3.14 mi^2); the downstream site monitors 66 percent (8.06 mi^2). The gages provided a continuous record of stream stage. Outflow from Otisco Lake is measured at Ninemile Creek at Marietta (fig. 1), a gaging station with 18 years of record. Discharge measurements obtained throughout the study over a range of stages were used to define stage-vs-discharge relationships for each site from which daily mean streamflows were calculated.

Nutrient and suspended-sediment samples were collected at the gaging-station sites by the depth-integrating methods described by Guy and Norman (1970). Samples from several verticals in the stream cross section were composited in a churn splitter from which aliquots were withdrawn for analyses. Samples were analyzed for the following constituents:

Suspended sediment
Total organic nitrogen as N
Total ammonia nitrogen (NH_3) as N
Total kjeldahl nitrogen
  (ammonia plus organic nitrogen) as N
Dissolved nitrite plus
  nitrate (NO_2+NO_3) as N

Total phosphorus as P
Total inorganic phosphorus as P
Dissolved phosphorus as P
Dissolved orthophosphate as P
Dissolved organic phosphorus as P

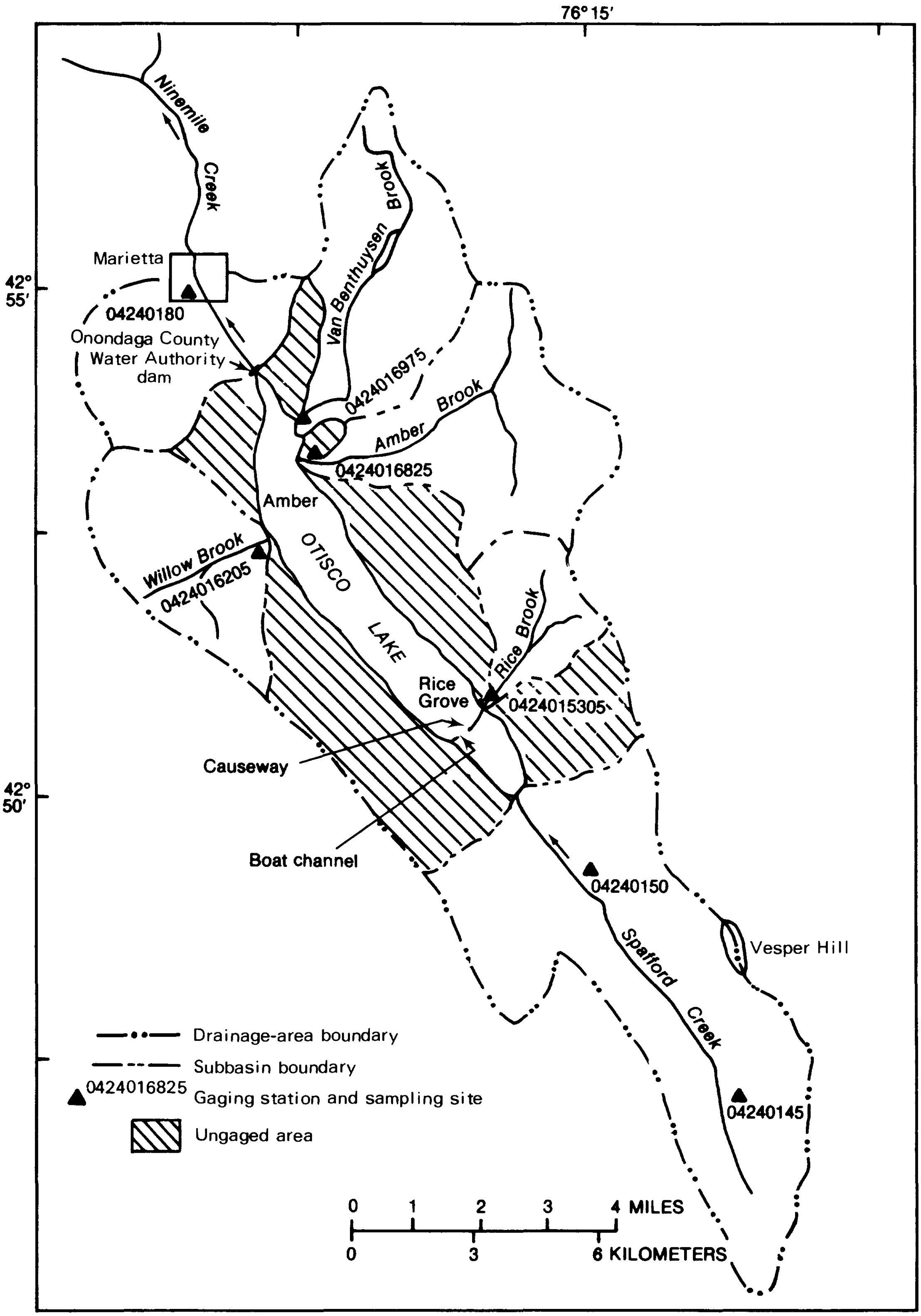
Samples to be analyzed for total concentrations (suspended plus dissolved), such as suspended sediment, total nitrogen, and total phosphorus, were withdrawn from the splitter first. Samples analyzed for dissolved constituents were withdrawn second and filtered through a 0.45-μ filter, and the analysis was performed on the filtrate.

Sampling frequency was determined primarily by hydrologic conditions. Samples were collected weekly during high base-flow periods in the spring and every 2 to 3 weeks during low base-flow periods. Four or five samples were collected at each site during three or four high flows each year.

A particle-size-distribution analysis was done on selected suspended-sediment samples collected during high flows. Suspended-sediment concentration and particle-size distribution analyses were done by the U.S. Geological Survey District Laboratory in Columbus, Ohio, by methods described by Guy (1969).

Nutrient analyses were done by the Onondaga County Department of Drainage and Sanitation Laboratory from September 1981 through October 1982, and by the Upstate Freshwater Institute in Syracuse from November 1982 through October 1983, by methods described by American Public Health Association and others (1980). A quality-assurance plan was adopted to ensure that results from these analyses met U.S. Geological Survey standards. Results are presented in appendix B.

Nutrient loads in each tributary were calculated through regression analyses to relate instantaneous nutrient concentrations to instantaneous streamflow and sediment concentration. Daily mean nutrient concentrations were



Base from U.S. Geological Survey,
Skaneateles, NY, 1948, 1:62,5000

Figure 2.--Location of major tributaries, subbasin boundaries, and streamflow-gaging stations in Otisco Lake basin.

predicted from the regression equation coefficients by substituting daily mean flow and daily mean sediment concentration; daily mean nutrient loads were estimated by multiplying daily mean concentrations by daily mean discharge, and total monthly loads were obtained by summing daily mean nutrient loads.

Seasonal loads were calculated for fall (October and November), winter (December-February), spring (March-May), and summer (June-September). Even though climatic conditions for individual months can vary widely from year to year, months were grouped by season on the basis of general climatic similarities. Nutrient loads from the ungaged parts of the basin were estimated by multiplying each constituent's mean load per acre (yield) from the gaged area by the number of acres in ungaged areas. Suspended-sediment loads were calculated the same way, except that the yield for Spafford Creek was not used. Sediment concentrations and loads were calculated from a temporal concentration graph, a method described by Porterfield (1972).

Stepwise multiple regressions were done with logarithmic transforms of discharge, concentration, or load as the dependent variable; loads were normalized by dividing each value by the number of acres in each subbasin to obtain yields (runoff per acre or load per acre). The watershed characteristics and land-use values were used as independent variables and were normalized as follows:

(1) topographic factors and soil-erosion factors were given as mean values for each subbasin;
(2) geologic conditions, soil types, and land uses were given as percentages of subbasin area; and
(3) fertilizer application was given as lb/acre of cropland in each subbasin.

A detailed explanation of the regression analyses is given in appendix A.

Sixteen sediment cores, three from each of four transects south of the causeway (fig. 2) and four from a transect approximately 200 ft north of the causeway were collected by hand with a piston-type sampler to determine sedimentation patterns in the lake. Each core was separated into two or three sections on the basis of color and texture; the sections were submitted to the U.S. Geological Survey laboratory in Ocala, Fla. to be analyzed for percent organic and inorganic material.

Acknowledgments

Thanks are extended to the U.S. Department of Agriculture, Soil Conservation Service, who provided detailed information on land use and agricultural practices within the Otisco Lake basin and to the Onondaga County Water Authority who provided physical, chemical, and biological data on Otisco Lake.

DESCRIPTION OF STUDY AREA

Otisco Lake occupies a 20-mi-long, northwest-southeast-oriented valley in the southwest corner of Onondaga County (fig. 2). The valley is of preglacial origin and has undergone extensive alteration by glacial activity. The drainage area of the lake, excluding the 3.4 mi^2 of lake surface, is 38.8 mi^2. Outflow from the lake, which is controlled by a gated dam, is through Ninemile Creek at the north end of the lake. Ninemile Creek flows into Onondaga Lake, which discharges to the Oswego River, which in turn flows into Lake Ontario (fig. 1).

Topography

The topography of the basin is characterized by gently rolling hills in the upland regions and a steep-sided valley at the south end that gradually becomes less steep toward the north. Watershed altitudes range from 788 ft above sea level at the lake surface to 1,900 ft at Vesper Hill, along the southeastern border of the basin (fig. 1). Average stream gradients of the five major tributaries range from 46 ft/mi at Van Benthuysen Brook near the north end of the lake to 197 ft/mi at Rice Brook near the southeast end, just north of the causeway. The small intermittent streams that drain directly into the west side of the lake are less than 0.75 mi long and have gradients of about 800 ft/mi. The lower reaches of these streams have much steeper gradients than the upper reaches. The small streams entering the lake from the east generally range in length from 0.5 mi to 1 mi and have average gradients of 500 ft/mi. Topographic characteristics of each major subbasin are summarized in table 1.

Drainage

Otisco Lake is about 6 mi long, averages 0.75 mi wide, and has a mean depth of 33 ft, a maximum depth of 60 ft, and a surface area of 2,176 acres (3.4 mi^2). The 3,500-ft-long causeway that crosses the south end of the lake forms a shallow bay about 1 mi long, 0.5 mi wide, and 3 to 9 ft deep. This bay is connected to the main body of the lake by a 12-ft-wide boat channel through the causeway (fig. 2).

The level of Otisco Lake has been raised twice, 10 ft in 1869 to increase water storage for Erie-Barge Canal feeder purposes (fig. 1), and 4 ft in 1908, when the Syracuse Suburban Water Supply Company increased storage in the lake for a public water supply. The causeway was built in 1899 to replace a road at the south end of the lake that had been flooded out when the water level was first raised; it was rebuilt in 1908 when the lake level was again raised. The causeway was repaired in 1983, but the road has not been rebuilt.

Five major tributaries and several small intermittent streams drain into Otisco Lake (fig. 2). Spafford Creek, the largest tributary, with a drainage area of 12.0 mi^2, flows into the south end of the lake. Rice Brook flows into the east side of the lake just north of the causeway. Van Benthuysen Brook and Amber Brook enter the lake on the northeast side, and Willow Brook enters on the west side. These five tributaries drain about 70 percent of the Otisco

Lake watershed. The land area that drains directly into Otisco Lake and the area drained by small intermittent streams is about equally distributed on either side of the lake.

Geology

The Otisco bedrock valley is of preglacial origin but has been profoundly altered by the invasion of ice (Birge and Juday, 1914). Its present form is largely a result of glacial scouring and deposition from the advance and

Table 1.--Topographic characteristics of subbasins of the Otisco Lake basin.

[Data from U.S. Soil Conservation Service, 1983. Basin locations are shown in fig. 2. A dash indicates no data.]

	Subbasin area					
	Amber Brook	Direct[1] drainage	Rice Brook	Spafford Creek	Van Benthuysen Brook	Willow Brook
Total drainage area, in acres	2,377	7,040	1,690	7,680	2,240	2,354
Mean basin altitude, in feet	1,188	1,110	1,282	1,290	1,111	1,145
Mean basin slope, in feet per 1000 feet	75	120	74	170	76	58
Main channel slope, in feet per mile	122	--	197	72.1	45.6	131
All land with greater than 20 percent slope, in acres. (Percentage of total subbasin area is in parentheses)	0 (0)	986 (14)	0 (0)	2,765 (36)	0 (0)	0 (0)
Cropland in need of treatment[2] with less than 8 percent slope, in acres. (Percentage of total cropland needing treatment is in parentheses)	448 (35)	415 (40)	144 (25)	357 (19)	567 (58)	250 (41)
Cropland in need of treatment with greater than 8 percent slope, in acres. (Percentage of total cropland needing treatment is in parentheses)	816 (65)	630 (60)	422 (75)	1,518 (81)	405 (42)	366 (59)

[1] Direct drainage refers to those areas of the Otisco Lake basin that are ungaged and drain directly to the lake through small intermittent tributaries.

[2] Cropland in need of treatment is considered by the Soil Conservation Service to be cropland having erosion rate greater than 3 (ton/acre)/yr.

retreat of the ice sheet during the Wisconsin glaciation. The depression in which the lake lies was created by a rapid melting of an ice lake in the rock-scoured basin (von Engeln, 1961).

The bedrock underlying the glacial deposits is part of the Skaneateles Formation, which is composed of shale, limestone, and calcareous sandstone. Debris from the last glaciation mantles the watershed, and the distribution of the resulting soil materials and drainage patterns was largely determined by the activity of the glacier. Local variations in composition of glacial deposits and in slope produce a variety of soil types and vegetative cover. The landscape also has been changed by the activities of man (Rickard and Fisher, 1970). The percentage of several types of surficial deposits in each subbasin are summarized in table 2.

Table 2.--Distribution of surficial geologic deposits within Otisco Lake subbasins.

[Values are percentage of total subbasin area. Data from U.S. Department of Agriculture, 1977. Basin locations are shown in fig. 2.]

Type of deposit	Amber Brook	Direct[1] drainage	Rice Brook	Spafford Creek	Van Benthuysen Brook	Willow Brook
Alluvial silt, sand, and clay--postglacial stream deposits	2	3	0.3	1	6	0.1
Peat, marl, muck, and clay--postglacial bog deposits	2	0	4	2	3	0
Lake silt and clay--preglacial or post-glacial offshore deposits	0	0	0	21	0	0
Kame and kame terrace sand and gravel--glacial deposits	3	5	9	13	15	0
Outwash sand and gravel--stream deposits from melting ice sheet	3	1	0	0	6	0
Lodgment till--deposited at base of glacier	0	0	0	0	7	0
Sedimentary bedrock	1	0	0	16	0	2
Thin till overlying bedrock	89	91	86.7	47	63	97.9

[1] Direct drainage refers to areas that are ungaged and drain directly to the lake through small intermittent tributaries.

Soils

The soils south of Otisco Lake along the valley of Spafford Creek are predominantly level Wayland-Teel and Schoharie-Odessa association. These soils are formed from alluvial deposits and lacustrine sediment and are classified as somewhat poorly drained to very poorly drained (U.S. Department of Agriculture, 1977).

The sloping to gently sloping soils at higher altitudes around the lake are mostly Honeoye-Lima and Lansing-Conesus association interspersed with some Palmyra-Howard and Aurora-Angola-Darien associations. They are moderately deep, well-drained soils formed on till.

The steep valley sides adjacent to the lake and tributaries contain soils of the Honeoye-Lansing association, which are well drained. Interspersed on the steeper slopes of the Spafford Creek subbasin are small areas of the Arnot-Lordstown-Mardin association, which are also well drained.

The distribution of hydrologic soil groups, which are designated according to relative infiltration and transmission rates (U.S. Department of Agriculture, 1972), and of soil families of croplands (U.S. Department of Agriculture, 1977), is summarized in table 3 as the percentage of total drainage area covered by each soil type.

Land Use

Principal land uses within the Otisco Lake basin are woodland (39 percent) and cropland (49 percent), which are scattered evenly throughout the watershed. Willow Brook, the third smallest subbasin, has the highest percentage of cropland (80 percent) and the lowest percentage of woodland (9 percent); Spafford Creek, the largest subbasin, is only 35 percent cropland and 55 percent woodland. The distribution of land uses in the subbasins is summarized in the upper part of table 4; the middle and lower parts summarize tillage and soil-conservation practices. The primary method of tilling the cropland in the Otisco basin is spring moldboard (conventional tillage). The Rice Brook subbasin had the highest percentage of tillage other than spring moldboard, with 32 percent of the cropland tilled by chisel. Conservation practices such as contour farming, strip cropping, and diversion ditches are applied to approximately 47 percent of the cropland in the basin. The conservation methods used and percentages of cropland to which they are applied vary among subbasins. Willow Brook has the highest percentage of cropland on which conservation measures are used (78 percent); Van Benthuysen Brook has the lowest (18 percent).

About 50 percent of the cropland is classified as prime agricultural land (U.S. Department of Agriculture, 1983); the principal crops are corn, hay, and oats, which support dairy farming. Of the remaining 12 percent, about 5 percent is hayland and pasture, and about 7 percent is classified as other use. Urban development is minimal (about 2 percent of the land area) and consists primarily of second-home developments adjacent to the lake. The village of Amber and the settlement of Rice Grove lie within the basin (fig. 2). The proportions of these land uses are not expected to change significantly within the next 20 years (U.S. Department of Agriculture, 1983).

Table 3.--Distribution of hydrologic soil groups and soil families within cropland areas of the Otisco Lake basin.

[Values are percentage of total cropland area. Data from U.S. Department of Agriculture, 1977. Basin locations are shown in fig. 2.]

Soil group or family	Amber Brook	Direct[1] drainage	Rice Brook	Spafford Creek	VanBenthuysen Brook	Willow Brook
Hydrologic Soil Groups[2]						
Low runoff potential (A)	7	13	2	2	2	0
Moderate infiltration rates when thoroughly wetted (B)	71	73	84	51	81	80
Slow infiltration rates when thoroughly wetted (C)	22	14	12	43	17	16
High runoff potential (D)	0	0	3	4	0	4
Soil Families[3]						
Fine-loamy, mixed, mesic (13 soil series)	90	86	91	64.5	82	85
Fine-loamy, mixed, nonacid, mesic (1 series)	1	0	0	0	4	9
Coarse-loamy, mixed mesic (3 soil series)	0	0	0	25	0	0
Loamy-skeletal, mixed, mesic (1 series)	7	2	1	0	2	0
Fine-loamy, over sand or sandy-skeletal, mixed, mesic (2 series)	2	11	8	0	7	0
Fine-silty, mixed, mesic (1 series)	0	0	0	1	5	0
Fine-silty, mixed, nonacid mesic (1 series)	0	0	0	2	0	3
Fine-illitic, mesic (3 series)	0	1	0	7	0	2
Coarse-silty, mixed, mesic (1 series)	0	0	0	.5	0	1

[1] Direct drainage refers to those areas of the Otisco Lake basin that are ungaged and drain directly to the lake through small intermittent tributaries.

[2] U.S. Department of Agriculture, 1972.

[3] U.S. Department of Agriculture, 1977.

Table 4.--Land use, tillage, and conservation practices in subbasins of Otisco Lake basin.

[Basin locations shown in fig. 2.]

	Subbasin						
Type	Amber Brook	Direct[1] drainage	Rice Brook	Spafford Creek	Van Benthuysen Brook	Willow Brook	Total
Land use [Upper value indicates number of acres; lower value (in parentheses) indicates percentage of total subbasin area.]							
Cropland	1,593	2,816	1,103	2,688	1,523	1,860	11,583
	(67)	(40)	(65)	(35)	(68)	(79)	(49)
Pasture	119	493	38	384	45	141	1,220
	(5)	(7)	(2)	(5)	(2)	(6)	(5)
Woodland	475	2,957	507	4,224	403	212	8,778
	(20)	(42)	(30)	(55)	(18)	(9)	(39)
Other (industrial, roads, and other urban lands)	190	774	42	384	269	141	1,800
	(8)	(11)	(3)	(5)	(12)	(6)	(7)
TOTAL	2,377	7,040	1,690	7,680	2,240	2,354	23,381
Percentage of Otisco Lake basin area	(10)	(30)	(7)	(33)	(10)	(10)	(100)
Tillage (percentage of cropland)							
Spring moldboard	100	*87	68	89	*86	100	
Fall moldboard	0	0	0	11	0	0	
No till	0	0	0	0	0	0	
Chisel	0	11	32	0	0	0	
Conservation practices (percentage of cropland)							
Field strip	10	23	14	7	11	31	
Contour strip	24	19	39	25	4	33	
Contour farming	8	0	6	0	3	0	
Diversion	6	5	2	8	0	13	
Waterway	2	0	0	0	0	1	
TOTAL	50	47	61	40	18	78	

* No tillage data for remaining cropland.

[1] Direct drainage refers to areas that are ungaged and drain directly to the lake through small intermittent tributaries.

Climate

The climate of the Otisco Lake basin is characterized as humid-continental with a mean annual temperature of 46°F and average annual precipitation of 37.5 in/yr. Monthly precipitation for October 1981 through September 1983 is plotted in figure 3. Precipitation during the first year of study was about normal, 37.0 inches; that in the second year was 32.8 inches, about 4 inches below normal. Precipitation is usually greatest in July and least in January but is relatively uniform at about 2.5 to 3.5 inches per month. During the first year, October, May, and June were the wettest months, and August was the driest (fig. 3). During the second year, November, April, and May were the wettest months, and July was the driest. Much of the precipitation that falls from May to October, instead of running off, is lost through evapotranspiration.

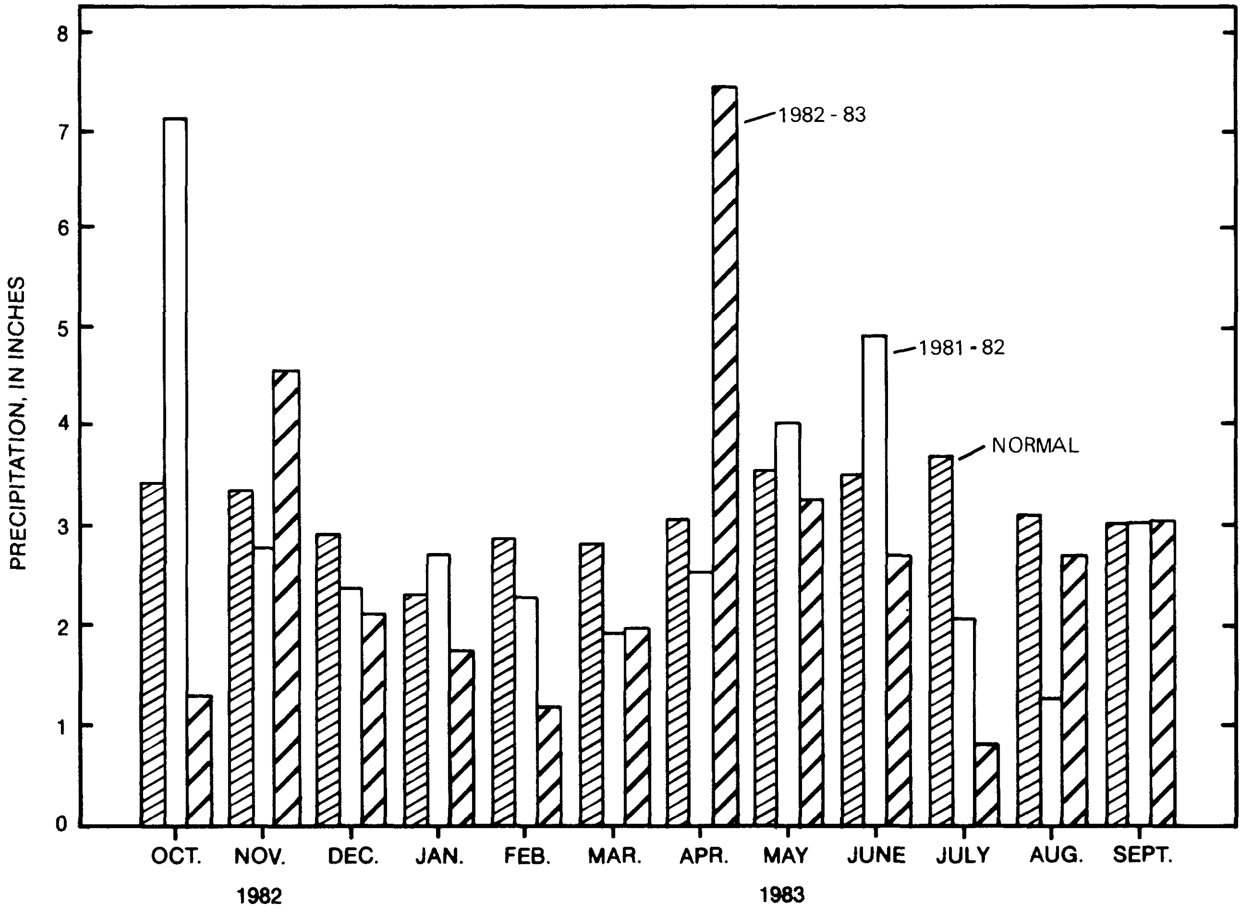


Figure 3.--Monthly precipitation in the Otisco Lake basin, October 1981 through September 1983. (Data from National Oceanic and Atmospheric Administration precipitation station at Skaneateles.)

STREAMFLOW

Streamflow data were collected on the five major tributaries entering Otisco Lake. Spafford Creek, the largest tributary, was monitored at two locations. The downstream gage site on Spafford Creek was placed at Sawmill Road, at the most downstream bridge. This site represents about 66 percent (8.06 mi^2) of the Spafford Creek drainage basin. Inflow to the lake from Spafford Creek was estimated by multiplying flows measured at the gage by 1.5 to account for runoff from the intervening area between Sawmill Road and the mouth (4 mi^2). This factor overestimates flows from the mouth of Spafford Creek during low-flow months because little increase in flow was observed from Bromley Road to Sawmill Road during low-flow periods. However, 80 percent of the runoff is associated with storms or snowmelt (above the 75-percent quartile), and more than 90 percent of the sediment and nutrient loads are carried during high flow. The overestimates of the low flows by the 1.5 factor did not have a significant effect on calculated annual loads. The gaging sites on the other four tributaries were near the mouth, so that virtually all subbasin outflow was monitored.

During high flows, part of the flow from the Spafford Creek drainage area north of Sawmill Road is intercepted by two agricultural drainage ditches, one on each side of the creek. The ditch on the west side is small, carries little water, even at high flows, and flows into Spafford Creek several hundred feet downstream of Sawmill Road. The ditch on the east side is larger and receives runoff from two or three smaller ditches and flows directly to the lake. Flow carried by this ditch during storms and high flows is less than 10 percent of the flow carried by Spafford Creek, however.

The amount of streamflow contributed by the many small tributaries that drain the ungaged part of the basin was estimated by balancing inflow, outflow, and change in lake contents. Inflow included streamflow from the gaged watersheds, estimated ground-water inflow, and precipitation directly on the lake. Aquifers at either end of Otisco Lake may each have contributed from 0.4 to 2 Mgal/d or 0.62 to 3.1 ft^3/s (Weist and Geise, 1969). For the purpose of this calculation, a maximum ground-water contribution was assumed, which gave a total of 6.2 ft^3/s to the lake from the two ground-water sources. Outflow from the lake was calculated from flow through Ninemile Creek (adjusted for change in lake contents), diversion by Onondaga County Water Authority for water supply, and evaporation from the lake surface. These calculations indicate that about 34 percent of the inflow to the lake comes from the ungaged area.

Comparisons of Study-Period Values with Long-Term Values

Annual discharges of several streams during the study period were compared with long-term records to determine whether they were representative of long-term conditions. These long-term stations were selected because of their hydrologic similarity to the project stations; these were Ninemile Creek at Marietta, West Branch Tioughnioga River at Homer, and Fall Creek at Ithaca (fig. 1). Mean values are given below for general comparisons; however, because the distributions of runoff were highly skewed, median values were used to compare for statistically significant differences (McGill and others, 1978). A discussion of statistics used in this study is given in appendix A.

During the 1982 water year (October 1981 through September 1982), the total annual precipitation of 37.0 inches at the Skaneateles weather station, 4 mi northwest of Otisco Lake (fig. 1), was near the 30-yr mean of 37.6 in/yr. During the 1983 water year it was lower--only 32.8 inches. Streamflow during the study reflected this pattern, as summarized below.

The 1982 mean discharge of 49.5 ft^3/s at Ninemile Creek at Marietta (the outlet of Otisco Lake) was higher than the period-of-record mean of 40.3 ft^3/s, but the 1983 mean discharge was only 26.4 ft^3/s. The median flow of 33 ft^3/s for the 1982 water year was also somewhat higher than the period-of-record median flow of 20 ft^3/s, and, again, the median flow of 6 ft^3/s for the 1983 water year was significantly lower. Flow in Ninemile Creek is regulated by the Onondaga County Water Authority at the north end of the lake (fig. 1) and is not representative of other streams in the area for specific time intervals. Period-of-record averages, however, may be indicative of long-term averages for other streams in the Otisco Lake basin.

The mean discharge of the West Branch of the Tioughnioga River at Homer (drainage area 71.5 mi^2), 8 mi south of Otisco Lake, was 146 ft^3/s for the 1982 water year and 104 ft^3/s for the 1983 water year, as compared to the period-of-record mean of 128 ft^3/s (water years 1972-84). Although annual mean flows differed considerably during the study, a statistical analysis of the median flows for the 1982 and 1983 water years, 118 ft^3/s and 91 ft^3/s, respectively, indicate that they are not significantly different statistically from the period-of-record median flow of 100 ft^3/s.

The mean discharge at Fall Creek at Ithaca (drainage area 126 mi^2), 30 mi southwest of Otisco Lake (fig. 1), was 249 ft^3/s for the 1982 water year and 163 ft^3/s for the 1983 water year, as compared to the 60-yr mean of 186 ft^3/s. Again, although annual mean flows differed considerably during the study, a statistical analysis of the median flows for the 1982 and 1983 water years (221 ft^3/s and 120 ft^3/s, respectively) indicates that they are not significantly different statistically from the period-of-record median flow of 132 ft^3/s.

These comparisons indicate that the discharges at Otisco Lake tributary and outlet stations during the study period were fairly representative of long-term flows even though the individual stream averages for the first year were higher than average and those in the second year lower.

Comparison Among Tributary Subbasins

Runoff (in inches) from the five subbasins was compared in terms of total monthly, mean monthly, and study-period values to relate any differences in runoff to subbasin characteristics. Median values were used to determine significant differences among subbasins because distributions were highly skewed. Total monthly runoff values from each subbasin are shown in table 5.

Total discharge for the period of study, total monthly discharge, and mean monthly discharge were significantly higher at Spafford Creek at Sawmill Road than at any of the other stations, and total discharge for the study period at Rice Brook was lower than any other station. (This is because Spafford Creek has the largest drainage area, and Rice Brook the smallest.) The total runoff (in inches) during the study varied considerably among the subbasins; it was highest at Spafford Creek at Bromley Road (46.21 in) and Van Benthuysen Brook (43.11 in.) and lowest at Willow Brook (29.97 in) and Rice Brook (31.3 in). Runoff at Spafford Creek at Sawmill Road and Amber Brook was 38.32 in and 35.43 in, respectively.

The subbasins with the lowest runoff had high percentages (80 to 84 percent) of soils with moderate infiltration rates and cropland to which

Table 5.--Total monthly runoff at gaging stations in subbasins of the Otisco Lake basin, November 1981 through September 1983.

[Values are in inches. Locations are shown in fig. 2.]

Station name and number[1]	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
	1981			1982									
Spafford Creek 04240145 at Bromley Road	--	3.97	2.43	1.15	1.46	3.81	4.41	2.24	2.31	1.60	1.06	0.88	25.32
04240150 at Sawmill Road	--	3.11	1.77	.77	1.13	3.95	3.73	1.25	1.72	.96	.57	.55	19.51
Rice Brook 0424015305	--	3.11	1.63	.78	1.10	3.60	2.54	.70	1.68	.77	.27	.32	16.50
Willow Brook 0424016205	--	2.57	1.48	.47	.70	3.43	2.11	.36	1.13	.44	.02	.03	12.74
Amber Brook 0424016825	—	3.19	1.77	.82	1.16	4.17	3.00	.81	1.55	.71	.20	.24	17.62
Van Benthuysen Brook 0424016975	--	4.90	2.54	1.27	1.82	5.63	3.20	1.03	1.42	.54	.22	.16	22.73
	1982			1983									
Spafford Creek 04240145 at Bromley Road	.75	1.44	1.82	1.39	1.66	1.77	4.45	3.49	1.51	1.04	.84	.74	20.89
04240150 at Sawmill Road	.47	1.26	1.63	1.60	1.87	1.62	4.99	3.30	.88	.41	.36	.32	18.81
Rice Brook 0424015305	.25	1.18	1.38	.97	1.82	1.21	5.05	2.27	.54	.07	.03	.03	14.80
Willow Brook 0424016205	.00	.84	2.47	1.42	2.41	1.38	6.14	1.97	.56	.04	.00	.00	17.23
Amber Brook 0424016825	.19	1.20	1.83	1.60	2.00	1.42	5.73	2.60	.77	.21	.11	.15	17.81
Van Benthuysen Brook 0424016975	.19	1.32	1.80	1.50	2.27	1.56	6.58	3.33	1.32	.20	.13	.18	20.38

[1] The 8- and 10-digit numbers reflect the downstream order of the gaging station.

conservation practices had been applied (61 to 78 percent). Van Benthuysen Brook, which had fairly high runoff, also had a fairly high percentage (81 percent) of soils with moderate infiltration rates, but only 18 percent of the cropland, which comprises 68 percent of the basin, was protected by adequate conservation practices. Spafford Creek at Bromley Road, which had the highest runoff, drains the upper 25 percent of the subbasin. The Spafford Creek basin as a whole has the steepest mean basin slope (36 percent of the total basin has a slope greater than 20 percent) and the highest percentage (43 percent) of soils with low infiltration rates. The downstream part of the Spafford Creek basin is less steep and contains soils that have higher infiltration rates and less runoff.

Statistically the medians of monthly values for runoff, in inches and in cubic feet per square mile, did not significantly differ among the subbasins. Discharge figures for July, August, and September 1983 indicated that the two sites on Spafford Creek had nearly equal flow; the Sawmill Road pattern during this period suggests that occasional withdrawal of water from Spafford Creek for irrigation may be the reason (Howard Schuster, U.S. Department of Agriculture, Soil Conservation Service, oral commun.).

The relative contributions of runoff from the subbasins to the lake are summarized below:

Subbasin	Drainage area (percentage of lake watershed)	Total runoff during study period, as $(ft^3/s)/d$ (percentage of total basin runoff)
Amber Brook	10	9
Rice Brook	7	6
Spafford Creek	33	33
Van Benthuysen Brook	10	11
Willow Brook	10	8
Ungaged area	30	34
Total	100	101

SEDIMENT AND NUTRIENTS IN TRIBUTARY STREAMS AND OTISCO LAKE

Streams that drain agricultural basins receive sediment and nutrients from overland runoff. The quantities received are directly related to such factors as basin slope, extent of farming, and the methods of farming. The bodies of water to which those streams are tributary generally exhibit increased rates of eutrophication.

Sediment in Tributary Streams

Source

Sheet and rill erosion are the major forms of soil erosion in the Otisco Lake basin. Soil erosion is influenced by seasonal runoff, ground cover, rainfall intensity, slope, surficial geology, soil types, types and intensity of agricultural practices, and conservation practices. Of the estimated 77,000 ton/yr of gross erosion in the basin (U.S. Department of Agriculture, Soil Conservation Service, 1983), less than 15 percent (10,600 tons) reaches the lake; most of the sediment is trapped, at least temporarily, at slope changes, fence rows, tree lines, ponds, or manmade barriers.

Woodland, pasture, and other idle lands in the basin exhibit the lowest erosion rates, about 1 (ton/acre)/yr, which results in gross erosion of 11,470 ton/yr. Of the 11,600 acres of active cropland in the basin, only 5,460 receive adequate conservation practices such as diversions, grassed waterways, strip cropping, subsurface drains, and conservation tillage (U.S. Department of Agriculture, 1983). The gross erosion rate is estimated to be 1.5 (ton/acre)/yr, resulting in a gross erosion rate of 8,040 ton/yr. The remaining 6,340 acres produce from 3 to more than 30 (ton/acre)/yr, which yields a gross erosion of 57,000 ton/yr. These cropland areas, which account for 75 percent of the total estimated gross erosion in the watershed, are considered by the Soil Conservation Service to be in need of treatment to reduce erosion rates. The mean erosion rate for all land in the Otisco Lake basin is 3.2 (ton/acre)/yr. Erosion characteristics of the croplands inventoried by the Soil Conservation Service in each subbasin are summarized in table 6.

Table 6.--Mean values and standard deviations of soil erosion-characteristics of inventoried cropland in subbasins of the Otisco Lake basin.

[Standard deviations are in parentheses. Data from U.S. Soil Conservation Service, site inventory, 1981.]

	Drainage area and percentage of cropland inventoried					
	Amber Brook	Direct drainage[1]	Rice Brook	Spafford Creek	Van Benthuysen Brook	Willow Brook
Equation constants[2]	75	63	57	36	44	90
Soil-erodibility factor (K)	0.33 (±.03)	0.33 (±.04)	0.31 (±.07)	0.31 (±.07)	0.32 (±.03)	0.34 (±.04)
Slope-steepness factor (S)	.08 (±.04)	.07 (±.05)	.06 (±.04)	.08 (±.05)	.07 (±.04)	.05 (±.03)
Slope-length factor (L)	386 (±229)	285 (±153)	281 (±118)	247 (±116)	302 (±201)	295 (±115)
Cover and management factor (C)	.15 (±.06)	.16 (±.05)	.12 (±.07)	.13 (±.08)	.15 (±.03)	.14 (±.04)
Erosion rate ((ton/acre)/yr)	7.5 (±6.7)	6.6 (±6.8)	3.3 (±4.0)	6.0 (±9.0)	5.8 (±6.5)	3.1 (±3.4)

[1] Direct drainage refers to areas that are ungaged and drain directly to the lake through small intermittent tributaries.

[2] Universal soil-loss equation A = RKLSCP; see explanation on p. 20.

Streambank erosion may be a significant source of the annual sediment load of Amber and Van Benthuysen Brooks. The U.S. Soil Conservation Service (U.S. Department of Agriculture, 1983) estimated that sediment from streambank erosion in Amber Brook may be 120 ton/yr (of 240 ton/yr total) and in Van Benthuysen Brook may be 78 ton/yr (of 174 ton/yr total). However, sources of sediment can not be distinguished through data from this study nor from the U.S. Soil Conservation Service estimates. Also, some of the sediment produced in the upstream part of the Van Benthuysen basin is trapped in Smith Hollow Pond (fig. 2) and does not reach Otisco Lake.

Gross erosion rates in the Otisco Lake subbasins were calculated by the U.S. Soil Conservation Service through the Universal soil-loss equation:

$$A = RKLSCP \tag{1}$$

where: A = computed soil loss per unit area,
R = rainfall and runoff factor,
K = soil-erodibility factor,
L = slope-length factor,
S = slope-steepness factor,
C = cover and management factor, and
P = support practice factor.

This equation was developed to predict long-term average soil losses in runoff from specific field areas. With appropriate selection of its factor values, it predicts the soil loss for a particular site. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but because these fluctuations average out over the long run, the Universal soil-loss equation generally predicts long-term averages more reliably than it does short-term or specific events.

Concentrations and Loads

The total sediment load delivered to the lake by all tributaries (including ungaged areas) during the 23-month study was 10,600 tons. Of this total, Spafford Creek contributed the most--approximately 7,630 tons, or 1 ton/acre, and had the highest concentrations of sediment of all major tributaries. Van Benthuysen Brook contributed the smallest load, with 334 tons or 0.15 ton/acre. Rice Brook contributed 325 tons or 0.20 ton/acre, Amber Brook contributed 460 tons or 0.19 ton/acre, and Willow Brook contributed 550 tons or 0.23 ton/acre. Concentrations of sediment ranged from < 1 mg/L at most sites during low flow to a maximum of 5,910 mg/L at Spafford Creek at Sawmill Road during a storm on July 8, 1982.

Suspended-sediment loads at all sites were calculated for October 1981 so that 2 complete years of data would be available for computation of annual sediment yields. Calculations were made from estimates of runoff and sediment concentration in each subbasin. Runoff from each subbasin in October 1981 was estimated from the values for West Branch Tioughnioga River and Fall Creek (fig. 1), both of which, although considerably larger in drainage area than the Otisco Lake tributaries, are similar in basin characteristics. Suspended-sediment load was estimated from sediment-transport curves.

October 1981 was unusual in that a storm caused high runoff and sediment loads that made the suspended-sediment load for the 1982 water year considerably higher than expected in a normal year. The calculated sediment load from Spafford Creek in October 1981 was about 2,400 tons, making the total load for the first year approximately 6,000 tons, whereas the total load for the second year was only 4,027 tons. To obtain a more representative estimate for October 1981, an inches-of-runoff value based on the period of record for October in Ninemile Creek at Marietta was assumed. Monthly mean flows calculated from this assumed figure and used with a sediment-transport curve gave a more representative sediment load for October 1981 for each of the stations. The resulting average annual sediment load for Spafford Creek is about 3,800 tons.

The October 1981 storm had a recurrence interval exceeding 10 years. The effect of a storm of this magnitude on subsequent high flows is difficult to assess. Because of several factors, such as the relatively small size of the subbasins, their general steepness, their fairly high stream gradients, and the shortness of the tributaries, the probable result is that it had a cleansing effect and that sediment and particulate nutrient loads associated with subsequent high flows were somewhat less than might be expected. The magnitude and duration of the influence of such a storm cannot be estimated from the short-term data of this study.

The suspended-sediment load at the upstream site on Spafford Creek during the study was 502 tons or 0.25 tons per acre, which indicates that about 95 percent of the sediment load generated in the Spafford Creek basin originates downstream of Bromley Road. This is probably because watershed characteristics downstream of Bromley Road differ from those upstream in that the soils are derived from more erodible lake sediments and clays, and the greater amount of agriculture exposes more soil to erosion.

The total calculated loads of suspended sediment from each gaged tributary during the study are given in appendix table C-1, the seasonal loads in table C-2, and the monthly loads in table C-3.

Sediment in Otisco Lake

Sediment has been accumulating in the south end of Otisco Lake since 1869, when the area was inundated by the first artificial increase in lake level. Since 1899, when the causeway was constructed, most of the sediment has accumulated south of the causeway because it prevents the migration of sediment particles to the main body of the lake. Until the spring of 1929, when the causeway was severely eroded, the only opening in the causeway was a boat channel where the original Spafford Creek channel had been. After 1929, the causeway was breached at several points by high lake levels, usually during the spring of each year. The most serious break was on the east side of the causeway near Rice Grove (fig. 2). Clay-size suspended sediment moved to the main body of the lake while the causeway was breached; this is particularly evident in aerial photographs taken during years when lake levels were high (fig. 4).

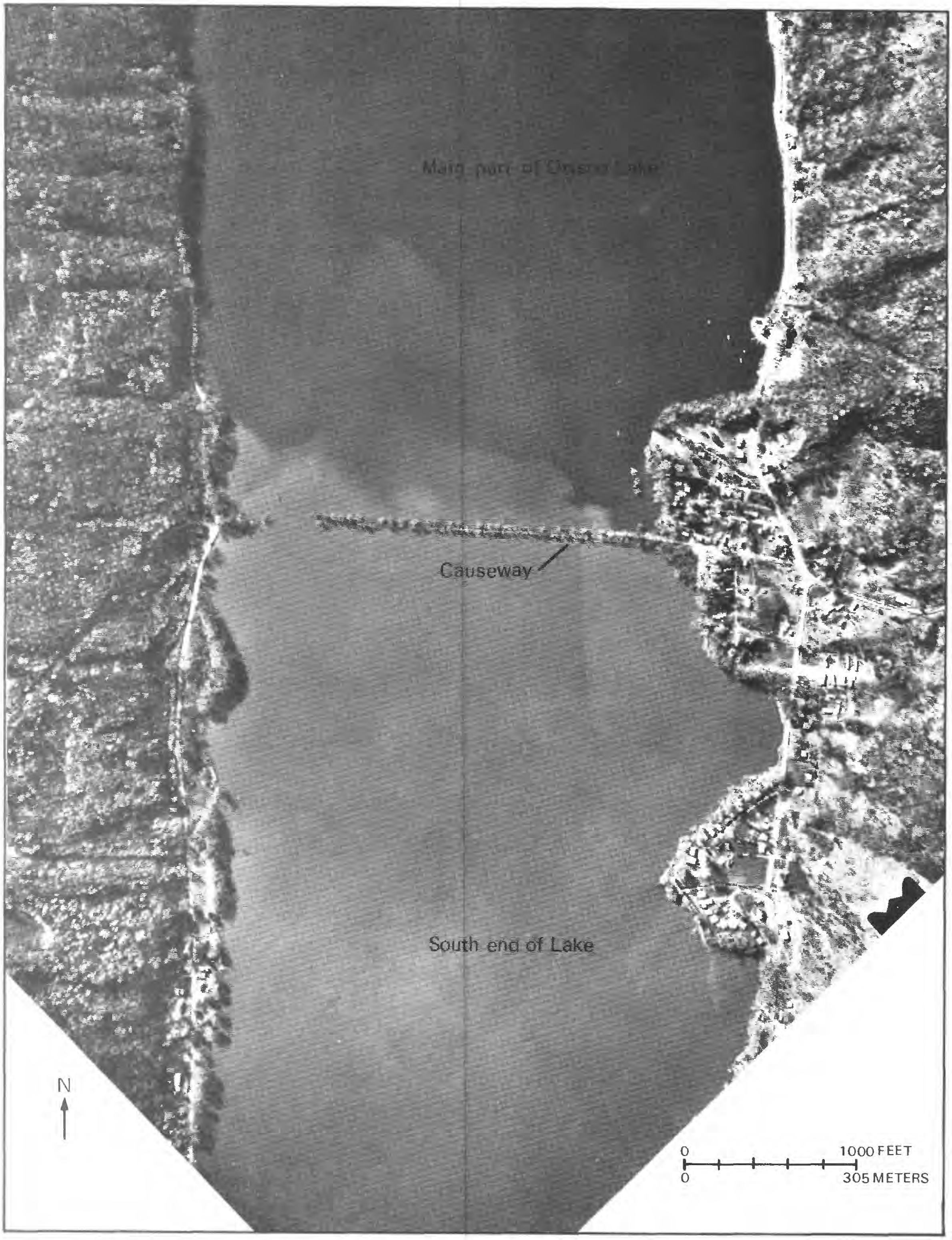


Figure 4.--Aerial photograph of April 29, 1972, showing northward migration of sediment to the main part of the lake through deteriorated parts of the causeway when lake level was high. (Courtesy of Kucera and Associates, photogrammetric engineers, Mentor, Ohio.)

Source

The primary contributor of sediment to the lake is Spafford Creek, which delivered a load of more than 7,630 tons (10.9 ton/d) during the study. The highest daily load during the study, 421 tons, occurred on April 24, 1983. Particle-size analysis showed that during high flows, 55 percent of the suspended sediment is silt, 35 percent is clay, and 10 percent is sand-sized or larger particles, which indicates that most of the sediment would remain suspended for long periods, and the potential for adsorption of nutrients to the suspended particles would be large.

Sediment loads to the lake from the other major tributaries during the 23-month study totaled 1,670 tons--330 tons (0.5 ton/d) each from Van Benthuysen Brook and Rice Brook, 460 tons (0.7 ton/d) from Amber Brook, and 550 tons (0.8 ton/d) from Willow Brook. The largest mean daily sediment load was 101 ton/d at Willow Brook on April 26, 1983. On many days of low flow, the loads were less than 0.01 ton/d. Except at Rice Brook, where sand and clay fractions were nearly equal, the size distribution of sediment particles from these sites was nearly the same as at Spafford Creek.

Sedimentation Patterns

The 12 lake-bottom cores from south of the causeway indicate that sediment deposited since the lake level was raised in 1869 (top-layer sediments or muck) contains 1 to 10 percent organic matter, whereas the underlying material, which was farmland or wetland before the lake level was raised, consists of peat and clay and contains 10 to 40 percent organic matter. Contours showing the thickness of recent sediments are plotted in figure 5. The contours were drawn from information obtained by analysis of the cores; the core data are plotted in figure 6.

Sediment thickness north of the causeway was considerably less than that south of the causeway except near the boat channel. The contours in figure 5 show sediment thickness to be greatest near the mouth of Spafford Creek and to decrease gradually toward the causeway. The two arms of sediment deposition extending to the causeway are the result of flow patterns toward the boat channel on the west side of the causeway and toward the break in the east side of the causeway near Rice Grove.

A physical model of the south end of the lake was built to simulate general rates and patterns of sediment movement from Spafford Creek through the impoundment south of the causeway, through the causeway, and into the main body of the lake. Dye was introduced in the model through Spafford Creek to identify circulation patterns. Most of the dye was trapped south of the causeway and circulated counterclockwise. Dye passing through the boat channel in the causeway circulated counterclockwise to the east side of the lake, just north of the causeway. Circulation patterns in the model are consistent with those estimated by Morelli (1983) and with deposition patterns observed during this study.

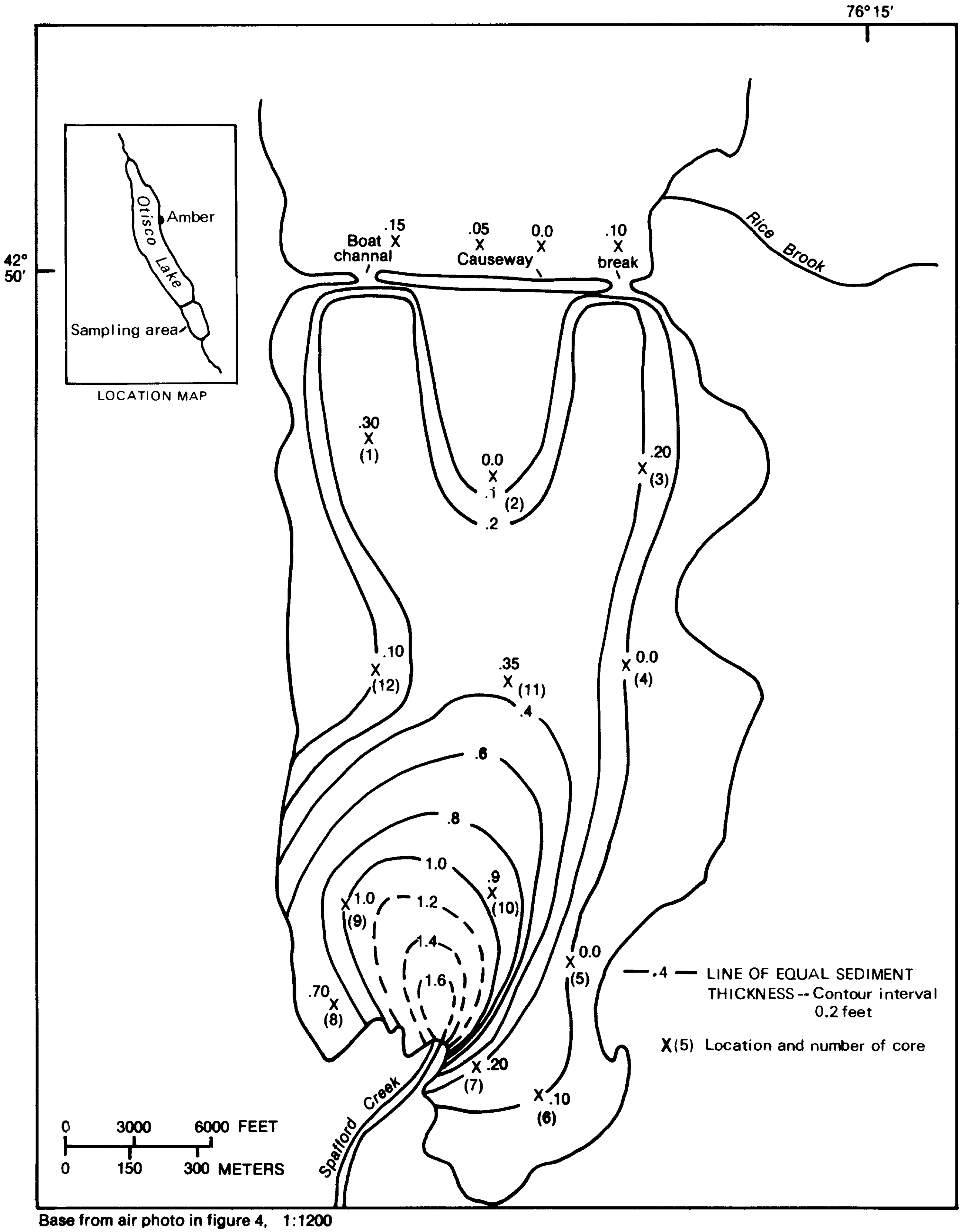


Figure 5.--Sediment thickness and location of sediment cores in Otisco Lake south of the causeway.

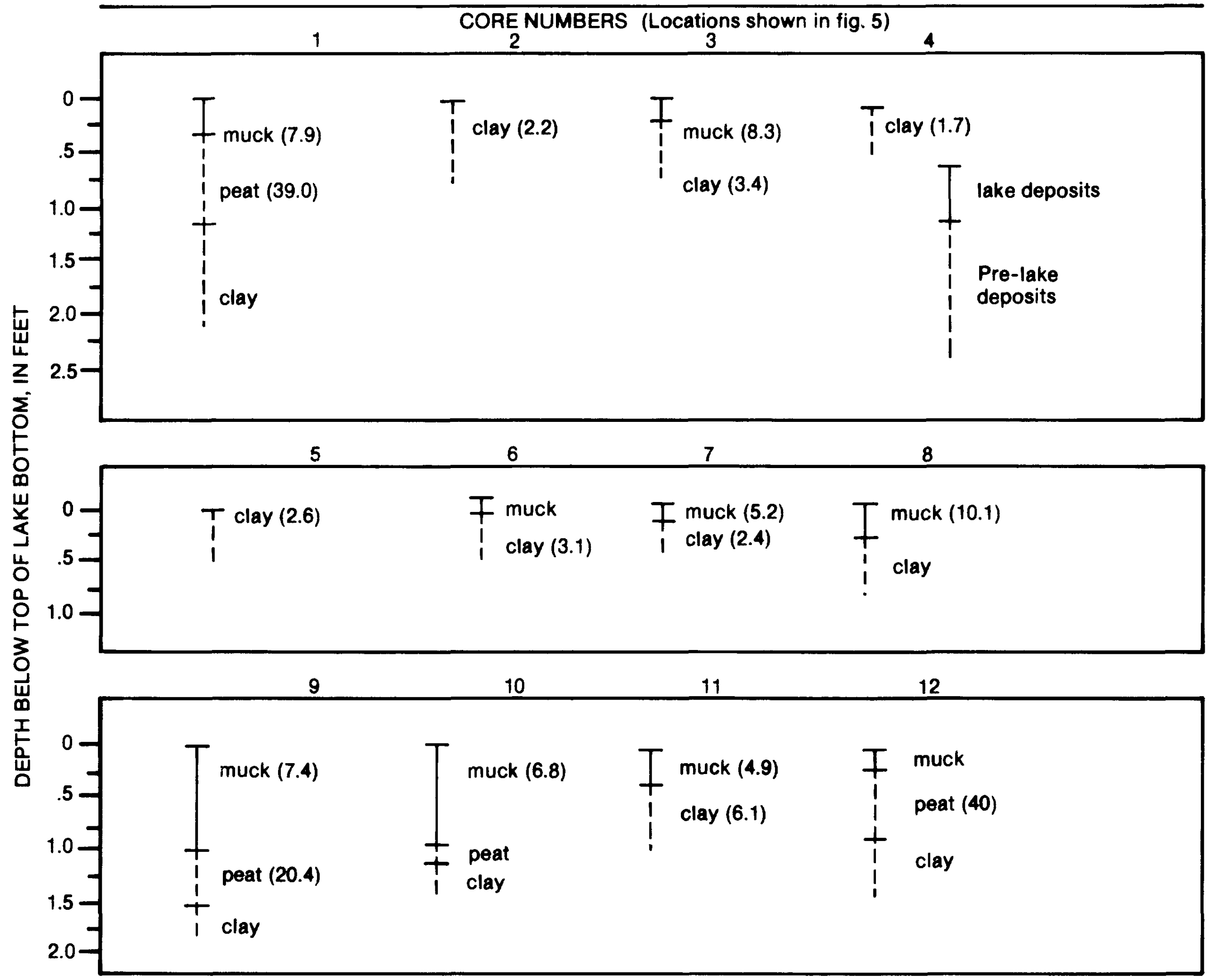


Figure 6.--Sediment columns and organic content of lake-bottom sediments in shallow cores taken south of causeway. Numbers in parentheses indicate percentage of sample consisting of organic matter. (Sampling locations are shown in fig. 5.)

Deposition Rates

Fifteen suspended-sediment samples from Spafford Creek were analyzed for particle-size distribution; results are presented in table 7. The size fractions are divided into sand, silt, and clay, and the settling times are expressed in percentage of material remaining in suspension after the specified time interval. Settling distance is 80 cm (31.5 in). The mean of all samples indicates that approximately half the sediment settles 80 cm after 1.2 hours, and 70 percent settles out after 8 hours. These settling times reflect laboratory conditions; settling times under natural conditions are subject to factors such as water velocity, water temperature, and depth, which can greatly influence the rate of settling.

Table 7.--Particle-size analyses of suspended-sediment samples from Spafford Creek at Sawmill Road, 1982-83

Date	Time	Dis-charge (ft^3/s)	Suspended sediment concen-tration (mg/L)	Composition (percent)			Percentage of sediment left in suspension after selected settling time (minutes)								Instan-taneous sediment load (tons)
				Sand	Silt	Clay	0	4.6	27	72	160	453	1120	3200	
3-13-82	1300	45	637	9	84	7	91	80	54	38	27	15	7	0	77
6-06-82	830	42	250	5	53	41	95	89	74	61	51	39	31	22	28
6-17-82	900	33	497	2	52	46	98	94	82	69	57	43	32	22	44
6-17-82	1000	22	372	3	47	50	97	94	83	72	61	46	35	25	22
6-29-82	910	101	1880	11	62	27	89	77	54	42	34	25	19	12	513
6-29-82	920	122	1600	10	62	29	90	79	56	44	36	26	20	13	527
6-29-82	1040	150	1450	9	53	38	91	83	66	55	46	36	28	20	587
6-29-82	1045	150	1860	7	55	38	93	86	68	56	46	36	28	20	753
6-29-82	1110	151	1310	18	49	32	82	72	57	47	39	30	23	16	534
2-3-83	955	93	873	6	59	35	94	84	67	54	44	33	25	17	219
4-10-83	1300	42	1040	4	54	42	96	91	76	63	52	39	29	20	118
4-15-83	1315	73	1160	6	59	35	94	85	65	53	43	33	25	18	229
4-15-83	1500	82	1290	6	59	35	94	86	67	53	44	33	25	18	286
4-15-83	1900	78	764	10	58	35	90	79	59	47	39	30	24	18	161
4-15-83	2100	131	2610	13	59	27	87	76	54	43	34	26	19	13	923
Means		88	1173	8	58	34	92	84	65	53	43	32	25	17	335

Calculations based on the volume of sediment containing 1 to 10 percent organic material indicate that about 390,000 tons of sediment have been deposited south of the causeway since the lake level was first raised in 1869. The estimated long-term mean deposition rate of 3,420 ton/yr south of the causeway compares well with the mean of 3,573 ton/yr from Spafford Creek, estimated by the U.S. Soil Conservation Service through the Universal soil-loss equation (eq. 1) and with the 2-year mean annual load of 3,820 ton/yr from Spafford Creek, measured by the U.S. Geological Survey during this study.

The calculated 3,420 ton/yr of sediment deposited south of the causeway was approximately 90 percent of the 3,820 ton/yr contributed by Spafford Creek. The causeway retains most of the sediment that enters the south end of the lake; the rest is either transported beyond the causeway or is retained in the wetland near the mouth of Spafford Creek. An annual load of 3,820 ton/yr from Spafford Creek, if distributed uniformly south of the causeway, would increase sediment depths by only about 0.07 in./yr.

Sediment entering the lake from major tributaries north of the causeway (excluding ungaged areas) totals about 830 ton/yr. Some of the sediment is deposited near the mouths of these tributaries, but deposition patterns and rates are difficult to identify because they vary according to lake elevation, lake currents, and wind direction. The annual load of 830 ton/yr calculated by the U.S. Geological Survey is far less than the 7,089 ton/yr calculated by the U.S. Soil Conservation Service from the Universal soil-loss equation. The disparity is probably due to simplifying assumptions and aggregation procedures used by the U.S. Soil Conservation Service to estimate erosion rates and delivery ratios for entire subbasins on the basis of a partial inventory of the active cropland.

Nutrients in Tributary Streams

Source

Crop yield depends heavily on the application of fertilizer to supplement or replace nutrients lost from soil by erosion, plant uptake, and leaching. Commercial fertilizers are generally applied during the spring, and manure is usually applied from late fall through early spring. Fertilizer type and usage for each subbasin are listed in table 8. Manure and fertilizer, depending on the type, supply varying amounts of nitrogen and phosphorus to the soil.

The application of commercial fertilizers can be fairly well quantified, but application of manure is more difficult to evaluate. Typically, manure is applied to land to be planted in corn or on hay fields as a fertilizer substitute during late fall and early spring and to land planted with hay during July and August. Rates of manure application vary widely, from 4 to 8 (ton/acre)/yr, depending on weather conditions, distance from barn to field, and field slope. The U.S. Soil Conservation Service has estimated the total phosphorus production from animal sources within the Otisco Lake watershed to be 44,000 lb/yr, 1,730 lb/yr of which is transported to the lake. Some of this nitrogen and phosphorus is adsorbed by the soil, some is used by plants, some is removed by leaching, and some is removed by overland runoff.

Table 8.--Annual commercial fertilizer use on cropland in Otisco Lake watershed.

[Based on figures from U.S. Department of Agriculture, Soil Conservation Service, 1983. Locations are shown in fig. 2.]

Subbasin	Rate (lb/acre) Commercial fertilizer	Rate (lb/acre) N	Rate (lb/acre) P	Total (lb/yr) N	Total (lb/yr) P
Amber Brook	332	48	57	76,464	90,801
Ungaged	304	53	55	149,248	154,880
Rice Brook	191	53	59	58,459	65,077
Spafford Creek	283	42	62	112,896	166,656
Van Benthuysen Brook	384	52	64	79,196	97,472
Willow Brook	344	42	61	78,120	113,460
Mean for cropland in basin	--	48	59	--	--

Table 9.--Possible sources and concentration range of sediment and nutrients in tributaries to Otisco Lake.

[Concentrations are in milligrams per liter.]

Constituent	Possible sources	Concentrations minimum	Concentrations maximum
Suspended sediment	Erosion of mineral and organic soil	<1	6,000
Nitrogen			
total organic	Bacterial, plant, and animal proteins and wastes	.06	9.8
total ammonia	Bacterial decomposition of organic nitrogen, reduction of nitrite	.01	1.9
total kjeldahl (ammonia plus organic N)	Naturally occurring sources such as animal wastes	.02	10
dissolved nitrite plus nitrate (oxidized)	Fertilizers, oxidation of ammonia and nitrogen gas.	.02	6.4
Phosphorus			
total	Fertilizers, detergents, and animal metabolic wastes	.002	1.4
total inorganic	Same	.01	.95
dissolved	Same	.01	1.0
dissolved orthophosphate	Detergents and fertilizers	.01	.92
dissolved organic	Products of animal and plant metabolism (food, wastes)	.01	.10

Some possible sources of nutrients and the ranges of concentrations of nutrients detected in the tributaries to Otisco Lake are given in table 9; the mean instantaneous concentrations and seasonal maximum concentrations of sediment and nutrients for each of the tributaries are given in appendix table C-4.

Concentrations and Loads

Nutrient loads were calculated from streamflow and from sediment and nutrient concentrations. Sediment and nutrient concentrations in streamflow were monitored at selected locations from November 1981 through September 1983. Total discharge and sediment and nutrient loads from tributaries are summarized in appendix table C-1; seasonal values are given in table C-2, and monthly values are given in table C-3.

Comparison of median values (box plots with approximately 95-percent confidence intervals) confirmed that the concentrations of constituents differed significantly among the tributaries, as described below.

1. Total kjeldahl nitrogen (TKN) and total organic nitrogen.--Concentrations in Van Benthuysen Brook were significantly greater than those in the upper reaches of Spafford Creek at the Bromley Road site. High TKN and organic nitrogen are characteristic of forest soils, where nitrification is unusually slow. The actual source could not be determined.

2. Dissolved $NO_2 + NO_3$.--Concentrations in Rice Brook and Willow Brook were significantly higher (usually characteristic of higher nitrification or fertilizer use), and concentrations in Van Benthuysen Brook were significantly lower (nitrogen in more reduced form--see item 1 above) than those in the other tributaries.

3. Total phosphorus.--Concentrations in Spafford Creek at Sawmill Road were significantly greater than those in Van Benthuysen Brook and are probably related to the high sediment yields at Sawmill Road.

Spafford Creek at Sawmill Road had the highest concentrations of total organic nitrogen, total kjeldahl nitrogen, total phosphorus, and dissolved organic phoshorus. Rice Brook had the highest concentrations of NH_3 (equaled by Willow Brook), total dissolved phosphorus, dissolved orthophosphate, and total inorganic phosphorus. Willow Brook had the highest concentrations of $NO_2 + NO_3$.

Generally, concentrations of TKN and total phosphorus were highest in spring and summer (March-August), when sediment load was highest (organic nitrogen and phosphorus adsorb to soil particles) and fertilizer use was also highest.

Nitrogen.--Nitrogen was the most abundant of the nutrients entering Otisco Lake. Total loads of the nitrogen species to Otisco Lake (from all tributaries, including estimated contributions from ungaged areas) during the study were 236,000 lb of $NO_2 + NO_3$ and 199,000 lb of total kjeldahl nitrogen, of which 23,700 lb was NH_3. Spafford Creek, which had the highest level, discharged 73,400 lb of total kjeldahl nitrogen, of which 6,100 lb was NH_3, and 63,200 lb of $NO_2 + NO_3$. Rice Brook contributed the smallest loads of NH_3 (1,550 lb) and total kjeldahl nitrogen (12,100 lb); Van Benthuysen Brook had the smallest loads of $NO_2 + NO_3$ (17,400 lb). Concentrations of NH_3 were fairly uniform throughout the basin and showed little response to changes in streamflow. Concentrations of total kjeldahl nitrogen were also fairly uniform throughout the basin but showed significant increases during high flows, which reflects the particulate nature of the organic fraction of total kjeldahl nitrogen.

Concentrations of $NO_2 + NO_3$ were highest in Willow Brook and lowest in Van Benthuysen Brook. $NO_2 + NO_3$ concentrations during high flows were nearly uniform among all tributaries except Van Benthuysen Brook. Minor differences were noted, however, at the beginning of high flows. At Spafford Creek and Amber Brook, concentrations of $NO_2 + NO_3$ decreased at the beginning of a rise, then increased, probably as a result of an initial dilution followed by an increase due to soil erosion. No such initial dilution was observed at Rice Brook or Willow Brook, however, possibly because more agricultural fields and barnyards are close to the streams here than in other basins, which allows more rapid transport of nutrients to the stream. At all sites except Spafford Creek, concentration of $NO_2 + NO_3$ continued to increase for a while during recession before decreasing. Because measured $NO_2 + NO_3$ concentrations were in the dissolved form, residual runoff after the peak flow may have continued to carry $NO_2 + NO_3$ to these tributaries. Concentrations of $NO_2 + NO_3$ in Van Benthuysen Brook remained fairly constant throughout high flows, probably because the $NO_2 + NO_3$ carried to Van Benthuysen Brook by overland runoff is diluted by increased discharges from Smith Hollow (fig. 2) pond during high flows.

Although the loads of all nutrients were highest in Spafford Creek, other tributaries had higher concentrations of some constituents (appendix table C-4). Nutrient loads are primarily a function of streamflow. Nutrient concentrations in water from the ditches on either side of Spafford Creek during high flows were about equal to those in Spafford Creek; sediment concentrations were slightly less. Contributions to the lake from the drainage ditch are negligible compared to those from Spafford Creek. The relative contributions of sediment and selected nutrients to the lake are summarized in table 10.

Phosphorus.--The total phosphorus load to Otisco Lake from all tributaries (including the ungaged area) during the study was 20,600 lb, including 7,045 lb dissolved and 3,140 lb of orthophosphate, which are the forms available for plant uptake; the remainder is dissolved organic and total inorganic phosphorus. Spafford Creek contributed the largest amount, nearly 9,600 lb (about 2,000 lb of which was dissolved). Amber Brook contributed 1,140 lb, the lowest amount. Ratios of dissolved to total phosphorus load ranged from 49 percent in the Willow Brook watershed to 21 percent in Spafford Creek. The ratios at each site did not vary significantly through the study. In contrast, total phosphorus concentrations increased significantly during high flows because of their association with suspended sediment, while concentrations of dissolved phosphorus remained relatively constant or decreased slightly during the stormflows. Total phosphorus is readily adsorbed onto sediments and microorganisms; therefore, significant increases in sediment result in significant increases of phorphorus. Annual loads of orthophosphate ranged from

239 lb at Amber Brook to 785 lb at Spafford Creek. Orthophosphate concentrations generally remained fairly constant throughout the year, with slight increases during high flows.

Although the tributaries transport phosphorus at a natural background level, the application of fertilizers and other phosphorus-bearing substances to the soil, and subsequent erosion of soil particles, increases the amount of phosphorous in the tributaries. Data from this study are insufficient to estimate the magnitude of the increase, however.

Table 10.--Relative contributions of sediment and selected nutrients to Otisco Lake from major tributaries, November 1981 through September 1983.

[Values are percentage of total. Locations are shown in fig. 2.]

Subbasin	Drainage area	Suspended sediment	Dissolved NO_2+NO_3	Total kjeldahl nitrogen	Total phosphorus
Amber Brook	10	4	9	8	6
Rice Brook	7	3	9	6	6
Spafford Creek	33	72	27	37	46
VanBenthuysen Brook	10	3	7	10	8
Willow Brook	10	5	16	11	11
Ungaged area	30	12	32	28	24

RELATION OF SEDIMENT AND NUTRIENT LOADS TO BASIN CHARACTERISTICS

Sediment and nutrient loads were examined in relation to the basin and land-use characterstics to discern significant relationships between subbasin characteristics and nutrient or sediment loads. Results are summarized in tables 1 through 6.

Total Loads

The analyses for total loads indicated significant relationships between runoff per acre and yields and subbasin characteristics (slopes of regression curves were significantly different from zero at the 95-percent confidence level), and most equations fit the data reasonably well (R^2 = 0.47 to 0.89). Most of the yields were related to topography, surficial geology, or soil characteristics. Total phosphorus yields were lowest in basins with the largest percentage of contour farming and in areas in which waterway improvements have reduced streambank erosion (R^2 = 0.81).

Monthly Loads

The analyses for monthly and seasonal values indicated significant relationships among runoff per acre, yields, and subbasin characteristics, but none of the equations provided a reasonable fit to the data (R^2 less than

0.43). Generally, runoff per acre and yields were positively related to total area and to precipitation (the more precipitation and subbasin area, the greater the runoff or yield). Neither monthly runoff per acre nor yields from individual subbasins showed significant relationships to subbasin characteristics (slopes of regression curves were not significantly different from zero)--probably because of the small sample size and large variation within the individual data sets. Regression analysis of runoff and loads from stormflows and snowmelt showed significant relationships to total subbasin area and soil series or geologic type but did not give reasonable fits to the data. (R^2 less than 0.3).

Regression analyses of monthly values were also done with interaction terms of percent cropland and rainfall. Other regression analyses were done by forcing selected independent variables into the equations. Variables for sediment yield were soil-erodibility factor, slope-steepness factor, management-practice factor, slope-steepness and length factor, precipitation per acre, percentage of basin occupied by cropland plus pasture, percentage of basin occupied by woodland, and total acres; those for nutrient loads were suspended sediment concentration, amount of fertilizer (lb/acre), precipitation per acre, percentage of basin occupied by cropland plus pasture, percentage of basin occupied by woodland, and total number of acres. Again, the relationships were significant (slopes of regression curves significantly different from zero), but the equations did not explain the variance in the data (R^2 less than 0.5).

Effects of Land Use and Rainfall

The effects of land use and rainfall on sediment and nutrient yields are not reflected by the regression relationships. This does not mean that these factors do not affect yields, but rather, that the aggregate effects of land use and rainfall masked their effects on runoff and yields. The percentages of land use and the subbasin characteristics remained constant over time, and the rainfall did not differ from basin to basin. Also, the water-quality sampling was done essentially at the mouth of each tributary, which effectively integrated land-use effects and masked differences within each subbasin. To compare the effects of different land uses on water quality would require sampling of runoff from specific sites, such was done in Pennsylvania by Lietman and others (1983) in forest, cornfield, rural, residential land, and pasture land.

Generally the highest concentrations of $NO_2 + NO_3$, phosphorus, and sediment can be expected from cropland where little or no conservation measures are applied because here the land is more easily eroded and more nutrients are applied in an effort to maintain crop yield. Sediment and nutrient yields from cropland receiving adequate conservation practices such as strip cropping, contour plowing, or conservation tillage are generally lower than those from cropland without such measures. Forestland generally yields the lowest concentrations of nutrients, although organic nitrogen (which is not considered a nutrient) is generally higher in forests than in other areas. Other factors that influence sediment and nutrient concentration are associated with erosion potential, such as slope steepness, soil type, ground cover, and rainfall intensity. Some general comparisons between cropland and woodland with sediment and nutrient yields can be drawn from the data in table 11.

Table 11.--Percentage of subbasin area covered by cropland and woodland in relation to sediment and nutrient loads.

[Locations are shown in fig. 2.]

Station	Land use (percentage of subbasin)			Sediment (ton/acre)	Nutrients (lb/acre)		
	Cropland	Woodland	Other		NO_2 NO_3	Total kjeldahl nitrogen	Total phosphorus
Amber Brook	67	20	13	0.19	8.9	6.6	0.5
Rice Brook	64	32	4	.16	10.3	6.0	.6
Spafford Creek	35	55	10	1.0	8.2	9.6	1.2
Van Benthuysen Brook	68	18	14	.15	7.8	8.9	.7
Willow Brook	79	9	12	.23	15.8	9.7	.9
Ungaged areas	40	42	18	.18	10.8	7.8	.7

Yields of NO_2 + NO_3 seem to be greater in areas with high percentages of cropland, but sediment and phosporus yields show no obvious relationship to land use. Other factors, such as detention of sediment by ponds, as along Van Benthuysen Brook, or large areas with minimal vegetation, such as around Spafford Creek, may have a greater influence than land use alone.

Effects of Runoff on Sediment and Nutrient Loads

Most of the runoff and sediment and nutrient loads entering the lake during the study were the result of storms and snowmelt. Stormflows were identified as peaks in the discharge record that corresponded to precipitation events. High flows were defined as periods when discharges (both storms and snowmelt) were at or above the 75-percent quartile. The percentages of runoff and loadings during storms and snowmelt periods are given in table 12; the sediment and nutrient loads during high flows are summarized below.

1. Storm runoff constituted 46 to 65 percent of the total runoff in the tributaries. From 58 to 90 percent of the sediment load in these tributaries and 30 to 90 percent of the nutrient load was transported in storm runoff.

2. Snowmelt contributed 13 to 36 percent of the runoff in the tributaries. Between 9 and 39 percent of the sediment load and 4 to 61 percent of the nutrient load was transported by runoff from snowmelt.

3. High flows, both from storm runoff and snowmelt at or above the 75-percent quartile, contributed between 78 and 82 percent of the runoff in the tributaries. Between 93 and 99 percent of the sediment load and 70 to 98 percent of the nutrient load were transported during high flows.

Sediment loads (except in Amber and Rice Brooks) and all nutrient loads were greatest at all sites during spring, when runoff was highest. About 70 percent of the sediment, 60 percent of the total kjeldahl nitrogen, 58 percent

Table 12.--Contributions of sediment and nutrients to Otisco Lake from major tributaries during storms and snowmelt, November 1981 through September 1983.

[Values are in percentage of total. Locations are shown in fig 2.]

Station	Runoff	Suspended sediment (tons)	Nitrogen				Phosphorus				
									Dissolved		
			Organic	Ammonia	TKN	NO_2+NO_3	Total	Total inorganic	Total	Orthophosphate	Organic
Storms											
Amber Brook	46	58	29	54	81	50	74	49	49	41	79
Rice Brook	56	90	53	72	81	66	89	80	78	78	73
Spafford Creek	65	88	87	78	89	80	82	58	58	33	69
Van Benthuysen Brook	43	69	54	42	56	44	62	55	53	47	67
Willow Brook	50	75	57	51	60	64	69	54	52	52	46
Snowmelt											
Amber Brook	36	39	67	38	17	41	24	18	48	56	4
Rice Brook	26	9	32	22	12	25	9	17	18	20	16
Spafford Creek	13	10	12	9	9	11	15	35	34	61	15
Van Benthuysen Brook	37	24	41	53	38	49	34	41	22	49	25
Willow Brook	28	20	40	42	35	24	27	42	44	43	46
Storms and snowmelt combined											
Amber Brook	82	97	96	92	98	91	98	97	97	97	83
Rice Brook	82	99	85	94	93	91	98	97	96	98	89
Spafford Creek	78	98	99	87	98	91	97	93	92	94	84
Van Benthuysen Brook	80	93	95	95	94	93	96	96	95	96	92
Willow Brook	78	95	97	93	95	88	96	96	96	95	92

of the total phosphorus, and 53 percent of $NO_2 + NO_3$ were transported during spring high flows. Amber Brook and Rice Brook both had greater sediment loads during the summer of 1982 as a result of the storm of June 29. The smallest loads of sediment and nutrients occurred during the summer or fall, when streamflow was lowest.

RETENTION OF SEDIMENTS AND NUTRIENTS IN THE WETLANDS

Wetland Characteristics

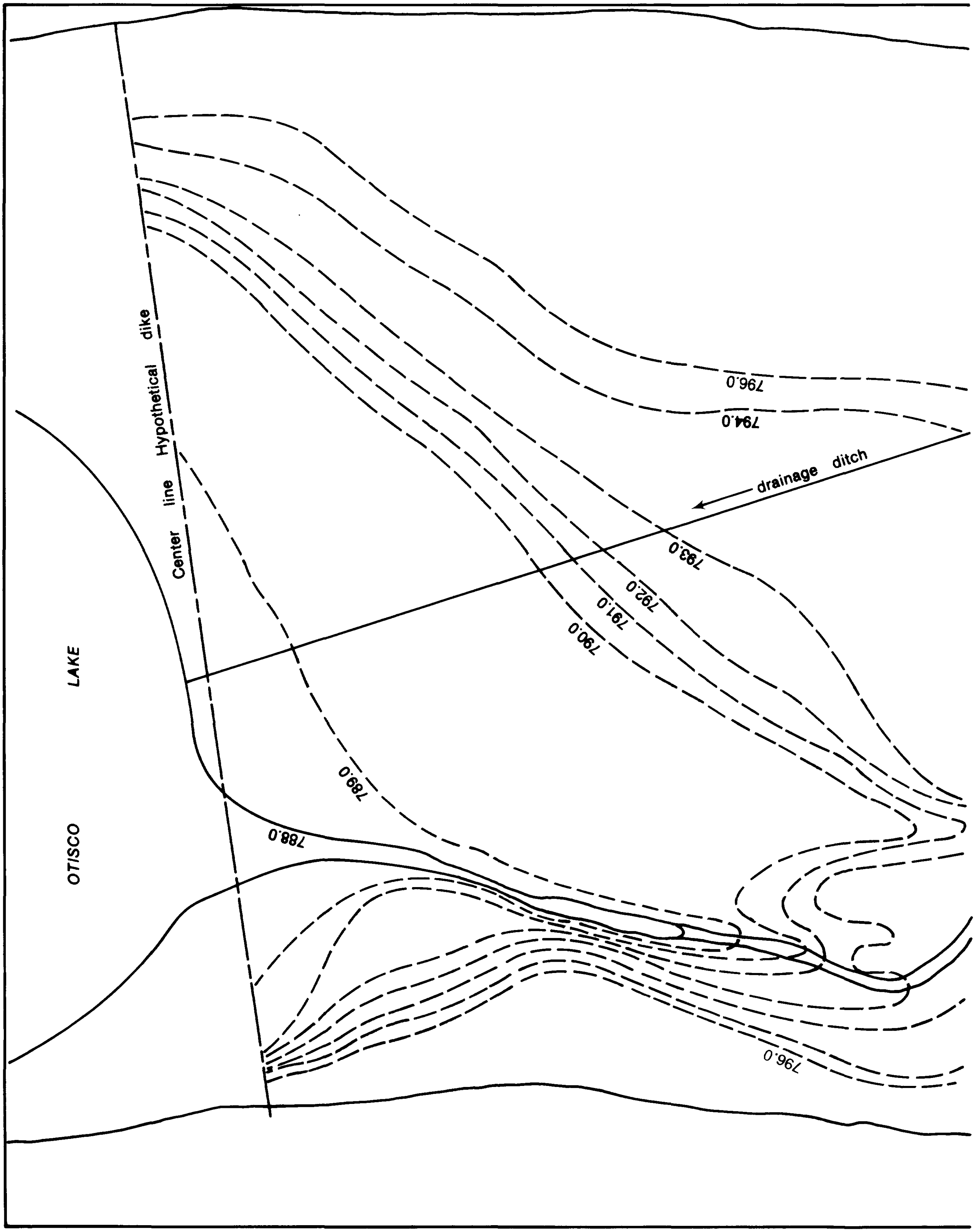
The wetland and lowlands that border Spafford Creek at the south end of Otisco Lake are vegetated by deciduous and evergreen trees, brush, and marsh grass; they also contain some areas of cropland. The large drainage ditch that drains active agricultural land is fed by several smaller ditches and routes storm runoff to the lake through the wetland (fig. 7). Much of the flooding in the wetland and in the agricultural land between Sawmill Road and the wetland is direct drainage from the surrounding hillsides. Flood contours in this part of the lake are shown in figure 7.

Present Loads

Most of the sediment and nutrient load carried by Spafford Creek to the lake occurs from February to May of each year (about 60 percent during the 1982 water year). During the 1982 water year (excluding October), five high flows produced 37 percent of the total annual load. (The highest daily sediment load of the 1982 water year occurred on July 8, however.) The total sediment load for February to May of the 1983 water year accounted for 92 percent of the total annual load, with five high flows contributing a total of 70 percent of the annual load. Reduction of the high-water sediment loads in Spafford Creek by 60 to 80 percent would result in a 40- to 60-percent reduction of the yearly loads to the lake from Spafford Creek.

Reconnaissance of the Spafford Creek wetland indicates that only about 20 percent of the wetland and adjacent lowlands is inundated by high water annually or biennially and that the residence time of the water in the flooded part is only a few hours, which is sufficient for only the heavier sediments or particulate nutrients to settle out.

The two most important factors that now influence the extent of the flooding and residence time in the wetland are the amount of flow in Spafford Creek and the level of the lake at the time the flow occurs; for example, high flows and low lake levels would produce less flooding and shorter residence times than high flows and high lake levels. To increase both the residence time and the size of the flooded area, flow from the mouth of Spafford Creek would have to be obstructed. Under conditions at the time of the study, a lake level of 790 ft above sea level (an increase of 3 ft above the current mean) would cause inundation of about 70 acres of the wetland and adjacent lowlands, regardless of flow. Flooding in the wetlands reaches the 790-ft altitude approximately 2 percent of the time each year; this probably decreases sediment loads to the lake by 14 percent or less per year.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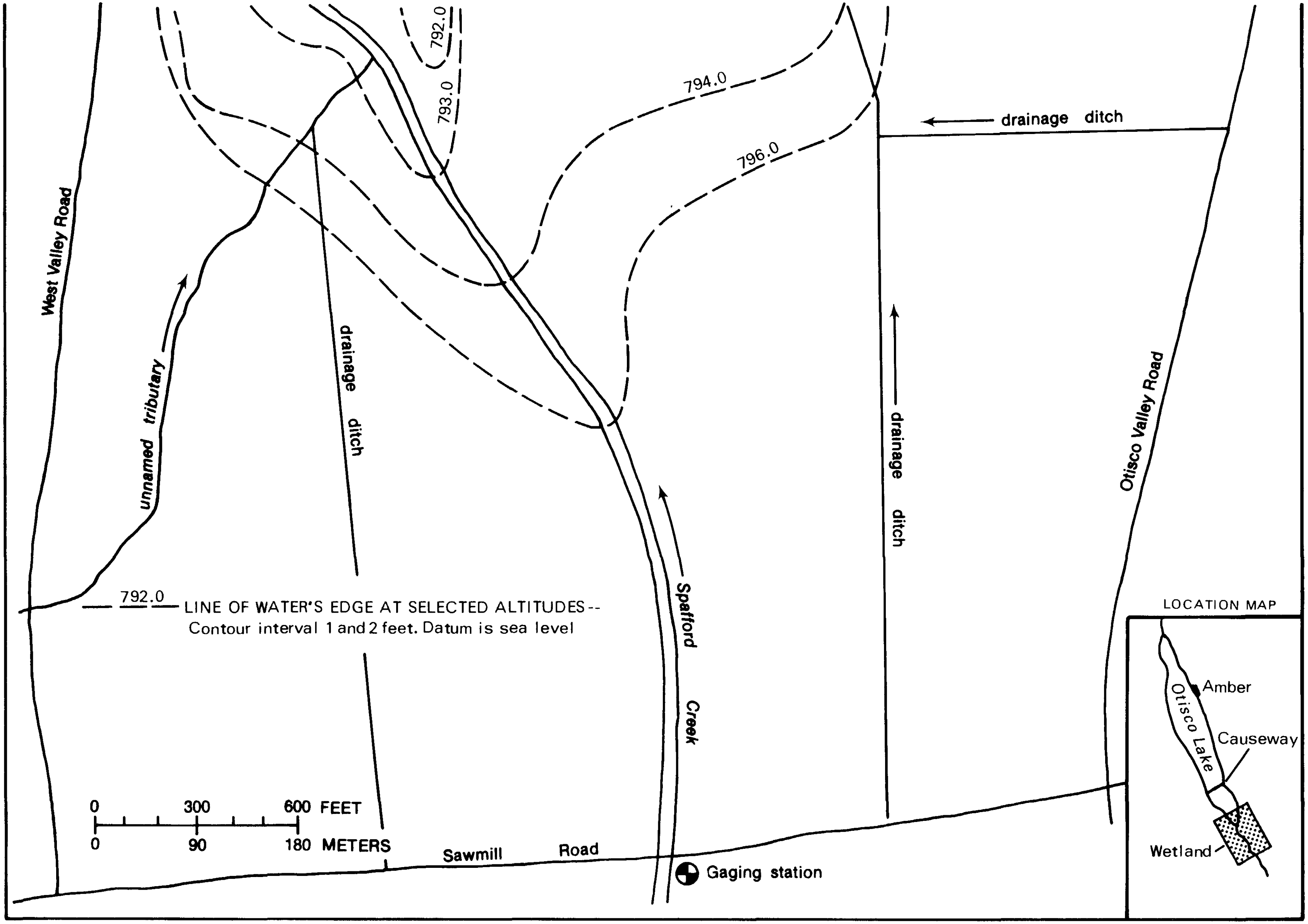


Base from U.S.Army Corps of Engineers, 1981 1:4800

Figure 7.--Contours of flooded area in wetlands at south end of Otisco Lake at selected water-surface altitude.

To evaluate the effects of wetland flooding on sediment and nutrient yield, the yield of Spafford Creek at the mouth would need to be measured, but access to the mouth is difficult.

Potential for Sediment and Nutrient Management

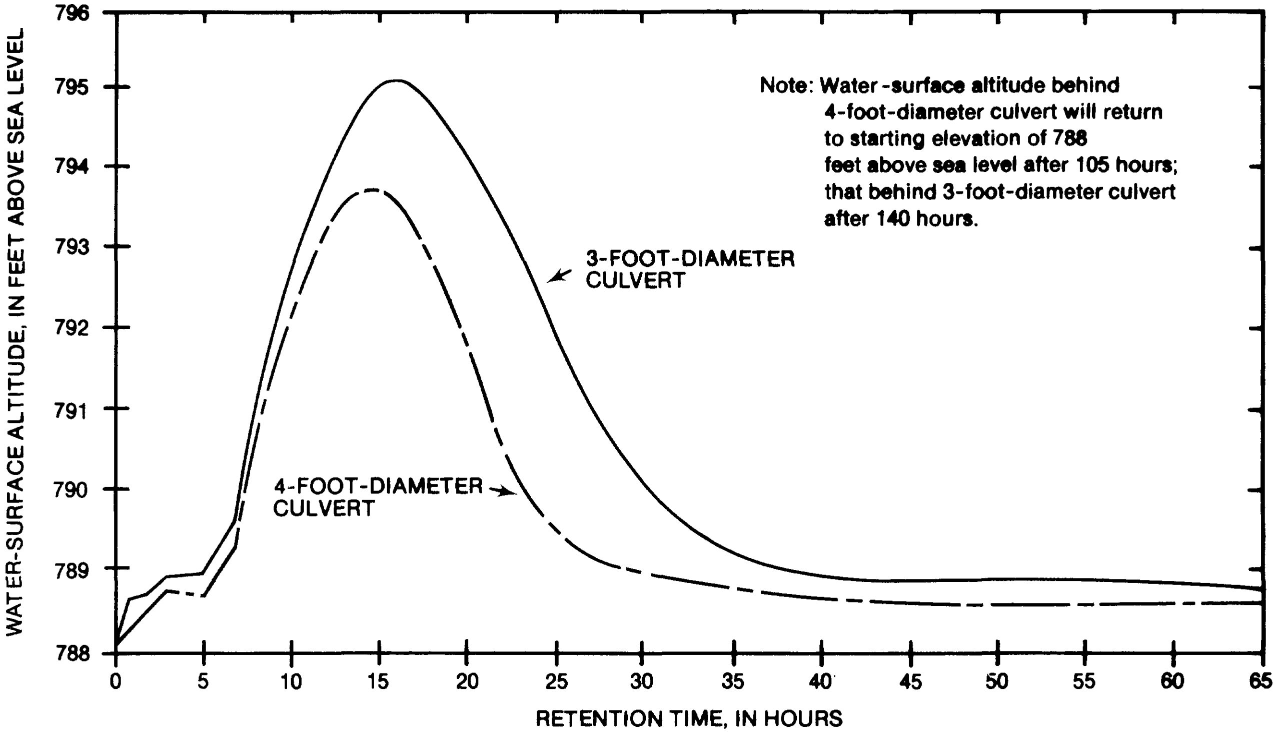
Wetlands have significant potential for reducing loads of suspended sediment and associated nutrients. One method of reducing the sediment and nutrient load to Otisco Lake from Spafford Creek is to increase the extent and duration of periodic flooding in the wetland at the south end of the lake and thereby let sediment and nutrients settle in that area. Retention of suspended solids in the wetland is directly related to the characteristics of flow through the wetland, which is in turn influenced by vegetation, which impedes flow and reduces velocity and thus enhances sedimentation. (The dissolved fraction of constituents such as phosphorus, $NO_2 + NO_3$, and NH_3 generally are not retained in wetlands because their removal depends on biological processes that require extended residence times).

Flooding the wetlands by artificially restricting the outflow could be used to increase the area of inundation or to significantly prolong residence times of water within the wetland. A numerical flood-routing model was used to predict the effects of artificial structures on flooding in the wetlands. First, a dike that spans the width of the wetland with an uncontrolled circular culvert opening in the Spafford Creek channel was superimposed on the model. With the culvert in the channel, water levels would not rise in the wetland under base-flow conditions. Second, for comparison, two different culvert sizes were used in the simulation, both of which would readily pass low and moderate flows but to restrict high flows (which transport 60 to 90 percent of the total annual sediment load in Spafford Creek). Flow ratings were developed for a 3-ft and a 4-ft-diameter culvert through methods described by Bodhaine (1968), and the storage capacity of the area upstream of the dike was calculated for various water-surface altitudes. The resulting inundation contours are shown in figure 7. A storm that occurred on June 29, 1982, was imposed on this hypothetical situation through the Reservoir Routing model (modified Puls method of Jennings, 1977). The recorded peak flow of Spafford Creek at Sawmill Road during this storm was 160 ft^3/s (19.9 ft^3/mi^2), and the mean daily discharge was 62 ft^3/s. The resulting model inundation with the 4-ft diameter culvert reached a maximum altitude of 793.8 ft and exceeded 792.0 ft for about 9 hours. (See plot of water-retention time, fig. 8). A maximum pool storage and maximum outflow of 125 ft^3/s were reached about 4 hours after peak inflow. Under the same conditions, but with a 3-ft-diameter culvert, the water level in the wetlands reached a maximum of 795.2 ft and exceeded 792.0 ft for 16 hours (fig. 8). The maximum pool storage and maximum outflow of 95 ft^3/s with a 3-ft-diameter culvert were reached about 5 hours after peak inflow. A water level of 792 ft would cover 77 acres in the wetland to a mean depth of about 2 ft.

Retention of Spafford Creek flows in the wetland and adjacent lowlands to a mean depth of about 2 ft for 8 hours or more could achieve a 60- to 80-percent reduction in storm-related sediment loads. This would reduce annual sediment and associated particulate nutrient loads to the lake from Spafford Creek by 40 to 60 percent and total loads from all sources by 30 to 50 percent.

Increased retention times beyond 8 hours result in only minor improvements in load reduction because much longer times are needed for the fine particles to settle out. To gain an additional 10-percent decrease in load, the residence times would have to be extended to nearly 19 hours.

Another approach to reducing diffuse source loading would be reduction in the application of nutrients to the land surface and(or) reduction in the quantity of nutrients being transported by the rainfall-runoff process. The most effective approach would probably be to control erosion through upland management practices such as conservation tillage and no-till farming.



Note: Water-surface altitude behind 4-foot-diameter culvert will return to starting elevation of 788 feet above sea level after 105 hours; that behind 3-foot-diameter culvert after 140 hours.

Figure 8.--Model-generated effects of hypothetical dike with 3-ft and 4-ft diameter culvert on water-surface altitude and retention time in wetland at storm discharge of June 29, 1982.

SUMMARY

Otisco Lake, the smallest and easternmost of the Finger Lakes of central New York, is part of the Onondaga County Water Authority public water-supply system. The lake has had a history of high turbidity that occasionally exceeds the New York State Department of Health drinking-water standards. Recreational use of the lake is sometimes impaired by turbidity and summer algal blooms that are due in part to soil erosion and runoff from fertilized croplands within the watershed. The U.S. Soil Conservation Service has allocated funds to implement a watershed-protection project in the Otisco Lake basin to reduce soil erosion and fertilizer runoff.

The Otisco Lake watershed contains 38.8 mi^2 and is approximately 49 percent cropland, 39 percent woodland, and 12 percent other uses. Five tributaries that drain 70 percent of the watershed were monitored for flow, sediment, and nutrients from November 1981 through September 1983. The largest tributary, Spafford Creek, has a drainage area of 12.0 mi^2 and contributes 33 percent of the flow to the lake. The remaining four subbasins are nearly equal in size, ranging from 2.6 to 3.7 mi^2, and together contribute 33 percent of the flow to the lake. The ungaged area of the basin contributes about 34 percent of the flow to the lake.

An analysis of period-of-record mean and median discharges at two streamflow-gaging stations on streams near the basin indicate that streamflows within the Otisco Lake basin during the study were representative of long-term flows even though the individual means were different.

Gross erosion rates from all land in the basin ranged from less than 1 (ton/acre)/yr to more than 30 (ton/acre)/yr, depending on soil type and land use. The average was 3.2 (ton/acre)/yr for all land.

During the 23-month study, Otisco Lake received 10,600 tons of sediment, 20,600 lb of phosphorus, and 435,000 lb of nitrogen. Spafford Creek contributed 72 percent of the sediment load and 46 percent of the nutrient load to the lake. Although the largest sediment and nutrient loads were in Spafford Creek, other tributaries had higher concentrations of some nutrients.

Most of the total runoff and sediment and nutrient loads occurred during storms and snowmelt flows that exceeded the 75-percent quartile. These events accounted for 70 to 90 percent of the runoff, 90 to 99 percent of the sediment load, and 70 to 98 percent of the nutrient loads in the tributaries.

Sediment and nutrient loads were greatest during the spring (March through May), when 70 percent of the sediment, 60 percent of the total kjeldahl nitrogen as N, 58 percent of the total phosphorus as P, and 53 percent of the NO_2+NO_3 as N that entered the lake were transported during high flows.

Stepwise multiple-regression analyses of runoff per acre and yield in relation to selected basin characteristics showed significant relationships between monthly, seasonal, and 1981-83 total values. Most equations for total values fit the data well ($R^2 = 0.45$ to 0.89), but the equations for monthly and seasonal values gave poor fits ($R^2 = 0.05$ to 0.43). Total phosphorus seems to be lower in subbasins where contour farming is practiced and where streambank improvements have reduced erosion ($R^2 = 0.81$). Relationships between water quality and land use would require water-quality data from specific land-use areas, which was beyond the scope of this study.

Sediment depths, measured from lake-bed cores, indicate that 390,000 tons of sediment have been deposited south of the causeway since the lake level was first raised in 1869; this indicates an average deposition rate of 3,420 ton/yr for the 114 years between 1869 and this study. The U.S. Soil Conservation Service, using the Universal soil-loss equation, estimates an average delivery rate of 3,573 ton/yr to the lake from Spafford Creek alone. The U.S. Geological Survey measured 7,635 tons delivered to the lake by Spafford Creek during the 23-month study, or an average annual load of about 3,820 tons. Under conditions at the time of the study, less than 15 percent of the nutrient and sediment load is retained by the wetlands at the south end of the lake. Flooding in the wetlands and adjacent lowlands by artificial means to an altitude of 792 ft above sea level would inundate about 80 acres for 8 to 9 hours, long enough to decrease sediment and particulate nutrient loads in Spafford Creek during high flows by 60 to 80 percent. Yearly loads to the lake from all sources would be reduced by 30 to 50 percent.

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APPENDIX A--STATISTICAL METHODS

Depending on the shape of a distribution, a mean or median is the measure of the most likely value for the whole distribution of values--the measure of central tendency. Plots of the distributions of flows, concentrations, and loads indicated that the distributions obtained in this study were highly skewed; therefore, median values were used instead of the means because they were considered more representative of the distributions than the mean values. A statistical test that compares significant differences between medians of distributions uses "box plot" diagrams with "notches" (McGill and others, 1978). An example is given in figure A-1. The box plots consist of selected values for each distribution--the median, the 25-percent and 75-percent quartiles, which form the box, outliers which represent values 1.5 times the distance between the quartiles, and far outliers which represent 3.0 times the distance between the quartiles. The notches represent an approximate 95-percent confidence interval around the median--a measure that includes the median, the difference between the quartiles, the standard deviation of the population, the variability of the sample median, and a factor used in setting confidence limits. If the notches of one distribution do not overlap those of another distribution, the differences between the two distributions are considered significant at the 95-percent confidence interval.

Figure A-1 shows the distributions of $NO_2 + NO_3$ concentrations in the five tributaries to Otisco Lake. As shown by the position of the brackets around the medians, Rice Brook and Willow Brook have significantly higher concentrations than the other tributaries, and Van Benthuysen Brook has significantly lower concentrations than the other tributaries.

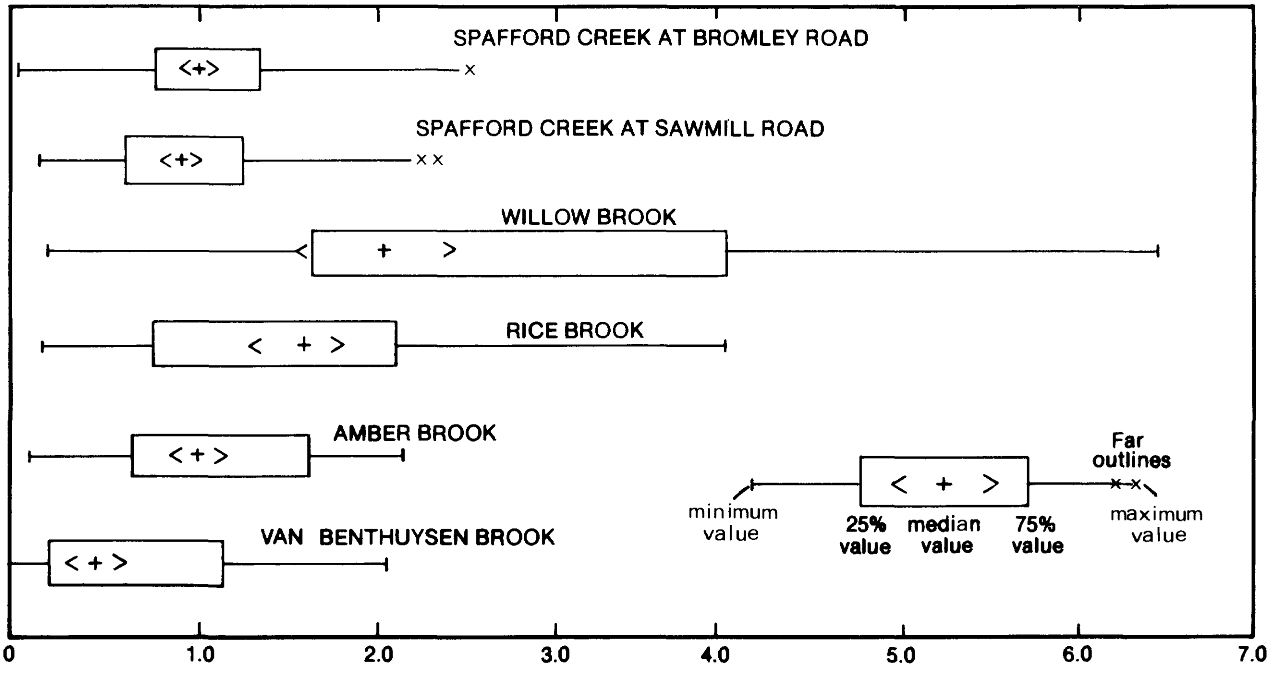

Figure A-1.--Example of notched box plots for determining significant median differences between distributions.

Mean daily nutrient loads were estimated through regression plots that relate nutrient concentrations to runoff and sediment concentrations. The coefficients for equations for each nutrient in each tributary were obtained by plotting instantaneous values of nutrient concentration against associated instantaneous values of sediment concentration and runoff. The equations were of the form:

$$Y = aX_1^{b1}X_2^{b2} \tag{1}$$

where:
Y = nutrient concentration,
a = y-intercept,
X_1 = runoff, in ft^3/s,
$b1$ = coefficient for runoff,
X_2 = concentration of suspended sediment, in mg/L, and
$b2$ = coefficient for concentration of suspended sediment.

The equations for each nutrient concentration in each tributary are given in table A-1.

Table A-1.--Relation of nutrient concentrations to discharge and suspended-sediment concentration, as determined by linear regression.

[Q = runoff in ft^3/s, and ss = suspended sediment and nutrient concentrations, in mg/L.]

Station	[1] R^2	F ratio[2]
AMBER BROOK		
Nitrogen concentrations		
Total organic = $0.298(ss)^{.284}$	0.58	13.5
$NH_3 = 0.087(ss)^{.145}$	.12	8.35
Total kjeldahl nitrogen = $0.308(Q)^{.405}$	.36	19.8
$NO_2+NO_3 = 0.744(Q)^{.176}$	.16	11.7
Phosphorus concentrations		
Total = $0.024(ss){\cdot}297$	.18	13.4
Total inorganic = $0.013(ss)^{.263}$	.19	13.6
Total dissolved = $0.013(ss)^{.229}$	.06	4.76
Dissolved orthophosphate = $0.004(ss)^{.386}$	.17	10.1
Dissolved organic = $0.008(Q)^{.038}$	.0	0.49*
RICE BROOK		
Nitrogen concentrations		
Total organic = $0.607\ (Q)^{.292}$	.002	1.02*
$NH_3 = 0.076(ss)^{.184}$	.12	7.84
Total kjeldahl nitrogen = $0.352(Q)^{.506}$	.57	43.4
$NO_2+NO_3 = 1.046(Q)^{.263}$	.50	52.7
Phosphorus concentrations		
Total = $0.025(ss)^{.451}$	.67	111
Total inorganic = $0.015(ss)^{.332}$	.35	28.5
Total dissolved = $0.020(ss)^{.289}$	.25	18.7
Dissolved orthophosphate = $0.007(ss)^{.383}$	.32	24.7
Dissolved organic = $0.011(Q)^{-0.017}$	.0	.03*

Table A-1.--Relation of nutrient concentrations to discharge and suspended-sediment concentration, as determined by linear regression (cont.).

[Q = runoff in ft^3/s and ss - suspended sediment and nutrient concentrations in mg/L.]

Station	R^2[1]	F ratio[2]
SPAFFORD CREEK		
Nitrogen concentrations		
Total organic = $0.019(ss)^{.741}$	0.82	97.8
$NH_3 = 0.094(Q)^{-0.010}$	.0	.01*
Total kjeldahl nitrogen = $0.134(ss)^{.455}$	.82	197
$NO_2+NO_3 = 0.725(Q)^{.090}$	.04	4.23
Phosphorus concentrations		
Total = $0.015(ss)^{.486}$	.70	192
Total inorganic = $0.011(Q)^{.271}$	.11	10.9
Total dissolved = $0.018(Q)^{.172}$	.02	2.84
Dissolved orthophosphate = $0.006(Q)^{.234}$	.05	4.73
Dissolved organic = $0.011(ss)^{-0.047}$	.0	.75
VAN BENTHUYSEN BROOK		
Nitrogen concentrations		
Total organic = $0.225(ss)^{.418}$	.73	25.2
$NH_3 = 0.097(Q)^{.208}$	.14	9.58
Total kjeldahl nitrogen = $0.349(Q)^{.373}$	.28	13.5
$NO_2+NO_3 = 0.487(Q)^{.197}$	.10	6.89
Phosphorus concentrations		
Total = $0.023(ss)^{.388}$	.47	47.6
Total inorganic = $0.014(ss)^{.240}$	.12	7.89
Total dissolved = $0.020(ss)^{.152}$	.02	2.18
Dissolved orthophosphate = $0.006(ss)^{.232}$	.05	3.43
Dissolved organic = $0.005(ss)^{.229}$	.12	5.59
WILLOW BROOK		
Nitrogen concentrations		
Total organic = $0.253(ss)^{.462}$	0.66	26.7
$NH_3 = 0.071(ss)^{.218}$	.09	5.24
Total kjeldahl nitrogen = $0.325(ss)^{.438}$	.71	70.3
$NO_2+NO_3 = 2.512(ss)^{-0.028}$	.0	0.22*
Phosphorus concentrations		
Total = $0.033(ss)^{.421}$	.56	58.2
Total inorganic = $0.023(ss)^{.275}$	.21	12.6
Total dissolved = $0.030(ss)^{2.48}$	.19	11.3
Dissolved orthophosphate = $0.009(ss)^{.395}$	.23	14.2
Dissolved organic = $0.008(Q)^{.249}$	.25	10.4

* Slope of line not significantly different from zero at the 95-percent confidence interval.

[1] R^2 is the coefficient of determination, measures how much variation in the dependent variable can be accounted for by the model.

[2] F ratio is the ratio of mean explained variance to mean unexplained variance: test to see if the variance explained by the line is significantly greater than variance not explained by the line (is ratio significantly greater than 1 for number of cases at selected confidence limit?).

The mean daily nutrient concentrations were then calculated from the regression coefficents, the mean daily concentrations of nutrients, and the mean daily discharges. The mean daily loads were calculated by multiplying the estimated mean daily concentrations by the daily mean discharges.

In this study, multiple regression techniques were used to define differences in water quality as a function of basin characteristics and land use. A set of statistical computer programs known as PSTAT[1] was used to transform variables, compute regression coefficients, and perform other statistical tests. The following dependent variables were normalized as loads per acre (yield):

suspended sediment
total organic nitrogen
NH_3
total kjeldahl nitrogen
NO_2+NO_3
total phosphorus
total inorganic phosphorus
total dissolved phosphorus
dissolved orthophosphate
dissolved organic phosphorus

Except for total area, the independent variables (tables 1 to 6) were normalized as follows:

total area (mi^2)
mean altitude
mean basin slope (ft/mi)
mean channel slope
percentage of land with >20 percent slope
percentage of cropland needing treatment with <8 percent slope
percentage of cropland needing treatment with >8 percent slope
percentage of basin covered by each type of geologic deposit (8 types)
percentage of basin covered by each type of hydrologic soil group (4 groups)
percentage of basin covered by each soil type (26 types)
mean of soil-erosion characteristics (4 Universal soil loss equation factors)
mean erosion rate (ton/acre)
percentage of basin covered by each land-use type (4 types)
percentage of basin using each type of tillage on cropland (4 types)
percentage of basin using each type of conservation practice on cropland (5 types)
nitrogen fertilizer use, as lb/acre
phosphorus fertilizer use, as lb/acre

The general form of the multiple regression equation was:

$$y = a + b_1X_1 + b_2X_2 + . . . b_nX_n \tag{2}$$

where: y = water-quality characteristic (dependent variable)
X_1, X_2, X_n = basin characteristics or land use (independent variables)
a = regression constant (Y-intercept)
b_1, b_2, b_n = regression coefficients
n = number of independent variables

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[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

A nonlinear form of the equations was also used by transforming variables to logarithms. The form of the transformed equations was:

$$\log y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots b_n \log X_n \quad (3a)$$

or equivalently:

$$y = aX_1^{b_1} X_2^{b_2} \ldots X_n^{b_n} \quad (3b)$$

Because the logarithm of zero is undefined, a constant of 0.01 was substituted for zero values.

In most analyses, stepwise multiple regression was used to enter independent variables into the equation one at a time; the purpose was to include all variables that contribute significantly to the dependent variable and to exclude those variables which have little additional effect on the dependent variable.

The PSTAT regression program requires the user to specify an F-value for entering and deleting independent variables--it does not calculate the F to enter or delete on the basis of significance level. The F to enter was set at 5, and the F to delete was set at 4--approximate values appropriate for the number of cases and variables used in this study. Stepwise regression is more selective and more robust than nonstepwise regression; if two independent variables are highly correlated, only one is likely to be included in the stepwise-developed equation.

Other stepwise regressions were done that include interaction effects of cropland and rainfall to determine whether multicollinearity among the independent variables was masking the significance of some variables. The form of the equations was:

$$y = a = b_1X_1 + b_2X_2 + b_3X_1X_2 \ldots \quad (3c)$$

where: $X_1X_2 = X_1 \cdot X_2$ = interaction effect between X_1 and X_2

Both linear and nonlinear (log transformed) regressions were done.

Nonstepwise nonlinear regressions were done for sediment and nutrient yields with selected independent variables--all the variables were forced into the equation. The equations developed were:

$$SS_y = f(K, C, P, LS, PPT, CROP{+}PAST, WOODL, TOTAL) \quad (4)$$

where: SS_y = suspended-sediment yield,
f = function of,
K = soil-erodibility factor,
C = cover factor,
P = management-practice factor,
LS = slope-steepness and length factor,
PPT = mean monthly precipitation,
CROP+PAST = percentage of cropland plus pasture,
WOODL = percentage of woodland, and
TOTAL = total average in subbasin.

and

$$N_y = f(SS_c, \text{FERT}, \text{PPT}, \text{CROP+PAST}, \text{WOODL}, \text{TOTAL}) \qquad (5)$$

where: N_y = nutrient yield,
SS_c = suspended-sediment concentration, and
FERT = nitrogen or phosphorus fertilizer, in lb/acre.

In all regressions, the residuals were approximately normally distributed and independent of predicted yields.

APPENDIX B--QUALITY ASSURANCE PRACTICES FOR CHEMICAL ANALYSIS

A quality-assurance/quality-control program was adopted to ensure that the analytical results of the contract laboratories were comparable with each other and with U.S. Geological Survey standards. The quality-assurance program was carried out in accordance with the methods outlined by Friedman and Erdman (1982). The program consisted of the regular submittal of reference samples of known concentrations and of split samples. Reference samples were prepared by the project office from ampouled concentrates supplied by the U.S. Environmental Protection Agency (USEPA). Split samples consisted of a sample divided into eight parts, four of which were sent to the cooperating laboratory and four to the U.S. Geological Survey Central Laboratory in Atlanta, GA. The laboratories were also required to participate in the U.S. Geological Survey Standard Reference Water Sample program of testing reference samples twice per year. The quality-assurance/quality-control sample analyses formed about 20 percent of the total number of analyses done during the study.

Results of the quality-assurance program were as follows:

1. In three reference samples sent to the Onondaga County laboratory, the high-level concentrations of total phosphorus had a significantly low bias at the 95-percent confidence level; the low-level total kjeldahl nitrogens had a high bias but were still within the 95-percent confidence interval. All other nutrients were within acceptable limits. In nine sets of four split samples, group differences of total phosphorus, dissolved phosphorus, and hydrolyzable plus orthophosphorus were significantly different from zero.

2. In seven reference samples sent to the Upstate Freshwater Institute (UFI) laboratory in Syracuse, N.Y., tests for bias showed that the high concentrations of NH_3-N had significantly low bias, and the low values for NO_3-N had significantly high bias; the UFI laboratory did not analyze each sample for all constituents. In 11 sets of four split samples, group differences of orthophosphate and ammonia were significantly different from zero.

The statistics from the two laboratories are summarized in tables B-1 and B-2, respectively.

Table B-1.--Quality assurance results for the Onondaga County Laboratory, Syracuse, N.Y., September 1981 through October 1982.

				Paired t-test on split samples			
	Number of pairs	Mean values (mg/L)		Mean differ-ence	Standard deviation		Degrees of freedom (n-1)
Constituent	(n)	USGS Central Laboratory	Onondaga County Laboratory	(d)	STD	t	DF
Orthophosphorus	9	0.018	0.017	+0.001	0.008	0.378	8
Total phosphorus	9	.035	.080	-.045	.017	7.941*	8
Dissolved phosphorus	9	.019	.058	-.039	.016	7.312*	8
Hydrolyz & Ortho phosphorus	9	.019	.049	-.030	.015	5.890*	8
Total kjeldahl nitrogen	9	.454	.642	-.188	.404	1.390	8
NO_2+NO_3	9	1.000	1.104	-.104	.232	1.350	8
NH_3-N†	9	--	--	--	--	--	--

				Paired t-tests on reference samples				
				on bias			on differences	
				Mean bias	t	DF	d	t
NH_3-N (low)	3	0.37	0.39	+7.6	0.900	2	-0.02	0.654
NH_3-N (high)	3	1.23	1.19	-2.3	.494	2	.04	.613
NO_3-N (low)	3	.17	.16	-7.5	1.039	2	.008	.866
NO_3-N (high)	3	.93	.89	-4.9	2.599	2	.04	2.665
PO_4-P (low)	3	.017	.016	-9.9	1.954	2	.001	1.732
PO_4-P (high)	3	.325	.324	-1.4	.441	2	.001	2.994
**Total kjeldahl nitrogen-N (low)	3	.29	.62	+104	4.177	2	-.332	2.805
Total kjeldahl nitrogen-N (high)	3	5.27	4.83	-10.3	1.371	2	.437	1.205
Total P (low)	3	.118	.122	+3.3	1.414	2	-.003	1.039
Total P (high)	3	.594	.540	-9.7	5.879*	2	.054	10.392

* Differences were significant at the 95-percent confidence level

**U.S. Environmental Protection Agency's low-level total kjeldahl concentrates supplied by U.S. Geological Survey's laboratory in Denver. Two different laboratories analyzing a total of 4 samples reported the same results, which were roughly twice the stated concentration.

† Minimum detection limits for Onondaga County laboratory were all above values found by Atlanta Central Laboratory.

Table B-2.--Quality assurance results for the Upstate Freshwater Institute Laboratory, Syracuse, N.Y., November 1982 through October 1983.

		Mean values (mg/L)		Paired t-test on split samples			
Constituent	Number of pairs (n)	USGS Central Laboratory	Freshwater Institute Laboratory	Mean difference (d)	Standard Deviation STD	t	Degrees of Freedom (n-1) DF
Orthophosphorus	7	0.011	0.005	0.005	0.004	3.307*	6
Total phosphorus	11	.027	.034	-0.007	.014	1.660	10
Dissolved phosphorus	10	.019	.012	.005	.016	.988	9
Total kjeldahl nitrogen	10	.475	.241	.223	.660	1.059	9
NO_2+NO_3	10	1.320	1.243	.077	.191	1.275	9
NH_3-N	11	.036	.123	-0.089	.105	2.810*	10

				Paired t-tests on reference samples				
				on bias			on differences	
Constituent	Number of pairs (n)	USGS Central Laboratory	Freshwater Institute Laboratory	Mean bias	t	DF	d	t
NH_3-N (low)	7	0.25	0.24	-4.5	0.496	6	0.022	1.712
NH_3-N (high)	7	1.35	1.22	-11.7	6.203*	6	.171	5.729
NO_3-N (low)	8	.17	.18	.3	3.086*	7	0	0
NO_3-N (high)	7	1.24	1.23	-4.3	.790	6	.041	.544
PO_4-P (low)	3	.032	.031	-10.3	3.611	2	.004	2.309
PO_4-P (high)	5	.295	.272	-2.7	1.499	4	.004	2.236
Total kjeldahl nitrogen-N (low)	8	.30	.36	+33.6	1.630	7	-0.081	1.273
Total kjeldahl nitrogen-N (high)	8	4.45	4.35	-3.1	.652	7	.246	.682
Total P (low)	3	.142	.144	+1.4	.165	2	-0.002	.165
Total P (high)	6	.649	.646	-.9	.451	5	.002	.169

* Difference was significant at the 95-percent confidence interval.

APPENDIX C--TABLES OF SEDIMENT AND NUTRIENT DATA FROM TRIBUTARIES TO OTISCO LAKE, NOVEMBER 1981 THROUGH SEPTEMBER 1983.

Table C-1.--Total discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and period	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
			Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Dissolved		
									Total	Orthophosphate	Organic
Amber Brook											
Nov '81-Sep '82	1,747	199	6,565	1,252	7,517	10,429	559	266	246	116	84
Oct '82-Sep '83	1,767	261	6,863	1,279	8,126	10,753	584	276	255	123	86
Rice Brook											
Nov '81-Sep '82	1,172	196	6,615	836	5,969	10,769	687	264	314	147	65
Oct '82-Sep '83	1,050	126	6,313	714	6,129	10,200	550	217	262	120	59
Spafford Creek[2]											
Nov '81-Sep '82	6,322	3,608	26,333	3,104	40,739	32,137	5,302	850	1,011	398	304
Oct '82-Sep '83	6,114	4,027	22,161	3,003	32,609	31,103	4,253	832	980	388	296
Van Benthuysen Brook											
Nov '81-Sep '82	2,137	189	9,692	1,859	10,277	9,112	915	334	375	142	110
Oct '82-Sep '83	1,917	145	7,971	1,692	9,644	8,285	756	283	322	121	94
Willow Brook											
Nov '81-Sep '82	1,276	152	7,639	935	9,000	15,792	862	364	438	222	95
Oct '82-Sep '83	1,728	396	11,795	1,323	13,752	21,484	1,308	524	624	333	148
Totals from gaged areas		9,299	111,947	15,997	143,762	160,064	15,776	4,210	4,827	2,110	1,341
Ungaged area		1,301	49,633	7,734	55,066	75,746	4,865	1,977	2,218	1,035	579
Totals from entire basin		10,600	161,580	23,731	198,828	235,815	20,641	6,187	7,045	3,145	1,920

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations, and difference reflects the effects of averaging to obtain line of best fit.

[2] Loads include the ungaged part of Spafford Creek.

Table C-2.--Seasonal discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983.

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

				Nitrogen[1]				Phosphorus				
										Dissolved		
Station and water year	Season[2]	Discharge (second foot days)	Suspended sediment (tons)	Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	Orthophosphate	Organic
Amber Brook												
1982	Fall	316	19	1201	230	1402	1941	102	49	45	21	15
	Winter	372	11	1132	241	1241	2005	95	47	44	18	18
	Spring	792	82	3184	589	3980	5069	271	128	118	57	38
	Summer	267	87	1053	193	902	1418	90	42	39	20	12
83	Fall	138	6	451	92	410	704	38	18	17	8	6
	Winter	539	22	1739	358	1982	3038	147	71	67	29	26
	Spring	967	230	4324	754	5469	6477	371	173	157	82	48
	Summer	122	3	344	76	264	542	29	14	14	5	5
Rice Brook												
82	Fall	221	22	1320	173	1197	2143	147	57	67	31	12
	Winter	249	14	1205	165	956	1994	118	49	59	26	14
	Spring	486	57	2962	348	2784	4791	283	109	130	61	27
	Summer	216	103	1130	150	1027	1846	140	49	58	28	12
83	Fall	101	5	462	64	360	767	42	18	22	10	6
	Winter	297	11	1542	184	1310	2531	115	50	63	26	17
	Spring	606	109	4160	440	4366	6638	379	142	168	80	33
	Summer	46	1	156	26	95	267	14	7	9	3	3
Spafford Creek[3]												
82	Fall	1010	444	4400	494	7219	5234	937	142	167	66	48
	Winter	1193	239	2769	589	5602	5782	709	138	173	66	58
	Spring	2901	2013	15174	1418	21669	15280	2848	432	496	200	137
	Summer	1219	912	3997	603	6280	5840	812	138	174	66	61
83	Fall	563	59	593	279	1552	2633	191	59	77	28	30
	Winter	1656	556	4241	816	7236	8243	926	209	253	99	84
	Spring	3252	3299	16521	1588	21954	17376	2900	508	571	233	149
	Summer	642	113	763	320	1886	2849	233	57	79	28	33

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[2] Fall season of the 1982 water year does not include estimated values for October 1981.

[3] These loads include the ungaged area of Spafford Creek.

Table C-2.--Seasonal discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and water year	Season[2]	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
										Dissolved		
				Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	Orthophosphate	Organic
Van Benthuysen Brook												
82	Fall	461	48	2551	429	2458	2097	238	82	88	35	27
	Winter	529	30	2170	422	2152	2077	207	79	91	34	26
	Spring	927	94	4102	859	4983	4198	387	142	160	60	47
	Summer	220	17	872	150	688	742	83	31	36	13	10
83	Fall	142	6	474	101	475	498	45	18	21	8	6
	Winter	523	34	2104	414	2119	2041	200	76	88	33	25
	Spring	1080	96	4811	1057	6470	5149	454	166	187	71	55
	Summer	172	9	585	121	575	597	56	22	26	10	8
Willow Brook												
82	Fall	258	37	1600	196	1887	3209	181	76	92	47	19
	Winter	265	22	1413	181	1670	3225	160	70	84	41	18
	Spring	591	68	3728	446	4384	7305	419	175	210	108	48
	Summer	162	25	902	112	1061	2050	102	43	52	26	11
83	Fall	85	6	424	58	506	1065	49	22	27	13	5
	Winter	631	54	3121	423	3710	7988	358	161	196	93	48
	Spring	952	300	7741	792	8951	11721	846	321	378	213	90
	Summer	60	36	507	50	584	735	55	20	24	14	4

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[2] Fall season of the 1982 water year does not include estimated values for October 1981.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983.

[Nutrient loads are in pounds. Locations are shown in fig. 2 .]

		Dis-charge		Nitrogen[1]				Phosphorus				
										Dissolved		
Station and year	Month	(second foot days)	Suspended sediment (tons)	Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	orthophos-phate	Organic
Amber Brook												
1981	Oct	--	[3]56(1)	--	--	--	--	--	--	--	--	--
	Nov	316	19	1200	230	1400	1940	102	49	45	21	15
	Dec	176	6	549	116	623	977	46	23	21	9	9
1982	Jan	81	2	241	51	254	422	20	10	9	4	4
	Feb	115	3	343	74	363	606	29	14	13	5	5
	Mar	414	58	1830	324	2400	2830	157	73	67	34	20
	Apr	298	21	1110	214	1370	1850	95	45	42	19	14
	May	80	3	238	51	206	386	20	10	9	4	4
	Jun	154	83	728	122	630	894	63	29	26	15	7
	Jul	70	3	209	45	198	351	18	9	8	3	3
	Aug	19	0	54	12	28	73	5	2	2	1	1
	Sep	24	1	63	14	47	100	5	3	3	1	1
Rice Brook												
1981	Oct	--	[3]93(1)	--	--	--	--	--	--	--	--	--
	Nov	221	22	1320	173	1200	2140	147	57	67	31	12
	Dec	116	7	583	81	472	961	59	24	29	13	7
1982	Jan	55	3	253	33	197	421	23	10	12	5	3
	Feb	78	4	369	52	286	612	36	15	18	8	4
	Mar	256	45	1730	201	1740	2770	184	68	79	38	14
	Apr	180	10	1030	120	911	1680	85	35	43	19	10
	May	50	2	199	26	136	336	13	6	8	3	3
	Jun	119	100	752	97	763	1210	112	36	41	22	7
	Jul	55	2	243	29	183	406	15	7	9	4	3
	Aug	19	0	57	10	31	98	5	2	3	1	1
	Sep	23	1	79	14	50	135	8	4	5	2	1

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[3] For the month of October 1981, larger figure is estimated sediment load based on estimated discharge for month of Oct. 1981. Figure in parentheses is estimated monthly load for typical month.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and year	Month	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
										Dissolved		
				Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	orthophosphate	Organic
Spafford Creek[2]												
1981	Oct	--	[3]2400(16)	--	--	--	--	--	--	--	--	--
	Nov	1010	444	4400	494	7220	5230	937	142	167	66	48
	Dec	576	139	1550	283	2980	2840	380	70	87	33	28
1982	Jan	252	46	528	125	1070	1190	135	27	35	13	13
	Feb	366	54	693	181	1540	1750	194	41	52	19	18
	Mar	1282	1150	8150	625	11200	6900	1480	204	228	93	59
	Apr	1212	816	6630	592	9440	6440	1240	184	211	86	57
	May	407	47	388	201	1010	1940	124	44	57	21	21
	Jun	559	404	2330	275	3550	2820	463	73	88	34	27
	Jul	314	462	1210	155	1620	1480	212	33	43	16	16
	Aug	184	11	153	92	473	824	57	17	23	8	10
	Sep	162	35	301	80	636	723	80	15	20	7	8
Van Benthuysen Brook												
1981	Oct	--	[3]53(1)	--	--	--	--	--	--	--	--	--
	Nov	461	48	2550	429	2460	2100	238	82	88	35	27
	Dec	239	14	1020	194	1000	954	97	37	42	16	12
1982	Jan	120	7	466	93	474	460	45	17	20	7	6
	Feb	171	9	687	135	678	663	66	25	29	11	8
	Mar	530	75	2710	533	3270	2590	253	88	96	37	29
	Apr	301	16	1100	261	1420	1280	106	42	49	18	14
	May	97	3	287	65	287	322	28	12	15	5	4
	Jun	134	14	652	102	509	505	61	22	24	9	7
	Jul	51	2	160	30	122	151	16	6	8	3	2
	Aug	21	0	29	10	34	51	3	1	2	1	1
	Sep	15	1	31	7	23	36	3	1	2	1	0

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[2] These loads include the ungaged portion of Spafford Creek.

[3] For the month of October 1981, larger figure is estimated sediment load based on estimated discharge for month of Oct. 1981. Figure in parentheses is estimated monthly load for typical month.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and year	Month	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
										Dissolved		
				Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	orthophosphate	Organic
Willow Brook												
1981	Oct	--	[3]71(1)	--	--	--	--	--	--	--	--	--
	Nov	258	37	1600	196	1890	3210	181	76	92	47	19
	Dec	149	18	932	110	1090	1860	104	43	52	27	11
1982	Jan	47	2	181	26	217	489	21	10	12	6	3
	Feb	70	2	300	45	361	874	35	17	21	9	4
	Mar	344	59	2730	293	3180	4220	303	118	140	77	31
	Apr	211	8	880	133	1060	2620	103	50	61	27	15
	May	36	1	114	20	140	463	14	7	9	4	2
	Jun	113	23	756	86	882	1420	84	34	40	21	8
	Jul	44	2	131	24	160	567	16	8	11	4	2
	Aug	2	0	5	1	7	30	1	0	0	0	0
	Sep	3	0	10	2	13	39	1	1	1	0	0

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[3] For the month of October 1981, larger figure is estimated sediment load based on estimated discharge for month of Oct. 1981. Figure in parentheses is estimated monthly load for typical month.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and year	Month	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
				Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Dissolved		
										Total	orthophosphate	Organic
Amber Brook												
1982	Oct	19	0	44	10	27	71	4	2	2	1	1
	Nov	119	6	407	82	383	633	34	17	16	7	6
	Dec	182	8	621	125	663	1020	52	25	24	10	9
1983	Jan	159	5	489	103	520	856	41	20	19	8	8
	Feb	199	9	629	130	799	1160	53	26	24	10	10
	Mar	141	4	434	92	440	742	37	18	17	7	7
	Apr	568	216	3040	487	3910	4170	262	120	106	61	28
	May	258	10	855	175	1120	1560	72	35	33	14	13
	Jun	76	3	241	50	196	369	20	10	9	4	3
	Jul	21	0	45	11	30	78	4	2	2	1	1
	Aug	11	0	29	7	13	37	2	1	1	0	0
	Sep	14	0	29	7	25	57	2	1	1	0	1
Rice Brook												
1982	Oct	17	0	50	9	27	88	4	2	3	1	1
	Nov	83	5	411	55	333	679	38	16	20	9	5
	Dec	98	4	480	63	384	793	41	18	22	9	6
1983	Jan	69	2	298	42	214	500	24	11	14	6	4
	Feb	130	5	764	79	712	1240	50	22	27	11	7
	Mar	86	1	385	43	282	644	22	11	14	5	5
	Apr	358	101	2820	293	3210	4450	291	103	119	59	19
	May	161	7	949	103	871	1540	66	29	35	15	9
	Jun	37	1	135	21	86	230	12	5	7	3	2
	Jul	5	0	12	3	6	21	2	1	1	0	0
	Aug	2	0	4	1	2	7	1	0	0	0	0
	Sep	2	0	5	1	2	8	1	0	0	0	0

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

Station and year	Month	Discharge (second foot days)	Suspended sediment (tons)	Nitrogen[1]				Phosphorus				
										Dissolved		
				Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	orthophosphate	Organic
Spafford Creek[2]												
1982	Oct	152	3	69	76	273	663	32	13	18	6	8
	Nov	411	56	524	203	1280	1970	159	46	59	22	21
	Dec	529	116	1060	261	2170	2600	274	64	79	30	27
1983	Jan	520	26	461	256	1410	2530	171	61	76	29	27
	Feb	608	414	2720	299	3660	3110	481	84	98	39	30
	Mar	528	20	354	261	1180	2570	141	61	77	29	28
	Apr	1622	2900	12900	789	14900	8990	2010	282	306	128	67
	May	1102	375	3310	538	5850	5820	752	164	189	76	53
	Jun	286	54	393	142	927	1330	115	29	38	14	15
	Jul	133	5	91	67	305	573	37	11	15	5	7
	Aug	117	21	125	59	319	500	39	9	13	5	6
	Sep	105	33	154	53	335	447	42	8	12	4	5
Van Benthuysen Brook												
1982	Oct	18	0	33	8	28	42	3	2	2	1	1
	Nov	124	6	441	92	447	456	42	16	19	7	5
	Dec	169	10	685	131	652	645	65	25	29	11	8
1983	Jan	141	6	493	101	471	501	48	19	23	8	6
	Feb	213	18	925	182	996	894	87	32	36	14	11
	Mar	147	4	440	107	506	530	43	18	22	8	6
	Apr	620	80	3330	671	4410	3250	311	107	115	45	35
	May	314	12	1040	279	1560	1370	100	41	49	18	14
	Jun	125	8	480	97	488	476	46	18	20	8	6
	Jul	18	1	40	9	34	47	4	2	2	1	1
	Aug	12	0	24	5	18	28	2	1	1	0	0
	Sep	17	0	40	9	34	46	4	2	2	1	1

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

[2] These loads include the ungaged portion of Spafford Creek.

Table C-3.--Monthly discharge and sediment and nutrient loads from tributaries to Otisco Lake, November 1981 through September 1983 (continued).

[Nutrient loads are in pounds. Locations are shown in fig. 2.]

				Nitrogen[1]				Phosphorus				
										Dissolved		
Station and year	Month	Discharge (second foot days)	Suspended sediment (tons)	Total organic	Total ammonia	TKN	Dissolved NO_2+NO_3	Total	Total inorganic	Total	orthophosphate	Organic
Willow Brook												
1982	Oct	0	0	0	0	0	0	0	0	0	0	0
	Nov	85	6	424	58	506	1060	49	22	27	13	5
	Dec	247	14	1150	165	1380	3120	134	62	76	35	19
1983	Jan	142	3	471	81	576	1830	57	29	37	15	9
	Feb	242	37	1500	177	1760	3030	167	69	83	43	20
	Mar	139	2	411	74	504	1740	50	26	33	13	9
	Apr	616	288	6550	598	7500	7440	705	250	290	176	67
	May	198	10	783	120	943	2530	92	44	55	24	14
	Jun	56	36	499	49	574	686	54	20	23	13	3
	Jul	4	0	7	2	9	48	1	1	1	0	0
	Aug	0	0	0	0	0	0	0	0	0	0	0
	Sep	0	0	0	0	0	0	0	0	0	0	0

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[1] Organic nitrogen is not equal to total kjeldahl nitrogen minus ammonia because mean monthly loads were calculated from equations and difference reflects the effects of averaging to obtain line of best fit.

Table C-4.--Seasonal mean and maximum sediment and nutrient concentrations and associated streamflow for samples collected in Otisco Lake subbasins during November 1981 through September 1983.

[Upper numbers are mean values, lower numbers (in parentheses) are maximum values. Concentrations in milligrams per liter. Locations are shown in fig.2.]

			Nitrogen as N				Phosphorus as P				
									Dissolved		
Station and season	Stream flow (ft^3/s)	Suspended sediment	Total organic	Total ammonia	Total kjeldahl nitrogen	Dissolved NO_2+NO_3	Total	Total inorganic	Total	Orthophosphate	Organic
Amber Brook											
Fall	6.14	21.14	0.75	0.08	0.48	0.44	0.04	0.03	0.04	0.02	0.01
(Oct-Nov)	(66)	(129)	(1.30)	(0.27)	(1.40)	(1.36)	(0.14)	(0.13)	(0.14)	(0.12)	(0.01)
Winter	12.54	24.70	.26	.09	.29	1.72	.02	.01	.01	.01	.01
(Dec-Feb)	(55)	(95)	(.71)	(.23)	(.90)	(2.21)	(.11)	(.05)	(.05)	(.01)	(.01)
Spring	13.72	43.16	1.18	.17	.74	1.49	.08	.04	.05	.03	.00
(Mar-May)	(42)	(433)	(2.60)	(.80)	(3.40)	(2.12)	(.54)	(.36)	(.37)	(.33)	(.03)
Summer	7.90	26.48	1.05	.10	1.24	.97	.08	.03	.03	.01	.01
(June-Sept)	(127)	(564)	(3.50)	(.22)	(5.60)	(2.25)	(.79)	(.05)	(.06)	(.02)	(.02)
Rice Brook											
Fall	3.38	12.21	.68	.14	.63	.82	.07	.03	.05	.03	.01
(Oct-Nov)	(37)	(127)	(.90)	(.30)	(1.20)	(1.76)	(.14)	(.11)	(.12)	(.10)	(.01)
Winter	9.97	21.26	.50	.08	.41	2.20	.07	.03	.03	.01	.01
(Dec-Feb)	(60)	(74)	(.59)	(.16)	(.70)	(4.04)	(.22)	(.07)	(.08)	(.03)	(.02)
Spring	9.44	42.38	2.40	.26	1.69	1.96	.15	.09	.11	.08	.02
(Mar-May)	(40)	(517)	(6.70)	(1.90)	(7.00)	(3.40)	(1.05)	(.95)	(1.02)	(.92)	(.07)
Summer	7.13	73.60	--	.12	1.12	1.36	.15	.04	.05	.02	.01
(June-Sept)	(78)	(2060)	(1.90)	(.34)	(5.20)	(3.40)	(1.28)	(.11)	(.11)	(.13)	(.02)

Table C-4.--Seasonal mean and maximum sediment and nutrient concentrations and associated streamflow for samples collected in Otisco Lake subbasins during November 1981 through September 1983. (continued).

Station and season	Stream flow (ft^3/s)	Suspended sediment	Nitrogen as N				Phosphorus as P				
			Total organic	Total ammonia	Total kjeldahl nitrogen	Dissolved NO_2+NO_3	Total	Total inorganic	Dissolved		
									Total	orthophosphate	Organic
Spafford Creek											
Fall (Oct-Nov)	29.36 (330)	94.69 (1120)	0.85 (2.50)	0.06 (0.13)	0.61 (2.60)	0.68 (0.80)	0.08 (0.52)	0.06 (0.49)	0.06 (0.51)	0.05 (0.48)	0.01 (0.02)
Winter (Dec-Feb)	40.77 (194)	85.85 (873)	- (-)	.07 (.16)	.50 (.80)	.99 (1.49)	.14 (.84)	.02 (.09)	.04 (.11)	.01 (.03)	.02 (.10)
Spring (Mar-May)	55.20 (196)	299.88 (2610)	0.55 (2.10)	.08 (.60)	.68 (2.70)	.99 (1.65)	.29 (1.40)	.04 (.45)	.05 (.47)	.03 (.41)	.01 (.08)
Summer (June-Sept)	55.12 (294)	432.68 (5910)	3.32 (9.80)	.12 (.46)	2.28 (10.00)	1.19 (2.35)	.20 (1.20)	.04 (.09)	.04 (.11)	.02 (.43)	.01 (.03)
VanBenthuysen Brook											
Fall (Oct-Nov)	3.09 (23)	8.79 (44)	0.10 (0.10)	.09 (.13)	.22 (.40)	.29 (.60)	.04 (.06)	.02 (.04)	.03 (.04)	.01 (.02)	.01 (.01)
Winter (Dec-Feb)	16.60 (94)	32.26 (163)	0.59 (0.78)	.17 (.42)	.46 (1.20)	1.36 (2.14)	.06 (.24)	.02 (.07)	.02 (.07)	.01 (.02)	.01 (.02)
Spring (Mar-May)	19.11 (99)	23.75 (277)	1.33 (2.60)	.29 (1.20)	1.19 (3.60)	1.14 (2.12)	.11 (.56)	.06 (.37)	.07 (.41)	.03 (.29)	.01 (.05)
Summer (June-Sept)	4.24 (30)	17.34 (165)	0.98 (2.60)	.09 (.27)	.87 (2.60)	.46 (5.26)	.06 (.33)	.03 (.08)	.04 (.08)	.01 (.07)	.01 (.03)
Willow Brook											
Fall (Oct-Nov)	11.76 (63)	16.33 (82)	1.30 (1.30)	.06 (.10)	1.25 (1.40)	2.08 (3.05)	.10 (.15)	.08 (.13)	.09 (.14)	.08 (.13)	.01 (.01)
Winter (Dec-Feb)	12.57 (68)	25.78 (145)	0.74 (1.10)	.16 (.44)	.73 (1.50)	3.95 (6.40)	.06 (.37)	.03 (.10)	.03 (.11)	.02 (.06)	.00 (.01)
Spring (Mar-May)	15.18 (80)	78.18 (1150)	2.41 (4.90)	.31 (1.90)	1.52 (6.80)	2.40 (5.94)	.20 (.89)	.10 (.54)	.12 (.58)	.08 (.50)	.02 (.08)
Summer (June-Sept)	8.15 (81)	46.87 (880)	1.39 (5.40)	.10 (.40)	.99 (5.60)	2.47 (5.55)	.10 (.66)	.05 (.16)	.06 (.19)	.04 (.32)	.01 (.04)

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