THE LIMNOLOGY OF LAKE GEORGE, NEW YORK

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ABSTRACT

This description of Lake George, New York and its environs defines and characterizes the geographic, morphometric, hydrologic, limnologic, and nutrient condition of the water body and the surrounding watershed. Some pertinent information concerning time-series physical, chemical and biological data describing this lake are given.

Lake George, classified as an oligotrophic-mesotrophic mountain lake, is located in the eastern Adirondack Mountains of New York State. The biological populations (especially diatoms) have experienced changes toward those characteristic of more eutrophied lakes. The lake is long and narrow; its major axis extends in a north-northeasterly direction and may be considered as two basins, the south and north. The south basin of Lake George, with its denser population, has experienced more significant changes in biological population and receives a greater nutrient loading than does the northern lake basin.

Lake George lies in a glacial scoured basin of Precambrian metamorphic, plutonic, and igneous rock, with small patches of Cambrian deposits mainly at the southern end of the basin. Most of the drainage basin is covered with shallow soil from glacial debris with numerous outcroppings present. Much of the beauty of the lake -- sometimes called the Queen of American Lakes -- and the surrounding region is attributable to its geologic origin.

INTRODUCTION

Lake George, known as the Queen of American Lakes, is located in the eastern Adirondack Mountains of New York State and in the southeastern portion of the Adirondack State Park (Figure 1).

Prior to the colonization of the New World this lake was part of a natural trail, and was the site of numerous Indian conflicts. Its location between the Hudson River and Lake Champlain made it a strategic battle area during the French and Indian Wars and the Revolutionary War.

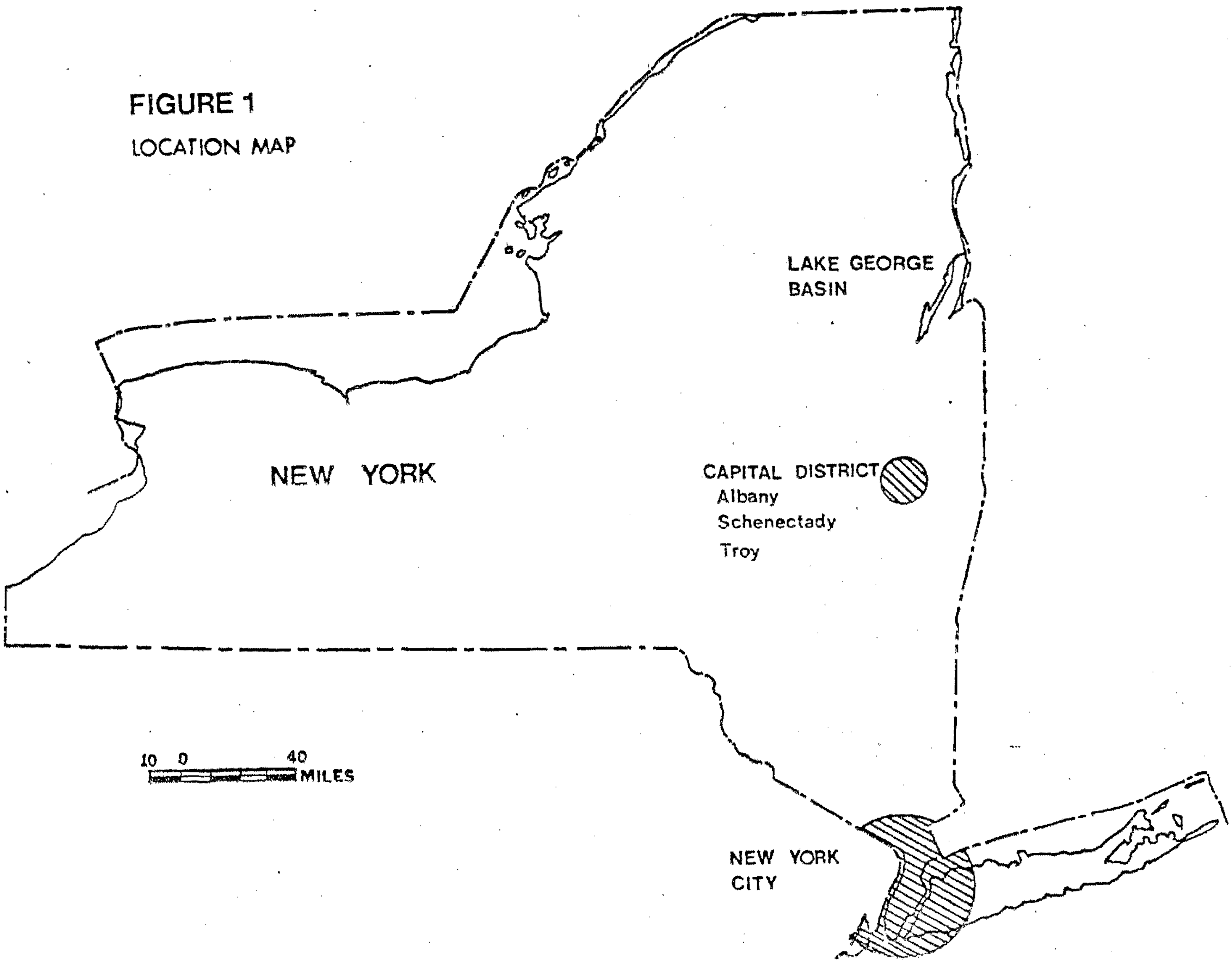
During the latter part of the nineteenth century, mining operations in the region produced a large portion of the nation's high-grade graphite as well as some iron ore. An active logging industry also existed supporting several wood and pulp mills in the Village of Ticonderoga, located on the extreme north end of Lake George. Virtually all of this industry, however, ceased within the first three decades of the twentieth century.

A flourishing tourist trade, drawn by the beauty of the lake and its scenery, has replaced it. The recreational accessibility of the area was enhanced by the completion of the Adirondack Northway in 1967. Recently, several universities have carried out extensive scientific research lead by the Rensselaer Fresh Water Institute at Rensselaer Polytechnic Institute, Troy, New York. Much of this research was done as part of the United States' effort in the International Biological Program, for Lake George was a key research site.

Lake George lies in a glacial-scoured basin of Precambrian metamorphic, plutonic, and igneous rock, with small patches of Cambrian deposits mainly at the southern end of the basin. Most of the drainage basin is covered with shallow soil from glacial debris, with numerous outcroppings present. Much of the beauty of the lake and surrounding region is attributable to its geologic origin, which dates back to the pre-Grenville rock assemblage of approximately

FIGURE 1

LOCATION MAP



3.5 billon years. Upon this complex sands, muds, and marls were deposited by the Primordial Sea which covered much of what today is North America, exclusive of the sourthern sectors. Movements and molten matter intrusions of the earth's crust compacted the original sediments. The resultant metamorphic and plutonic rock types comprise most of the rock mass of the Lake George area, including the high ranges.

The basin of the lake has a drainage area of 606 km^2, with the lake occupying 114 km^2 of the basin's area. Precipitation is the major water input to the lake, with an annual deposition of approximately 93 cm (Colon, 1972). About 0.1 km^3 of water falls directly on the lake each year and 0. 2 km^3 enters through the more than 80 streams discharging into it.

Lake George is long and narrow; its major axis extends in a north-northeasterly direction. It may be considered as two basins commonly referred to as North and South Lake George, respectively. The South Lake is further divided into two basins, south and central, on a morphometric and circulation basis (Langmuir, et al., 1966; Needham, et al., 1922); each basin contains a very deep section and several shallower areas. The deep south basin, also called the Caldwell Basin, is exposed to much greater anthropogenic influence than is the North Lake. The North and South Lake basins are separated by the Narrows.

Crustal disturbances and faulting produced two large depressions in the lake's formation. One was from the Narrows northward, and the second was in the area known as Northwest Bay. These two depressions were occupied by rivers, one flowing southwards (from the Northwest Bay region) toward the present Hudson River Basin and the other northwards to the Lake Champlain area. After the glacial period, both outlets became blocked and the lake filled with water from the melting ice, eventually forming Lake George. The basins were connected through the Narrows and the lake water escaped northwards past the slopes of Mount Defiance at Ticonderoga.

The lake shore is irregular, steep, and rocky, with the lake at a rather low level amid elevations of some considerable height, creating a steep and fjord-like appearance (Colon, 1972). A shallow soil cover which was formed from glacial debris covers most of the drainage basin, with numerous rock outcroppings occurring. Deciduous forest, with numerous conifers also present, covers most of the watershed. Much of the original biogeologic character of Lake George still exists, and is being analyzed today in an attempt to maintain its beauty and quality.

PREVIOUS STUDIES

Since its discovery by Europeans, Lake George has served as a vital waterway, being situated between Lake Champlain, the waterway to the north, and the Hudson River, the waterway to the south. This role imposed both a military and a commercial impact on the surrounding area through the nineteenth century. The natural beauty of the lake and its environs, however, has taken on increasing importance, even as the previous points of importance have faded. In the present century, the major considerations for Lake George have been the recreational potential afforded by its waters and its capacity as a potable water supply for its peripheral inhabitants.

The outflow from Lake George forms Ticonderoga Creek which falls 68 meters to the level of Lake Champlain, through the LaChute River. This potential energy was harnessed in the nineteenth century through a series of dams that supplied energy to a number of industries in the Village of Ticonderoga, which straddled the river. The total length of stream flow betwwen the Lakes is approximately 5.6 km (3.5 mi).

Before the construction of these dams a natural rock ledge, from which five channels carried water to the outlet stream, controlled the water level of Laker George. The first artificial dam was constructed approximately 1,340 meters downstream of the rock ledge, with a crest one meter above the natural lake level. Before the construction of this dam, lake levels fluctuated a maximum of 0.76 meters; following construction, the range became 1.30 meters. The date of original construction is unknown, although it is believed to be well before 1903 (Report, 1945), and probably around 1830. Researchers believe that the artificial dam permanently raised the lake level 0.6 meters.

The conformation of various areas of the Lake have been changed due to the increase in surface level. Long Island, in the central basin of the Lake, was submerged in part, creating a second island, South Island. Records and maps from the late 1700's indicate the existence of a single island in the area. A 1913 report notes; "... the two islands were caused by artificial interference with the lake level probably seventy-five years ago and that the new conditions have ever since existed keeping the lake at a level which caused it to overlfow a depression across Long Island. The action of this water no doubt in course of time worked away soft material and led to a situation which was apparently natural and, so far as the eye could detect, primeval."

The Triplet Islands, northeast of Long Island, also were formed by the submergence of lowlands. A 1922 report states: "That the islands were a portion of the uplands is strongly indicated by the fact that there is only a few inches depth of water between them and the present main shore of the lake, which water shows stumps of trees formerly growing therein" (Report, 1945).

Although the lake level has been artificially controlled since early in the nineteenth century, hydrographic data have been collected only since the turn of the century. The U.S. Geological Survey initiated lake level monitoring on July 10, 1913 near Rogers Rock in the northwestern reaches of the lake. On November 11, 1936, this station was placed on a continuously-recording basis, replacing the previous procedure of making one observation per day. Regulation of lake levels, based on the Rogers Rock gage, is established by New York State law.

Rainfall data for the Lake George basin has been collected since 1896, but station location and number have varied since that time. During this period, stations have been located in the communities of Lake George, Bolton, Silver Bay and Ticonderoga.

In the summer of 1920, researchers measured the limnological characteristics of Lake George for the first time (Needham, et al., 1922). Physical and chemical measurements confirmed the apparent quality of the water. Secchi disk depths were ten meters or greater, and oxygen saturation exceeded 80% at the greatest depths measured. Alkalinity values were in the "soft water" range, being 22 mg $CaCO_3$/L in the surface waters, and rising to 25 mg/L at 49 meters depth.

In early August 1920, the phytoplankton was dominated by diatoms, principally <u>Asterionella sp.</u>; also present in quantity were <u>Fragilaria</u>, <u>Synedera</u> and <u>Tabellaria spp.</u> Green algae were represented by <u>Consmarium</u> and <u>Staurastrum spp.</u>; blue-green algae, by <u>Aphanocapsa</u> and <u>Microcystis spp.</u> Green and blue-green algae combined numbered less than 20% of the diatoms. Among the zooplankton, copepods, represented by <u>Cyclops</u> and <u>Diaptomus</u> almost completely, were dominant. Cladocera, composed of <u>Bosmina</u>, <u>Daphnia</u>, <u>Diaphanosoma</u> and <u>Holopedium</u>, existed largely in the upper 15 meters. Cladocera were less than than 20% of Copepoda in number.

The Protozoa represented the largest component of the zooplankton.

Ceratium and Dinobryon were dominant in the upper ten meters, while Mallomonas were dominant, in general, below 15 meters.

The benthos, surveyed at depths of 22 meters and greater, revealed only macroscopic forms including insect larvae, amphipods (Pontoporeia), mollusks (Pisidium), and worms (Oligochaeta). The total number of animals increased with water depth, ranging from 309 individuals per square meter at 22 meters depth, to 2,711 individuals at 50 meters depth. The large population at the latter station was due chiefly to large numbers of small specimens of Pontoporeia.

The local population divided macrophytes of the lake into three general groupings: "weeds," "grass," and "moss." The "weeds" were principally Potamogeton praelongus, P. robbinsii, and P. pectinatus. Ceratophyllum also was found intermixed with these species. The rooted macrophytes were found at depths between three and six meters, outside of the breaker line. Where the bottom slope is very gentle (on sheltered shoals), Eriocaulon was the dominant macrophyte inshore of the breaker line.

The "grass" consisted almost entirely of the species Nitella opaca. Nitella beds were found in a continuous zone at depths between seven and fourteen meters, with an average of eleven meters. The growth of Nitella was most extensive at depths of twelve meters in areas sheltered from currents.

The "moss" identified as Dichotomosiphon tuberosus is a macroalga which was found at depths beyond the Nitella beds, between twelve and fifteen meters.

The beds of macrophytes supported large numbers of diatoms, gelatinous and filamentous algae, midge larvae, snails, caddisworms, scuds, rotifers, small crustaceous insects, molluscs, and worms. This associated population provided the fishes of the lake with substantial feeding grounds. Needham, et al. (1922) comment, "It is over the large 'grass' beds that most still fishing is done in Lake George by the initiated."

While the golden shiner (Abramis crysoleucas Mitch) and Cayuga minnow (Nitropis cayuga Meek) fed mainly on algae, e.g., diatoms and flagellates, and plant material, e.g., bud ends of the larger aquatics, or vascular plants, all other non-piscivorous fish fed on zooplankton, larval forms, insects, scuds and crayfishes. Among the non-piscivorous fish examined were: Yellow perch (Perca flavescens (Mitcheel)), a "very common" species usually found in the "weed" and "grass" beds; Longeared sunfish (Lepomis auritus (Linneaus)), "common" in shallow water; Common sunfish (Eupomotis gibbosus (Linneaus)), "very common" in shoal water; and Rock bass (Ambloplites rupestris (Rafinesque)), "very common" in shoal water. Whitefish or "Seneca Lake Smelt" (Leucichthys osmeriformis (Smith)) was the only pelagic non-piscivore found and examined. Rock bass occasionally ate small fish, including their young, but their preferred diet appeared to be crawfish. It was suggested, also, that older perch would occasionally eat fish.

The major piscivorous fish found in the lake included: Northern pike (Esox lucius (Linnaeus)), reported to be greatly reduced in numbers by disease; Smallmouth black bass (Micropterus dolomieu (Lacepede)), "fairly abundant" and generally distributed in the lake; and Lake trout (Cristivomer namaycush (Walbaum)) found in the deeper waters of the lake. The trout fed primarily on the whitefish, but other fish, including yellow perch were eaten when available. Insects were a small part of the trout diet in the summer sampling.

The desire of Lake George fishermen for more abundant catches led to the introduction of stocking. The Needham, et al. (1922) report noted that between 1900 and 1920 thirteen distinct species were introduced. These were not identified. Lake trout were stocked in "liberal" number in the period 1916-1920. Much effort was reported to introduce the Landlocked salmon (Salmo salar sebago (Girard)) into Lake George. At least 15,000 to 20,000 were stocked annually "for a long period of years" (by 1920). However, the survey found them to be "rather rare."

Note that species studied have been listed as they were originally in the Needham, et al. (1922) report. Present day nomenclature may differ, particularly for the fishes, following alterations by the American Fisheries Society (1970); ie. the Longeared sunfish Lepomis auritus (Linnaeus) as reported by Needham is in reality the redbreasted sunfish. Lepomis auritus. The present designation for the Longeared is Lepomis megalotis (Rafinesque) a species that does not occur in the Lake George system.

The quality of Lake George waters aroused interest in developing the lake as a metropolitan water supply, even for New York City (Fanning, 1881). Bordered by the Adirondack Mountains, Fanning (1881) looked upon the watershed as indefileable: "We know without demonstration by skillful analysis that these rocks do not freely infuse themselves into their waters; we know that villages upon the mountain slopes are few and their manufactures unimportant. We know that but a small fraction of their area has come under the influence of the agriculturist, and we may, with great confidence, predict that their waters will for many generations to come remain among the purest and best adapted for domestic and commericial uses obtainable within the borders of the State." With this assuming confidence, Needham, et al. (1922) could state almost forty years later that Lake George was "a beautiful sheet of water that has been much admired and but little studied."

GEOGRAPHIC DESCRIPTION

Lake George is a relatively large lake located in the southeastern Adirondack Mountain region of New York State. The basin boundary is between latitude 43° 22' and 43° 51' North, and longitude 73° 24' and 73° 47' West. The lake surface stands at 97 meters above mean sea level, and encompasses 114 km^2. The drainage basin surface area is 492 km^2, giving a total catchment area of 606 km^2. Thus, the tributary watershed to lake surface ratio is only 4.3.

Streams

Physical characteristics of the basin, such as vegetation cover, areal variation and distribution of precipitation, soil moisture and groundwater, and development of the area by man, greatly affect the surface runoff into the lake. These factors work in various ways, tending to increase or decrease surface runoff. Their effects may be evaluated qualitatively but become increasingly complex when quantitites and degree of influence are considered.

The relatively small size of the drainage basin limits the size of the influent streams. Vegetation cover intercepts part of the precipitation, greatly reducing that which reaches the ground. The shallow soil cover, abrupt topography, steepness of slopes, and short time of travel make storm runoff very rapid and tumultuous.

The land portion of the watershed occupies about 81 percent of the drainage area. The shape of the basin is elongated and not too wide, closely following the shape of the lake, except for the area around Indian Brook and Northwest Bay Brook (Figure 2). This factor, coupled with the topography, creates a large number of streams with relatively small drainage areas. There are some 88 streams flowing into the lake; about one-fourth are intermittent, while the majority of those remaining have barely any sustained flow during the late summer months.

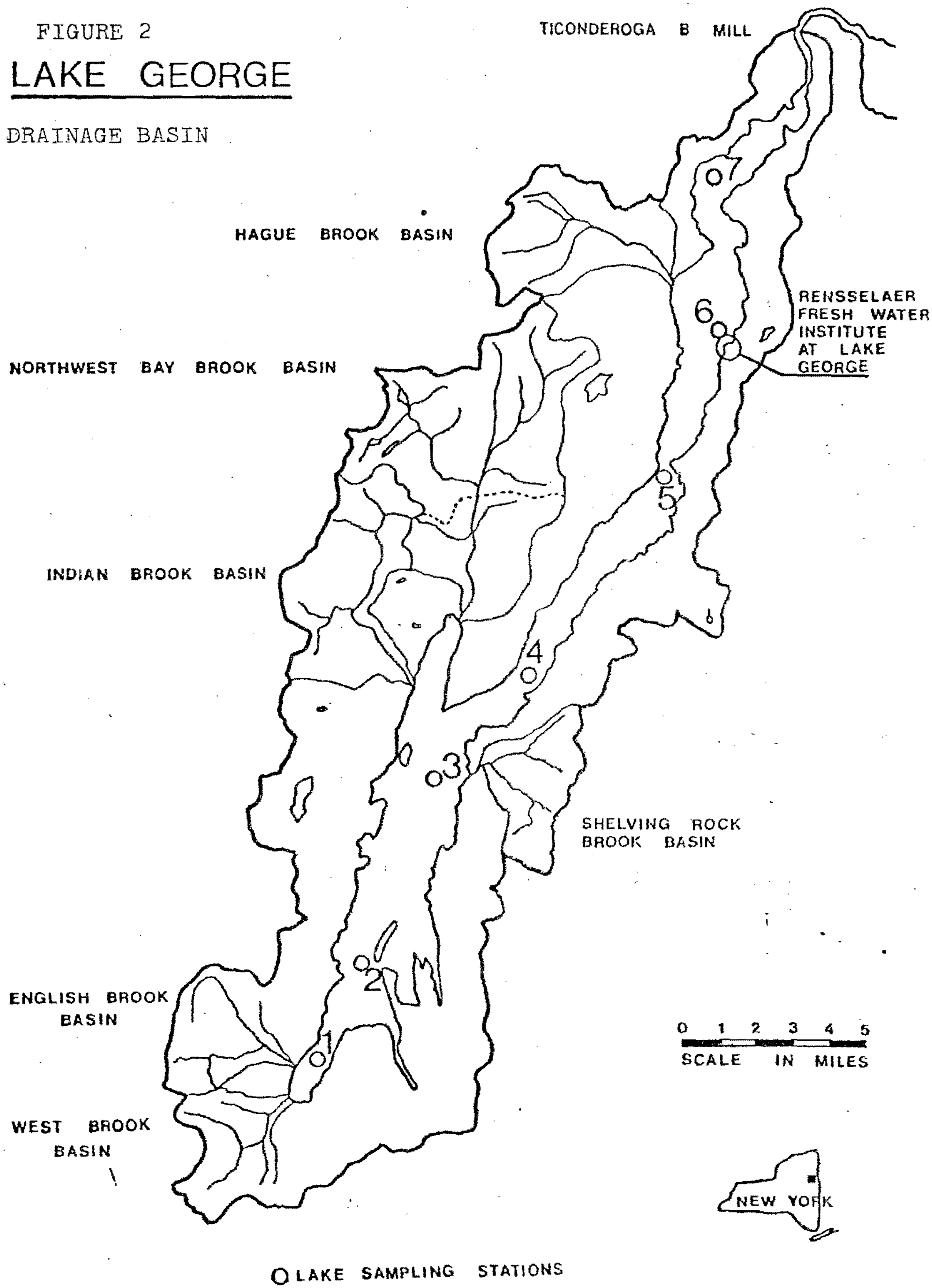
General Geologic Characteristics (Schoettle and Friedman, 1971)

Lake George occupies a graben in Precambrian bedrock. This bedrock consists of plutonic, metamorphic, and igneous rock, such as gneisses and schists, syenite, granite and gabbro. At a few locations along the southern shore of

FIGURE 2

LAKE GEORGE

DRAINAGE BASIN



Lake George there are exposures of Cambrian sandstones (Potsdam sandstone) and dolostones (Little Falls dolomite).

The linear straight shorelines and sheer slopes are the combined effect of erosion following prominent faults, and a deepening of the fault-controlled valleys by the sweep of the Pleistocene glaciers which deepened the rock channels. Prior to glaciation, two rivers drained the Lake George basin. One stream originated in the narrow trench now occupied by Northwest Bay Brook, and flowed into the southern Lake George basin; the second river flowed from the Narrows northward.

A preglacial divide existed where the Narrows are now located. When the glaciers plowed their way through the deep narrow Lake George Valley, they deepended the Narrows by ice erosion. Pleistocene glacial sediments, which block the river outlets at the north and south end of the lake, now hold the waters of Lake George in place. At the south end of the lake, glacial sand and gravel deposits rise 500 feet above lake level. After the retreat of the glaciers Lake George was a glacial lake, as evidenced by the presence of varved clay flooring the bottom of the lake in the Narrows; this varved clay also occurs above the present lake level at elevations up to 230 to 245 m (750 to 800 feet).

Surficial sediments of the Champlain basin, of which Lake George forms a part, have been mapped. Sand and gravel are abundant in the delta and ice-contact gravels southwest of Lake George Village.

Climatology

The Lake George Basin is located within the humid continental climatic region of the Northeastern United States. Characteristically then, its climatic patterns show both annual and daily changes. Summers are warm and pleasant, whereas winters are cold and severe. The Glens Falls, New York climatological records show a mean July temperature of 21°C (70°F) and a mean January temperature of -7°C (19°F). The diurnal temperature extremes average about 11°C (20°F) the year round. The record extremes are 37° and -34°C (99° and -29°F).

Precipitation in the Lake George area is moderate and well distributed throughout the year. The average for four climatological stations surrounding the basin is nearly 89 cm (35 in.) annually. The bulk of this precipitation comes from storms which originate in the mid-west or western states, and then move in an easterly direction across New York State. In summer this rainfall is enhanced by thunderstorms, and in winter by northeastward moving coastal storms.

Snowfall in winter generally covers the ground from late November through mid-April. Yearly amounts vary widely, but average 1.5 to 2 m (60 to 80 in.). Snow depths often reach 0.6 to 1 m (2 to 3 ft.) by late winter. The lake itself, because of its location between two north-south oriented mountain ranges, and its size and depth, provides some noticeable modifications to the local climate. The lake tends to retard temperature changes of the advancing seasons because of its stored heat. In spring, when areas distant from the lake are experiencing mild weather, the cold lake water keeps the local air chilly. In the autumn, the reverse occurs and early frosts in the immediate vicinity of the lake are delayed.

The lake generally freezes over in late December of early January; ice break-up generally occurs around mid-April. The ice usually reaches a thickness of about 0.6 m (2 ft.).

Table 1 presents the monthly average solar radiation for Lake George for the period July 1971 thru August 1972 (Stewart, 1972). During this time period the solar radiation ranged from 101 to 523 cal cm^{-2} day^{-1} in December (1972) and July (1971), respectively.

TABLE 1. Solar Radiation Monthly Averages

July 1971 - August 1972 (after Stewart 1972)

Month	Mean Solar Radiation, cal cm^{-2} day^{-1}
July	523
August	469
September	313
October	220
November	131
December	101
January	146
February	229
March	277
April	399
May	435
June	400
July	472
August	449

Temperature and rainfall data for the Glens Falls airport are available from 1911, excluding 1936-1946 when data were not reported. The data include maximum, minimum, and average temperatures, both daily and monthly, as well as daily and monthly precipitation.

Table 2 presents the normal monthly average temperature and precipitation and the maximum and minimum temperatures at the Glens Falls, NY airport.

TABLE 2. Normal and Extreme Temperatures and Normal Precipitation

Glens Falls, New York

Month	Temperature Mean		Temperature Max		Temperature Min		Precipitation Mean	
	°F	°C	°F	°C	°F	°C	in	cm
January	18.9	-7.3	54	12.2	-29	-33.9	2.48	6.30
February	21.4	-5.9	60	15.6	-22	-30.0	2.49	6.32
March	31.1	-0.5	67	19.4	- 4	-20	2.73	6.93
April	45.3	7.4	83	28.3	13	-10.6	3.16	8.03
May	55.5	13.1	90	32.2	25	- 3.9	2.91	7.39
June	65.4	18.6	95	35.0	37	2.8	2.87	7.29
July	69.8	21.0	99	37.2	44	6.7	2.99	7.59
August	67.6	19.8	96	35.6	38	3.3	3.11	7.90
September	59.4	15.2	97	36.1	26	- 3.3	2.61	6.63
October	49.1	9.5	87	30.6	18	- 7.8	2.38	6.05
November	38.1	3.4	70	21.1	- 1	-18.3	3.04	7.72
December	24.8	-4.0	60	15.6	-18	-27.8	3.09	7.85
Annual	45.6	7.6	99	37.2	-29	-33.9	34.31	87.15

Table 3 gives the average monthly snowfall observed over a 10 year period.

The annual average of 153.4 cm (60.4 in) is approximately 20 cm (8 in) more than the annual average observed at the Albany Airport.

TABLE 3. SNOWFALL - 10 YEARS

Glens Falls Airport

Month	Snowfall in	Snowfall cm
September	0	0
October	0.3	0.76
November	2.4	6.10
December	11.0	27.94
January	16.3	41.40
February	16.6	42.16
March	13.1	33.27
April	0.7	1.78
May	0	
	60.4	153.42

Stewart (1972) studied the wind conditions for the period September 1971 to August 1972 and found that the vector averages indicate that the wind flow is predominantly southerly seven months of the year, with a dominant northerly flow in November, December, February, March and April. The only predominantly easterly flow was in May. The highest average winds were recorded in February and March, with the lowest in October and July.

Vegetation

A survey was made of the types and numbers of each type of tree in the

Lake George drainage basin (Nicholson and Scott, 1972). Hemlock (72% of stands), sugar maple (69%), white pine (64%) and red maple and northern oak (57%) were the most frequently encountered of 35 tree species occurring in 75 randomly selected stands. Hemlock led in density (32% stands), followed by white pine (13%), beech (12%), northern red oak (9%), and red/sugar maple (8%). Distribution patterns of hemlock and pine showed that the former is more abundant in sloping stands at the lowest elevation (100 m) and generally prevalent on the east side of the basin, while white pine is better represented in level stands about 200 m, but uncommon on the east side.

Biomass and net production of the tree layer (stems > 10.2 cm, dbh) were estimated for 79 stands in the Lake George drainage basin by dimension analysis. Typical biomass and production ranges (100-300 x 10^3 kg/ha; 5-11 x 10^3 kg/ha/yr, respectively) were comparable to estimates for similar communities elsewhere. Since site factors were masked by past disturbance, biomass and production were largely a function of successional status. They increased linearly throughout the range sampled, except for a plateau at 80 years on coarse textured sites. Biomass and production in conifer and angiosperm dominated stands of comparable site and successional status did not differ appreciably.

Population

The human population of Lake George varies seasonally since this lake is a popular resort area. As Table 4 shows, the permanent population for south Lake George and north Lake George is 4,445 and 1,130, respectively. While there are no public sewers in north Lake George, more than half of the populace around south Lake George do have sewer services. The permanent year-round population of south Lake George is approximately 17% of the total population, whereas 25% of the total population of north Lake George is permanent.

TABLE 4. Population Distribution in the Lake George, NY Basin*

Ref.: Aulenbach and Clesceri, 1973

	South Lake George		North Lake George	
Population Type	Number Sewered	Total Number	Number Sewered	Total Number
Permanent, Year-Round	2,930	4,445	0	1,130
Summer Camp	1,750	8,775	0	3,205
Resort Hotel and Motel	9,111	12,558	0	47
Total Average Summer	13,791	25,778	0	4,382

* Compiled from 1970 census data

Of the population breakdown (Table 5), approximately 30,000 people inhabit the Lake George drainage basin during the summer, with approximately one-third of this number in motel and hotel resorts in the Town of Lake George (south Lake George). These population shifts are important factors in assessing the potential for water quality changes resulting from man's activities.

Historical Socioeconomic Aspects of the Lake George Area

Presently, Lake George has a concentrated and developed recreational economy. Lake George lies mostly within Warren and Washington Counties; the northern tip of Lake George at Ticonderoga is within Essex County. Most of Lake George's commerce is located along the south-western shores of the lake, which is within Warren County. The eastern shore is much less commercialized and lies within Washington County. The commercial district at Lake George is concetrated mainly at the southern tip of the lake at Lake George Village. Other major points of tourist-oriented commercial activity are the villages of Diamond Point and Bolton Landing along the western shore, and the town of Ticonderoga at the northern tip of the lake. The south-eastern shore has some commercial activity which rapidly diminishes as one proceeds north. The eastern shore is much less accessible north of Pilot Knob, with the major access points along the eastern shore widely spaced at Huletts Landing, Gull Bay, Glenburnie and Black Point. There are a few jeep trails in between these areas, such as at Shelving Rock.

The Lake George area is steeped in the history of the American Revolution. The celebrated Jesuit father and Catholic missionary, Father Isaac Jogues, was the first European to gaze upon the clear blue-green waters of Lake George in 1646. Father Jogues, exercising an explorer's right and feeling the presence of the majesty of this beautiful lake, christened it Lac du St. Sacrement -- the Lake of the Holy Communion (Van de Water, 1946). His Algonquin guides

TABLE 5. Total Populations and Those Serviced by Sewers in the Lake George Drainage Basin

4. Ref.: Aulenbach and Clesceri, 1972

	Permanent Year Round[1] Population		Summer Camp Population[2]		Motel and Hotel Resort Population		Total Average Summer Population	
	Total	Sewered	Total	Sewered	Total	Sewered	Total	Sewered
Warren County								
Lake George Town	2630	2130	2000	1500	10215	8661	14845	12291
Bolton Town	1165	800	2400	250	2343	450	5908	1500
Hague Town	640	0	1425	0	47	0	2112	0
Queensbury Town	410	0	2375	0	0	0	2785	0
Lake Luzerne Town	0	0	0	0	0	0	0	0
Warrensburg Town	0	0	0	0	0	0	0	0
Horicon Town	10	0	0	0	0	0	10	0
Washington County								
Fort Ann Town	230	0	2000	0	0	0	2230	0
Putnam Town	150	0	700	0	0	0	850	0
Dresden Town	190	0	1050	0	0	0	1240	0
Essex County								
Ticonderoga Town	150	0	30	0	0	0	180	0
TOTAL	5575	2930	11980	1750	12605	9111	30160	13791

[1] Data were adjusted to conform to drainage basin lines by the Environmental Quality Research and Development Unit, New York State Dept. of Environmental Control.

[2] A normal summer occupancy of 5 persons per camp was assumed.

called the lake Andia-ta-rochte, while the Mohawks called it Caniad-eri-oit, meaning Tail of the Lake (Brown, 1963). Father Jogues was among the earliest of the many French captives who were dragged by the cruel Iroquois along the old war-trails and tortured. Later, Sir William Johnson, then a general and superintendent of Indian affairs under the British crown, renamed the beautiful body of water Lake George, not merely as a compliment to his King, but to strengthen the British claim of the lake (Clarke, 1940). Johnson built a fort on Lake George and named it Fort William Henry.

Lake George and its larger neighbor, Lake Champlain, were for generations the natural waterways for the elm-bark canoes of Indian hunting and war parties. The great Indian Confederacy of Five Nations (the Iroquois Federation) claimed proprietorship of both lakes, and their war parties sought the villages of their northern enemies, the Huron and the Algonquin. The canoes of the Huron and the Algonquin carried them south on retaliatory raids against the Iroquois.

These small savage forays by the Indians, before the presence of the white man, set the stage for more bitter conflicts to be seen principally between the French and the British. The combined Lake George and Lake Champlain was regarded as an easy road to war by canoe while the water remained open, and by snowshoe over the ice during the winter months. The natural waterways of the Lake Champlain-Lake George valley were the setting which channeled the fate of the country (Van de Water, 1946).

The region historically known as the principle war route of the Iroquois and the Algonquin nations, was later witness to conflicts such as those between France and England from 1689 to 1697, and other wars through the 1700's. The French and Indian War began in 1755, although war was not declared until 1756 (Brown 1963).

In the colonial days, the Adirondacks were rich beaver hunting grounds. Fortunes were made through the extensive fur trade carried on with the Mohawk and the Algonquin Indians by the French, Dutch, and English traders. The local economy of Lake George was geared from the early 1800's to about 1840 to lumbering. Saw mills were built along the Hudson and the Schroon Rivers, and on some smaller streams. Although lumbering was the main commercial activity through the early 1800's, smaller industries were potash, tanning, and mining (iron, titanium and graphite). There also were grist mills, forges, and machine shops (Legis. Doc., 1945). The lumbermen, claiming that the forests would last for centuries, proceeded to destroy them in a single human life-span (Van de Water, 1946). The forests within the Adirondacks abounded in towering white pines, many of them more than 200 feet (60 m) high. White oak and spruce were removed after the white pines. Later, the hemlocks, poplar, basswood, and birch were cut. Believing that the Adirondack forests were inexhaustible, lumbermen stripped hillsides of the best timber, reducing them to bare eroded areas (Van de Water, 1946).

The character of Lake George has been greatly changed by the tourist trade. It was said of Lake George back in the early days (the mid 1800's to early 1900's) that "The natives of this region live upon fish and strangers" (Van de Water 1946). People traveled mainly by military trails, eventually using stage coaches, lake steamers, horsecars, and railways at various stages of development of the area. The golden age of stagecoaching in Warren County was 1869-1882, and as stated by Brown (1963):

> "... were it not for those vehicles, the popularity of Lake George and more northerly communities as resorts would not have developed to such an extent in the early days."

The early modes of transportation made the journey to Lake George less than comfortable. The railroad which went to Glens Falls was extended to Lake George Village in 1882, but in the late 1940's passenger service dwindled. In 1957, the Delaware and Hudson gave up its last summer train to Lake George (Brown, 1963). This shift away from railroad transportation resulted from the concurrent development of improved roads and the use of automobiles, the predominant means of transportation throughout the 1900's.

Thus, the tourist industry gew rapidly coincident with highway improvements and automobile travel. As these shifts in modes of travel occurred, and as leisure time and general affluence increased, the tourist trade became more prominent. Cabins replaced hotels destroyed by fire, and the cabins themselves yielded to motels, which provided greater numbers of temporary accommodations (Brown, 1963). In 1962, more than one hundred motels, one hotel and five rooming houses served the thousands of summer visitors who came to Bolton Landing on Lake George, for instance. As of 1967 there were approximately three hundred and fourteen motels in Warren County, most of these in the Lake George area (Temp. Study Commission, Tech. Report #5, 1970).

The Gold Cup races of 1914 and 1936 introduced the Lake George and Bolton area to the speedboating world and drew large crowds (Brown, 1963). During the winter, the lake provided horse races and now car races and other activities. The growth of winter activities such as snow skiing became another important resource of the Lake Champlain-Lake George region (Sno-Engineering, Inc., 1968).

Lake George Village provides many tourist shops, hotels and motels, amusements, and other activities for the present day recreationist. One can find a complete range of facilities and attractions in the Lake George area, from a completely commercialized to a wilderness character. Together with the 113 state-owned islands, and three public and several private mainland campsites, the lake is frequented by many recreationists and seasonal residents from many places.

Land Use

The drainage basin of Lake George, New York, is included in the counties of Essex, Washington, and Warren. Within these counties the drainage basin makes up part of the towns of Ticonderoga, Putnam, Fort Ann, Dresden, Warrensburg, Queensbury, Lake Luzerne, Horicon, Hague, Lake George, and Bolton. None of these towns is completely within the drainage basin, and several have only a small fraction of their total land area within the basin. The complete drainage basin of Lake George is within the limits of the Adirondack State Park, and is subject to the minimum land use and development restrictions set up by the Adirondack Park Agency.

The categories of land usage and percentage of the basin are; active agriculture (1.6%); woodlands (73.8%), which also includes non-productive land; wetlands (2.2%); water (17.0%); residential (2.3%): commercial (1.0%); industrial (0.1%); extractive (0.1%); public and semi-public (0.3%); outdoor recreation (1.0%); and transportation (0.6%), as shown in Table 6. These land usages can be related to the land classifications of the Adirondack Park Land Use and Development Plan Map, (1973) (Figure 3) and the Land Use Planning Guide for Washington County (1976). The predominant land usage is woodlands, which covers alsmost three-quarters of the drainage basin; the reason why this land is undeveloped is because there is no vehicular access, the terrain is too rough or it is under State ownership. Table 6 shows the mix between private (59%) and public ownership (41%).

Development around Lake George is primarily along or near the shore line of the lake (Figure 3) The largest center of population is Lake George Village, within the Town of Caldwell (or Lake George), and is located at the southwestern tip of the lake.

FIGURE 3
ADIRONDACK PARK LAND USE AND DEVELOPMENT PLAN MAP

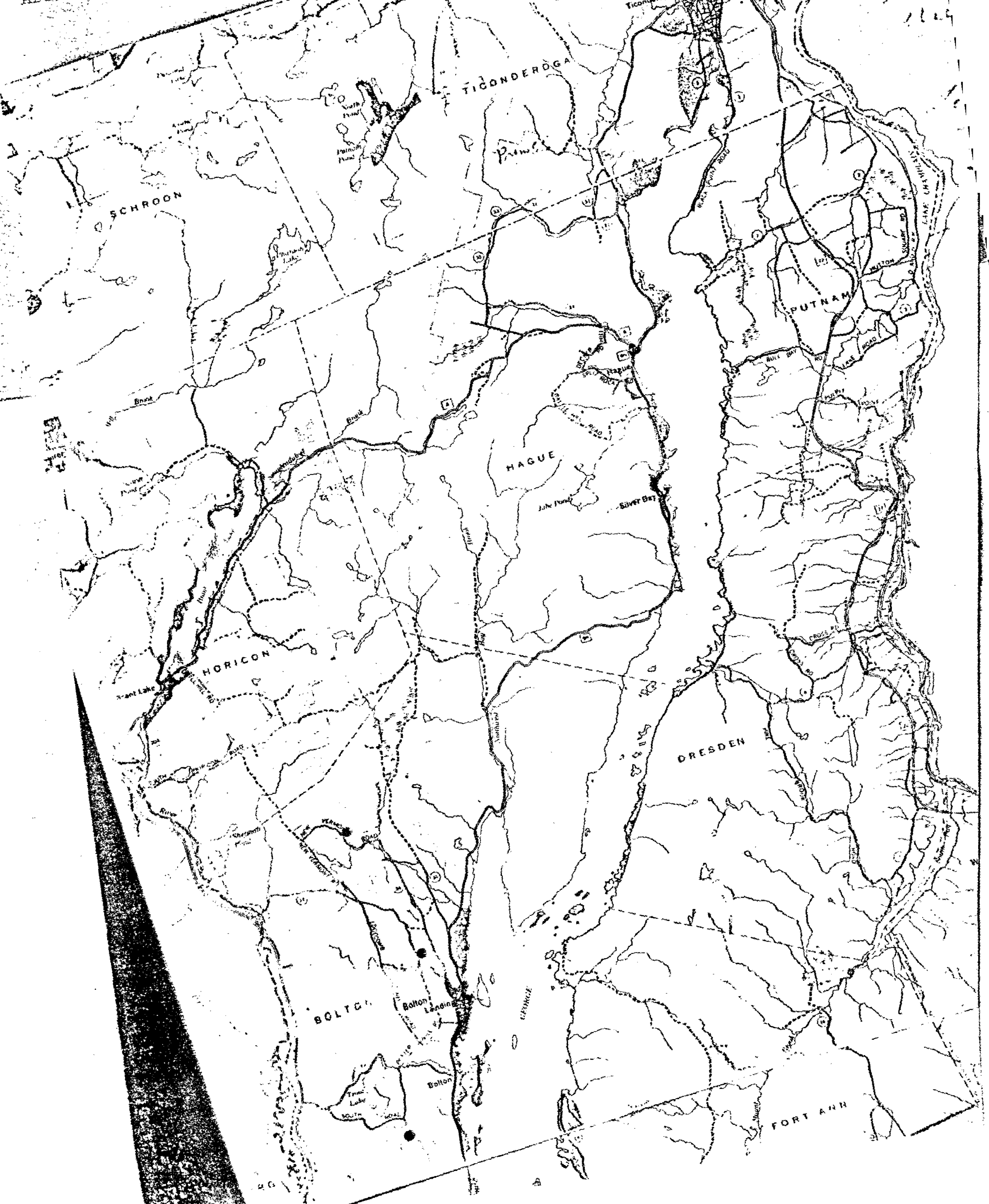


TABLE 6. Land Usage Within the Lake George Drainage Basin

Type of Usage	Area[1-5]		% of Total	Private[3]		State[3]	
	mi^2	km^2		mi^2	km^2	mi^2	km^2
Active Agriculture	4.32	11.06	1.6	4.32	11.06	----	----
Woodlands	196.35	502.66	73.8	134.38	344.01	61.97	158.64
Wetlands	5.91	15.13	2.2	5.15	13.18	0.76	1.95
Water	45.19	115.69	17.0	----	----	45.19	115.69
Residential	6.18	15.82	2.3	6.18	15.82	----	----
Commercial	2.81	7.19	1.0	2.81	7.19	----	----
Industrial	0.19	0.49	0.1	0.19	0.49	----	----
Extractive	0.12	0.31	0.1	0.12	0.31	----	----
Public and Semi-public	0.70	1.79	0.3	0.70	1.79	----	----
Outdoor Recreation	2.74	7.01	1.0	2.74	7.01	----	----
Transportation	1.64	4.20	0.6	----	----	1.64	4.20
Total	266.15	681.35	100	156.59	400.86	109.56	280.48

[1] Hetling, 1972

[2] U.S.G.S. Topographic Maps

[3] State of NY Adirondack Park Agency, 1973

[4] Washington County Planning Board, 1976

[5] Shelton, R.B. et al, 1973

Water Use

Lake George is basically a recreational lake with many lakeside summer homes and cottages. Kooyoomjian and Clesceri (1974) conducted a comparative study of four lakes (Oneida, Schroon, George and Saratoga) to determine users' perception of each lake.

To evaluate user opinion, an extensive questionaire was distributed in the area during the summers of 1970 and 1971. The questionaires were mostly distributed by hand, although the cooperation of local groups and associations was obtained. The questionaires were directed toward 6 different groups of lake users with an additional questionaire to boaters: (1) recreationists; (2) cottage and home owners; (3) motel-hotel, lodging, commerce; (4) non-lodging commerce; (5) marinas; and (6) fishermen. The questionaires provided detailed data on the use of the lake. The following preferences were noted: (Kooyoomjian, 1974)

"While swimmers are more active than sightseers in lake swimming and sunbathing, sightseers are more active than swimmers... in such activities as pool swimming, all categories of boating, and skin or SCUBA diving. Island campers are at least as active in the lake swimming activity as the swimmers.

"Water Dependent Activities - By far, the most water dependent subset is the island campers, where as the sightseers and swimmers are much less oriented toward water dependent activities.

"Water Enhanced Activities - The water enhanced indices show that the subsets are rather similar and impartial, indicating only slight trends. Island campers are slightly more active than the other subsets, and swimmers are the least active subset for water enhanced activities.

"Land Oriented Activities - The sightseers are the most land oriented group, while swimmers are the least land oriented group. The island campers are between the activity extremes of both subsets."

"Sightseers - The sightseers appear ... heavily land oriented in their activities, and are not oriented strongly toward water dependent activities.

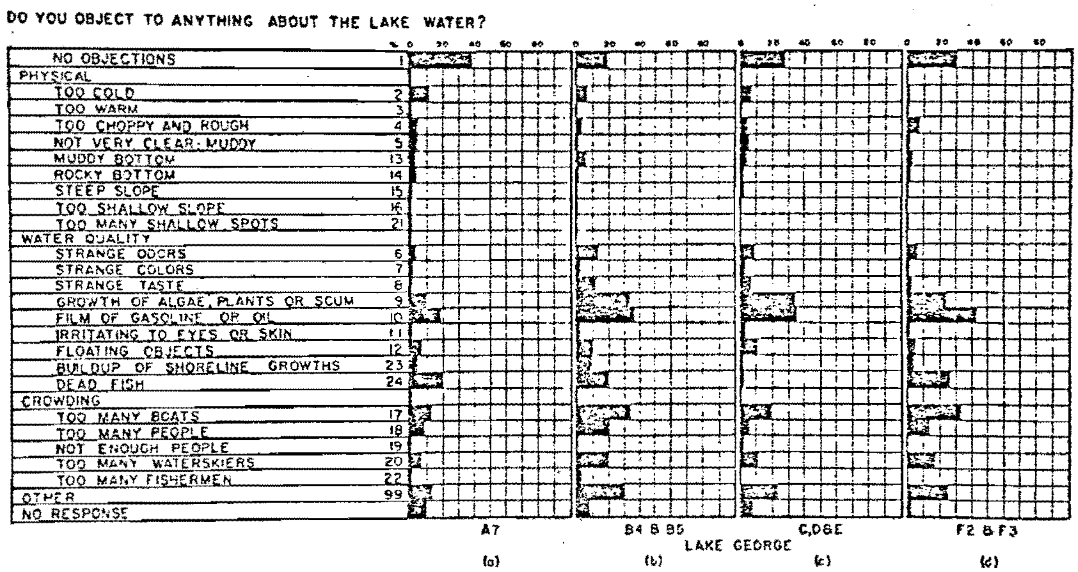
"Swimmers - Swimmers are ... less active over the broad spectrum of activities, with concentration on a few activities, such as lake swimming, sunbathing, and picnicking ... all indicative of a strong day-user transient type of population among the swimmers.

"Island Campers - The activities of island campers are intense, and are dispersed among all water contact categories. The activity profile for island campers also indicates a distinct bias toward intensive activity in water dependent activities, where there is a preference toward water as a focal point of activity. The least popular activities of the island campers are generally land oriented, where the activity pattern for island campers indicates a bias away from the land oriented activities."

In addition to the uses of the lake, the questionaires provided information on complaints made by lake users. The objections obtained from the recreationist respondent group are presented in Table 7.

Most recreationists (38%) had no objections to the water quality. The most common complaints were dead fish (22%), gasoline or oil film (18%), and too many boats (12%). Very few respondents complained about the common problems associated with cultural eutrophication, such as turbidity (5%), excessive vegetation (9%), and ordors (4%).

TABLE 7. Water Quality Perception Profiles at Lake George by Form Type Grouping (a-Recreationist Form A7, b-Cottage and Homeowner Forms B4 & B5, c-Commercial Forms C, D, & E, and d-Fishing Forms F2 & F3)



Lake George also is used as a public water supply, it and its tributaries being classified "Class AA - Special" by New York State (official Rules and Regulations) that the lake's water can be used for any purpose except disposal of waste material, such as municipal or industrial effluents. The water is suitable for drinking with chlorindation the only treatment required.

In addition, the New York State Environmental Conservation Law specifically prohibits the discharge of solid or liquid waste materials into Lake George or its tributaries. This law was amended in the 1979 legislature to prevent the future discharge of even treated municipal wastewaters within the basin, even the use of the sand filtration system which has been achieving complete phosphorus removal since its installation in 1939. The existing treatment may continue its present mode of operation until the presently proposed Warren County Sewage System No. 1 is completed.

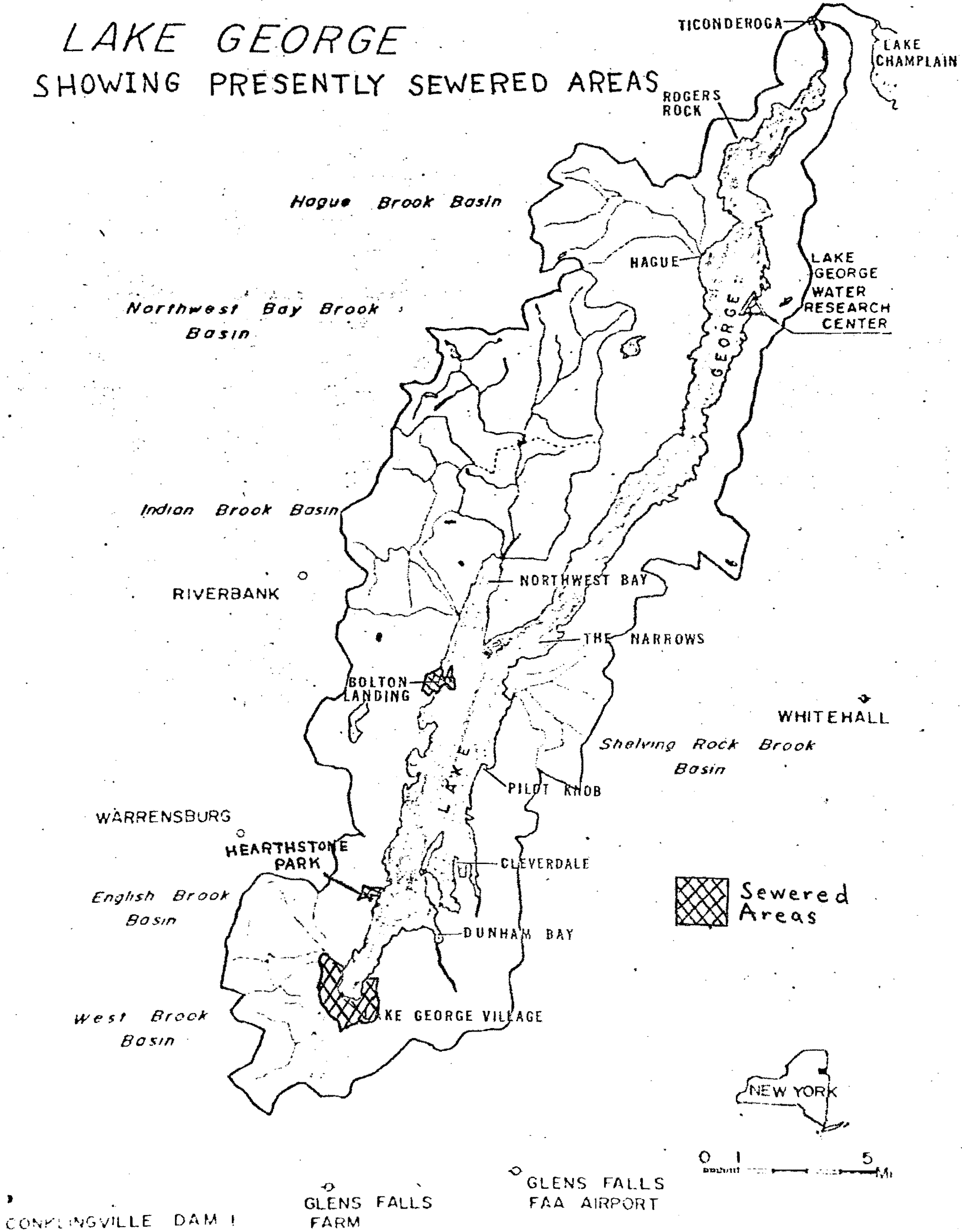
This special legislation recognizes the popularity and importance of Lake George both as a valuable natural resource and as a commercial attraction. Thus, Lake George is a water body used for water supply, recreation of all sorts (both active and passive types) and transportation. Swimming, fishing, and SCUBA diving are widespread pastimes, with power boating and sailing also popular. In fact, in the broadest sense of the definition, Lake George is a multi-use resource.

MUNICIPAL AND INDUSTRIAL DISCHARGES

There are four sewer systems in the Lake George watershed serving the Village and Town of Lake George, the Hearthstone Point State campsite and Bolton Landing. The sewered areas are shown in Fig. 4. There are no known industrial discharges within the watershed. In areas not served by these systems, septic tank systems treat residential wastes. Septic tanks are considered as a dis-

FIGURE 4

LAKE GEORGE
SHOWING PRESENTLY SEWERED AREAS



charge to ground water, not surface water and, hence, do not violate the section of the New York State Environmental Conservation Law which specifically prohibits direct discharges to Lake George or its tributaries (Environmental Conservation Law). Wastes from all four sewer systems ultimately receive treatment by conventional trickling filter systems followed by land application for tertiary treatment and eventual return to ground water.

The area in the Town of Bolton serviced by sewers is within the hamlet of Bolton Landing and is designated as Bolton Sewer District #1. The collection system of 8 and 10 inch (20 and 25 cm) diameter asbestos cement gravity sewers was constructed in 1960. There are two pumping stations within the systems; the north pump station, which discharges through a 6 inch (15 cm) force main to a gravity sewer on Saginaw Road, and the main pump station, located on the Lake George shoreline in the vicinity of Park Road, which discharges through a 10 inch (25 cm) force main to the sewage treatment plant. Both force mains also are constructed of asbestos cement pipe.

The Bolton Landing sewage treatment plant also was built in 1960. Sewage from the pump station enters the plant through a grit chamber and Parshall flume, and then flows into the upper compartment of a circular Imhoff tank for primary sedimentation. The clarified effluent is piped to a high rate trickling filter, followed by two rectangular settling tanks. The effluent from the final settling tanks is applied to constructed sand percolation beds for disposal. A portion of the effluent from the final settling tanks is recirculated to the Imhoff tank influent. The sludge generated by the process is anaerobically digested in the lower compartment of the Imhoff tank. The digested sludge is dried on open sand beds, with the underdrainage returned to the Imhoff tank. The design capacity of this plant is 0.30 MGD (1100 m^3/day).

The trickling filter is operated approximately 9 months each year. It is bypassed during the winter when low flows and subfreezing temperatures would interfere with its operation.

In 1965 the land application area was expanded utilizing a natural sand deposit found adjacent to the plant. These four new infiltration beds are not used during the coldest winter months since the pipe from the secondary clarifiers to these beds is exposed at the surface of the ground.

The Caldwell Sewer District provides waste collection for the Town of Lake George. This system constructed in 1966 consists of vitrified clay pipe gravity sewers, ranging in size from 8 to 18 inches (20 to 46 cm) in diameter. There are two pumping stations in the system. The lower Caldwell pumping station is located south of Beach Road at the southern tip of Lake George near the Lake George Beach State Park, and discharges to the upper Caldwell pumping station through a 12 inch (30.5 cm) force main. The upper Caldwell pump station, located on Dowling Road, discharges to the Village of Lake George Treatment Plant through a 14 inch (35.5 cm) force main. Both pump stations, being of relatively large capacity and modern design, could be incorporated into a regional system, or modified to handle locally expanded sewer service without major difficulty or expense.

The Hearthstone Point State Campsite is located on the west shore of Lake George, south of Diamond Point, in the Town of Lake George. The campsite has 2246 sites, with access to the Lake. Campsite facilities include flush toilets, with the seasonal sewage flows of up to 50,000 gallons per day (200 m^3/day) pumped to the Village of Lake George sewage treatment plant for treatment and disposal.

The Adirondack Park Agency classifies the Village of Lake George as a "hamlet" area, although the area is technically a village because it is incorporated as such. The surrounding Town of Lake George is unincorporated; hence, they are separate political and economic entities, although their locations are concentric and incomes are based on the same population.

The Village of Lake George is completely sewered. The system, in operation since 1939, contains approximately 8 miles (13 km) of vitrified clay sewer pipe ranging in size from 8 to 15 inches (20 to 38 cm) in diameter. The pumping system consisted of four pump stations. One small pump station, which discharges into a gravity sewer, is located at the corner of Sewell and Dieskau Streets. Another small pump station, located along the Lake George shore front on Beach Road, is used primarily for pumping boat wates into the sewer system. The main pump station is located along the Lake George shore front at Shepard Park. This pump station discharged through a 10 inch (25 cm) force main to a relay pump station near Sewell Street, which in turn dischared via a 10 inch (25 cm) force main to the Village treatment plant.

In June 1979 a new pumping system went into operation. All sewage reaching the pumping station is pumped to the Town pumping station, eliminating the need for the relay pumping station. This new pump station can readily be incorporated into a regional system.

The original Lake George Village treatment plant was constructed at the same time as the sewer system, with expansion of its capacity to serve the Caldwell District in 1965. The original design concept, continued since plant inception in 1939, consists of primary settling, trickling filtration, secondary settling, and rapid infiltration into the natural sand beds. In addition to treating the sewage from the Village of Lake George, the plant also treats sewage from the Hearthstone State Park Campsite, and from the Caldwell Sewer

District in the unicorporated area of the Town of Lake George. Flows from both municipalities were separately measured by means of Parshall flumes at the plant influent structure. Since all flows are now combined at the new pumping station only one flow measurement flume is now used.

After flow measurement, the sewage is settled in the original circular Imhoff tank or in one of two newer circular mechanically cleaned settling-digestion tanks (Clarigesters). During summer operation, the settled sewage flows into one of two high-rate rotary arm trickling filters. In winter operation, one covered standard rate fixed nozzle sprinkling filter with intermittent dosing is used. The filter effluent then flows to the final settling tanks, consisting of two newer mechanically cleaned rectangular tanks and the two original circular tanks. The clarified effluent is then disposed of in natural sand percolation beds by the rapid infiltration technique. The secondary sludge is returned to the head of the plant while primary sludge is digested in the Imhoff tank and mechanically cleaned settling-digestion tanks. Digested sludge is dewatered on open sand drying beds. The design capacity of the Village treatment plant is approximately 1.75 MGD. (6600 m^3/day).

It is considered that this final treatment and disposal into the ground does not contravene the restrictions on discharge of sewage effluents into the lake or its tributaries. Thus, the problems associated with point discharges of sewage effluents do not prevail in the Lake George basin.

Land Development and Improved Sewerage Facilities

Issues relevant to the Lake George area currently are centering on the efficacy of public sewerage facilities. This discussion necessarily raises the whole specter of topics under the aegis of environmental quality. These include ecosystem preservation, waste disposal, institutional arrangements and social factors such as crowding. The proposed solution may trade distributed point sources of pollution (a collection of septic tank systems) for increased non-point sources of pollution (e.g., increased urban runoff, increased lawn fertilizer usage and increased lake usage). Admittedly this is a difficult problem, but a review of previous sewerage studies along with consideration of related questions may lead to some educated conclusions. (Aulenbach, 1979 and Aulenbach et al., 1979).

Five reports of sewerage studies have been reviewed, each involved with one or more of the muncipalities within the Lake George area. A summary of each report follows, noting their similarities, differences, conclusions, and recommendations.

The first contemporary, comprehensive sewerage study (Metcalf and Eddy, 1965) concerned the Towns of Lake George and Bolton, and the Village of Lake George. The report considered extending sewer service along the lake shore between the Village of Lake George and Bolton Landing. While the alternatives of deep well injection and pumping the sewage out of the watershed were suggested, they were not considered in detail. The study's conclusions and recommendations assumed that subsurface disposal in the area was an accepted and satisfactory method of sewage treatment and disposal. The report proposed subdividing the study area into four project areas, each served by a separate sewage treatment facility. The sewage treatment facilities were proposed at the existing treatment plant sites for the Village of Lake George and Bolton Landing, and additional facilities west of Trout Lake, and near Diamond Point (See Figure 4). Each of the proposed facilities utilized ground percolation for effluent disposal, to conform to the "Lake George Law" prohibiting discharge of effluent into the surface waters of the Lake George watershed (Environmental Conservation Law). Location of the proposed additional facilities was based on careful consideration of soil conditions within the study area.

The report included consideration of several alternative general plans with respect to sewage flow routings and the treatment plant capacity provided at each treatment site. The report recommended the formation of town districts, with intermunicipal contracts to provide appropriate apportionment of costs.

In 1969, a comprehensive sewerage study (Rist-Frost Associates, 1969) was submitted to the Warren County Board of Supervisors. This study was undertaken to provide additional information concerning those areas of Warren County not included in previous studies. With respect to the Lake George area, this study reiterated the conclusions and recommendations of the Metcalf and Eddy 1965 study with no additional analyses or consideration of alternatives.

In 1973, a comprehensive sewerage study was prepared for the Town of Lake George to investigate the alternatives of handling its anticipated future sewage needs. Among the alternatives considered were pumping all the treated Town sewage to the Schroon River for disposal, and directing all Town sewage to the existing Village of Lake George Sewage Treatment Plant. It was recommended, however, that the Town of Lake George utilize the Schroon River as the final sewage disposal location, since the Village sewage treatment plant had insufficient capacity to handle the flows anticipated from the future growth of the Town. Regarding the existing Village treatment plant, Barrow cited, "treated effluent contains a major amount of phosphorus compounds which are large relative to the natural amount of such compounds entering the Lake from its watershed. Another observation is that sedimentation and algae growth is appreciably larger in the southern tip of the lake than in other parts. The possible cause of this phenomenon is, or may be, the percolated effluent from the Village sewage treatment plant."

In 1975, a comprehensive sewerage study (Lawler, Matusky and Skelly, 1975) was authorized by the Warren County Board of Supervisors and the New York State

Department of Environmental Conservation, with the objective of developing a general plan for sewerage in the region. The study area includes the Towns of Bolton, Lake George, Queensbury, and Warrensburg, together with the Village of Lake George and the City of Glens Falls. The authorization for this study interpreted the Lake George Law (Environmental Conservation Law) to prohibit discharge of treated wastewaters by subsurface disposal within the Lake George watershed. For this reason, expansion of existing treatment facilities or the design of new facilities using subsurface disposal within the Lake George watershed was not evaluated.

The study found the Hudson River and the Schroon River to be the only practical receiving waters for sewage effluents originating within the region. Due to the long conveyance distance and large number of pumping stations, higher than normal charges to typical customers were expected for both these alternatives. This general plan presently is being considered by the involved municipalities, with a Step 1 design study by Hazen and Sawyer pending decision. (Hazen and Sawyer, 1977).

In 1976, Morrell Vrooman (Vrooman, 1976) evaluated the 1975 Warren County Sewer Plan for the Village of Lake George. Voorman disagreed with the Lawler, Matusky, and Skelly report, believing instead that State Law prohibited disposal of wastewater only to the surface waters of Lake George and not beneath the surface.*

*NOTE: By a letter from counsel for the New York State Department of Environmental Conservation (Coutant 1976) New York State stated that it was not able to establish a violation of Section 17-1709 of the Environmental Conservation Law, which prohibits the discharge of an effluent from a treatment facility to either Lake George or its tributaries, in regard to the discharges from the Lake George Village Treatment Plant.

Vrooman defended the performance of the Lake George Village treatment plant and made the following five conclusions: the existing treatment plant is functioning satisfactorily and is presently not overloaded; the Village wastewater treatment plant probably will not be up to full design capacity for many years; some improvements and additions to improve plant efficiency are advisable; waters from the plant apparently have no effect on the quality of lake water; and annual costs to homeowners would be high (approximately $250/one-family home) and would be higher if all the sewer districts are not formed. The report recommends that the Village should not endorse the County proposal as submitted because of major uncertainties in possible final costs.

The most recent plan for sewering the Lake George area (Hazen and Sawyer, 1977) makes it a part of the Warren County Sewer District No. 1. In this plan the area from Bolton Landing on the west around the south end of the lake to Pilot Knob on the east would be sewered, with all the collected wastewater being pumped out of the basin into a regional treatment plant at Glens Falls. Thus there would be no discharge of even treated wastewaters within the basin. In order to accomplish this, there would be 23 pumping stations within the basin. This proposed system has been criticized as to its cost-effectiveness, particularly in view of its allowing for additional development in the area, which development could produce more urban runoff which would carry more pollutional material and nutrients into the lake. Another concern is the diversion of up to 5.5 millions gal./day (21,000 m^3/day) of water from the basin by the year 2000. At the present time the merits of the proposed system are being weighed by the E.P.A.

Regional Land Use Regulations and Sewerage Facilities

There exists a land-use and development plan for the Adirondack Park which affects the needs for sewerage facilities. The Adirondack Park Agency (APA) has established several classifications of land use within the Adirondack Park boundary. In general, the APA land use objective appears to be limiting total population within Park area, rather than requiring a specific land area per housing unit as is the case with normal zoning requirements. To permit ready comparison with zoning-type requirements, the average land area requirement corresponding to each of the APA classifications is given in Table 8.

Examination of the APA classifications and land area requirements indicates that sewer systems will become economically feasible in areas designated "hamlet" and may be feasible for portions of those areas classified as "moderate intensity". It may also be economically feasible to sewer those portions of areas designated as "low intensity" which border sewered areas. It is extremely unlikely that sewer service would be extended to those areas designated as "rural" or "resource management," since low population density would make the costs of sewer service extremely high in relation to the number of persons benefited.

Since the Lake George drainage basin is located within the Adirondack Park boundary, the APA land use classifications have a significant effect upon the prospective sewer service area. The APA land use restrictions will confine sewer service to those areas which presently are developed to significant density; such areas appear in the "hamlet" or "moderate intensity" classifications.

A main issue to be addressed in the future is the balance of ecosystem function with the pressures for use and development of the Lake George area. A possibility exists for "corrective" action to be taken to limit wastewater inputs to the lake by constructing public sewerage systems. However, experience elsewhere suggests that the availability of sewerage facilities is a precursor to growth and development of an area; or stated in reverse, growth of an area is limited by the extent of public services, sich as water supply and sewer systems. So questions can be raised: Is growth desirable for the Lake George

TABLE 8. Adirondack Park Agency Land Use Classification (Adirondack Park Agency, 1973)

Classification	Max. # Units per sq. mile Permitted	Estimated Population per Unit	Estimated max. Population per sq. mile	Estimated max. Population per acre
Hamlet	No Limit	-	4,480-19,200	7-30
Moderate Intensity	500	4	2,000	3.13
Low Intensity	200	4	800	1.25
Rural Use	75	4	300	0.47
Resource Management	15	4	60	0.09
Intensive (N.Y. State)	No Limit	-	-	--

area? Who desires this growth? Does the presence of a sewer system preclude any other environmental problems, e.g., increased urban storm water runoff? Will crowding become an issue at Lake George with increased development prompted by a sewer system?

These and other questions must be raised and addressed by an informed public. The means to cope with these problems may require more comprehensive zoning regulations, population limitations and other means available in the institutional framework extent in the Lake George area.

MORPHOMETERIC AND HYDROLOGIC DESCRIPTION

Shape and Size

Lake George is 51 km (32 mi.) long, slightly winding, and oriented in a north-northeasterly direction. The lake's outlet is at its northern end and discharges through Ticonderoga Creek into Lake Champlain. The lake has a maximum width of 4.0 km (2.4 mi.), with an average width of 2.3 km (1.4 mi.) (Table 9). The ratio of drainage basin surface area (492 km^2) to lake surface area (114 km^2) is 4.3, indicating that the catchment area is relatively small for a lake of this size.

The glacial scouring and damming of two preglacial river channels formed the lake, creating a north and a south-central basin separated by a relatively shallow island-studded mid-portion called the Narrows. The lake, south of this island-studded region, has been further divided into two basins, south and main (Fig. 5), on the basis of morphometeric and circulation characteristics (Langmuir, et al., 1966; Needham, et al., 1922). The southern boundary of the north basin is considered to begin at the Narrows, the relatively shallow island-studded area which originally separated the two preglacial rivers. This region effectively reduces the interchange of water from the south and main basin with the north basin.

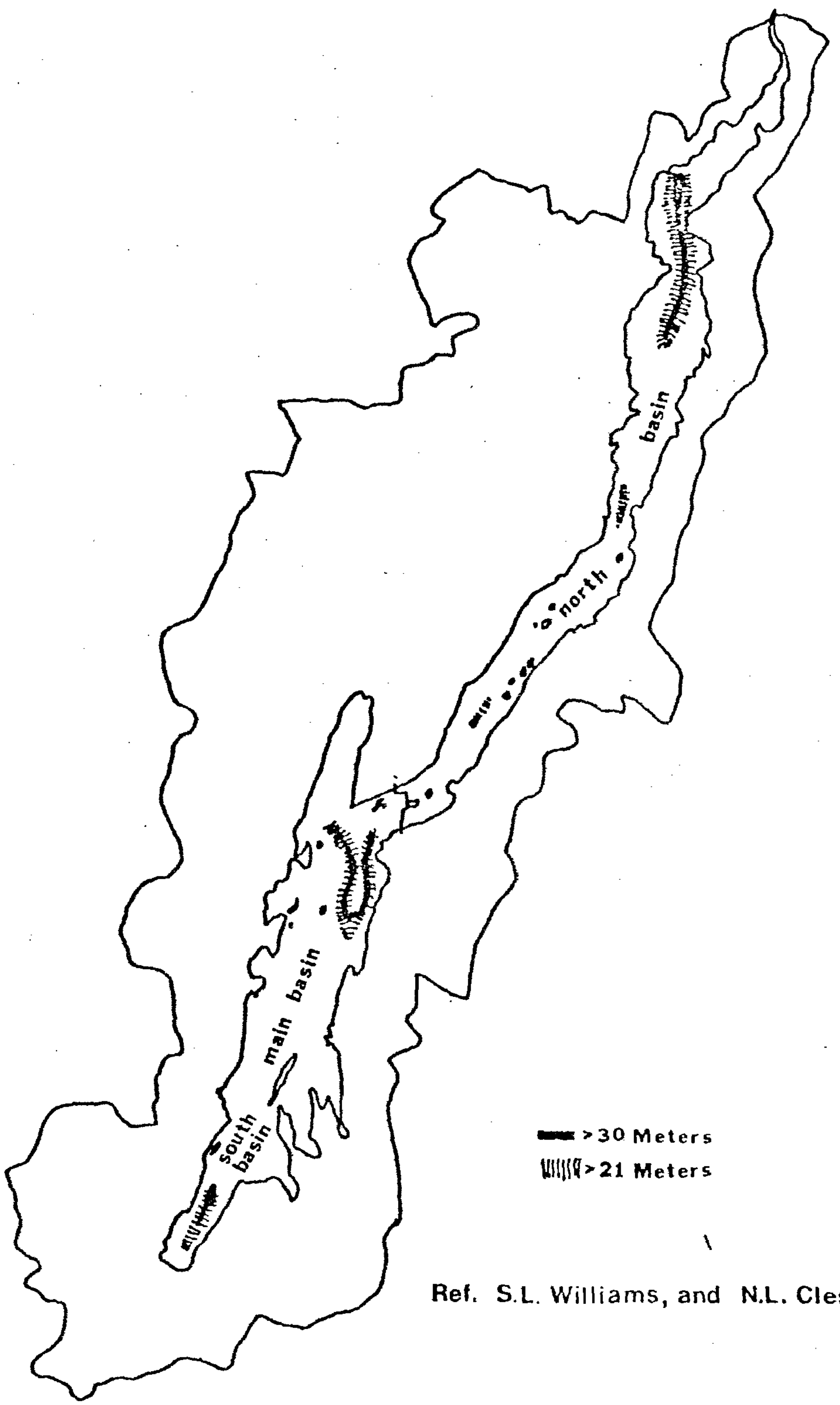
TABLE 9. Morphometric Characteristics of South and North Lake George

	South Lake		North Lake		Total Lake	
Length	22.4 km	13.9 mi	28.6 km	17.8 mi	51.0 km	32.0 mi
Mean Breadth	2.6 km	1.6 mi	2.0 km	1.2 mi	2.3 km	1.4 mi
Max. Breadth	4.0 km	2.4 mi	3.2 km	2.0 mi	4.0 km	2.4 mi
Area	57.6 km^2	22.2 mi^2	56.4 km^2	21.8 mi^2	114.0 km^2	44.0 mi^2
Max. Depth	58.0 m	191.0 ft	53.3 m	175.0 ft	58.0 m	191.0 ft
Mean Depth	15.5 m	50.9 ft	20.5 m	67.3 ft	18.0 m	59.0 ft
Length of Shoreline	76.0 km	47.2 mi	133.6 km	84.5 mi	209.6 km	131.0 mi
Volume	1.02 km^3	0.24 mi^3	1.08 km^3	0.26 mi^3	2.1 km^3	0.5 mi^3
Watershed Area (land)	313.2 km^2	121.0 mi^2	178.8 km^2	69.0 mi^2	492.0 km^2	190.0 mi^2
Catchment Area (including lake)	370.8 km^2	143.0 mi^2	235.2 km^2	90.6 mi^2	606.0 km^2	234.0 mi^2

Ref. Aulenbach and Clesceri, 1973.

FIGURE 5

PRINCIPAL BASINS OF LAKE GEORGE



Ref. S.L. Williams, and N.L. Clesceri, eds., 1972.

A very steep channel runs along the eastern shore of this region, in which the depth exceeds thirty meters for a width of about seventy meters. A southward or reverse current normally flows along the bottom of this channel. Above the Narrows, the north basin widens and contains a relatively broad channel along its center with water depths of about thirty meters. The water volume in the north and south basins is approximately equal, about one cubic kilometer, or 10^9 cubic meters.

Based on the volume and average outflow from the lake at the north, the average water retention time in the lake is 7.98 years. However, the average transit time of water from the south basin to the north basin is probably longer. This is attributed to the constriction at the northern boundary of the south basin and because the major source of water into Lake George is from Northwest Bay at the upper end of the central basin. This flow moves around Dome Island into the north basin, thereby causing a retention of water in the south basin (Williams and Clesceri, ed., 1972).

The Hydrologic Cycle at Lake George

Precipitation

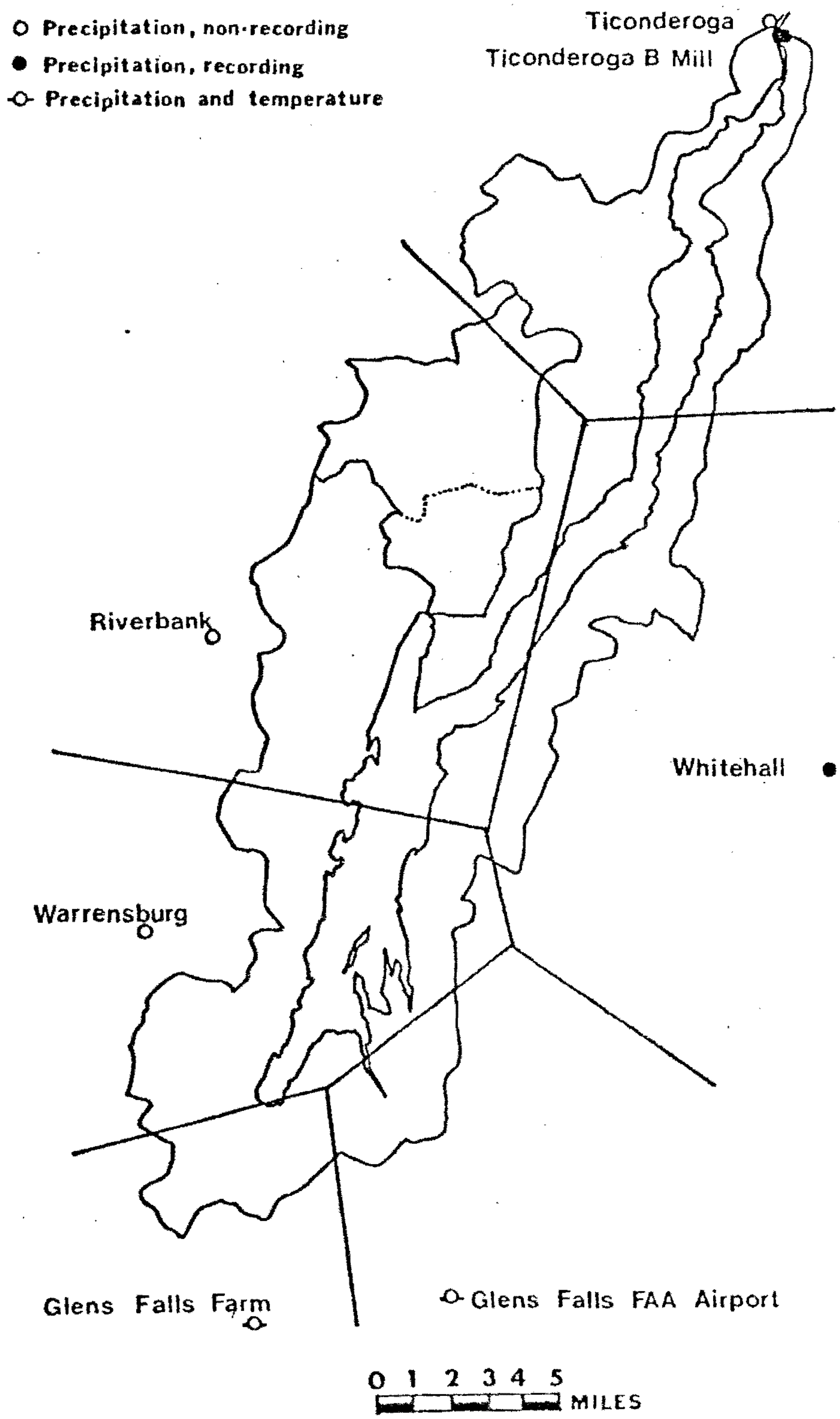
Precipitation is the dominant, if not the sole, water input into the Lake Goerge watershed. Because of its well defined watershed and the nature of its geologic formation, it is very difficult for substantial amounts of water to leak into or out of the basin.

The topography of the basin and the lack of a precipitation monitoring network within the watershed make difficult the precise determination of precipitation for hydrologic studies. Only one station from the U. S. Weather Bureau (now NOAA) network lies within the basin (Ticonderoga B Mill): all other local stations are located outside the watershed. Figure 6 shows the location of those precipitation stations. Because of the topography and the extent (mainly

FIGURE 6

CLIMATOLOGICAL STATIONS AND THIESSEN POLYGONS

U.S. WEATHER BUREAU



in length) of the watershed, the distribution of precipitation is quite variable. Brief local showers, of both low and high intensity, occur over limited parts of the basin. Some of these showers occur only within the basin, thus passing unregistered by the Weather Bureau's network.

Precipitation occurs in all its forms in the basin. However, in the water balance and budget, precipitation is expressed as its water equivalent.

Runoff

Since October 1941, the U.S. Geological Survey has operated a stream gaging station at the outlet of Lake George at Ticonderoga. Previous to this, there are records for the period between August 24, 1904 and December 31, 1905. Figures 7 and 8 locate the gaging station and the outlet of Lake George.

Table 10 shows the monthly mean flows from the outlet. The discharge from the lake was regulated by the powerplant wheel gate and flood gates upstream from the gaging station, and was performed by the International Paper Company, Ticonderoga, NY up until April 5, 1974 when the State of New York assumed responsibility for regulating the level of Lake George. The International Paper Company donated 7.04 acres (2.25 ha) of land surrounding the dam and $150,000 to help defray the cost of a badly needed reconstruction project, including the demolition of old buildings and foundations and construction of a new discharge gate. The discharge capacity of the new gate is approximately 25 per center greater than that of the old gate. The new gate can lower the lake level approximately one inch (2.5 cm) in 24 hours, which amounts to 780 million gallons (3 million cubic meters) of water, assuming no additional inflow. The capacity of the watershed to add water to Lake George, however, greatly exceeds the capacity of the dam to discharge it. For example, one inch (2.5 cm) of runoff from the entire watershed can raise the lake by 5.3 inches (13.5 cm) in a matter of 10 hours, while it takes almost a week to lower the lake by the same

FIGURE 7

LAKE GEORGE OUTLET AT TICONDEROGA

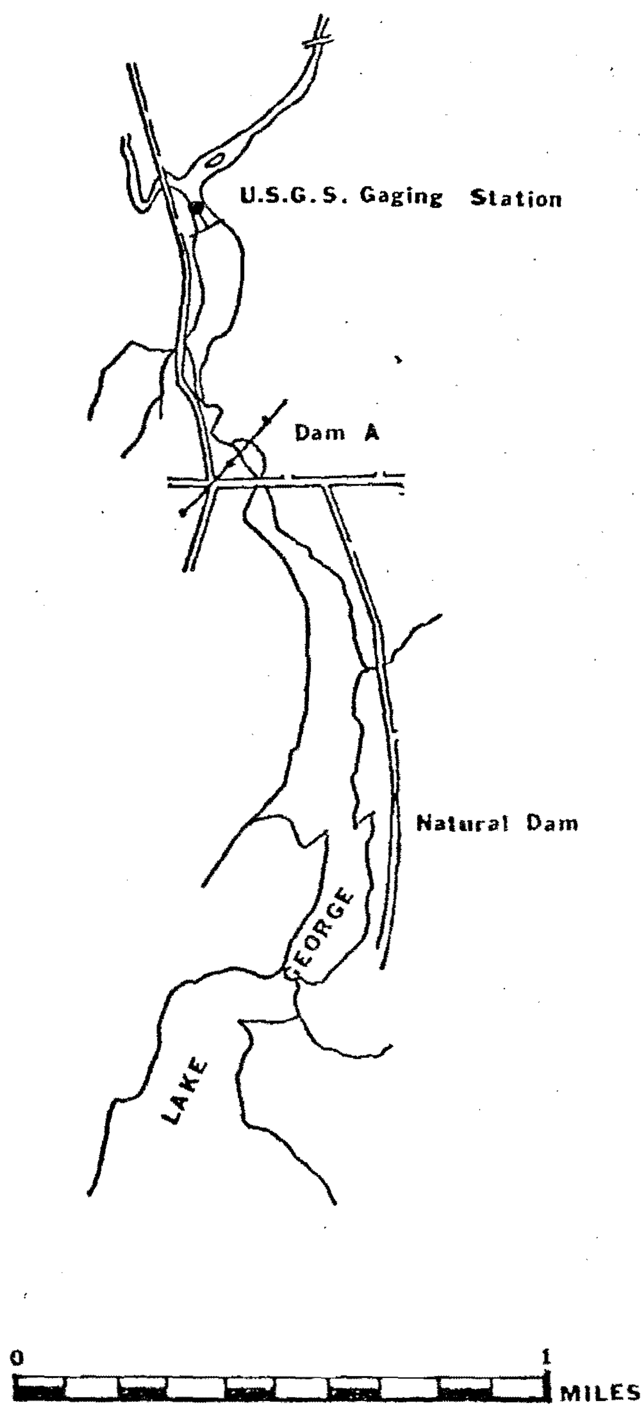


FIGURE 8

HYDROLOGICAL STATIONS

U.S. GEOLOGICAL SURVEY

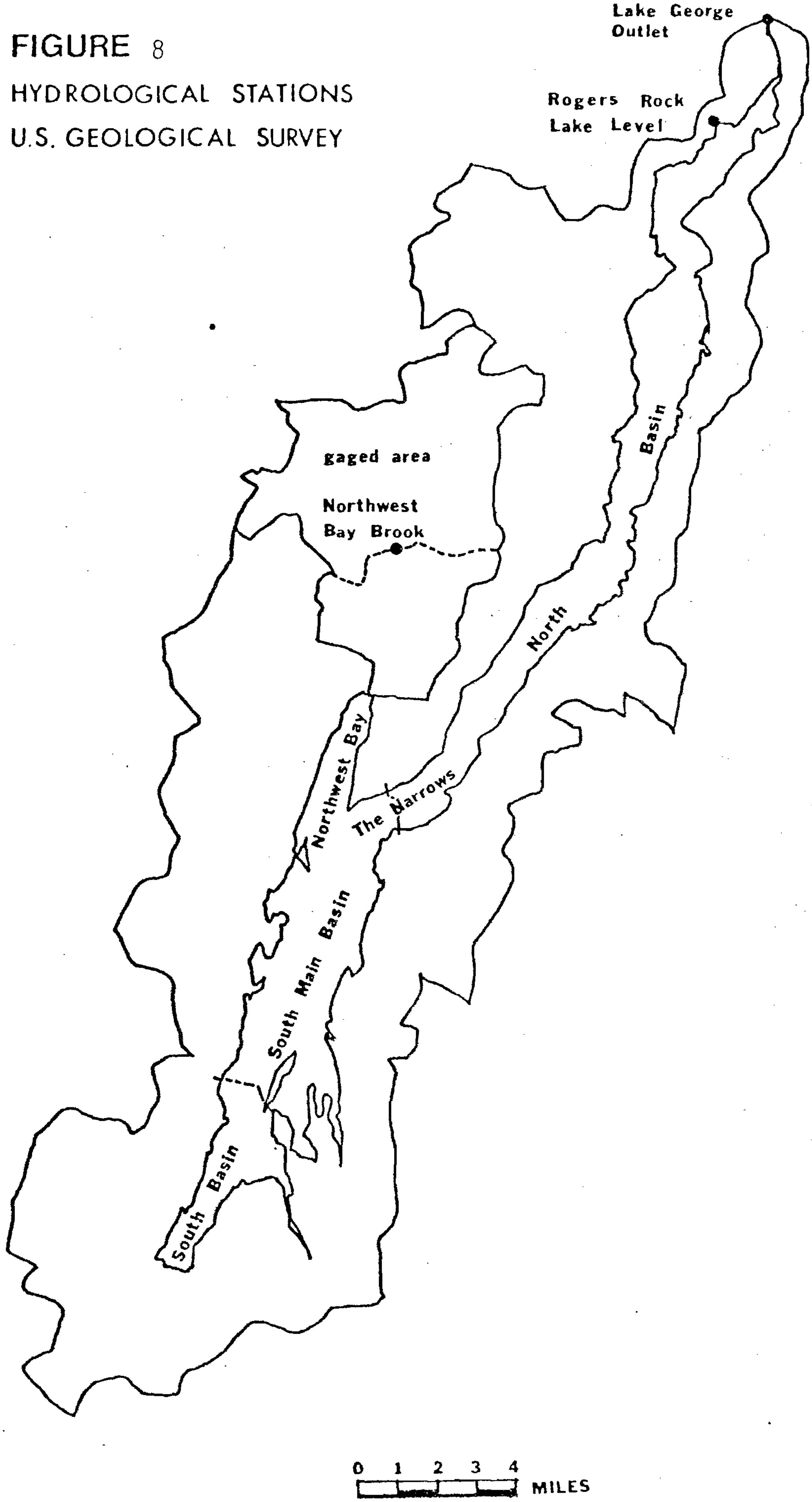


TABLE 10. Lake George Outlet at Ticonderoga
Mean Flow, Cubic Feet per Second*

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Mean
1961	187.0	148.0	99.1	116.0	104.0	119.0	635.0	445.0	369.0	207.0	196.0	166.0	233.0
1962	166.0	90.6	68.5	69.8	71.8	266.0	921.0	421.0	224.0	977.0	99.6	61.9	213.0
1963	115.0	157.0	210.0	170.0	232.0	436.0	304.0	392.0	236.0	113.0	83.2	70.2	210.0
1964	47.3	34.6	37.6	37.4	134.0	503.0	574.0	261.0	45.5	46.3	44.6	43.9	151.0
1965	51.1	36.4	40.9	124.0	122.0	49.6	38.8	79.1	47.1	50.1	50.8	54.4	61.7
1966	79.4	198.0	267.0	269.0	210.0	390.0	426.0	534.0	286.0	77.6	41.6	102.0	240.0
1967	159.0	159.0	142.0	229.0	258.0	269.0	395.0	582.0	240.0	162.0	120.0	62.6	232.0
1968	61.6	173.0	222.0	295.0	289.0	232.0	484.0	683.0	486.0	296.0	87.0	56.5	280.0

*1 cubic foot = 28.32 liters

amount. Basically, there are two reasons why the discharge capacity is limited. First, the Alexandria Avenue bridge is an upstream constriction that greatly controls the outflow under very high flow conditions. Second, and perhaps more important, is the constriction downstream at the Montcalm Street bridge. If the flow capacity of the bridge and its approach channel were exceeded, the village of Ticonderoga could be flooded.

Keeping the aforementioned factors in mind, what follows is a brief description of the operation of the control dam. Before winter freeze-up, the lake is drawn down to a level of 2.6$\pm$ on the Rogers Rock Gage. The lake is maintained as close to this level as possible throughout the frozen period both to minimize ice damage to docks and shoreline, and to provide the storage capacity needed to absorb the spring thaw runoff. Beginning in January and continuing periodically through the spring thaw, snow surveys are made to determine the potential amount of runoff available. The gates are opened when the spring thaw begins in an effor to keep the lake below 4.0 on the gage. Once the surge of the spring runoff is over, the lake is maintaned as nearly as possible at 3.5$\pm$ throughout the navigation season up to the winter freeze.

These guidelines are very general because variations arise due to the unpredictable nature of forecasting the weatehr in a specific location such as the Lake George watershed. The guidelines are followed whenever possible (Lake George Park Commission, 1974).

In October 1965, a stream gaging station was established on Northwest Bay Brook by the U.S. Geological Survey. It covers 23.4 mi^2 (60.6 km^2), about two-thirds of the stream's watershed. Figure 8 shows its location.

Stream base flow occurs between the middle of July and the beginning of September. During this period, streamflow is at its minimum, coupled with the period of greatest evapotranspiration. Soil moisture and groundwater are so depleted during this period that there is very little runoff, even after storms and heavy showers. During the following two months, the moisture storage builds up in the watershed, until reaching field capacity by the end of November. Heavy rains toward the end of November and early December thus produce a substantial rise in streamflow and recharge of groundwater. This is sufficient to sustain streamflow during the winter months. The time when the snowpack begins to accumulate, together with moisture in the soil, controls the volume of runoff produced in the spring. The development of a deep early snowpack usually causes the frozen soil to thaw. Ordinarily, frost penetration is limited to a few inches (several cm) when it exists at all.

The difference in streamflow between summer and winter months may be attributed to the difference in consumptive use and water input as precipitation. Consumptive use and evaporation are at a minimum, if occurring at all, during the winter months. Precipitation is mostly in the form of snow. Any increase in winter streamflow is due mostly to snowmelt or precipitation in the form of rain.

Toward the end of March and the beginning of April, the increase in solar energy and the rise in air temperature bring about snowmelt. The volume of snowmelt runoff greatly depends on antecedent soil moisture conditions, frost penetration, and periods of precipitation as rain. During the months of April and early May runoff reachs its peak, with streams sustaining high flows into the month of June. Streamflow then continues its recession until low flow is again achieved toward the end of July.

Evapotranspiration

The determination of evapotranspiration is difficult. On the water balance for a basin, both evaporation and transpiration must be considered while for the water budget of a lake, only the evaporation term is required.

Evapotranspiration encompasses the loss of water from the earth's surface to the atmosphere by direct evaporation of water from the soil and water surface, and transpiration resulting from consumptive use by vegetation. A direct measurement is difficult. A number of formulae are available to determine evapotranspiration by indirect methods, mostly utilizing meteorological data. Some methods are based on air temperature, while others use evaporation measured from tanks correlated with some meteorological data.

Lake level fluctuations

The lake level is controled at 319.25 feet (97.3 m) above mean sea level by a dam (Dam A). Figure 9 shows the relationship between the spillway of Dam A, mean lake level, Rogers Rock datum, and the natural dam and the volume of water in the lake at each elevation.

Since July 1913, the U.S. Geological Survey has recorded the stage level of Lake George. Figure 9 shows the location of the gaging station.

Efforts are made to maintain the lake level in the range between 4.00 and 2.5 feet (1.2 and 0.76 m), relative to the Rogers Rock Gage datum (315.93 ft. [96.3 m] above mean sea level). The fluctuations of the levels are a product of the overall hydrologic response of the Lake George watershed, including the effects of man.

The main function of the dam is to provide storage of the spring runoff, thereby providing an adequate volume of water during dry seasons and maintaining the minimum desired level for summer recreational usage of the lake. An additional function is a rapid release of the surplus water when accumulation is too great, thereby avoiding possible flooding of parts of the Village of Ticonderoga.

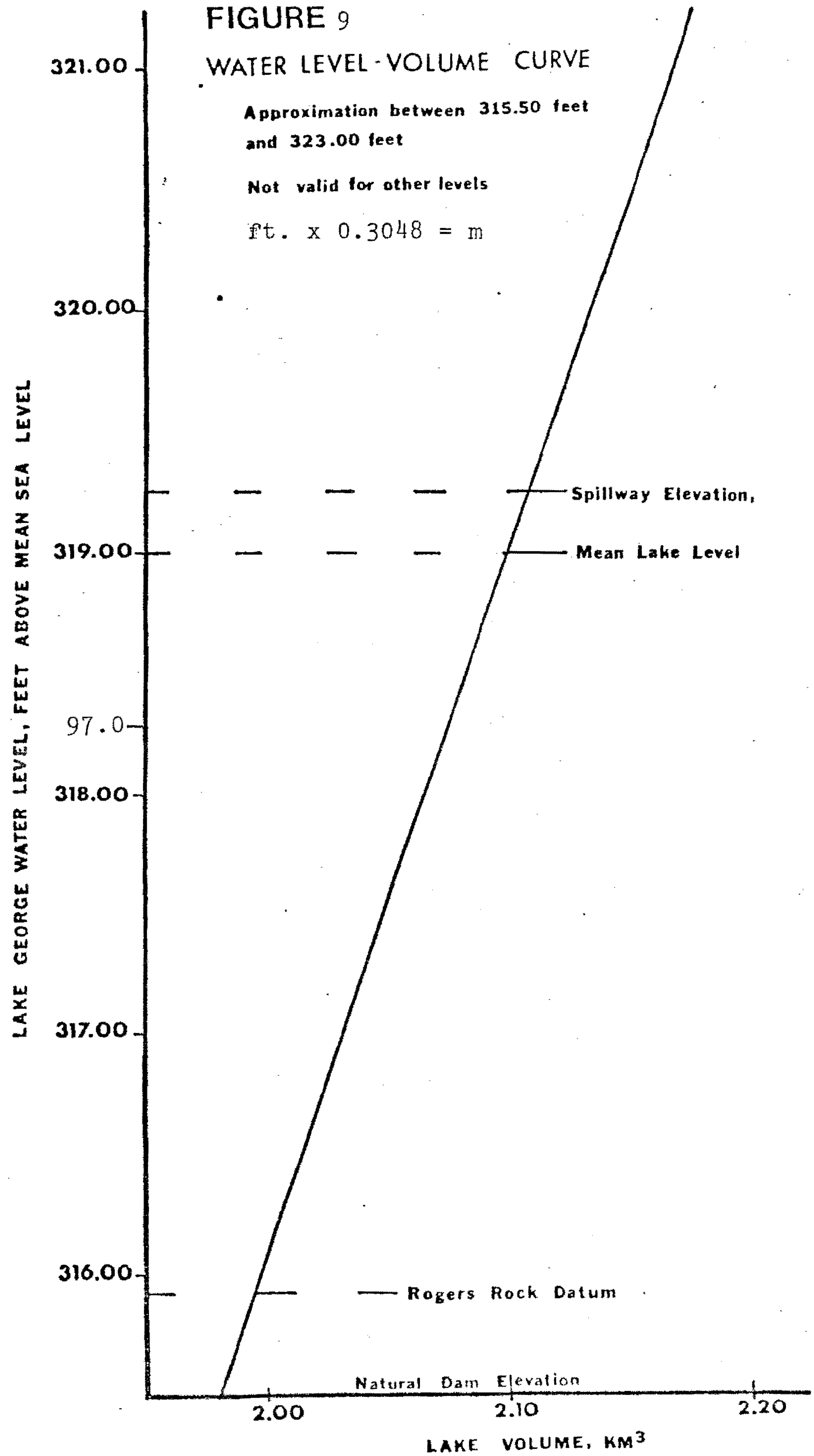


FIGURE 9
WATER LEVEL - VOLUME CURVE
Approximation between 315.50 feet
and 323.00 feet
Not valid for other levels
ft. x 0.3048 = m
321.00
320.00
319.00
97.0
318.00
317.00
316.00
Spillway Elevation,
Mean Lake Level
Rogers Rock Datum
Natural Dam Elevation
2.00
2.10
2.20
LAKE GEORGE WATER LEVEL, FEET ABOVE MEAN SEA LEVEL
LAKE VOLUME, KM3

The elements of the hydrologic cycle can best be illustrated for Lake George by data on its water balance and water budget (Colon, 1971). The water balance focuses on the interactions of climatic factors with water yield over the land surface of the basin, and is expressed as depth of water over the land area (i.e., 492 km^2). The water budget considers inputs from direct precipitation on the lake and runoff from the land, and losses by lake evaporation and lake discharge, with the lake storage term signifying the changes in lake volume in response to these inputs and losses. Table 11 lists the data that are measured (e.g., evapotranspiration). These data are subject to some error due to computational simplifications, but are indicative of the hydrologic cycle for water years 1966, 1967 and 1968 (Colon, 1971). Mathematical models were developed for this purpose (Colon, 1971, 1972).

Hydrography

An accurate map of the shoreline of Lake George, with numerous depth soundings, was published by S. R. Stoddard (1910). The Lake George Power Squadron (1956) published an excellent boating map with many depth soundings and the location of most of the present important landmarks. Neither of these maps contain plotted depth contours. Langmuir sounded the lake south of the Narrows during the summers of 1942-1946 by crossing between many known points, and plotted these on the map of Stoddard. More recently, Scott plotted Langmuir's cross sections on a copy of the Lake George Power Squadron map (Langmuir, et al., 1966).

No comparable detailed hydrographic map exists for north Lake George. However, information on depth has been compiled from the hydrographic map of south Lake George (Langmuir, et al., 1966) and the boating map of Lake George (Lake George Power Squadron, 1956) to construct a less detailed map showing depths in Lake George (Figure 5).

TABLE 11. Water Balance and Budget of Lake George
Annual Summary

Water Balance

Water Year	Precipitation Cm	Precipitation Inches	Runoff Cm	Runoff Inches	Actual Evapo-transpiration Cm	Actual Evapo-transpiration Inches	Soil Moisture Storage Cm	Soil Moisture Storage Inches
1966	92.075	36.25	36.39	14.70	60.20	23.70	-5.46	-2.15
1967	86.41	34.02	30.96	12.19	61.82	24.34	-6.38	-2.51
1968	92.63	36.47	41.53	16.35	54.03	21.27	-2.92	-1.15

Water Budget

Water Year	Precipitation Cm	Precipitation Inches	Runoff Cm	Runoff Inches	Lake Evaporation Cm	Lake Evaporation Inches	Lake Discharge Cm	Lake Discharge Inches	Change In Storage Cm	Change In Storage Inches
1966	93.60	36.85	161.21	63.47	60.20	23.70	188.14	74.07	6.48	2.55
1967	87.73	34.54	133.78	52.67	61.82	24.34	181.51	71.46	-21.82	-8.59
1968	94.51	37.21	179.43	70.64	63.27	24.91	219.99	86.61	- 9.32	-3.67

Ref. Colon, 1971.

Mixing

The waters of Lake George flow northward and empty into Lake Champlain via Ticonderoga Creek which becomes the Lachute River below the falls at Ticonderoga. The lake is divided into two nearly equal elongate basins by the islands of the Narrows. The Narrows has a cross-section of approximately 12×10^3 square meters, and any water flow from the southern basin must pass through this region to reach the northern part of the lake. Based on measurement of the relatively small volume of flow from Lake George into Lake Champlain, the flow of water through the Narrows northward should be small, producing only small exhange between the two basins. Wind stress on the surface of the lake, however, produces other currents, some of which might be modified by the coriolis force and viscosity, thereby producing geostrophic or Ekman components of flow. A surface seiche would cause oscillating currents through the Narrows, as would an internal sieche during periods of thermal stratification. The transport of water through the Narrows probably would be a function of a complex pattern of currents which cause mixing of the waters between the two basins.

Stewart (1972) studied some of the currents in Lake George. The flow of water through the lake from south to north was slow, less than one cm/sec, and generally masked by larger currents of a more transient nature. In general, the flow through the region of the Narrows could be divided into two separate layers. The upper layer extended down seven to ten meters into the lake. The lower layer extended from this level to the bottom. The flow in these layers would often be in opposite directions. A wind stress would cause the upper layer to flow in the direction of the wind and the lower layer would supply a return flow. A seiche having a period of 2 hour 42 minute current was observed superimposed on the two-layer current system. The wind driven currents were not dependent totally on the existing wind at the time of observation, but rather the wind over a period of up to two days. The volume of water exchanged by the flow was often 250 m^3/sec with a two to four m/sec wind. A net flow rate from one basin to the other of 120 m^3/sec was not uncommon. The water which was transported from one basin to the other was at least partially mixed before the current reversed. Thus, mixing in Lake George is both horizontal and vertical.

Horizontal Mixing

The occurrence of the 2h 42m surface seiche on Lake George is apparently a major factor in the exchange of water through the Narrows. This seiche occurs approximately 16% of the time, and has a maximum range of about 14 cm excluding set up. The average range is between 4 and 5 cm, with the oscillations continuing for 8-12 hours.

Based on the above data and the approximate basin statistics, it appears that a volume of water equivalent to 13×10^5 m^3/half-seiche-period is transported from one basin into the other during "average" conditions. This is equivalent (roughly) to 0.1% of the volume of either basin being displaced each one-half seiche period. If we now consider the 16% factor, average transport, and assume a 10% exchange factor, then in one day 3.6×10^5 m^3 are exchanged. This represents (theoretically) a total exchange of water between the two basins every eight years. Superimposed on this exchange is the natural turnover period of eight years.

Vertical Mixing

The vertical mixing depends upon the occurrence of Langmuir circulations and related assumptions (Scott, et al., 1969; Stewart and Schmitt, 1968; and Myer, 1971).

According to past studies, Langmuir circulations occur above a minimum wind speed with a dependence upon stability conditions (Figure 10). Under summer conditions a wind speed of approximately 3 m sec^{-1} is necessary to initiate Langmuir circulations (occurrence during 50% of observations), and a 6 m sec^{-1} wind or greater generates this motion approximately 90% of the time. By analysing wind records, these velocities were realized as shown in Table 12.

TABLE 12

Percent of Wind Speed Observations Exceeding Stated Velocity in 1971

Month	3 m sec^{-1}	6 m sec^{-1}
May *	43%	4%
June	40%	3%
July	40%	3%
August	40%	3%
September	35%	1%

* It is obvious that these wind speeds only apply when there is no ice on the lake thus winter records are not analyzed for this factor.

These studies further indicate that the observed downward vertical velocities in the lake undergoing Langmuir circulation are a function of wind speed (Figure 11). In July, measurable vertical mixing took place approximately 20% of the time, with velocities exceeding 4 cm sec^{-1} 3% of the time. This mixing dertermines the downward progression of the thermocline in late spring and early summer. It also affects biological activity. Continued analysis of past data will aid in completing this model, but the results clearly show that the distribution of biological (and possibly chemical) factors within a lake depend upon wind speed and organized circulations. This should be considered during sampling to avoid inadvertently biasing the data.

FIGURE 10

HISTOGRAM OF STREAK CONCURRENCE VS. WIND SPEED

THE TOTAL BAR GIVES THE NUMBER OF OBSERVATIONS AND THE HATCHED BAR GIVES THE NUMBER FOR WHICH STREAKS WERE OBSERVED.

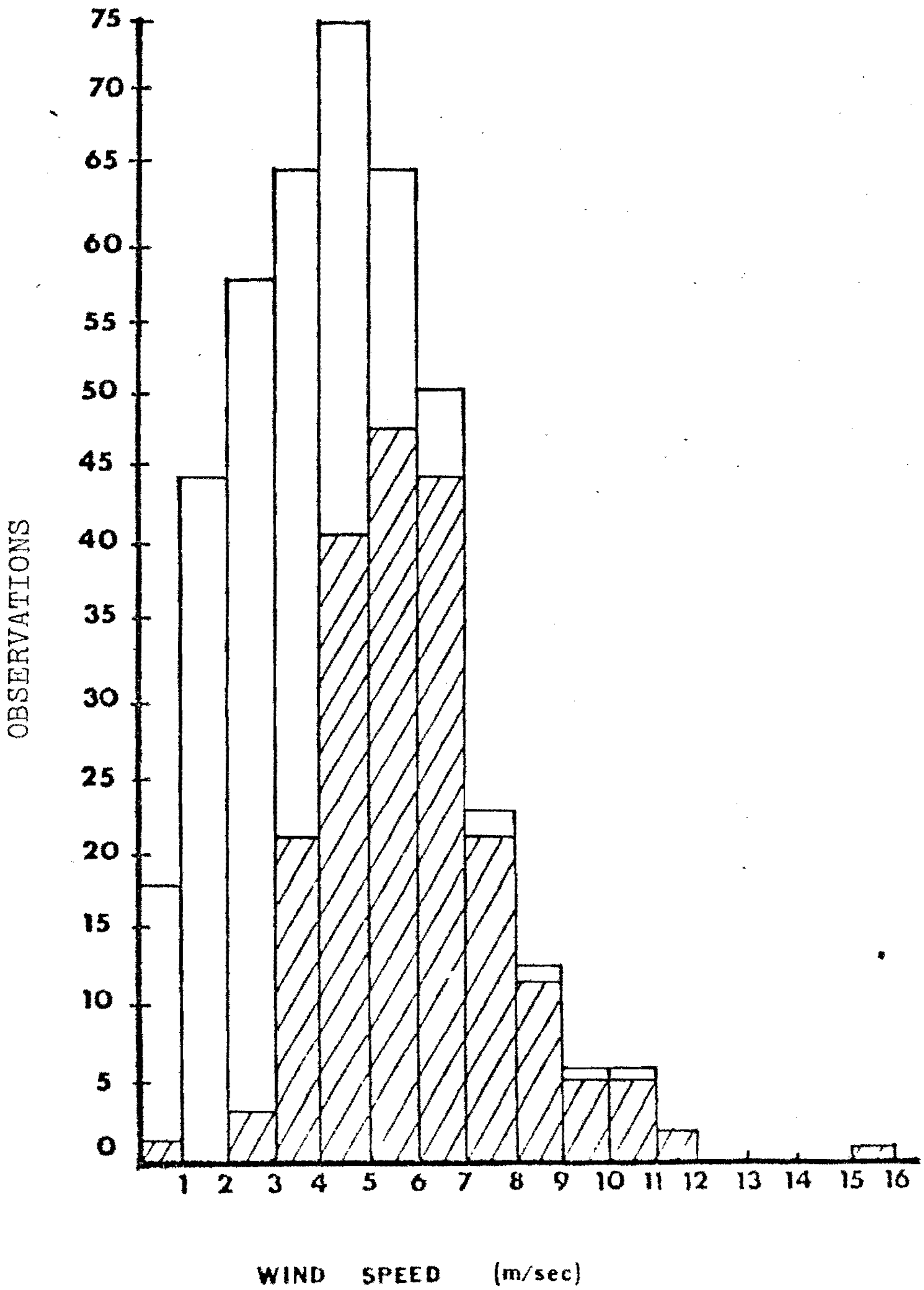
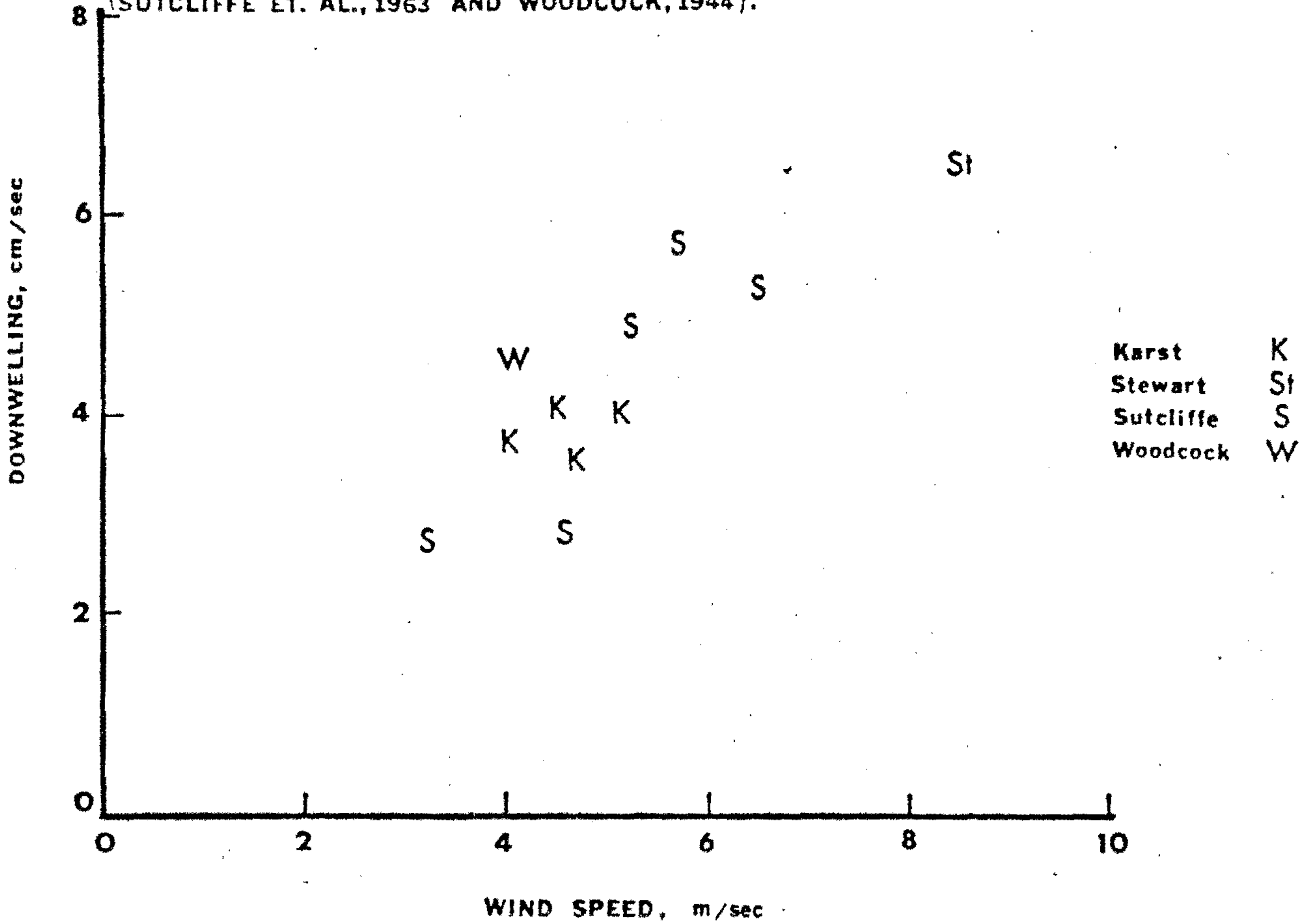


FIGURE 11

MEASURED SPEED OF DOWNWELLING CURRENTS IN STREAK ZONES VERSUS WIND SPEED

DATA ARE FROM LAKE GEORGE (KARST & STEWART) AND FROM OCEANIC CONDITIONS (SUTCLIFFE ET. AL., 1963 AND WOODCOCK, 1944).



LIMNOLOGICAL CHARACTERISTICS

Physical

Light Intensity and Water Clarity - The water clarity is usually greater in the northern basin, as indicated by the typical Secchi disc measurements shown in Table 14. Table 15 shows the differences in underwater light intensity in the north and south basins. Greater light penetration consistently occurred in the north basin (Station 6) than in the south basin (Station 1). This concurs with the Secchi disk measurements.

As noted in Table 15, the compensation point (1% of surface light intensity) occurs at shallower depths in the more southerly station (Station 1) than in the northerly station (Station 6). During the growing season, turbidity due to planktonic growth results in the compensation point being shallower for both stations. Figure 12 shows the incident solar radiation (langleys/day) reaching the surface of the lake throughout an entire year. As would be expected from a biological production viewpoint, there is a continual increase from January to mid-August, followed by a rapid decline in this parameter from September to January. Similar data have been noted by others (Williams and Clesceri, eds., 1972). From the data shown herein, and those noted, the average daily and total integrated radiation patterns are quite similar; however, some differences do occur due to varying exposure periods. These data were taken at a location adjacent to the lake shore at Station 6. Because of the limited length of the lake, they are considered representative of the solar radiation falling on the entire lake.

Profiles of solar radiation penetration into Lake George were taken on June 30, 1971 by Stewart (1972) at five different locations. The average of these data is shown in Figure 13, along with the formula which can be used to simulate solar radiation in the lake.

TABLE 14. Secchi Disk Measurements (Meters)

Date	Station 1	Station 6
3/26/70	7.0	8.5
6/26/70	8.5	10.0
7/17/70	7.0	13.5
8/16/70	7.0	9.0
9/28/70	7.0	9.5
10/05/70	7.0	10.0
10/11/70	6.0	9.0
11/08/70	6.5	10.0

See Figure 2 for location of sampling stations

TABLE 15. Relative Underwater Light Intensity With Depth

(percent)

Percent Transmission of Incident light at Various Depths

Depth (meters)	9/09/69		8/17/70		9/13/70		3/06/71*	
	Station 1	Station 6	Station 1	Station 6	Station 1	Station 6	Station 1	Station 6
1	85	87	54	75.7	75.7	85.8	28.8	16.7
3	60	60	33.7	50.0	46.0	65.5	7.8	3.1
6	32	32	20.2	27.5	26.3	36.3	2.0	1.3
9	18	19	10.2	18.0	13.8	21.6	0.62	0.67
12	9.2	13	4.0	12.0	7.5	15.4	0.28	0.36
15	4.0	6.6	1.5	4.8	2.8	8.6	0.12	0.18
18	1.8	3.0	0.42	2.4	1.2	5.4		
21	0.82	1.8	0.22	1.0	0.53	2.2		
24	0.42	0.85	0.10		0.27	1.0		

* Under ice cover

See Figure 2 for location of sampling stations

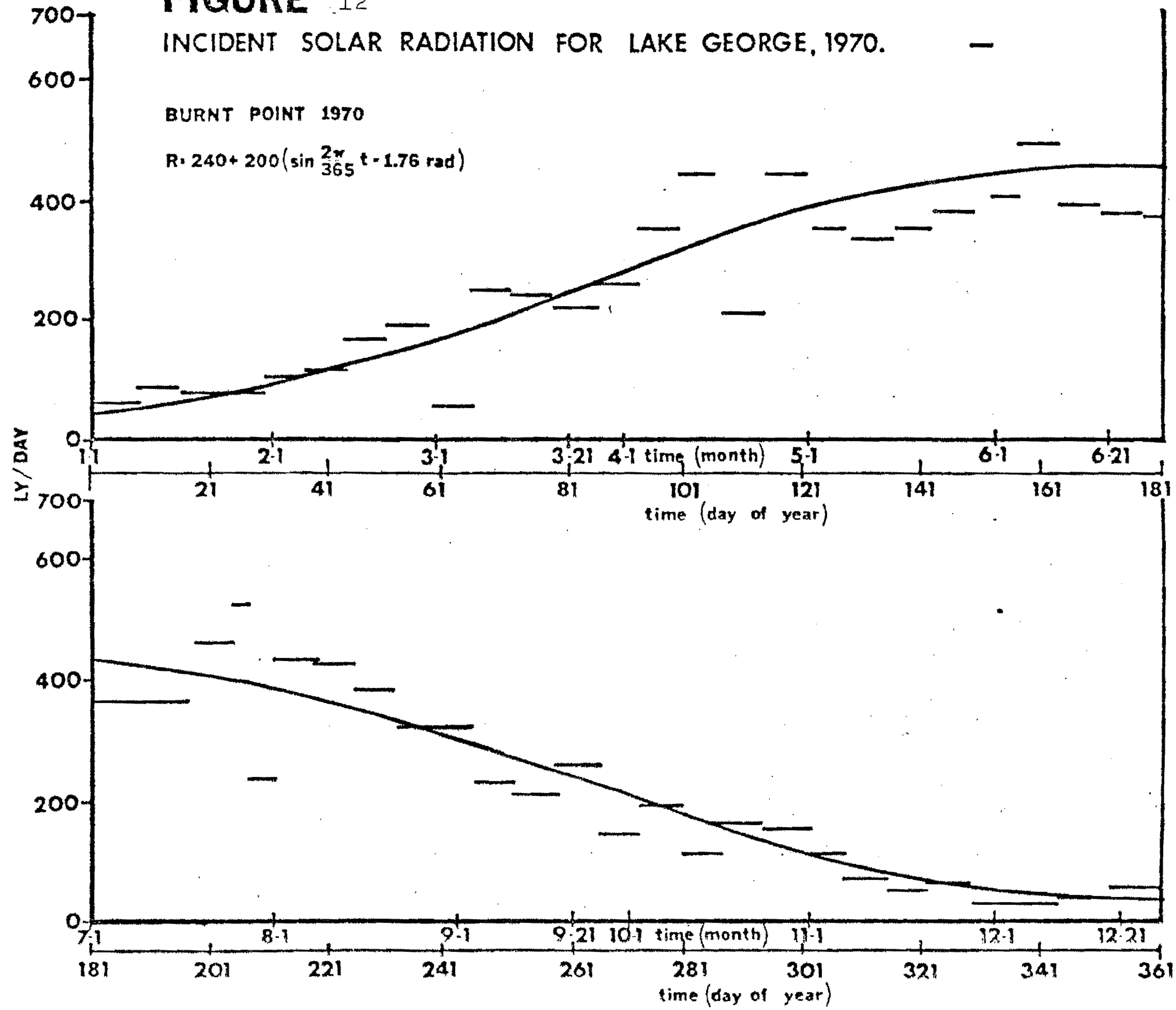
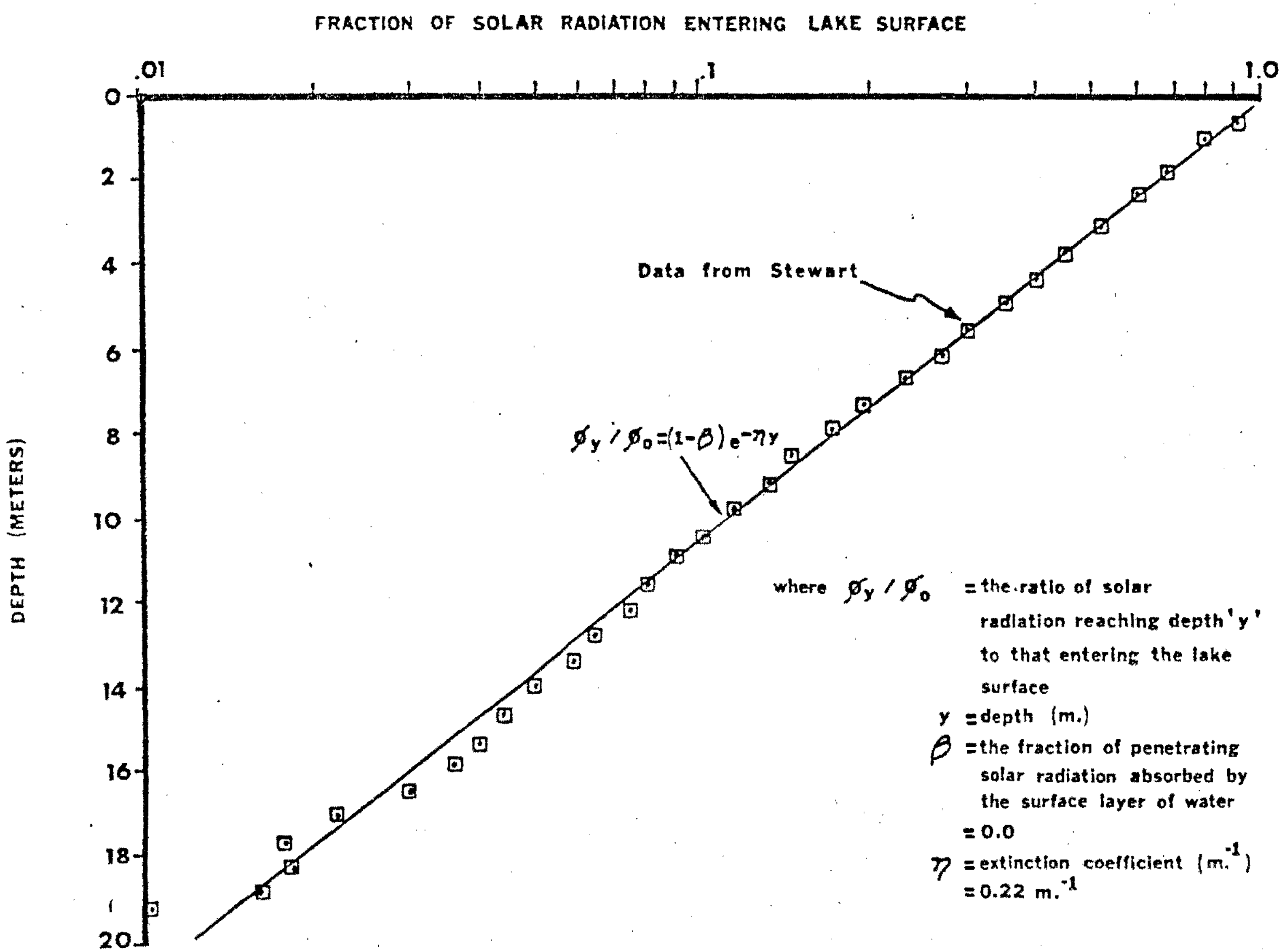


FIGURE 12

INCIDENT SOLAR RADIATION FOR LAKE GEORGE, 1970.

FIGURE 13

PROFILE OF SOLAR RADIATION PENETRATION IN LAKE GEORGE



Ref. Hickman, 1974

Temperature

Lake George is dimictic in its temperature stratification characteristics. The range of temperatures observed over the course of a year in this lake is 2° to 25° C. Figure 14 shows monthly temperatures at the three, nine, and fifteen meter depths for the period September, 1967 to November, 1970. In addition, this figure illustrates the period during which ice and snow covered the lake as well as the thickness of this cover. The ice cover was approximately 50 cm thick during this period. The typical ice cover period for this lake is mid-January to mid-April. Normally, significant thermal stratification exists from June through September. The epilimnion is usually nine to ten meters deep, with August temperatures reaching the mid-twenty degree level.

Figure 15 shows the seasonal changes in the location of the thermocline in Lake George; it also shows that the inverse temperature stratification associated with dimictic temperate lakes usually occurring during the winter is found in Lake George.

In a subsequent study of lake temperature, weekly temperature readings taken at Station 1 were recorded at 2 m intervals down to a depth of 28 m (Stewart, 1972).

According to Langmuir (1938), the temperature of Lake George at the time of freezing is almost uniform at 1.2° C, and at the time of ice break-up it is almost uniform at 3° C. Except for the layer of cold water immediately beneath the ice, the temperature rise of a lake during ice cover is uniform due to convective mixing.

The average length of ice cover for the years from 1965-1974 was 82 days. The amount of heat needed to raise the lake from 1.2° C to 3° C is 3.78×10^{12} kcal. Since most of the heating takes place during the latter half of the period of ice cover, it apparently is caused by solar radiation penetration.

FIGURE 14

LAKE TEMPERATURE AND ICE COVER

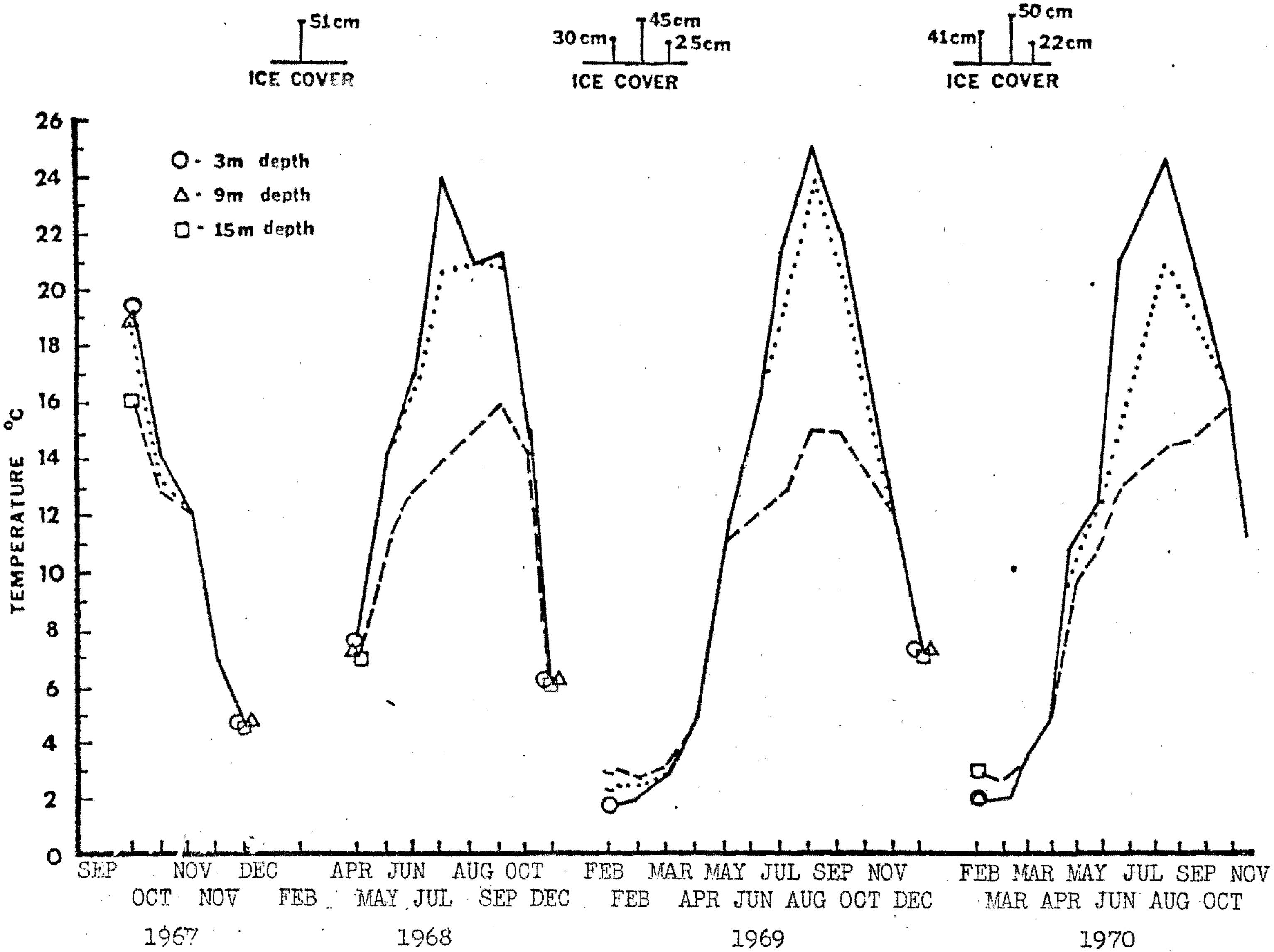
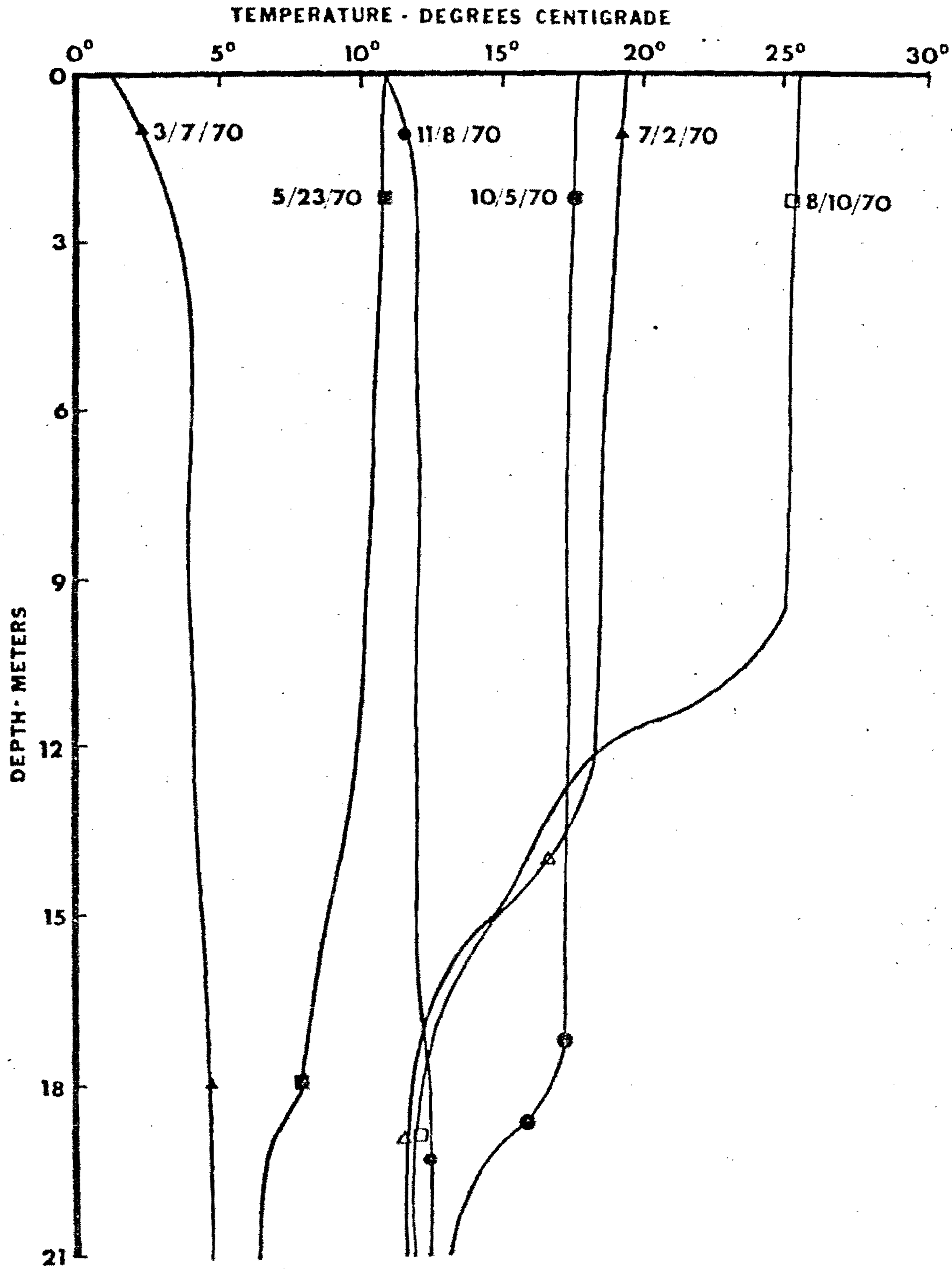


FIGURE 15

SEASONAL CHANGES IN THE LAKE GEORGE THERMOCLINE

Station 1



Averaged over the 82 day period, the rate of heating of the lake while under ice cover is 0.022° C/day.

In 1971, ice break-up occurred on April 28 (Julian date 71.118), two weeks later than the 1965-1974 average date of break-up of April 15. At the time of break-up the temperature of the lake (down to 28 m) was almost uniformly 3.3° C.

Upon ice-out the lake began to heat rapidly. A thermocline started form- in mid-June at a depth of about 9 m. The surface reached its maximum temperature of about 23° C in mid-August and then began to cool. The lower layers of water continued to heat, though. The maximum recorded temperature at 28 m was 10° C in mid-November. Langmuir reported a maximum temperature at 58 m of 9.6° C in November of 1926 and 100° C in November of 1927.

Cooling continued until January 27, 1972 (J. D. 72.027), when ice formed. At this time the temperature of the lake was nearly uniform at 1.5° C. Langmuir reported an average temperature of 1.2° C at the time of freezing.

After ice formed, the temperature remained stable until about the beginning of March, when it began to heat up to the ice break-up temperature of 3° C on April 26 (J. D. 72.117).

Figure 16 shows variation of the temperatures at the surface and at 18 m (the mean depth).

Dissolved Oxygen

Lake George is a cold oligotrophic/mesotrophic lake experiencing mostly oxygen-saturated conditions throughout. Data in Table ~~13~~ 16 revealed the range of values encountered for Lake George. Under ice-cover, a slight depletion of oxygen occurred at Station 1 with a minimum 86% saturation value. By the month of June the lake was somewhat thermally stratified and was 86 per cent saturated in the hypolimnion with 115 percent saturation at the 8 meter depth. For an extended sampling period (72 hrs) in the first part of August (7/31/73-8/2/73),

FIGURE 16

YEARLY VARIATION OF THE WATER TEMPERATURE OF LAKE GEORGE (71.124 - 72.124)

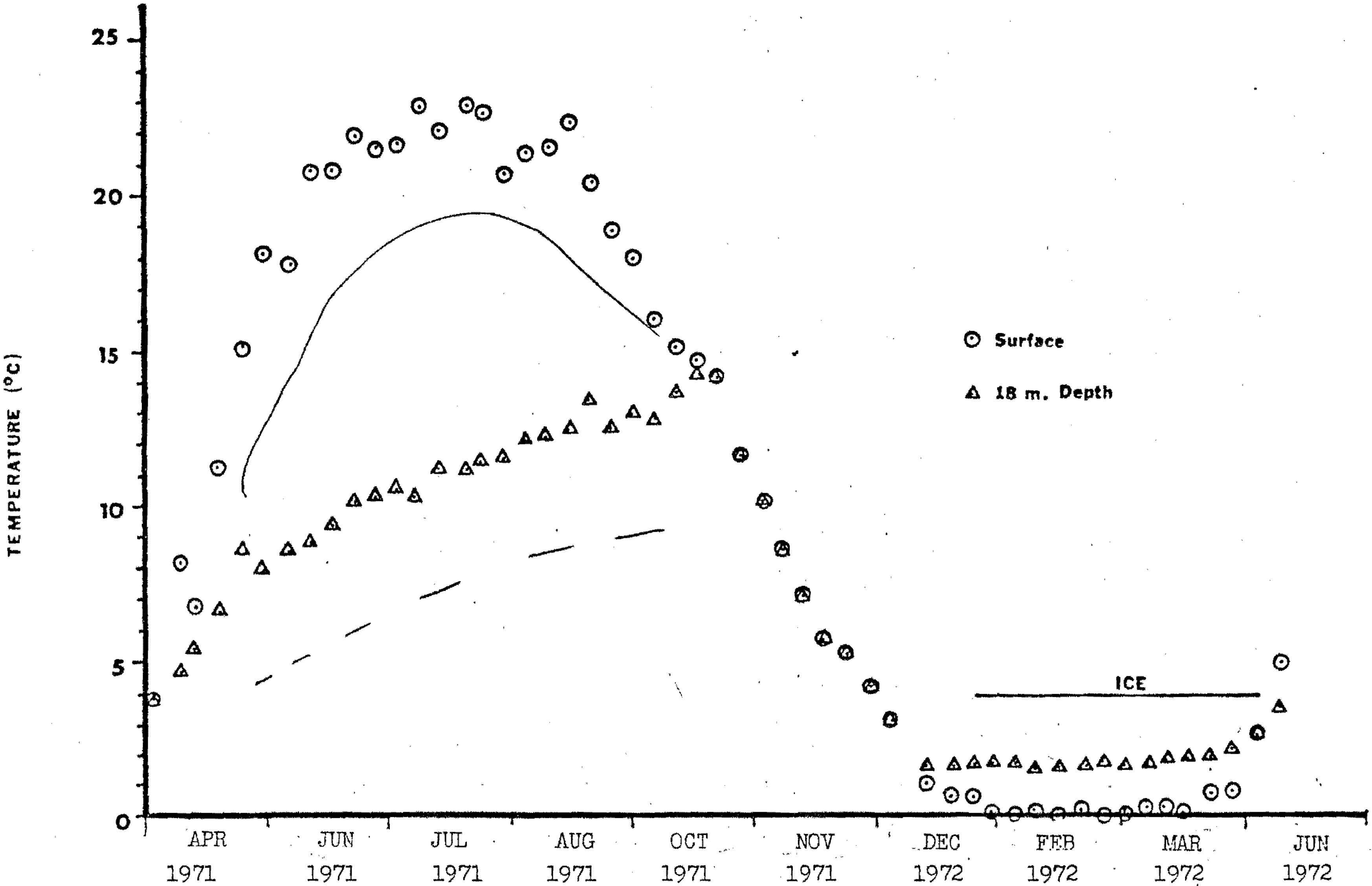


TABLE 16. Dissolved Oxygen Data

Station	Date	Depth of Water Column (m)	% Saturation Range*	D.O. Range* (mg/1)	Temperature Range * (^{o}C)
1	03/06/73 (ice-covered)	22	86-96	11.8-13.6	0-4
1	06/27/73	25	86-115	10.0-12.5	7-17.5
1	07/31/73-08/03/73	25	60-111	7.8-11.2	6-24
6	06/27/73	25	85-115	9.8-12.4	6-21
6	07/31/73-08/03/73	25	70-111	7.8-11.4	6-25

See Figure 1 for station locations

*Range is variation from top to bottom sampling at 1 m intervals the DO depletion resulted in 60% saturation in the hypolimnion and 111% super-saturation again in the thermocline. There were some diurnal changes in saturation in the epilimnion, with an approximate range of 90% to 105%. The 60% saturation value is a result of the decomposition of the organic component of the sediment.

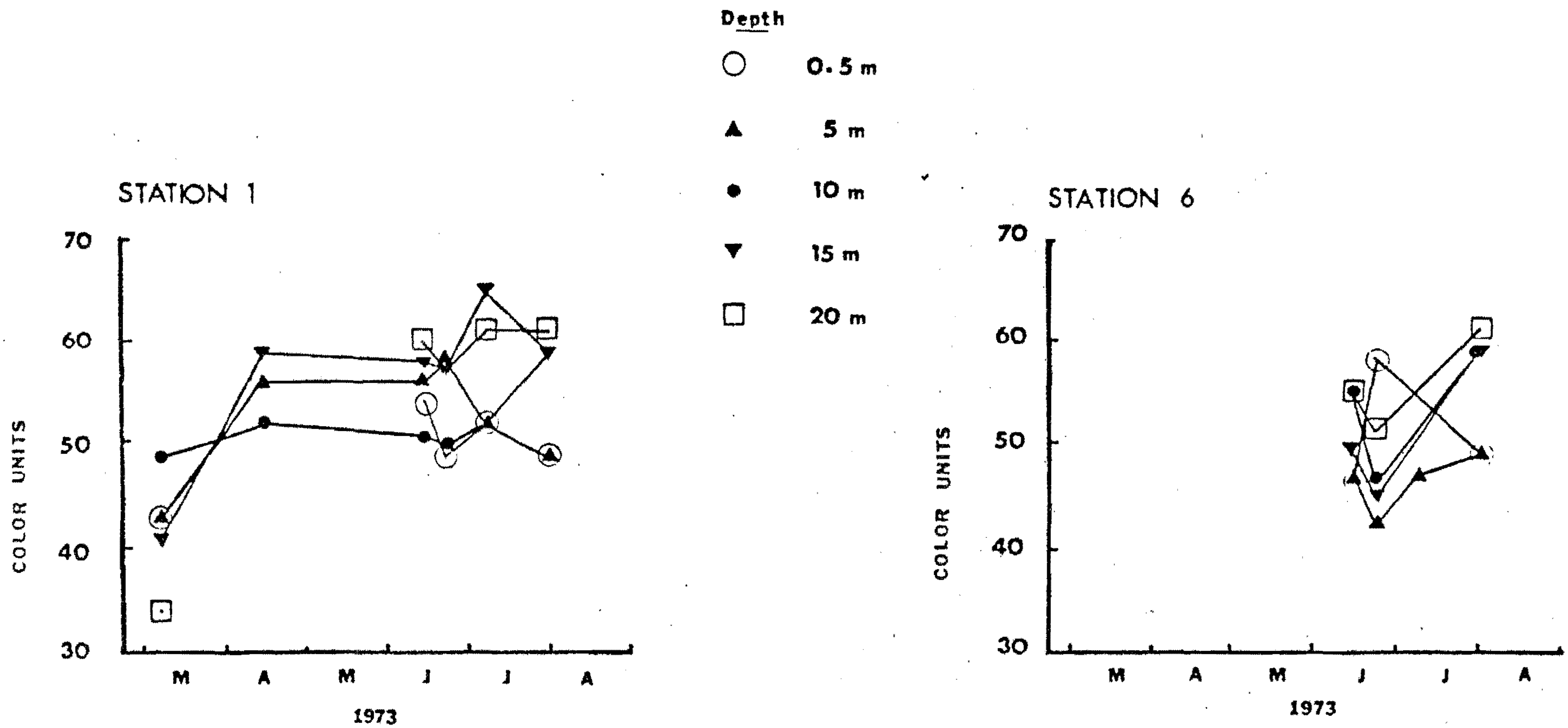
Data for the dissolved oxygen at Station 6 indicated somewhat similar results on the June sampling, i.e., 85% to 115% saturation, with the 86% saturation occurring in the hypolimnion and the 115% saturation also at the 8 m depth. For the extended sampling period in early August, the super-saturated conditions of 111% occurred at the 12 m depth in the thermocline; in fact, for this sampling period, the highest saturation values usually occurred at this depth. Saturation values of 90% to 100% were observed in the epilimnion over this 72 hour period. In the hypolimnion, the lowest value observed during this early August period was 70% of saturation.

Color

Color has not been explicity measured, but through indirect means some relative indications of color can be given. In the work of Kobayashi (1973) on dissolved organic carbon of Lake George, humic matter measurements were made as color units at 420 nm with a 5 cm light path shown in Figure 17. The "color" at the 0.5 m depth in early June at Station 6 was greater than at Station 1; however, the "color" at all the other depths of 5, 10, 15 and 20 m was less at Station 6 than Station 1. While samples at all depths were not taken at Station 6 in late June, the 5 m sample was considerably lower in "color" than the same depth sample at Station 1. The last measurements made in this series occurred in mid-July, where the "color" was equivalent for the same depth samples at both stations. While there were fluctuations in the amount of "color" as the year progressed, the 20 m depth samples were usually the highest in

FIGURE 17

COLOR IN LAKE GEORGE AT VARIOUS DEPTHS AT TWO DIFFERENT LOCATIONS



"color" for both stations, indicating either that the bottom sediments are a source of these materials or that these materials are accumulating in the hypolimnion due to lack of decomposition of this humic-matter-derived-"color."

Sedimentation Rates A study has been made of the sedimentation rates in Lake George (Williams and Clesceri, 1972). Duplicate plastic sediment collectors having a cross sectional area of approximately 500 cm^2 were positioned about 0.5 meters from the lake bottom on wooden stilts driven into the bottom before the collectors were opened. Sediment collectors were installed at two locations in the south basin and at three locations in the north basin on May 19, 1969. Collectors were recovered from Stations 1 and 6 on September 15, 1971, giving an exposure time of 2.3 years. The collectors were closed with a snap lid prior to removal to prevent loss of sediment. The collectors were allowed to settle for seven days after removal and then the thickness of the sediment was measured with a frame mounted vernier depth gage. Fifty measurements per collector were made; however, little deviation in the thickness of the sediments was noted and fewer measurements could have been made. Sedimentation rates of 0.48 mm/year at Station 1 and 0.28 mm/year at Station 6 were calculated from the thickness measurements.

To estimate an average sedimentation or accumulation rate over late post-glacial time, two-centimeter-thick sections from two cores from Station 1 were removed between the 12 and 14 centimeter depth of the cores and the average age of the sections was determined by radioactive carbon dating. The average age of the sections was found to be 3,140 $\pm$ 155 years. This measurement gives an average sedimentation rate of 0.041 mm/year, which is about one-tenth the present sedimentation rate in the south basin.

A three centimeter section between the 7 and 10 centimeters depth from a Station 2 core was also dated in the same manner and found to have an age of

1,155 $\pm$ 120 years B.P., giving an average sedimentation rate of 0.072 mm/year. The higher average sedimentation rate from 0 to 8.5 cm deep as compared with 0 to 13 cm deep and the much larger sedimentation rate currently indicated by the sediment traps, indicate a significant increase in sedimentation rate in recent years at Stations 1 and 2 in the south basin. Figure 18 shows that a major increase in numbers of diatoms/gram of sediment occurred at both Stations 1 and 2 between the 10 and 5 centimeter depths in the cores (fourfold increase at Station 1 and a ninefold increase at Station 2).

The present-day sedimentation rate measured at Station 1 suggests that this increase in diatom deposition could have begun as late as 100 years ago. This was when extensive agriculture was being conducted around the shores of the south basin and on Long Island. A four-to-ninefold increase in diatom production could easily result from the cultural eutrophication associated with the agricultural and village activities.

This change in diatom production could also have taken place as early as 1400 years ago, based on the .072 mm/year average sedimentation rate which would have made the change of natural origin. Figure 16 indicates that a similar fourfold increase in diatom deposition occurred between 5 and 10 centimeters in Stations 6C and 7 cores. Based on the sedimentation rate in the north basin (Station 6), this change could not have occurred later than about 200 years ago. This does not rule out a change in diatom sedimentation rates in both north and south basins due to cultural eutrophication, since agriculture was still being conducted in the latter part of the eighteenth century but to a more limited extent. Sections of two Station 7 cores between 24 and 28 centimeters had an average age of 6200 $\pm$ 180 years B.P. by carbon dating, giving an average sedimentation rate of 0.042 mm/year. At this average rate the change in diatom deposition in the north basin could have occurred as early as 2400 years ago.

Lake George Sediments

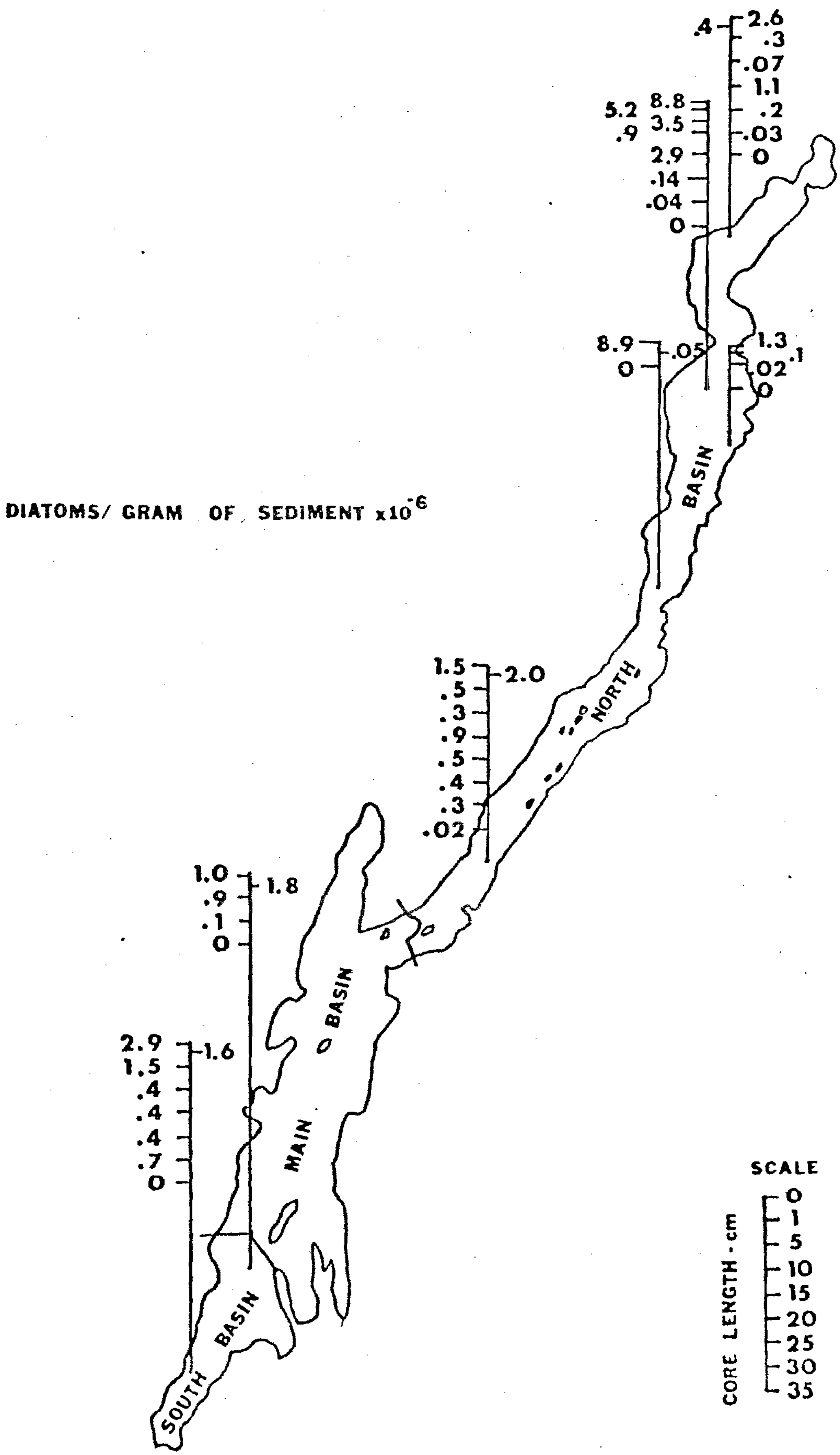
Lake George is a glacial lake located in a topographically rugged, heavily wooded area in the eastern Adirondack Mountains of New York State. Two types of sediment floor the lake: 1) relict glacial sediment, and 2) modern sediment. The relict sediment inclues varved glacial lake clays with iron-maganese nodules (Schoettle and Friedman, 1971) and sandy sediments derived from moraines, drumlins or deltas. Glacial lake clays probably underlie most of the lake; these clays, however, are concealed beneath a cover of modern organic-rich silty clay. Active currents have kept exposed the glacial lake clays in the Narrows between the north and south Lake George basins for at least 3,300 years.

The bottom sediments of most of the lake consist of organic-rich silty clays. Tree bark, spore capsules, leaves, and needles compose much of the structural organic matter of the nearshore bottom sediments. This organic material enters the lake, mostly in the fall, as part of the annual crop of organic material contributed by the vegetation in the drainage basin. In the deeper parts of the lake, structural organic matter cannot be positively identified because of advanced decomposition. However, the organic matter content of the bottom sediments of the southern Lake George basin generally exceeds that of the northern lake basin. This increase in organic matter correlates with increasing phytoplankton productivity in the southern basin. Increasing phytoplankton productivity relates to man's impact on the waters of the southern basin.

Organic matter together with other fine-grained clay size particles, such as quartz and clay minerals, gets trapped, especially in the deeper parts of the lake, where it accumulates rapidly on the lake floor.

FIGURE 18

TOTAL DIATOMS IN LAKE SEDIMENTS



In the south Lake George basin, bottom sediments containing more than 50% clay occur near the east shore and underlie the large central expanse of the lake. Bottom sediments with less than 25% clay, hence mostly sand, are restricted to the west shore of the south Lake George basin, although in two places a tongue of sandy sediment passes beneath the central area of the lake. The eastern Narrows are rich in clay, whereas the western Narrows are rich in sand. Clay-rich sediments underlie the southern part of the north Lake George basin. The cental part of the north Lake George basin has clay in the middle of the lake and sands closer to the shoreline. In the northermost part of the north Lake George basin near Ticonderoga, the bottom sediment consists mostly of sand. The sediments of the lake bottom in the Narrows and contiguous areas consist of a varved glacial clay in which iron-manganese nodules occur (Schoettle and Friedman, 1971). These sediments are unique among the Lake George bottom sediments.

All bottom sediments are black in color, except at the water-sediment interface. There the color is either black or brown; the brown color passes downward into black. The black color at the water-sediment interface dominates near the east shore in the south Lake George basin, especially near the bays, whereas brown colors are present near the west shore.

Chemical

Streams

In 1971, Fuhs conducted an extensive study under the New York State Department of Health of streams tributary to Lake George. A total of 18 streams representing 14 watersheds was sampled from July 1970 through July 1971. Samples were taken at roughly bi-weekly intervals and analyzed for major chemical constituents and algal nutrients. Concentrations were related to stream flow at the time of sampling and regressions of concentration and loading versus flow were then calculated (Fuhs, 1972).

Figure 19 shows streams sampled in this study, along with the numbered code used to refer to them in the data tables. From the information obtained on streamflow and chemical concentration, areal loading, that is, the amount of each chemical removed from a unit area of land per unit of time, can be determined. This loading rate is usually expressed as weight units per hectare of land per year.

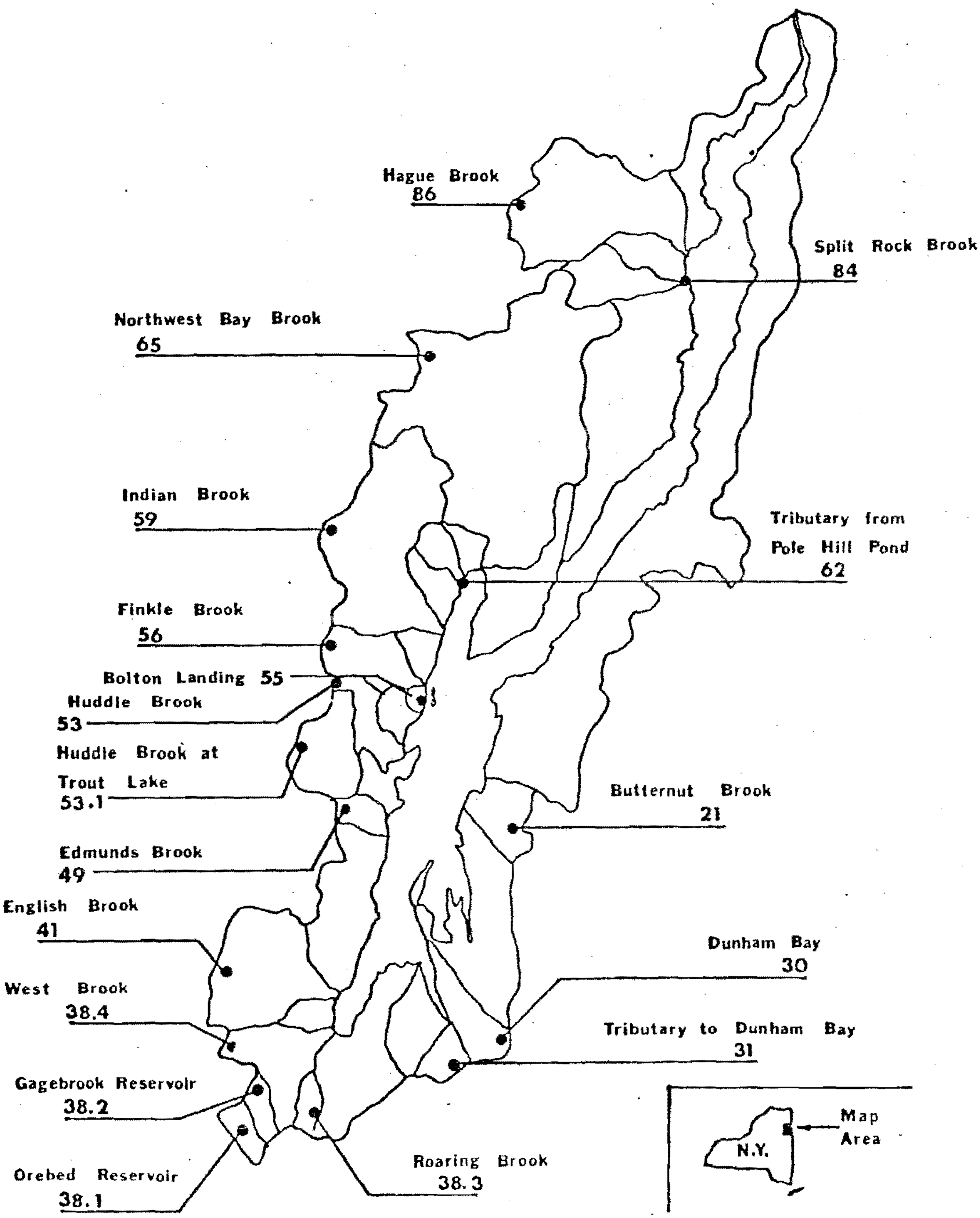
Table 16 lists the drainage basin areas as well as average flows for each stream sampled. These were used along with the concentrations to determine areal loading rates of total nitrogen, organic nitrogen (soluble and particulate), nitrate, nitrite, ammonia, total soluble phosphorus, total particulate phosphorus, and orthophosphate.

Table 17 shows the results of the loading determinations. These values represent loadings determined by multiplying the average flow in each tributary by the log mean concentration for the year and converting to units of g/ha-yr. Fuhs found that the chemical composition of the streams reflected the geochemistry and population characteristics of the watershed, and was affected by the amount of flow.

Subsurface seepage from sewage treatment plants and septic tank systems in the stream watersheds was found to contribute substantial amounts of soluble nitrogen constitutents, which have a greater solubility and mobility through soils. Nitrogen in the Lake George tributaries is derived largely from groundwater pollution, as evidenced by elevated concentrations found in the tributaries draining populated areas. Phosphates, however, showed little increase in the populated watersheds, presumably becuase the points of application are distant enough from the tributaries to permit nearly complete absorption of phosphates by the soil. This appears true also for the subsurface runoff of phosphorus from the recharge beds of the sewage treatment plants in the Lake George basin.

FIGURE 19

LAKE GEORGE TRIBUTARY SAMPLING SITES (WITH AREAS OF DRAINAGE BASINS)



Ref. Fuhs, 1972.

Table 16

Average Runoff in Lake George Tributaries

Tributary*	Log mean flow	Std. dev. (base-10 logarithm)	Drainage basin [sq. ha.]	Avg. flow (calc.) m^3/s]	Annual Runoff [cm/yr]	Avg. flow (direct) [m^3/s]
21	0.008	0.6542	6.5	0.0445	21.68	0.0470
31	0.005	0.2048	3.1	0.0087	8.86	0.0088
38.1	0.022	0.5503		0.096	89.9	0.0554
38.2	0.130	0.1445		0.190	60.80	0.2062
38.4	0.248	0.0896	20.2	0.3144	49.08	0.3420
41	0.063	1.215	17.9	1.5860	278.0	0.3805
41 (corrected)	0.063	0.6766	17.9	0.3805	67.15	0.3805
49	0.014	0.2869	3.4	0.0305	28.60	0.0268
53	0.048	0.6419	14.8	0.2616	55.89	0.0832
53.1	0.032	0.4292	8.8	0.1006	36.00	0.0781
55	0.010	0.0764	1.6	0.0118	24.02	0.0121
56	0.027	0.4533	8.5	0.0883	32.56	0.1220
59	0.113	0.6630	31.3	0.6540	64.74	0.3932
62	0.011	0.3204	3.4	0.0268	25.11	0.0240
65	0.323	0.3185	67.6	0.7505	35.01	0.7380
84	0.038	0.3404	8.3	0.0926	35.23	0.0896
86	0.198	0.2143	26.4	0.3486	41.61	0.3563

*See Figure 19

Ref.: Fuhs, 1972

TABLE 17

Annual Chemical Runoff
(g per hectare per year)

Tributary*	N (org, sol)	N (org, part)	NO_3^--N	NO_2^--N	NH_4^+ - N	N (total)
21	43	16	267	2.0	21	360
31	41	24	97	1.9	12	190
38.1	289	90	74	10.8	64	602
38.2	164	88	675	10.5	33	1119
38.4	121	80	5187	14.6	47	6483
41	238	75	1658	12.9	51	2532
49	134	31	609	3.8	20	609
53	335	111	721	9.7	30	1313
53.1	342	81	464	5.1	31	677
55	438	60	4754	13.0	40	6061
56	176	64	612	5.3	22	1026
59	586	142	959	15.4	55	1916
62	151	21	151	4.3	15	428
65	233	51	305	6.8	36	708
84	77	28	137	3.5	11	357
86	102	87	648	9.4	43	971
Basin	264	75	608	8.6	38	1105

*See Figure 19

Ref.: Fuhs, 1972

TABLE 17 continued

Annual Chemical Runoff
(g per hectare per year)

Tributary*	P (ortho)	P (total sol)	P (total, part)
21	0.80	2.7	10.2
31	0.65	1.5	6.7
38.1	8.22	28.2	27.7
38.2	2.74	13.6	25.1
38.4	1.33	9.1	21.8
41	3.02	8.3	22.0
49	2.58	5.8	13.7
53	2.78	13.6	26.6
53.1	0.03	6.6	27.1
55	0.67	3.9	13.4
56	0.72	6.4	12.1
59	1.86	8.6	29.8
62	0.75	13.8	12.1
65	0.27	3.6	14.7
84	0.50	3.7	12.3
86	1.67	7.6	15.4
Basin	1.34	6.9	18.9

*See Figure 19

Ref.: Fuhs, 1972

Correlations between concentration and stream discharge were poor or non-existent for most forms of nitrogen in these streams. West Brook, however, showed a strong correlation in the form of a depletion hyberbola for nitrates, demonstrating that this watercourse is constantly polluted by some source.

Correlations between phosphorus concentrations and flow were variable and difficult to predict. Particulate phosphorus exhibited a positive correlation with flow due to the mobilization of solids during high flow. Total soluble and soluble reactive phosphorus concentrations exhibited a negative correlation in some cases, but were quite variable from stream to stream. Regression analysis was performed for most nutrients and the results presented in Fuhs' report.

Fuhs found the sewered population in Lake George insignificant in accelerating cultural eutrophication of the lake waters. Since, in his opinion, phosphorus appears to be the limiting nutrient in Lake George and since the tributaries presently contribute relatively small amounts of phosphorus, stream chemistry alone cannot explain any increased rate of eutrophication in the lake. He believes that the increase in nutrient addition results from a contribution of phosphorus from several ungaged sources directly to the lake. A probable source cited by Fuhs was discharge of phosphorus rich sewage and wastewater from the large summer populations in the unsewered lake shore areas.

In 1976, Kasper and Palladine carried out a similar study under the Rensselaer Fresh Water Institute, in which two streams in the lake basin were selected for an intensive study over a five month period. West Brook, representing a disturbed watershed (high development and summer tourist population), and Northwest Bay Brook, draining a relatively undisturbed area, were sampled every 48 hours from March through July, 1976. This period was believed representative of the range of streamflow and population variations in each watershed. Areal loadings of nitrogen and phosphorus were then related to watershed characteristics and seasonal fluctuations in streamflow and population (Kasper, 1976 and Palladine, 1976).

Samples were analyzed for total Kjeldahl nitrogen, ammonia, nitrate, total phosphorus, total soluble phosphorus, soluble reactive phosphate, and dissolved organic carbon. Loading rates were then calculated for each nutrient, and cumulative loading was determined for each watershed over the five month period.

Table 18 shows the drainage basin area, and the range of streamflow, for each brook. These flows, along with the concentrations shown in Table 19, were used to determine the loading rates as shown in Table 20.

Figures 20 through 22 display the relationship between concentration and stream discharge. Some correlation was evident for Total Phosphorus (TP), Total Soluble Phosphorus (TSP), and Total Kjeldahl Nitrogen (TKN) in both streams, with concentrations increasing at higher flows. Soluble Reactive Phosphorus (SRP) showed little variation with flow, except for a slight depletion in West Brook at flows less than 1 m^3/sec. There was no apparent correlation between concentration and discharge for Dissolved Organic Carbon (DOC) or NH_3^+ in either stream. Fuhs likewise found no relation.

The strongest correlation existed for nitrates in West Brook, (Figure 21) where concentrations decreased with increasing flow. As Fuhs mentioned, this suggests dilution of a constant source of discharge, in this case the Lake George Village Sewage Treatment Plant. Nitrates in Northwest Bay Brook appeared to increase slightly with flow and then level off.

Overall conclusions based on this information tend to support the findings of Fuhs. Phosphorus loading in the West Brook watershed, which drains the Lake George Village area (a major summer resort) and receives the effluent of its sewage treatment plant, was only marginally higher than the phosphorus loading to Northwest Bay Brook draining undisturbed forest area. Phosphorus

TABLE 18. Hydrologic Values for West Brook and Northwest Bay Brook, Lake George, NY (Spring/summer, 1976) (1)

Stream	Watershed Area (ha)	Stream flow (m^3/sec) Maximum	Minimum	Mean
West Brook	2020	2.27	0.32	0.89
Northwest Bay Brook	6060	12.48	0.19	1.71

Stream	Watershed Area (ha)	Rainfall (cm/wk) Maximum	Minimum	Mean
West Brook	2020	6.53	0.00	2.53
Northwest Bay Brook	6060	5.46	0.25	2.42

(1)
Ref.: Palladine, 1976; and Kasper, 1976.

TABLE 19. Nitrogen, Phosphorus and Carbon Concentrations in Selected Inputs to Lake George (mg/l)

	Species	Maximum	Minimum	Mean
West Brook	TP as P	0.10	0.001	0.0117
	TSP as P	0.014	0.0003	0.0044
	SRP as P	0.010	0.00014	0.0031
	DOC as C	5.240	1.680	3.0488
	NO_3^- as N	1.30	0.05	0.65
	NH_4^+ as N	0.0335	0.0050	0.0142
	TKN as N	1.10	0.10	0.44
Northwest Bay Brook	TP as P	0.1000	0.0010	0.0111
	TSP as P	0.0470	0.0003	0.0045
	SRP as P	0.0045	0.0013	0.0023
	DOC as C	5.9300	1.9100	3.9065
	NO_3^- as N	0.80	0.04	0.18
	NH_4^+ as N	0.0595	0.0005	0.0095
	TKN as N	0.90	0.14	0.47
Rainfall	TP as P	0.075	0.005	0.031

Ref.: Palladine, 1976; and Kasper, 1976.

TABLE 20. Cumulative Loadings
(g/hectare)

Stream	TP (P)	TSP (P)	SRP (P)	DOC (C)	NO_3^- (N)	NH_4^+ (N)	TKN (N)
				OUTPUT - Bi-Daily			
West Brook	82.17	29.50	17.30	16,069.09	2,816.30	80.47	2830.68
Northwest Bay Brook	72.56	24.58	8.92	14,527.91	810.21	35.18	1936.22
				OUTPUT - Weekly			
West Brook	198.44	30.08	21.88	16,728.52			
Northwest Bay Brook	85.58	26.89	8.48	13,604.02			
				INPUT - Rainfall			
West Brook	142.38						
Northwest Bay Brook	138.39						

Ref.: Palladine, 1976; and Kasper, 1976.

FIGURE 20

WEST BROOK TP CONCENTRATION VS. DISCHARGE

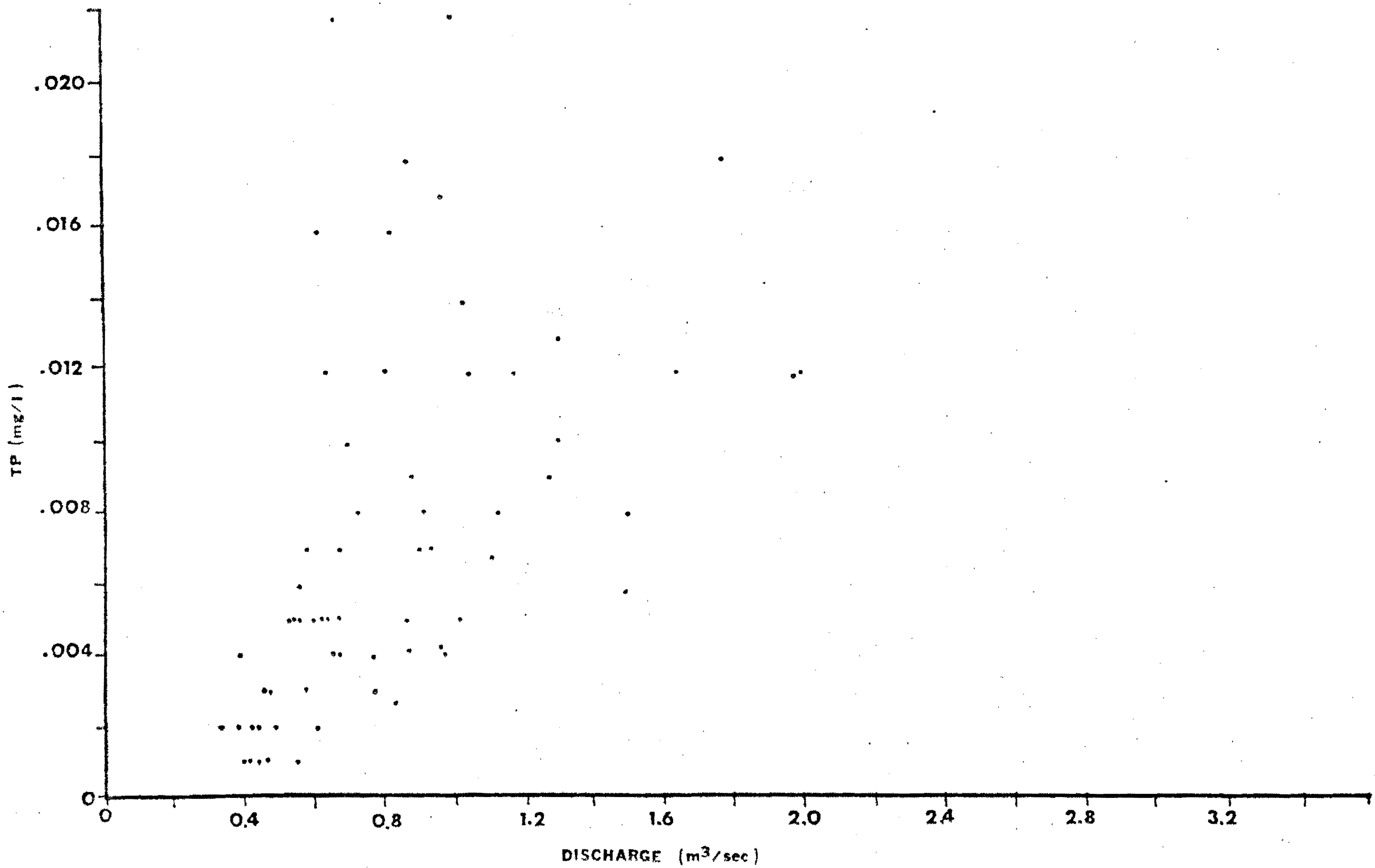


FIGURE 21

WEST BROOK NO_3^- CONCENTRATION VS DISCHARGE

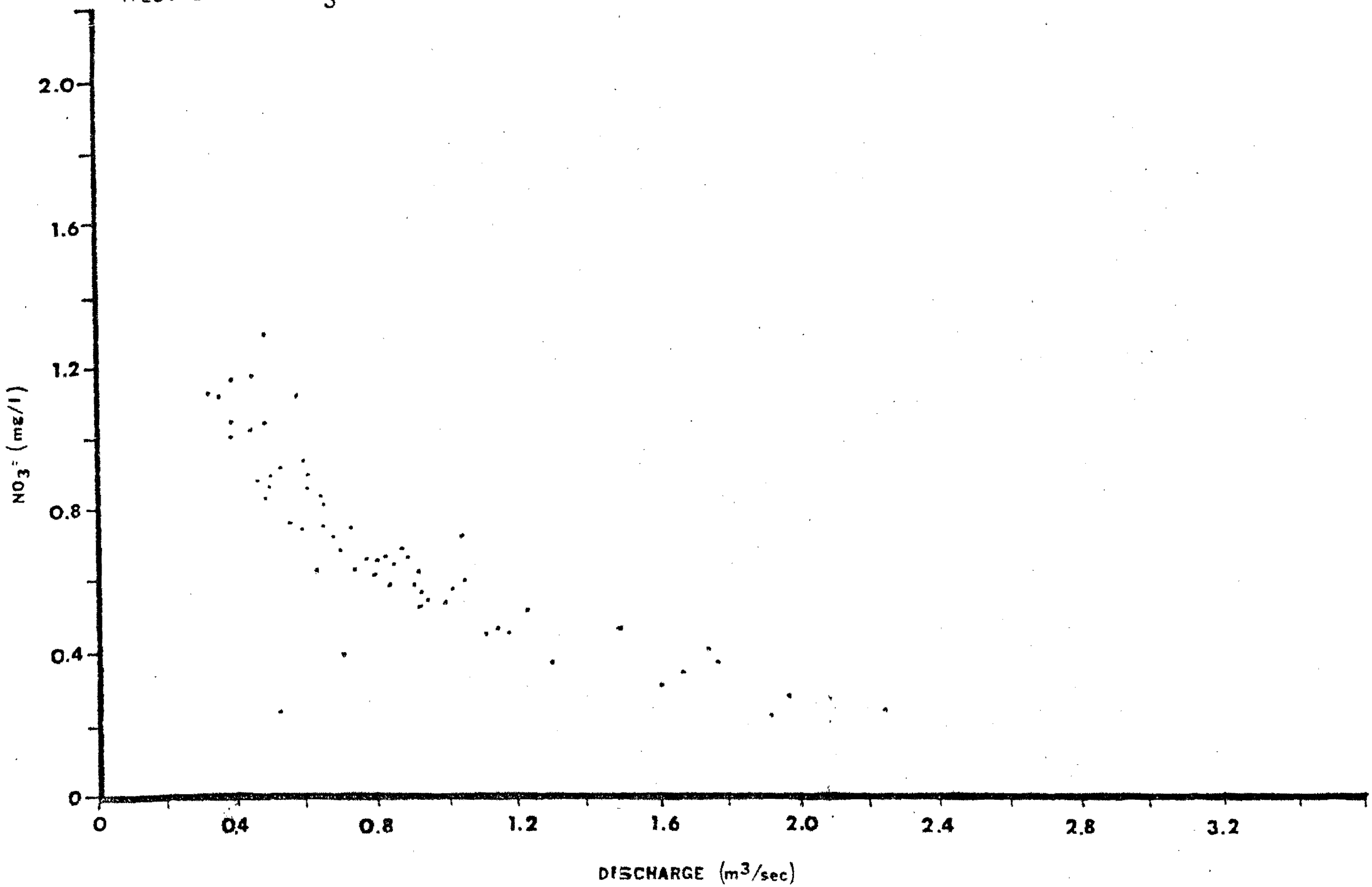
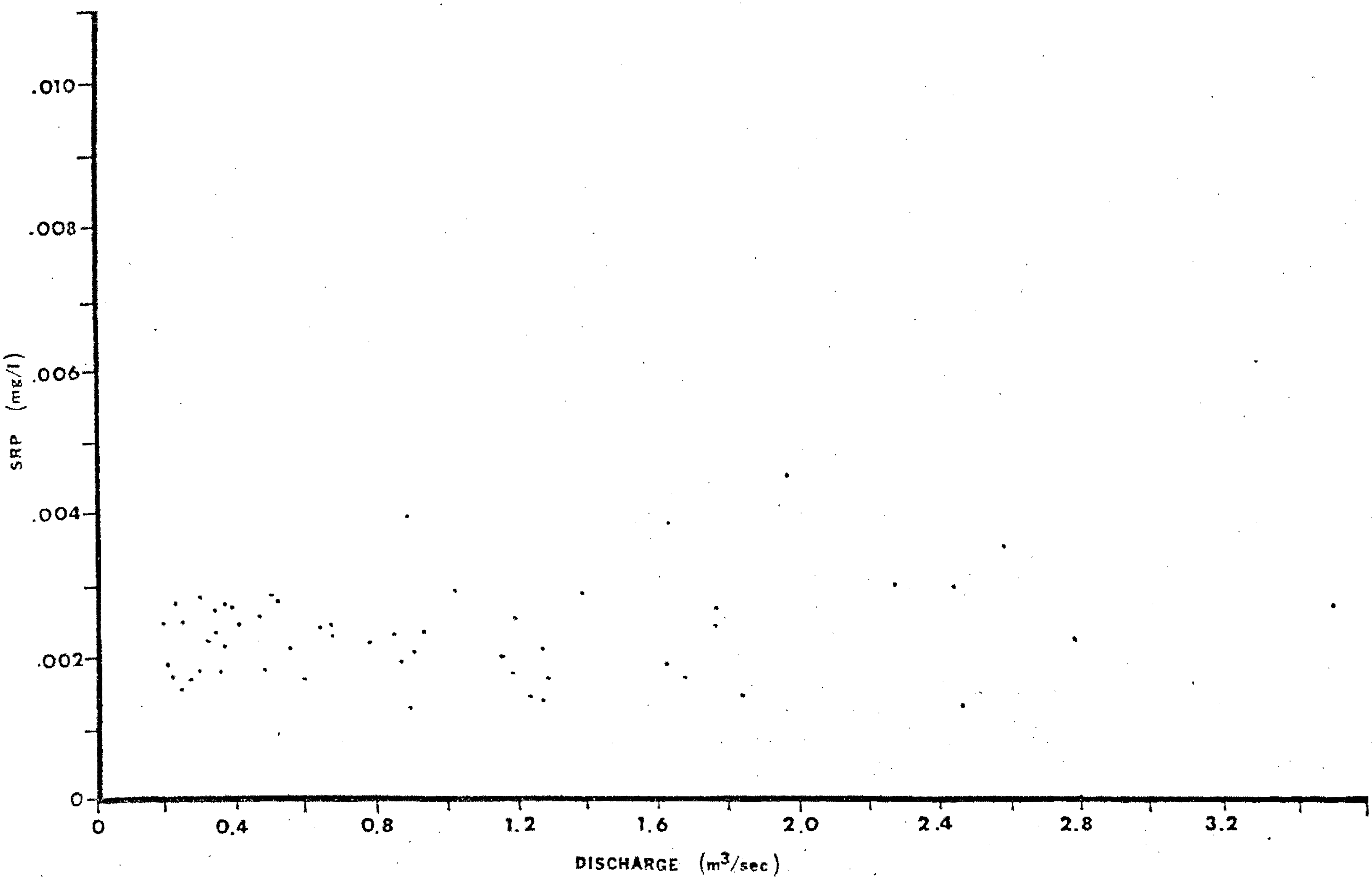


FIGURE 22

NORTHWEST BAY BROOK SRP CONCENTRATION VS. DISCHARGE



concentrations were not significantly increased over background levels by the sewered population of the resort areas.

Nitrate and ammonia concentrations were higher in West Brook than in Northwest Bay Brook. Higher loadings of nitrate and ammonia probably result from the subsurface seepage of the treatment plant effluent. The average TKN concentrations were similar for both streams, indicating that Northwest Bay Brook contains a higher percentage of TKN as organic nitrogen. Ammonia concentrations and loadings in Northwest Bay Brook remained low throughout the study period. The increased population and development in the Lake George basin seems therefore, to be increasing the input of nitrogen (as nitrate and ammonia) to the lake waters via tributaries.

Lake

pH - Lake George is a soft-water lake with near neutral pH values. These pH values are altered by biologic activity, principally carbon-dioxide uptake by photo-autotrophs. Table 21 contains pH data for Station 1 (see Figure 2) for a major portion of 1973. The values for March 6 were essentially consistent for the depths investigated, i.e., 6.92 to 7.03. The pH increased from this early sampling to a range of 8.07 to 8.19 by the April 17 sampling, possibly as a result of CO_2 uptake by photo-autotrophs beginning to increase their numbers prior to the spring growth. Both the March and April samplings were under ice cover, so the CO_2 uptake had a greater effect on the pH than if the lake surface were in contact with atmospheric CO_2. By the time of the next sampling on June 20, the pH decreased to values approximating 7.5, with little variation with depth. As the summer progressed, somewhat lower values were observed in the hypolimnion, as represented by the 20 m samples. The lowest pH value observed of 6.82 on September 12 may be a response to CO_2 production from decomposer activity in the hypolimnion. The pH values on November

TABLE 21. REPRESENTATIVE pH VALUES FOR THE SOUTH BASIN OF LAKE GEORGE

Station 1* 1973

Date:	3/6	4/17	6/20	7/18	8/2	8/29	9/12	10/31	11/20
Depth (m)									
0.5	6.97	8.17	7.54	7.76	7.72	7.77	7.50	7.30	7.43
5.0	6.96	8.07	7.60	7.71	7.61	7.78	6.99	7.14	7.41
10.0	7.03	8.13	7.72	7.84	8.09	7.70	7.00	7.50	7.50
15.0	6.95	8.14	7.59	7.38	7.58	7.37	6.95	7.42	7.40
20.0		8.19	7.56	7.15	7.55	7.22	6.82	7.16	7.46
21.0	6.92								
23.0								6.82	
23.5		8.19							
25.0			7.12						

*See Figure 2.

Ref.: Aulenbach and Clesceri, 1973.

20 were consistent with the depth because the lake was undergoing fall turnover. There appeared to be a downward trend in pH in the epilimnion, from a high of 8.17 (on April 17) to 7.43 (on November 20). Subsequent pH observations have indicated that these values were not atypical for Station 1.

Average values of pH for the south and north basins of Lake George vary seasonally from 7.2 (winter-spring) to 7.6 (summer and fall).

Alkalinity - The alkalinity of Lake George approximates 20 to 25 mg $CaCO_3$/L, with values as low as 16.5 mg $CaCO_3$/L. No significant spatial or temporal variations were observed. This alkalinity represents buffer capacity for the system, as well as being a source of carbon for photosynthesis by the equilibration of the $CO_2 \leftrightarrow HCO_3^- \leftrightarrow CO_3^{2-}$.

Hardness - Lake George is considered a soft-water lake, and this is borne out by the few measurements (USGS, 1975) of the calcium and magnesium concentration of its waters. The calcium is approximately 12 mg Ca^{2+}/L; the magnesium is approximately 2.3 mg Mg^{2+}/L. This corresponds to a total hardness of approximately 40 mg $CaCO_3$/L, of which 14 mg $CaCO_3$/L is carbonate hardness and 16 mg $CaCO_3$/L is non-carbonate hardness.

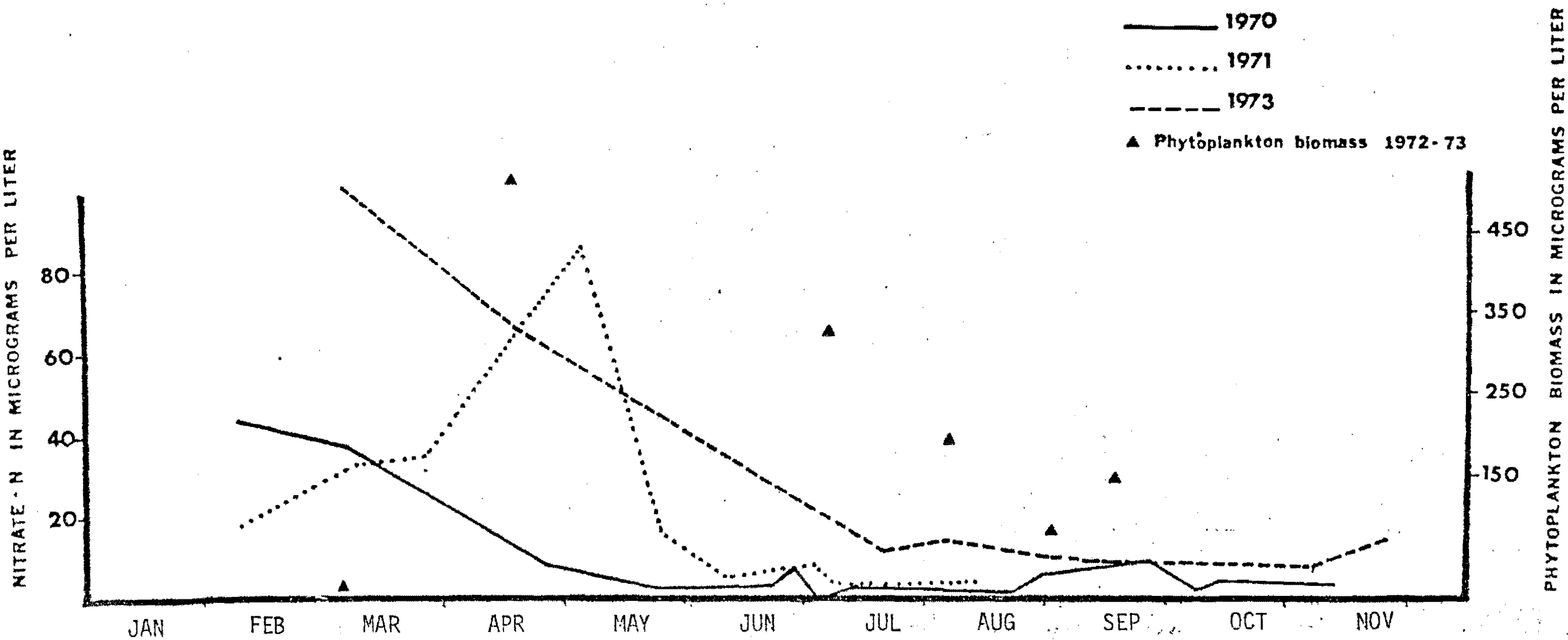
Nitrogen - The nitrogen in Lake George is present as ammonia-nitrogen, complex nitrogen, and nitrate-nitrogen. Like other north-temperate lakes, Lake George exhibits a late-winter to early-spring influx of nutrients, characterized by increases of nitrate concentrations (Figure 23) during this period. Accumulated precipitation, in the form of snowpack on the drainage basin, represents the primary nutrient source, augmented in the spring by soil leaching by the runoff.

The nitrate concentrations during the influx period depend upon both the pattern of spring warm-up and the total precipitation. Nitrate concentrations in the precipitation are usually 10X to 100X greater than in the lake water

FIGURE 23

NITRATE CONCENTRATIONS IN LAKE GEORGE, N.Y.

STATION 1 AVERAGED CONCENTRATIONS OF THE TOP 10 METERS



and are not diminished by adsorption, as in the case of phosphates. The Lake George area commonly experiences several thaws when the ice cover is on the lake, often substantially increasing the nitrate levels under the ice. During a winter with essentially no thaws, nitrate increases are delayed until the ice-out period. The ice cover itself increases this effect, since in the Lake George catchment area the lake surface represents approximately 19% of he total area.

This effect is illustrated by data observed near Station 1 for 1970-1973. A gradient of nitrate was observed from higher concentrations near the shore to lower concentrations as the distance from shore increased to Station 1. The concentration in the fall of 1970 was 5 ug N/L and increased to 85 ug N/L in spring of 1971; by May of 1971, the concentration had dropped significantly to 5 ug N/L, probably as a result of biotic uptake. Thus, nitrate-nitrogen may be a key nutrient in the functioning of the Lake George ecosystem.

Ammonia-nitrogen constitutes approximately 2-24 percent, of the total Kjeldahl-nitrogen. Table 22 has data for total Kjeldahl nitrogen, at various depths, for Stations 1 and 6 (Figure 2) in 1973. The mean value for Station 1 is 0.219 $\pm$ 0.046 mg N/L and the mean value for Station 6 is 0.198 $\pm$ 0.141 mg N/L. This Kjeldahl nitrogen does not vary considerably with time of year.

In contrast (Table 23), ammonia nitrogen apparently peaks in the beginning of the year (March 6), with approximately 30 ug N/L in solution, then decreases for April through July with an upswing in early September and a gradual decrease later in this month to values of 5 to 15 ug N/L in November of 1973. While no winter values are presented, ammonia, like nitrate, may build up under the ice, albeit not to as extensive a degree.

<u>Phosphorus</u> - Lake George has been described as a "double lake" (Aulenbach and Clesceri, 1973), divided as shown in Figure 5. The "south lake" receives

TABLE 22

TOTAL KJELDAHL N (mg N/L)

Station 1*

Date 1973	Depth (m)					
	0.5	5.0	10.0	15.0	20.0	23.0
3/6	0.218	0.237	0.187	0.157	0.198(21m)	
7/5	0.212	0.220	0.208	0.179	0.130	
7/18	0.176	0.260	0.269	0.186	0.202	
2/3		0.302		0.236	0.167	
2/29	0.230	0.146	0.132	0.168	0.189	
9/12	0.324	0.312	0.248	0.309	0.240	
9/26	0.195	0.277	0.235	0.216	0.202	
10/31	0.267	0.230	0.266	0.245	0.221	0.203
11/20	0.178	0.205	0.202	0.247	0.185	

Station 6*

Date	Depth (m)					
	.5	5.0	10.0	15.0	20.0	25.0
7/5	0.101	0.062	0.086	0.138	0.127	
7/18	0.193	0.212	0.196	0.269	0.343	
8/29	0.138	0.170	0.103	0.107	0.137	0.102
9/12	0.251	0.246	0.249	0.100		
9/26	0.199	0.191	0.191	0.190	0.207	0.208
						0.200(30)
						0.206(35)
11/20	0.173	0.186	0.175	0.177	0.197	

Station 1: Range: 0.130-0.324 Mean: 0.219 ± 0.046

Station 6: Range: 0.062-0.343 Mean: 0.198 ± 0.141

*See Figure 2.

Ref.: Aulenbach and Clesceri, 1973.

TABLE 23. AMMONIA CONCENTRATIONS IN LAKE GEORGE

µg/L

Station 1*

Date: 1973	3/6	4/17	7/18	8/29	9/12	10/31	11/20
Depth (m)							
0.5	32	18	14	33	26	07	8
5.0	24	12	29	23	29	10	5
10.0	26	15	32	24	6	8	
15.0	38	10	7	21	25	11	15
20.0		11	31	31	32	8	10
21.0	28						
23.0							
23.5							

*See Figure 2.

Ref.: Aulenbach and Clesceri, 1973.

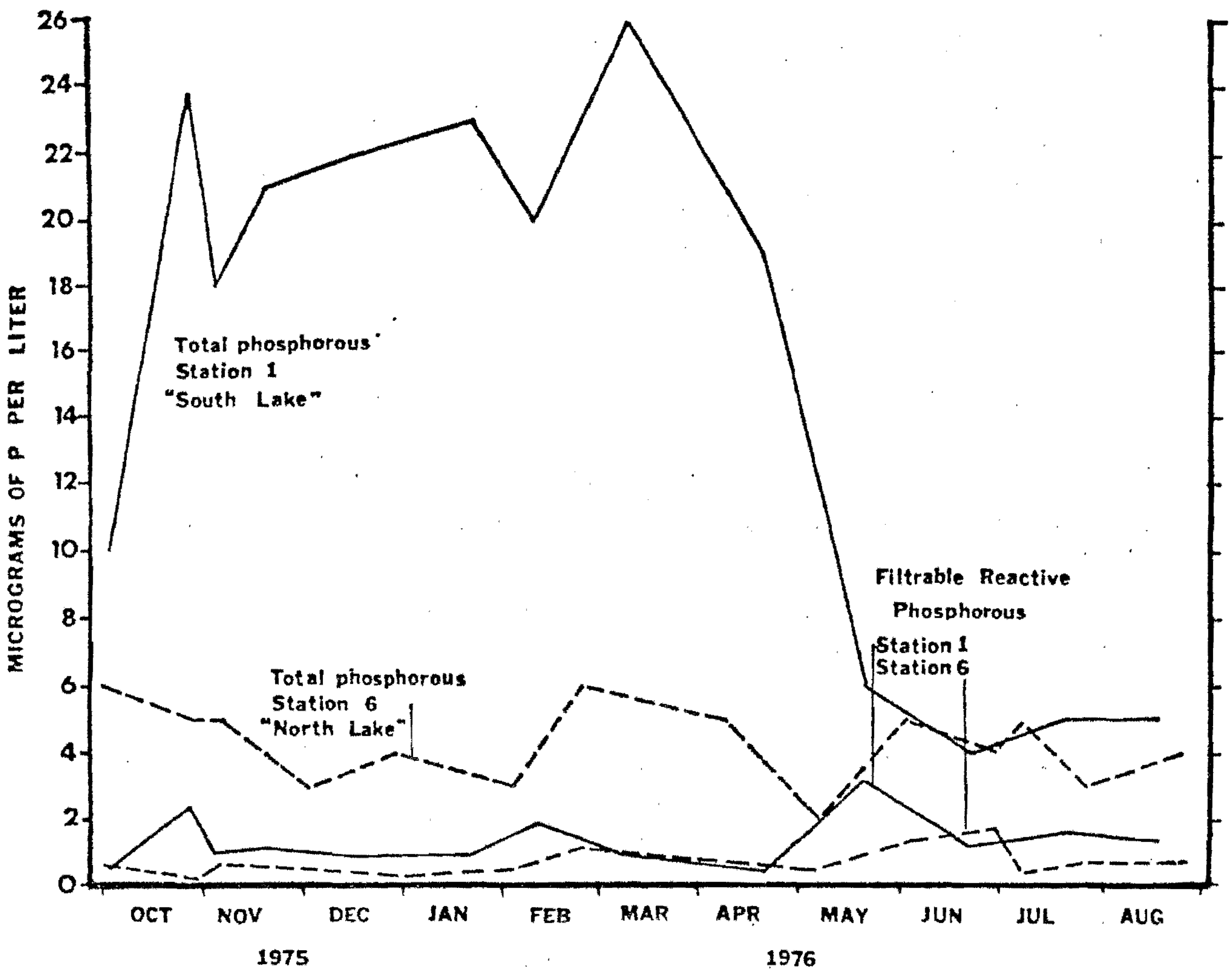
the greater quantity of allochthonous material, particularly from anthropogenic sources. Total phosphorus levels in 1975-76 were higher in the "south lake," but apparently this condition exists only from the late fall to early spring (Figure 24). Further, it is unknown if these higher levels of total phosphorus exist throughout the entire "south lake," or just in the south basin (see Figure 5) as exemplified by Station 1. Previous samplings at station 1 (Aulenbach and Clesceri, 1971, and Aulenbach, 1972) noted considerably lower concentrations of total phosphorus in the "south lake" than in 1975-76, with values in the "south lake" approximately 8 µg P/l and 6 µg P/l in the "north lake".

The relatively high levels of total phosphorus seem to coincide with the times of fall over-turn and spring ice-out. However, the completely oxygenated condition of Lake George waters makes phosphorus regeneration from the sediments unlikely, and also no stratification of phosphorus has been found. Thus, the increased level of phosphorus is unrelated to fall turnover and replenishment from hypolimnetic waters. Other processes which may result in increased phosphorus levels are related to the end of the growing season. These include the annual leaf-fall, with leaching of phosphorus occurring both in the individual watersheds and directly in the lake (which receives substantial quantities of wind-bourne leaves). Die-off of macrophytes also is a source of phosphorus. Macrophytes are more extensive in the "south lake" than in the north, and the major wetlands in the basin border the "south lake."

Precipitation is another significant source of phosphorus, with an average concentration of 20 µg P/l. Long-term precipitation records for the area show that greater amounts fall on the "south lake" than on the north. Following the onset of ice cover phosphorus is stored in the snowpack; this source then becomes available following ice-out. The reports of Aulenbach and Clesceri (1971), and Aulenbach (1972), show an increase in total phosphorus between

FIGURE 24

PHOSPHOROUS LEVELS IN LAKE GEORGE, N.Y., FOR 1975-76



March and April for the "south lake" station, which would coincide with the ice-out period.

The substantial decline in phosphorus levels in the "south lake" in the late spring undoubtedly relates to the uptake by phytoplankton. Stross (1972) found that mean daily production for phytoplankton peaked during the mid-April to early May period. The total phosphorus decline during this period implies that it has moved into the food web and into the sediments of the lake. Since the total phosphorus measurement is made upon the collected samples, higher organisms which have the capability of avoiding the sampling instrument are not included in the measurement. In addition, these organisms are not dispersed through the water column, e.g., the zooplankton and fish, and, therefore, are not representedly sampled.

Sinking of the phyto- and zooplankton transports the phosphorus out of the water column into the sediments where it is expected to be retained. In his nutrient budget for Lake George, Gibble (1974) estimated that sedimentation retained 73.8% of the phosphorus loading.

The lack of phosphorus dynamics in the "north lake" does not imply that the processes already discussed for the "south lake" do not occur. However, as noted in other sections of this report, the "north lake" receives a smaller phosphorus loading than does the "south lake," and also supports a smaller phytoplankton biomass. Thus, the processes occur at smaller magnitudes and may be "masked" by other factors such as those noted for sampling.

Silicon - The average level of silica in Lake George is 1.5 mg SiO_2 per liter, but variations occur spatially, with season, and with depth (Judd, 1972).

In Lake George, silica levels in the upper 10 meters are highest in the winter, decline through the early summer, and maintain their lower levels until fall turn-over. Silica concentration does exhibit stratification, this effect being most pronounced in the south basin. Much of this stratification probably is due to silica uptake in the photic layer by diatoms (which dominate the algal community), transport through the hypolimnion by settling, and dissolution of the frustules in the hypolimnion. Judd (1972) reports that reactive silica concentrations in unfiltered samples increased on standing, and this effect was particularly noticeable in the bottom-most samples collected. Judd, however, also found that substantial quantities of silica could be leached from the deep sediments, providing a potential source for the hypolimnetic waters.

The highest levels of silica were found (Judd, 1972) in the south basin; silica levels in the central and north basins were similar. Thus, average silica concentrations were 1.74 mg SiO_2/l in the south basin, 1.46 in the central basin, 1.53 in the Narrows, and 1.51, 1.58, and 1.48 in the north basin (each figure is for a separate sampling station in the lake).

The lower levels of silica in the upper 10 meter layer (1.3 mg SiO_2/l) would not be limiting to the diatom community (Hutchinson, 1957). Asterionella and Tabellaria would be limited at the 0.5 mg SiO_2/l level; Melosira, at the 0.8 mg SiO_2/l level.

Trace Metals - While extensive measurements of trace metals were not performed, periodic measurements of iron, manganese, copper and zinc, along with other chemical parameters, were made of the lake water as well as of the precipitation falling on the lake and in the influent streams during 1970-1971 (Williams, et al. 1973). Table 24 lists the mean seasonal dissolved concentrations of these four metals in the north and south lakes of Lake George at three depths. Table 25 lists the seasonal concentrations of these elements entering the lake in the precipitation and streams. The amount of iron, manganese, and zinc in the suspended material in the lake (filter residue) was too low to

TABLE 24

Mean Seasonal Concentrations of Fe, Mn, Cu and Zn in the North and South Lakes of Lake George

(Williams, et al 1973)

Season	Depth (m)	South Lake (µg/l) Fe	Mn	Cu	Zn	North Lake (µg/l) Fe	Mn	Cu	Zn
Winter	3	27.2	2.0	5.2	43.4	35.2	1.9	2.7	51.1
(Jan. 1-Mar. 31)	9	42.1	2.1	3.5	49.3	34.8	1.3	2.0	79.6
	15	30.6	1.6	3.7	44.4	50.7	2.3	2.2	76.6
Spring	3	25.1	3.2	3.9	32.7	41.5	2.9	2.6	33.5
(Apr. 1-June 21)	9	17.3	2.5	4.2	28.0	26.2	2.5	3.5	53.2
	15	16.9	4.0	3.8	30.4	35.4	3.2	3.2	38.6
Summer	3	29.0	2.6	3.4	46.4	29.8	2.0	3.0	74.9
(June 21-Sept. 21)	9	23.5	2.2	3.1	31.8	23.8	3.3	3.2	40.4
	15	28.8	4.1	2.9	34.2	23.6	1.9	2.9	23.9
Fall	3	46.1	1.8	3.1	25.1	13.8	1.4	1.6	71.1
(Sept. 21-Dec. 7)	9	39.9	1.7	2.5	23.3	20.5	1.2	1.7	88.3
	15	30.3	2.5	2.6	43.5	14.5	1.1	2.0	74.5

TABLE 25

Mean Concentrations of Fe, Mn, Cu and Zn in Lake George Influent Streams and Precipitation

(Williams, et al 1973)

	Streams (μg/l)				Precipitation (μg/l)			
	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn
Winter	48.8	7.1	3.6	27.7	43.1	3.8	6.4	31.3
Spring	38.5	2.1	3.9	8.9	75.0	8.1	11.2	48.5
Summer	39.7	7.5	3.7	7.3	45.1	3.2	7.6	32.1
Fall	42.5	7.2	6.8	10.0	36.0	7.5	21.4	84.9
Snowpack on Lake					6.2	5.6	23.8	23.0

measure (< 5 μg/l for Fe and < 0.25 μg/l for Mn and Zn). Copper was occasionally as high as 1 μg/l in the suspended material, but most of the time was less than 0.25 μg/l. The levels of dissolved iron, manganese, and copper in the lake are consistently lower than the concentrations in the entering streams and precipitation, indicating that these elements are being lost to the sediments.

Sediment Characteristics - Extensive studies of the bottom sediments of Lake George were conducted by Schoettle and Friedman. In the south Lake George basin, most of the bottom sediments contained between 5 and 10% organic carbon (Schoettle and Friedman, 1973). Close to the east shore and in bays of the east shore, however, the organic carbon content exceeded 10%. By contrast, near the west shore and in two tongues that pass beneath the central part of the lake, the organic carbon content was less than 5%. The bottom sediments of the Narrows were mostly depleted in organic carbon, whereas the bottom sediments of the north Lake George basin contained between 5 and 10% organic carbon in the center of the lake, but less than 5% near the shore. Near Ticonderoga, the bottom sediments of the northermost part of Lake George contained less than 5% organic carbon.

As the high amount of organic carbon indicates, with values exceeding 10% and with most of the bottom sediments containing between 5 and 10% organic carbon, a large part of the clay-size fraction consists of organic matter. Most lake sediments contain between 8.6 and 17.2% organic matter.

The recognizable structural organic matter in the nearshore sediments was mostly leaves, needles, spore capsules, and tree bark, which enter the lake mainly in the fall when the trees shed their leaves, and wind and water carry the debris into the lake. (Schoettle and Friedman 1971). This organic matter also gets trapped in the deeper parts of the lake where it becomes progressively degraded and unrecognizable. Hence, much of the incoming sediment load consists of the annual crop of organic material contributed by the vegetation in the Lake George drainage basin.

The high organic carbon content of the bays in the south Lake George basin results from the decomposition of actively growing aquatic plants (macrophytes) that live in the bays. Moreover, marshes feed the bays and the rooted aquatic plants baffle the introduced fine-grained organic-rich detritus which accumulates in the bays. Beds of Nitella occur in the three large bays along the southeast shore of the southern Lake George basin.

In addition, phytoplankton contribute to the sediments' high content of organic matter. The organic carbon content of the clay-size sediments in the deeper parts of the southern Lake George basin was by and large, greater than that in the northern Lake George basin. This increase in organic carbon correlates with the higher phytoplankton productivity in the southern basin. Phytoplankton productivity is 2-1/2 times higher in the southern than in the northern basin (Stross, 1970). In the northern basin between the Narrows and Huletts Landing, the organic carbon concentration of the lake bottom sediments was greater than that of the rest of the northern basin between Huletts Landing and Ticonderoga Creek.

Excluding organic matter, the clay-size material conisted of quartz and clay minerals derived from the local metamorphic and igneous bedrock, and the glacial sediments. The clay minerals identified included mostly illite and chlorite, with traces of kaolinite. Throughout the cores studied, the same clay mineral occured unchanged.

The shallower parts of the lake are bottomed by sand sediments. In fact, the shallows and sandy sediments match to the extent that two sandy tongues in the center of the southern lake basin follow shallows that advance into the lake from the western shore. Exceptions to this general rule, i.e., sand increases as the bottom shoals, are the bays in the southern Lake George basin.

In the sands the light minerals were quartz and feldspars with more plagioclase than orthoclase, some microcline, muscovite and biotite. Garnet dominated the heavy mineral fraction. Other less abundant heavy minerals included hornblende, sillimanite, epidote, hypersthene, augite, staurolite, kyanite, zoisite, zircon, tourmaline, rutile, titanite, and iron-rich biotite.

In the Narrows, a tough, greasy, varved glacial clay of brown coloration floors the lake bottom. This varved clay hosts iron-manganese nodules which occur in the uppermost 5 cm of the clay (Schoettle and Friedman, 1971). Some parts of the Narrows are solidly floored with a carpet of nodules. Iron-manganese nodules are confined to a stretch of lake extending for about 8 km (5 miles) north and south of the Narrows. In this stretch of lake, where the varved glacial clays occur, currents prevent organic matter from accumulating and keep the relict glacial clays exposed.

The iron-manganese nodules have been radiocarbon-dated (Mobil Research and Development Laboratory, Dallas, Texas; S M 1322) revealing an age of 3,316 $\pm$ 475 years. This represents an average age for the many nodules needed to provide enough material for a radiocarbon date analysis. Because this age is an average for many nodules, it does not reveal if nodules are presently forming. However, this confirms the absence of modern sedimentation in those areas where nodules floor the lake bottom. Active currents have, for at least 3300 years, kept the nodules exposed by sweeping away the sediment.

The nodules studied are surprisingly light. The density ranges between 1.86 and 2.57, with an average density of 1.99 g/ cm^3. They are, therefore, lighter than marine manganese nodules, which have an average density of 2.49 g/ cm^3 (Mero, 1965).

Table 26 gives the chemical composition (major and some trace elements) of the iron-manganese nodules and underlying glacial sediments for seven sampling stations in Lake George. The underlying glacial sediments consist mostly of clay material. This table shows that in comparison with the underlying sediments, both the major and the trace elements studied are enriched in the nodules.

Two core samples, each measuring about 50 cm, were collected, one from the northern basin and the other from the souther basin. Both cores were taken in trenches at a depth (> 30 m) known to act as a trap for organic matter and incoming sediment load.

The core from the northern basin penetrated the entire thickness of modern organic-rich sediment and terminated in relict glacial clays. The core from the southern basin did not reach the underlying relict glacial sediment; hence, the organic-rich clays are thicker in the southern basin than they are in the northern basin. The relict glacial clays contain much less organic carbon than the modern clays. The amounts of Fe, Cu, Cr and Zn (Table 27) were generally less in the deeper lying sediments. Thus, the deeper lying sediments reflect the Lake George source area background.

TABLE 27. Heavy Metals Content of Lake George Clays (Schoettle and Friedman, 1975)

	%				ppm					
	Fe		Mn		Cu		Cr		Zn	
Section	T	B	T	B	T	B	T	B	T	B
South Core	7.7	3.1	0.16	0.28	43	32	54	13	290	110
North Core	4.3	4.5	0.05	0.05	26	38	36	52	140	110

T = 0 - 5 cm
B = 40 - 45 cm

TABLE 26

Chemical Composition of Lake George, N.Y., Iron-Manganese Nodules and Underlying Glacial Sediments

Area		%Mn	%Fe	%Cu	%Co	%Ni	%Zn
North Lake George	N	2.55	40.20	0.1529	0.0350	0.0912	0.1341
	S	0.15	4.80	0.0080	0.0100	0.0220	0.0410
Narrows	N	2.25	30.70	0.1433	0.0250	0.0600	0.0734
	S	0.28	4.30	0.0220	0.0160	0.0240	0.0284
South Lake George	N	16.65	18.80	0.0939	0.0223	0.0777	0.1192
	S	0.30	4.50	0.0240	0.0130	0.0220	0.0296
	N	1.25	27.80	0.0938	0.0109	0.0783	0.2098
	S	0.57	6.30	0.0160	0.0150	0.0880	0.0500

N = Iron-manganese nodules; S = Underlying glacial sediment

BIOLOGICAL

Phytoplankton

Table 28 lists the principal species of phytoplankton found in Lake George.

Table 29 (Howard, 1973) shows the range of mean value (with depth) of biomass at Station 1. The highest estimated biomass concentration observed was on April 17, just before ice-out. Throughout the year the highest concentrations usually occurred at the 2 or 5 m depth.

During the period of study, diatoms dominated the net plankton biomass in 26 out of 31 observations. *Cyclotella comta* was the most frequently dominant diatom (September 1972, July and August 1973) while *Asterionella formosa* dominated in March and April 1973. *Stephanodiscus astrea* dominated at one depth on two occasions: September 1972 and July 1973. Other dominant plankton were *Anabaena sp.* (November 1972, 0.5 m), *Eudorina elegans* (November, 1972, 5 m), *Cryptomonas sp.* (March 2, 1973, 5 m), *Dinobryon divergens* (co-dominant with *Cyclotella* at 15 m in July, 1973), and unknown coccoid alga (November 1972, 10 m). Dominant organisms on any date were usually dominant at all depths.

In contrast to their importance in the biomass, diatoms were dominant only 13 times as particles. Unidentified flagellates or other forms were dominant in 11 samples. Particle dominants were also usually distributed uniformly with depth. Of the phyla identified in the phytoplankton, only the Pyrrophyta was not dominant as biomass or particles. Particle numbers ranged from 1.14×10^6 to 0.052×10^6/L.

When considering plankton size categories, net, nanno- and ultraplankton the latter two made up, on the average, about 90% of the organisms observed. Proportions of nanno- and ultraplankton were about equal, except in March, April, and July, 1973 when nannoplankton was most abundant. Ultraplankton exceeded nanno-plankton in August and September, 1973. The highest proportions of net plankton were in March, 1973 (24 percent), April, 1973

TABLE 28. SPECIES FOUND IN LAKE GEORGE PHYTOPLANKTON (Howard, 1973)

Net plankton (maximum dimension greater than 50 u)

Staurastrum furcigerum De Brebisson

Spondylosium planum (Wolle) W. & G. S. West.

Tribonema sp.

Melosira sp.

Fragilaria crotonensis Kitton.

Asterionella formosa Rassall.

Synedra sp.

Gymnodinium sp.

Peridinium cinctum (Muell.) Ehrenberg.

TABLE 28 (continued) SPECIES FOUND IN LAKE GEORGE

PHYTOPLANKTON

Nannoplankton (maximum dimension 50 u or less)

Eudorina elegans Ehrenberg.

Sphaerocystis Schroeteri: (Wolle) W & G. S. West.

Gloeocystis gigas (Kuetzing) Langerheim.

Elakatothrix gelationsa Wille.

Planktosphaeria gelotinosa G. M. Smith.

Oocystis crassa Wittrock.

Oocystis pusilla Hansgirg.

Oocystis submarina Lagerheim.

Oocystis sp.

Botryococcus braunii Kuetzing.

Dimorphococcus lunatus A. Braun.

Ankistrodesmus falcatus (Corda) Ralfs var. acicularis (A. Braun) G. S. West.

Selenastrum minutum (Naeg.) Collins.

Quadrigula closterioides (Boblin) Printz.

Tetraedron minimum (A. Braun) Hansgirg.

Scenedesmus bijuga (Turp.) Lagerheim.

Crucigenia rectangularis (A. Braun) Gay.

Crucigenia tetrapaedia (Kirch.) W. & G. S. West.

Cosmarium sp.

Cosmarium sp.

TABLE 28 (continued) SPECIES FOUND IN LAKE GEORGE

PHYTOPLANKTON

Nannoplankton (maximum dimension 50 u or less)

Ochromonas sp.

Bitrichia chodati (Reverdin) Chodat.

Dinobryon bavaracum Imhof.

Dinobryon cylindricum Imhof.

Dinobryon divergens Imhof.

Epipyxis sp.

Mallomonas sp.

Mallomonas sp.

Cyclotella comta (Ehren.) Kuetzing.

Cyclotella stelligera Clet & Grunow.

Stephanodiscus astrea (Ehren.) Grunow.

Tabellaria fenestrata (Lyngb.) Kuetzing.

Meridion circulare (Grev.) Agardh.

Glenodinium pulvisculus (Ehren.) Stein.

Cryptomonas sp.

Chroococcus dispersus (Keissl.) Lemmermann.

Chroococcus limneticus Lemmermann.

TABLE 29. PHYTOPLANKTON BIOMASS IN LAKE GEORGE [1]

All data collected at Station 1 and reported as micrograms per liter*

DATE DEPTH (m)	9/13/72	11/7/72	3/6/73	4/17/73	7/5/73	8/4/73	8/29/73
0.5	144.	11.0	10.0	511.	325.	189.	79.0
2.0			51.0	758.	129.	461.	72.0
5.0	188.	11.0	124.	558.	261.	260.	131.
10.0	631.	5.60	80.0	531.	190.		126.
15.0	271.		103.	721.	188.	260.	106.
Avg.	301	9.1	73.6	615	219	245	102

* Assuming a density of 1 gm/cm^3

1. Data from Howard (1973)

(20 percent) and September 1973 (14 percent).

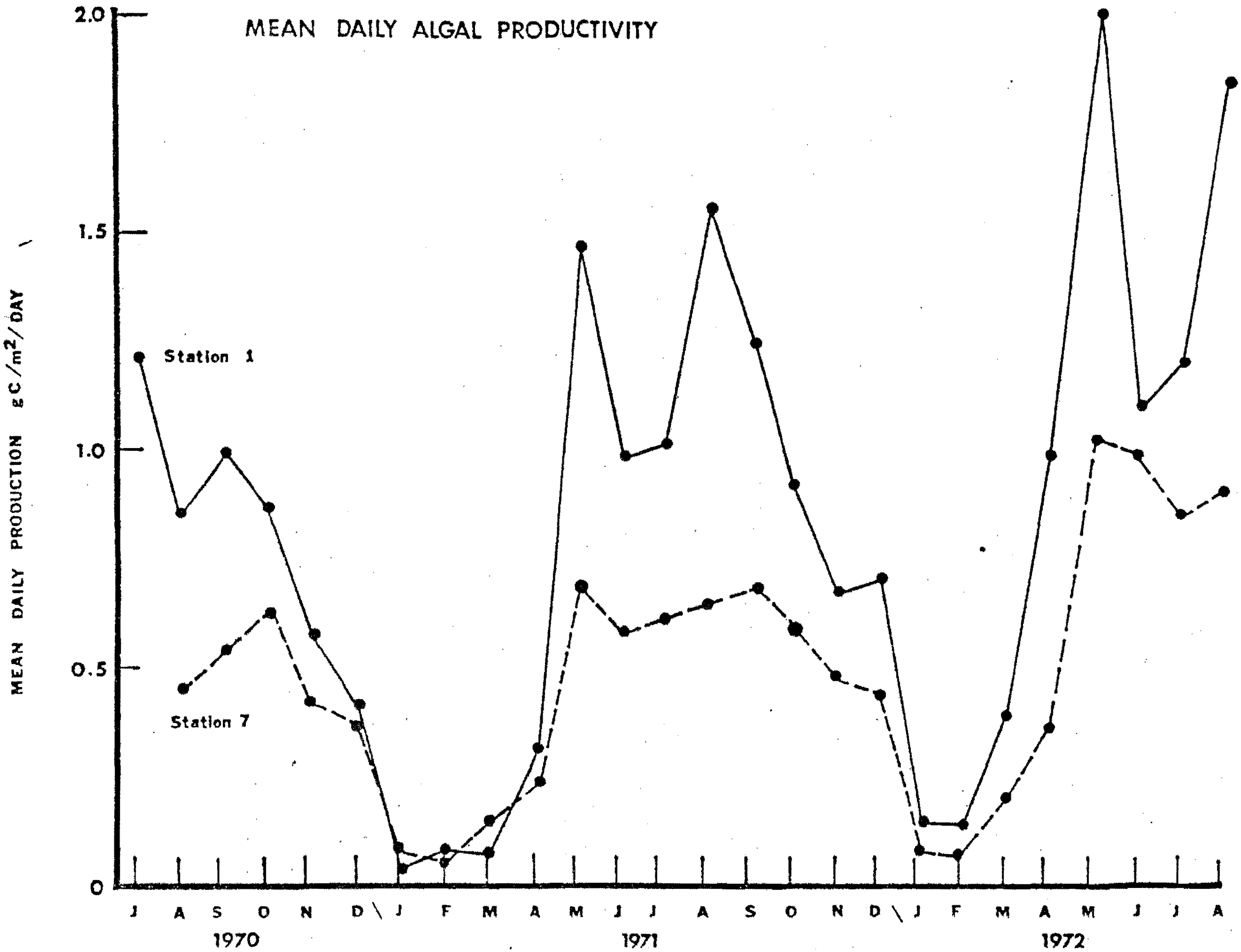
In Lake George, the general trend of light saturated rates of phytosynthesis is as expected (Stross, 1972). Maximum rates have been found for each year in the summer and autumn. P_{max} is usually greater at Station 1 in the south basin than at Station 7 in the north lake. Considering Station 1, an interesting pulse occurred during the summers of 1971, 1972, and 1973 which was restricted to the late July-August interval and repeated annually. The summer maximum recorded in 1970 was in July at 17.7 mg $C/m^3/hr$. In 1971 it was in August at 20.6 mg C/m^3 and in 1972 it occurred also in August at 31.1 mg $C/m^3/hr$. These hourly rates were converted to daily rates for th entire water column, and subsequently combined to give a mean daily rate for each month (Stross, 1972).

Figure 25 (Stross, 1972) shows these mean daily rates. Although the P_{max} were determined newly for each sampling date; the solar radiation data employed were for a single year from July 1971 to August 1972, exclusively. Consequently, the same light data were used. This results in the observation of a progressive increase in the mean daily production rate which approached a 50% overall increase in mean daily rate of phytoplankton photosynthesis over the 3 year period. The second pattern to emerge at Station 1 is an apparent bimodal distribution for the spring-summer interval. Since it occurs at this single station, it may not be attributed to the use of the same solar radiation data for each year.

Spatial-temporal patterns of photosynthesis in Lake George based on hourly rates of P_{max} estimates range from 4.4 to 31.1 mg C/ m^3/hr during the ice-free part of the year (Stross, 1970, 1971). However, these rates are more stable than is initially apparent. When variance from season, lake location, and time of day is removed, the algal metabolic activity becomes remarkably

FIGURE 25

MEAN DAILY ALGAL PRODUCTIVITY



stable. Indeed, seasonal variability at a station is about 2.2 to 3.0 fold when one excludes the period when the lake is covered by ice. This amplitude is quite small if one notes that solar radiation input at 45° is usually 2.0 in annual range. Regarding the variability in location or station in the lake, rates at Station 1 in the southern end of Lake George are usually 2.0 or more times higher than photosynthetic rates in samples at Station 7 near the northern end. Station 4, which is immediately north of the Narrows, may have rates the same as Station 1 or 7, or be intermediate. Combined, the sources of variability suggest a strongly fluctuating P_{max} when, in reality, the local variability at any one station is remarkably small indeed (Stross, 1972).

Local variability in P_{max} is quite small with few exceptions. In the overall analysis, profile and depth were set up with station as the main sources of variance. The main source of variance was station, and that was consistently significant. The only other main source of variance in the analysis was the effect of depth. During the late summer intervals, there was often an accumulation of photosynthetic standing crop (Newhouse, et al., 1967) in the thermocline at 10 and 15 meters depth.

Local variation was rarely, if ever, significant. In both the horizontal, as measured by comparison of profiles, and the vertical, as measured at five depths, variability in P_{max} was insignificant in a station-profile-depth three-way analysis of variance with exceptions. Vertical stratification of the photosynthetic standing crop was often associated with thermal stratification, especially in late summer. The larger than the mean P_{max} from depths of 10 and 15 meters were eliminated, however, from the mean P_{max} for each station. Error variance was always smaller than 10 percent of the variance at a station, and usually near 5 percent (Stross, 1972).

Diatoms

1. Total periphytic and planktonic diatoms

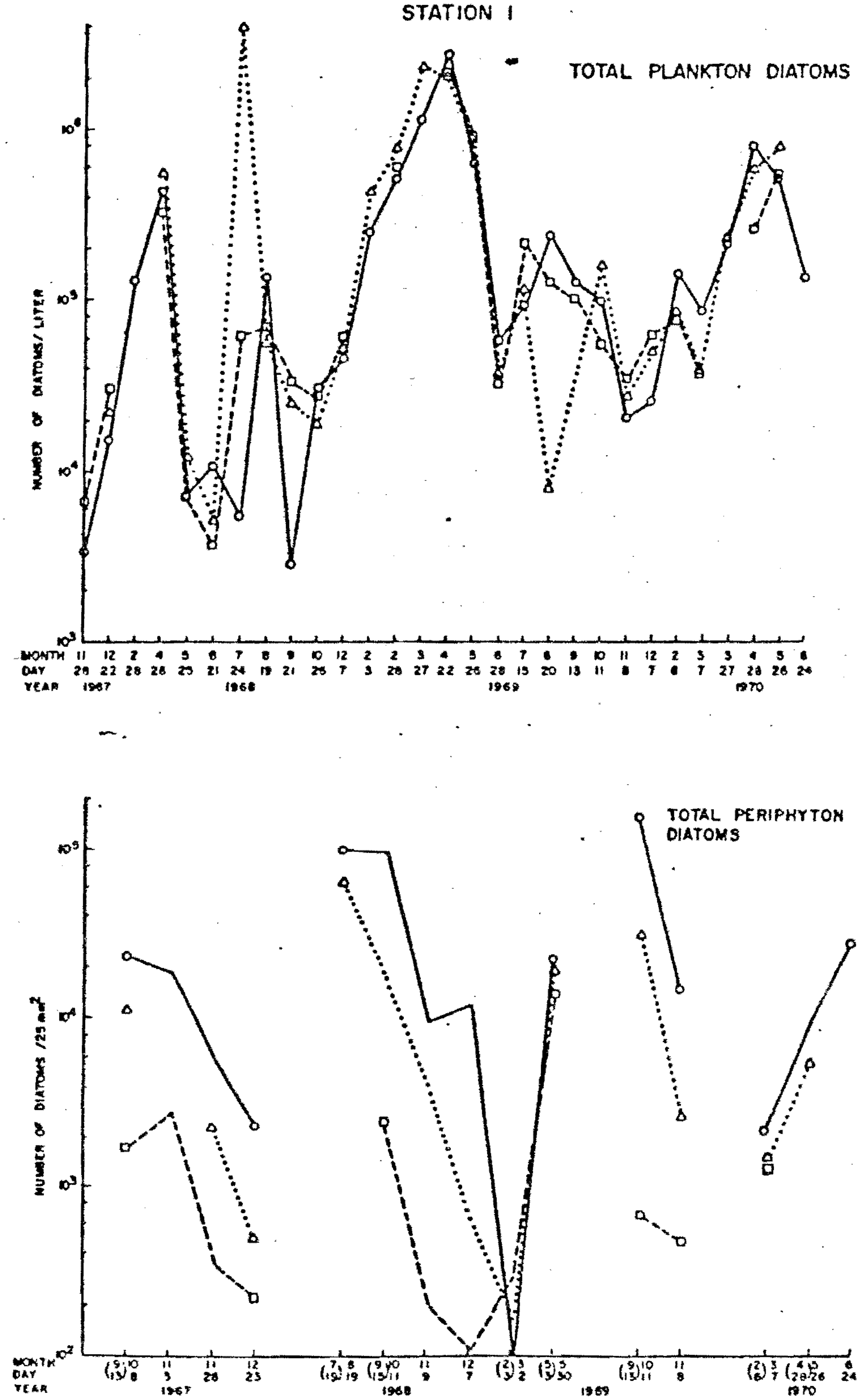
Figure 26 shows standing crops of planktonic and periphytic diatoms in the southern part of the lake (Station 1). (Williams and Clesceri, 1972). The standing crop of planktonic diatoms at 3 m started to increase each winter under ice cover, reaching a yearly maximum level during April. The 9 m and 15 m planktonic diatoms showed the same general behavior. In different years, however, the maximum standing crop occurred either in March, April or May. These dissimilarities may result from differences in light penetration resulting from variations in yearly ice thickness and overlying snow cover. The light penetration appeared greatest during the winter of 1968 and 1970 (Secchi disk reading of 7 m in March of 1970), with less snow cover in 1968.

During the winter of 1969 there was much greater snow cover and less dense (less transparent) ice cover. An earlier peak at 9 m in 1969 under these more adverse conditions may be due to the growth characteristics of *Synedra tenera**, which was the dominant diatom at all depths in March and April of 1969, as compared to *Asterionella formosa*, the dominant diatom during the comparable period for 1968 and 1970. Less pronounced secondary peaks appeared to occur in July or August, with the numbers declining in the fall. There was no increase at the end of October or early November when the fall turnover occurred. The growth at all depths measured in the winter under ice cover was high for all three years. The concentrations generally exceeded 100,000 diatoms/L at 3 m, reflecting the high degree of light penetration. The inverse temperature stratification occurring under the ice did not appear to have a reproducible

**Synedra tenera* and *Synedra radians* are used interchangeably. Recent scanning electron microscopic observations indicate that *Synedra tenera* rather than *Synedra radians* is probably the more prevalent of the two species in Lake George diatoms.

FIGURE 26

STATION I



See Figure 27 for Key

effect on the numbers of planktonic diatoms.

The periphyton data are not as complete as the data available for plankton. Periphytic diatoms are at a minimum during the winter under ice cover, attaining maximum concentration during the summer and early fall. Except for the period under ice cover when there was a slight inverse temperature stratification, the numbers of diatoms in the periphyton were consistently lower as the depth increased. In February 1969, under ice cover, the growth response was reversed, i.e., greater numbers were present at greater depths and higher temperatures. The absolute numbers during this period at all depths were very low: 101, 169, and 203 diatoms per 25 mm at 3 m, 9 m and 15 m respectively. As mentioned previously, however, the planktonic diatoms during this period were very high. In the winter of 1970, when the water at 3 m and 9 m was at the same temperature, the normal depth-growth pattern was observed but not at 15 m where the temperature was higher.

2. Principal diatom species in the plankton and periphyton

The principal diatom species found in the plankton and periphyton samples are listed in Table 30. Certain other genera and species found in the plankton and periphyton but which never reached 5% of the population in any sample and not listed in Table 30 include:

Achnanthes exigua and *A. coarctata*; *Amphora ovalis*, and *A. affinis*; *Cyclotella stelligera*, *C. kutzinghiana*, *C. antiqua*, and *C. comta*; *Cymatopleura solea*; *Cymbella ehrenbergii*, *C. affins*, *Diploneis elliptica*; *Eunotia formica*, *E. gracilis*, and *E. pectinalis*; *Fragilaria construents* and *F. brevistrata*; *Gyrosigma* sp.; *Gomphonema olivaceum*; *Melosira ambigua* and *M. roeseana*; *Navicula gibba*, and *N. bacillum*; *Nitzschia* sp.; *Pinnularia nobilis*; *Pleurosigma* sp.; *Stauroneis phoenicenteron*; and *Surirella* sp. (Williams and Clesceri, 1972).

TABLE 30

PRINCIPAL* DIATOM SPECIES IN LAKE GEORGE

PLANKTON AND PERIPHYTON SAMPLES

Achnanthes minutissima Kutz	Amphipleura pellucida Kutz
Achnanthes microcephala	Cocconeis placentual (Ehr.)
Asterionella formosa Hassal	Cocconeis pediculus (Ehr.)
Cyclotella operculata Ag.	Diatoma tenue v. elongatum Agardh
Cyclotella glomerata Bachm	Diatoma vulgare Bory
Fragilaria crotonensis Kitton	Eunotia arcus (Ehr.)
Fragilaria capucina Desmazieres	Eunotia major (W. Smith)
Melosira ambigua	Gomphonema acuminatum (Ehr.)
Melosira italica (Ehr.) Kutz	Meridion circulare (Grev.) Ag.
Melosira sp. -1**	Rhizosolenia eriensis H.L. Smith
Meridion circulare (Grev.) Ag.	Nitzschia palea
Stephanodiscus astrae	Navicula sps.
Stephanodiscus astrae var. minutula (Kutz) Grun.	Navicula sps.
Synedra acus Kutz	Rhopalodia gibba Epithemia zebra
Synedra tenera (W. Smith)	Cymbella cistula
Synedra ulna (Nitzch)	Cymbella tumida
Tabellaria flocculosa (Rothe) Kutz	
Tabellaria fenestrata (Lyngbye) Kutz	

* Species making up 5% or more of the total diatoms in one or more of the samples obtained at Station 1.

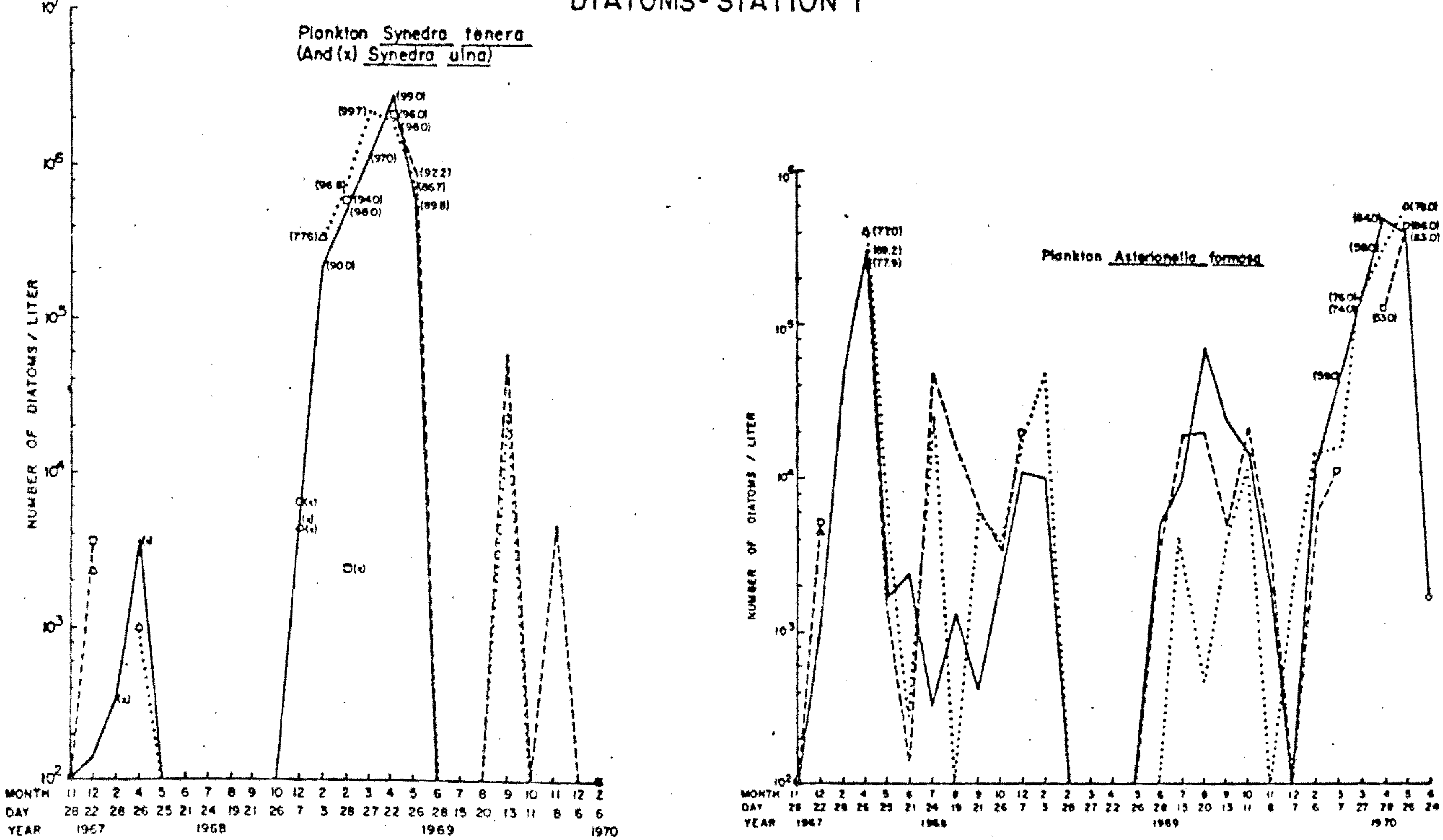
** The identity of this species has not yet been satisfactorily established.

3. Seasonal variation in the dominant diatom species;

Of the principal diatom species previously listed, seven of these species, or related pairs of species, were found at some time to exceed 50% of the total diatom population in the plankton of that sample, and their seasonal abundances are plotted in Figures 27 through 30. The greater than 50% criterion only represents one of many expressions of dominance. _Asterionella formosa_, _Cyclotella glomerata_ and _C. operculata_ combined, _Fragilaria crotonensis_ and _Tabellaria fenestrata_ not only on occasion were greater than 50% of the total plankton population, but also usually were abundant in the plankton samples throughout this entire period. _Stephanodiscus astrae_ and _S. astrae var. minutula_, while never meeting the 50% criterion, usually were as abundant as the diatoms mentioned above. _Melosira sp._ and _M. ambigua_ combined met the 50% criterion only once (9 m sample on 12/7/69), and did not occur as frequently as the diatoms metntioned above. _Synedra tenera_ and _Achnanthes minutissima_ were present as isolated "blooms" occurred. (Williams and Clesceri, 1972).

Of the diatom species listed in Table 30, only two species ever were found to exceed 50% of the diatom population in any of the periphyton samples. These two species were _Achnanthes minutissima_ and _Synedra tenera_, and their seasonal abundances are plotted in Figure 31. _Tabellaria fenestrata_ and _T. flocculosa_, when combined, reached 50% of the periphytic diatom population in one sample (11/9/68-12/7/68 at 3 m). The other diatom species which at some time dominated the plankton also were abundant in the periphyton, but were never dominant, and are shown in Figures 32 through 34. _Achnanthes minutissima_ usually was the most abundant species in the periphyton.

FIGURE 27
DIATOMS- STATION I



3 METERS —o— 9 METERS ····Δ···· 15 METERS ---□---

FIGURE 28
DIATOMS- STATION I

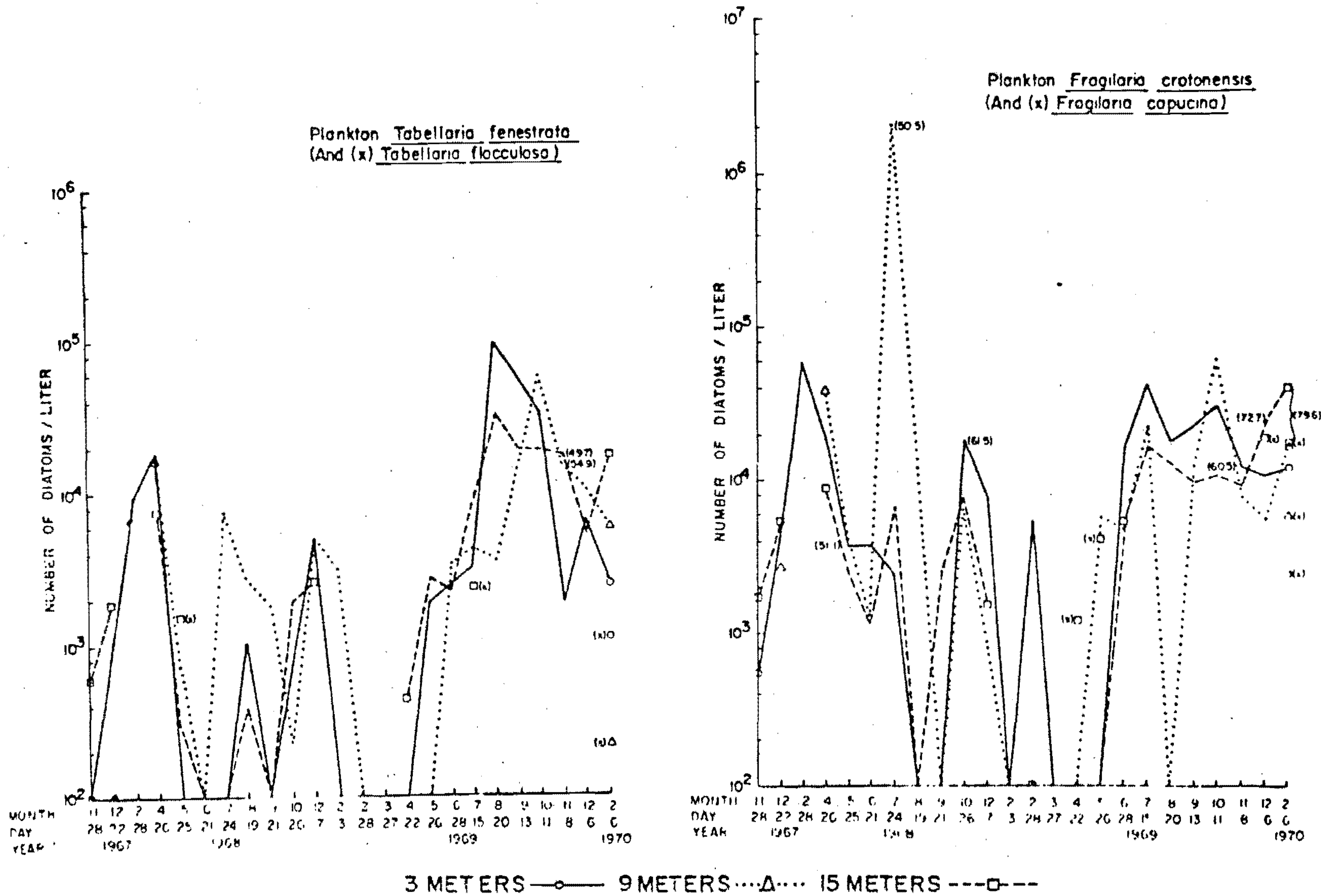
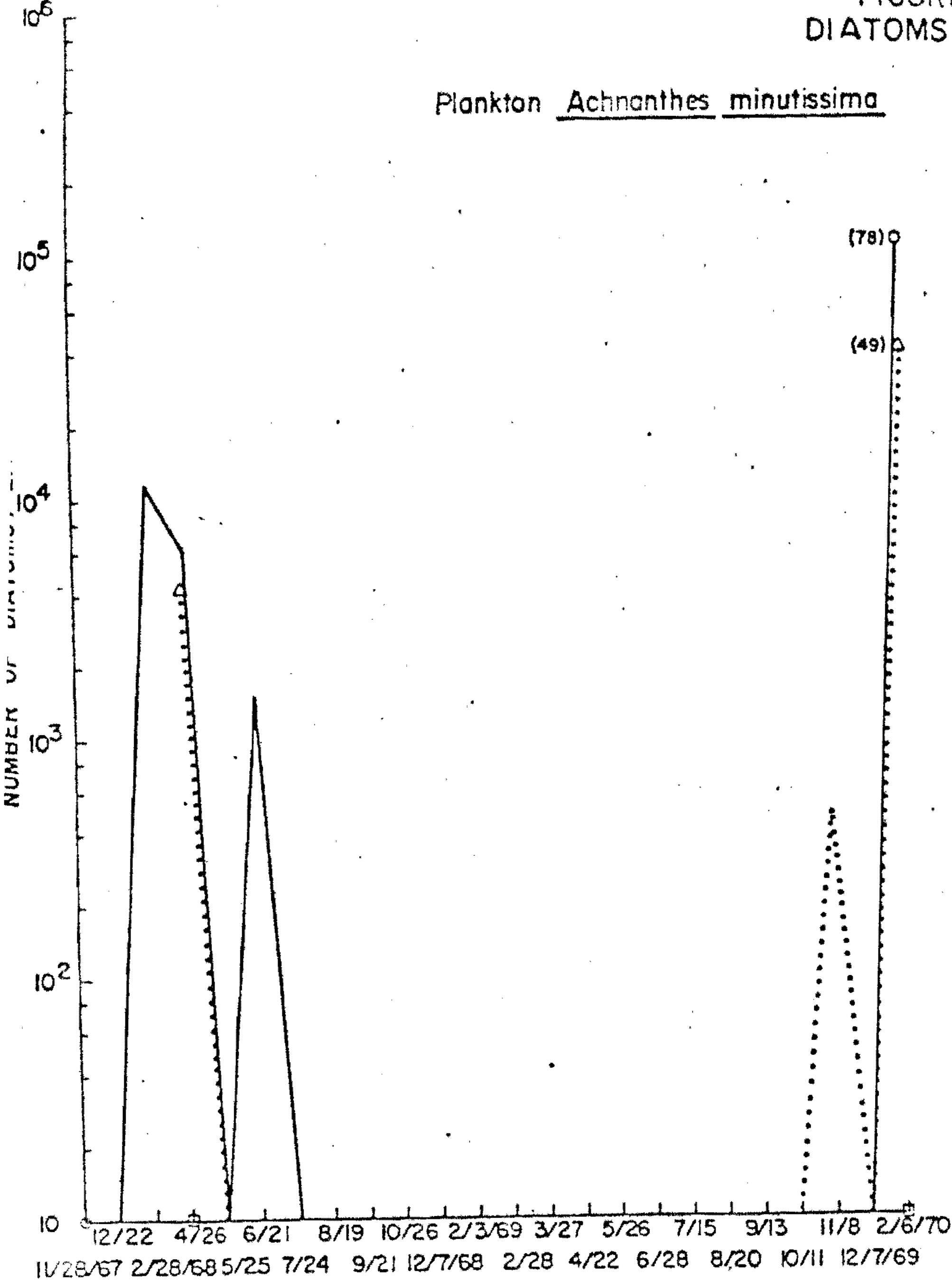
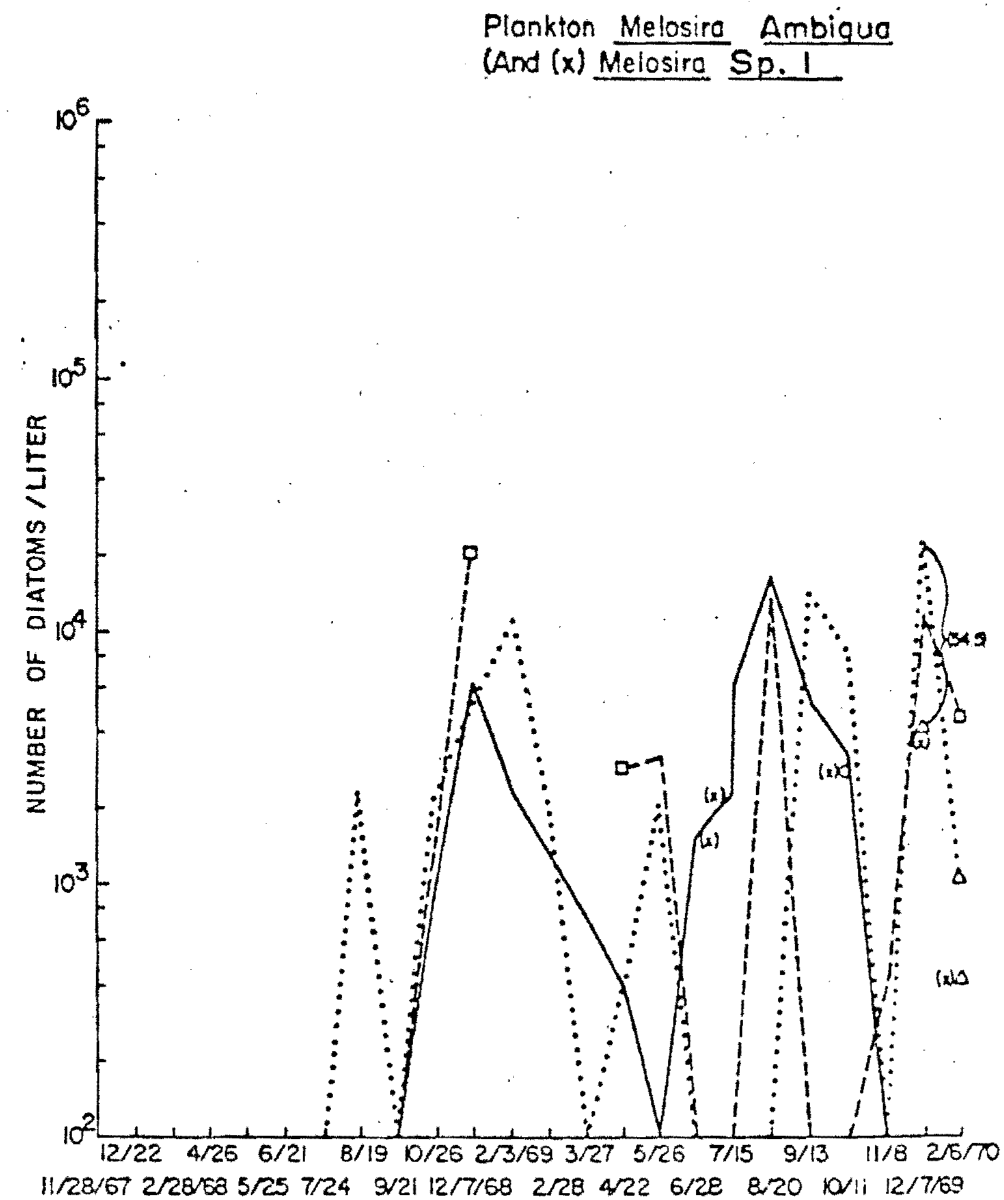


FIGURE 29
DIATOMS - STATION I





3 METERS —o— 9METERS ···Δ··· 15METERS - - -□- - -

FIGURE 30
DIATOMS - STATION I

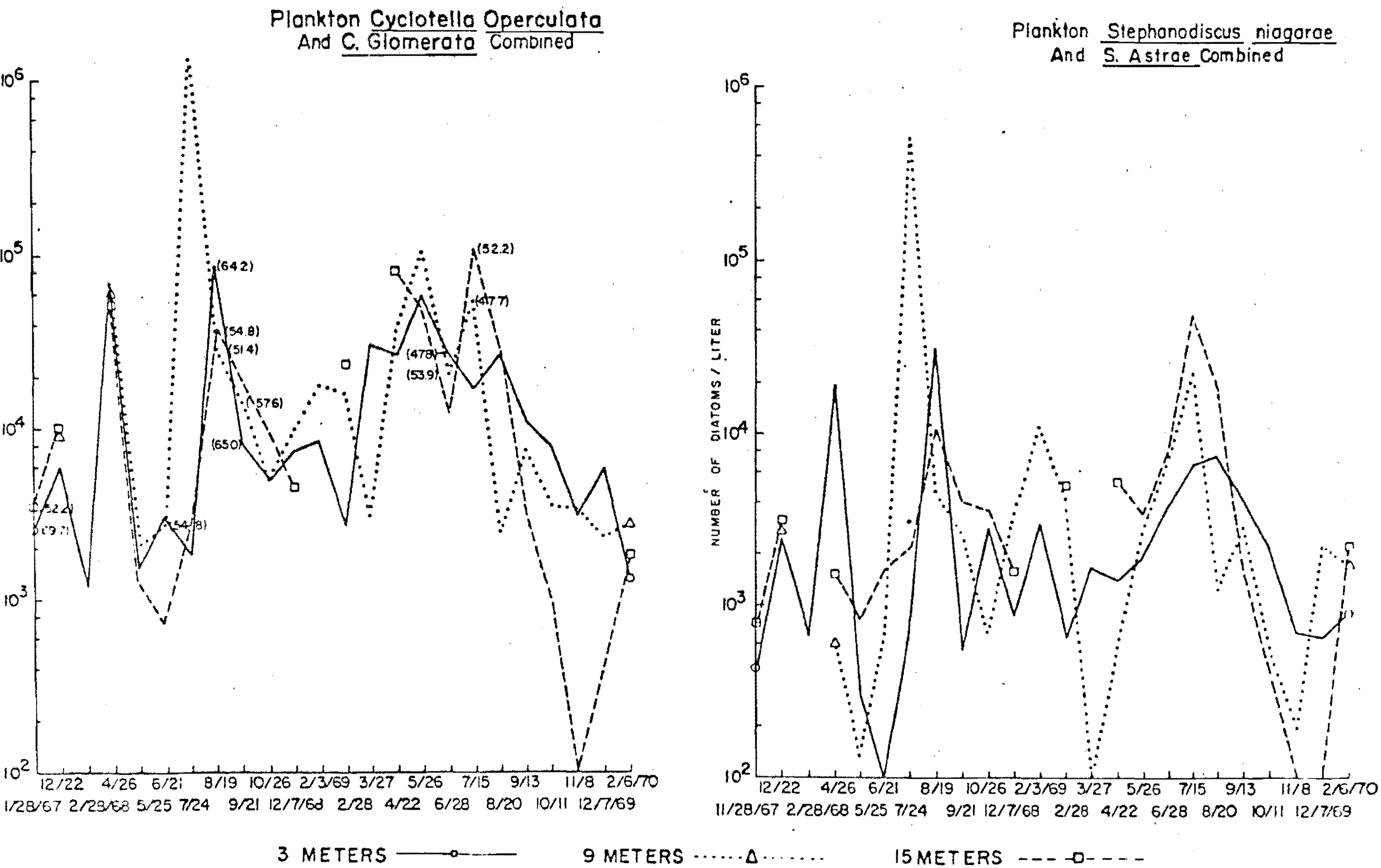
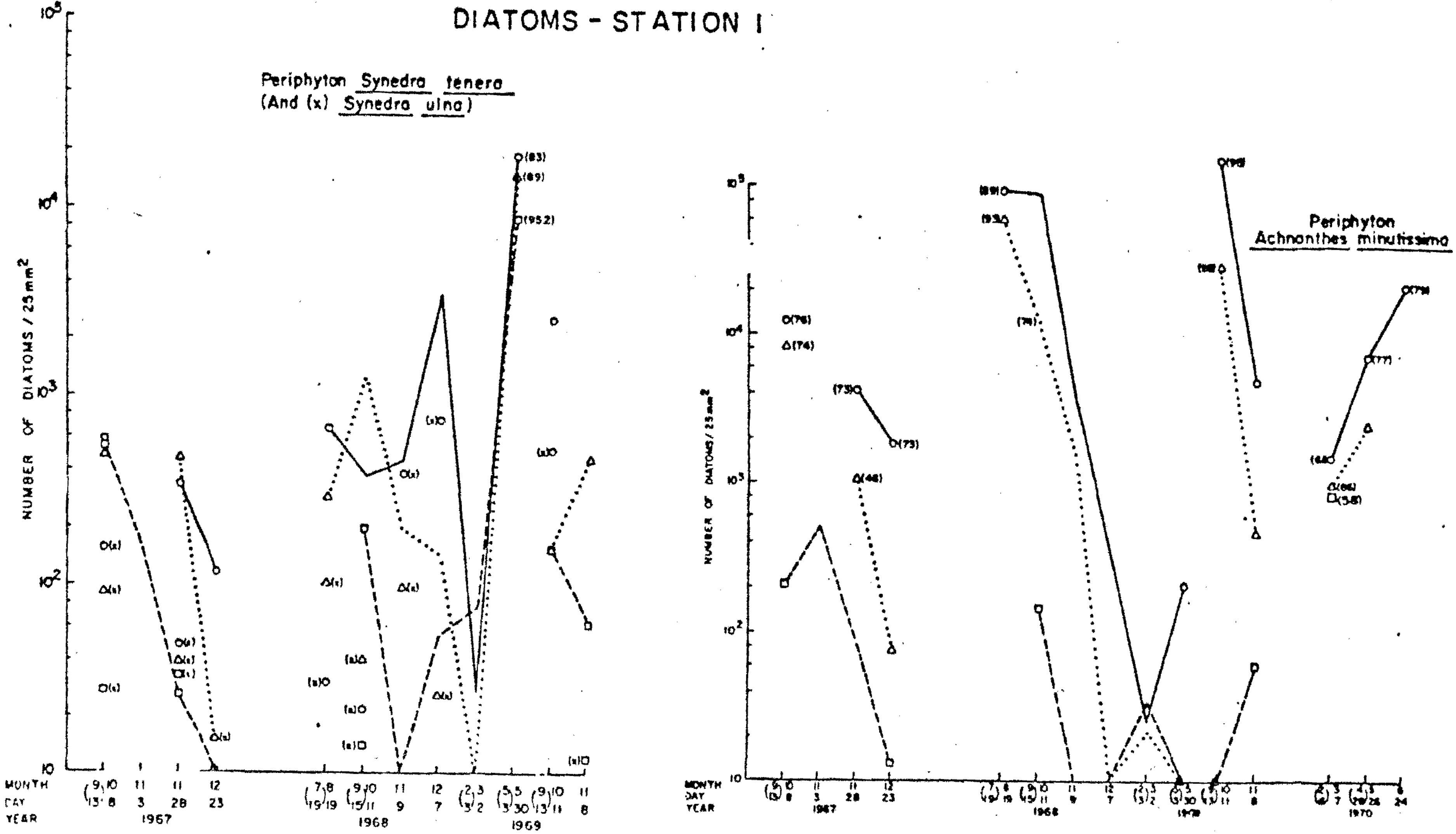


FIGURE 31
DIATOMS - STATION I



3 METERS —o— 9 METERS ····Δ···· 15 METERS ——□——

FIGURE 32

DIATOMS - STATION I

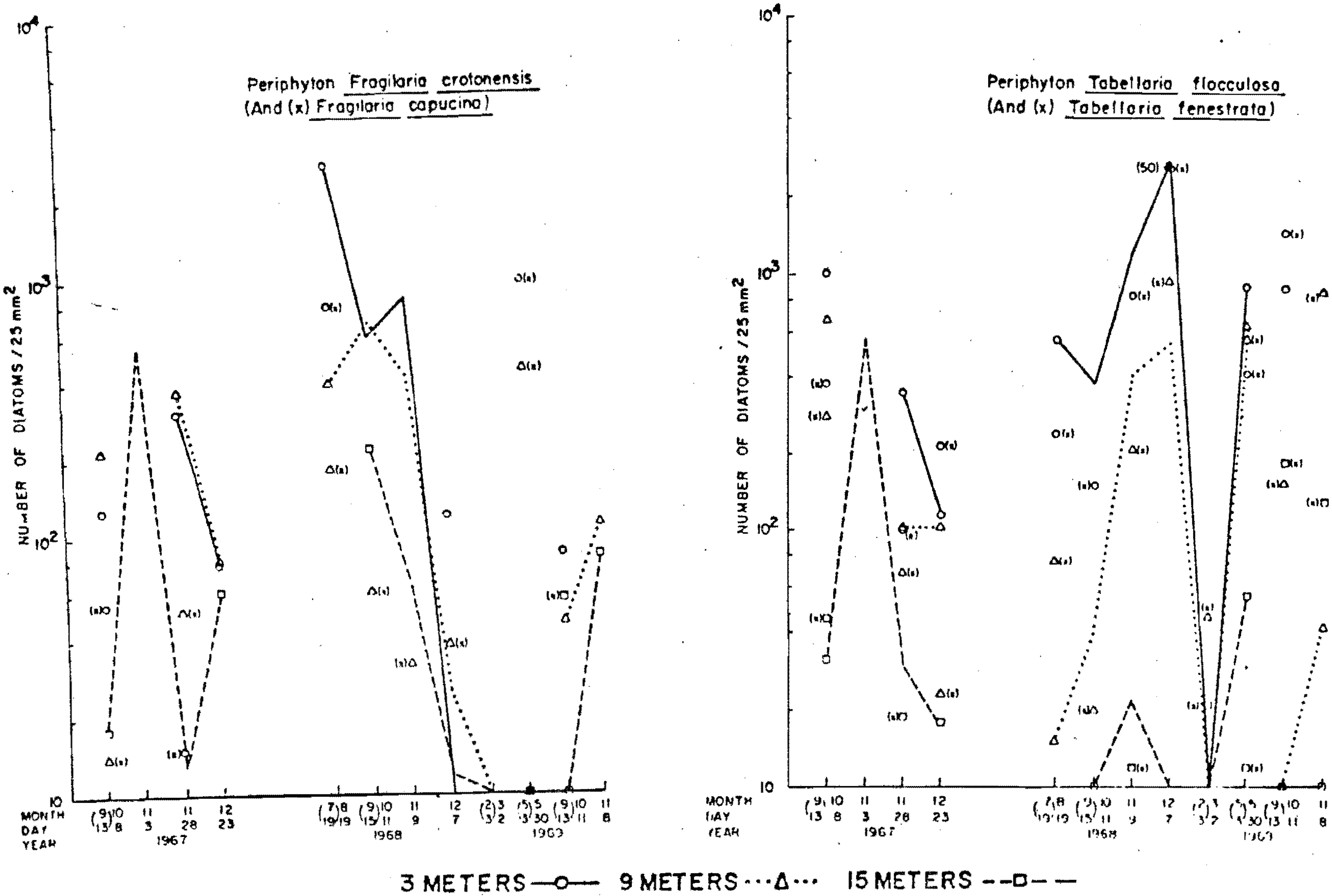


FIGURE 33
DIATOMS-STATION I

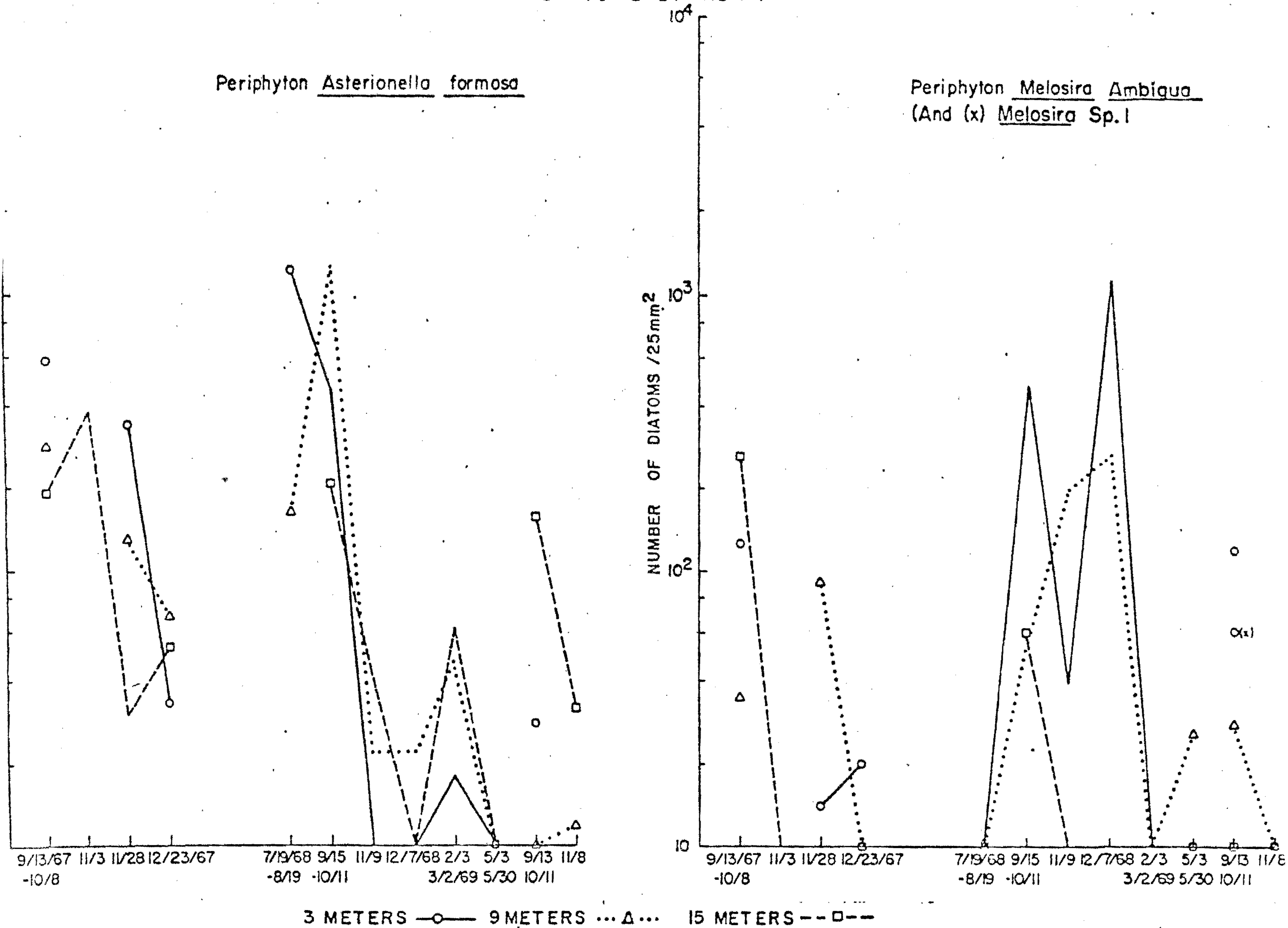
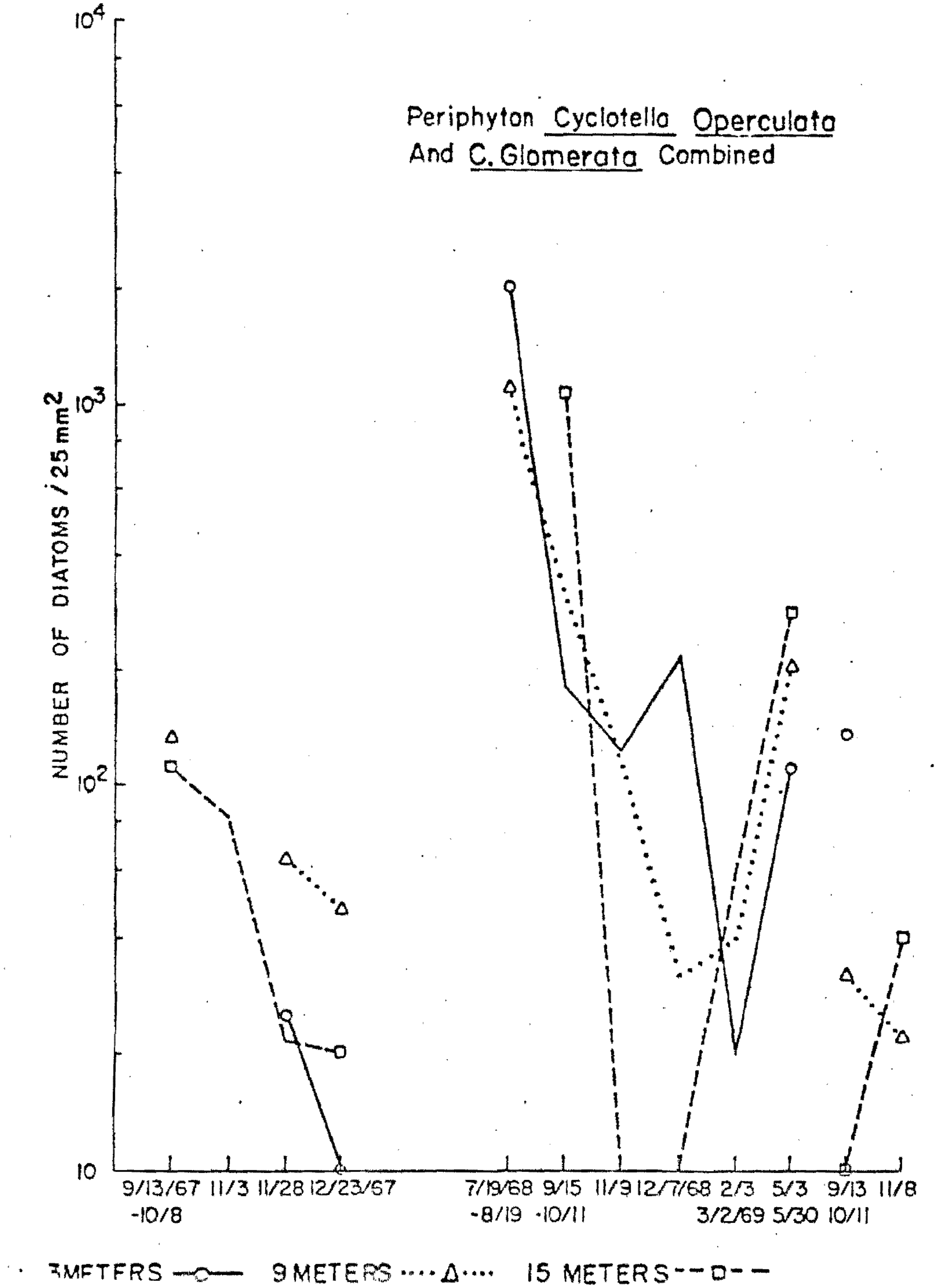


FIGURE 34
DIATOMS-STATION I



Generally there was no correspondence between the relative numbers or growth trends of a diatom species in the plankton and in the periphyton. There were only two instances in which the same diatom dominated both the periphyton and plankton during the same time interval: Achnanthes minutissima was dominant in the plankton (3 m and 9 m) on 2/6/70 and also dominated the periphyton between 2/6/70 and 3/7/70. Synedra tenera dominated the plankton 2/3/69 through 5/26/69, and dominated the periphyton between 5/3/69 and 5/30/69, but not between 2/3/69 and 3/2/69.

Juday (Needham, et al., 1922) reported finding only Asterionella, Fragilaria, Tabellaria, Cyclotella, and Synedra in Lake George plankton in August, 1920. He found only the Synedra below 15 m. In August, 1968 and 1969, the 3, 9, and 15 m samples showed, in addition to the first four genera found by Juday, Stephanodiscus and Melosira to be the principal genera. The abundance of Cyclotella has changed little since 1920, although its species composition may have changed considerably. Juday, with a nannoplankton bottle sampler, obtained values of 31,000, 26,000 and 20,500 Cyclotella per liter at 5, 10 and 15 m respectively, while an average of 57,000, 16,000 and 33,000 per liter at 3, 9 and 15 m was observed in August 1968. The C. glomerata and C. operculata which comprised most of the Cyclotella are usually associated with more enriched environments than Cyclotella comta-bodanica, which was found to a much lesser degree in the plankton but was abundant in the recent lake sediments and in the plankton of a small undeveloped lake adjacent to Lake George.

The seasonal variations seen in most of the principal genera and species of the Lake George plankton are similar to the variations seen in many other lakes as reported by Hutchinson (1967) and Macan (1970). The spring maxima at 3 m occurred regularly in April with A. formosa dominating the plankton maxima in 1968 and 1970, and Synedra tenera dominating the maximum in 1969. In this latter instance A. formosa started to increase as it did in the other years, but apparently was inhibited after 12/7/68 by the more rapid growth of S. tenera and was not present in the late February, March or April samples. As S. tenera decreased rapidly from dominance on 5/26/69 to zero on 6/28/69, Asterionella increased rapidly to reach a peak at three meters in August. The decrease in the Asterionella and increase in the Synedra appeared unrelated to a depletion of silicon by either organism, since the soluble silicon concentration at 3 m, as determined by atomic absorption spectroscopy on concentrated filtrate samples, was 0.11 mg/L on 9/21/68 when the Asterionella started to increase and 0.10, 0.18, 0.14 mg/L on the corresponding dates when the Asterionella reached a peak on 12/7/68-2/3/69 and disappeared by 2/28/69. The soluble silicon level at 3 m increased to 0.82 mg/L on 3/27/69, despite the massive growth of the Synedra. The subsequent growth and decline of Asterionella during the summer of 1969 appeared to be associated with a decrease in the silicon level. The 4/28/70-5/26/70 Asterionella peak was also associated with a decrease in silicon levels to 0.04 mg/L (3 m) on 5/26/70, and a subsequent decrease in the A. formosa population.

In recent flocculent sediments, 29 genera and over 70 species of diatoms were identified from the flocculent layer of the sediments (Table 31). Thirteen genera dominated the samples, all of which were also common in the plankton and in periphyton samples. (Bloomfield, et al., 1972). The composition of many of the samples was typical of a deep, oligotrophic lake, and exhibited a high percentage of Cyclotella comta, Cyclotella operculata and Tabellaria fenestrata. However, in samples taken near areas of high human population, mesotrophic-eutrophic indicator species such as Fragilaria crotonensis, Synedra acus, Synedra ulna, Asterionella formosa and Stephanodiscus astrae were dominant.

TABLE 31

DIATOMS IDENTIFIED IN THE SEDIMENTS OF LAKE GEORGE

Melosira granulata*	Opephora martyi
Melosira islandica	Stephanodiscus astrae*
Melosira crenulata	Stephanodiscus niagarae
Melosira italica	Cyclotella comta*
Diatoma vulgare	Cyclotella operculata*
Diatoma anceps	Cyclotella bodanica
Fragilaria crotonensis*	Cyclotella stelligera
Fragilaria brevistrata*	Cyclotella kutzinghiana
Fragilaria capucina	Cyclotella glomerata
Fragilaria construens	Cyclotella meneghiniana
Fragilaria pinnata	Synedra acus*
Tabellaria fenestrata*	Synedra ulna*
Tabellaria flocculosa	Synedra tenera
Navicula spp. * (8 common spp.)	Asterionella formosa*
Cymbella lanceolata	Pinnularia gibba
Cymbella cistula	Achnanthes lanceolata
Cymbella tumida	Achnanthes minutissima
Diploneis elliptica	Achnanthes exigua
Nitzschia palea	Cocconeis pediculus
Nitzschia paradoxa	Cocconeis placentula
Surirella ovalis	Stauroneis phoenicenteron
Surirella ovata	Cymatopleura solea
Gyrosigma acuminatum	Gomphonema acuminatum
Amphora ovalis	Gomphonema olivaceum
Frustulia rhomboides	Amphipleura pellucida

TABLE 31 (continued)

DIATOMS IDENTIFIED IN THE SEDIMENTS OF LAKE GEORGE

Eunotia major	Meridion circulare
Eunotia arcus	Epithemia sorex
Eunotia pectinalis	Epithemia zebra
Neidium dubium	Caloneis bacillum

* Species common in flocculent layer of bottom sediment

Ref.: Bloomfield and Park, 1972.

The few shallow water samples showed high proportions of epiphytic and benthic forms.

Analysis of diatom distributions in sediment cores from Lake George suggest a similar post-glacial successional history to that of other large temperate lakes. From a taxonomic and bionomic grouping viewpoint, twenty-two genera of diatoms were identified. Of these, seven (Cyclotella, Melosira, Stephanodiscus, Fragilaria, Synedra, Tabellaria, and Achnanthes) have been speciated.

As Table 32 shows, these diatoms can be classified as either planktonic or benthic. All species reported as epipelic, epilithic, epiphytic, or littoral are considered herein as benthic. Two species reported as being both planktonic and benthic are considered as benthic due to their cluster response with those forms as reported by Del Prete (1972). These organisms are Fragilaria pinnata and Fragilaria construens.

Chlorophyll a - Phytoplankton

Chlorophyll a is a measure of the degree of productivity within a lake and indicates the availability of the correct nutrient balance to support a biological system. During 1978 Wood and Fuhs (1979) sampled the length of Lake George on four separate sampling periods. Secchi disk measurements were made during each sampling period and samples were secured for phosphorous and chlorophyll a analysis. There was a definite trend of increasing Secchi disk depths from the south to the north lake end of the lake and decreasing chlorophyll a concentrations in the same direction. In general the highest Secchi disk depth readings at each station and the lowest chlorophyll a concentrations were observed on the August 16 - 17 samples. Cholorophyll a measurements at Wood and Fuhs' Station 1 (equivalent to Station 1 shown in Figure 2) and at Wood and Fuhs' Station 13 (equivalent to Station 6 in Figure 2) are shown for the

1978 sampling period in Table 32a. These results are typical of values found in the south lake and in the north lake. The highest values were consistently found on the October 23 sampling period, which was during the period of fall overturn.

TABLE 32a. CHLOROPHYLL a CONCENTRATIONS (µg liter^{-1}) IN LAKE GEORGE, 1978

Station No.	7/13-14	8/16-17	9/19-20	10/23	Mean	Standard Deviation	Coefficient of Variation
1	3.54	3.5	3.7	4.56	3.82	0.50	13.03
6	1.56	1.0	2.1	3.00	1.91	0.85	44.58

Needham (1922) took Secchi disk measurements just east of Dome Island during the period August 2-9, 1920. During this period the Secchi disk depths varied between 10.1 and 10.7 m. Wood and Fuhs' Station 7 approximated the same location as Needham's Secchi disk measurements. On August 16-17, 1978, Wood and Fuhs observed a secchi disk depth of 8.6 m, indicating some deterioration in the clarity of the water over the 58 year period. Wood and Fuhs further calculated a possible cholorphyll a value for 1920, which was as high as 1.31 mg/L. The corresponding value at Wood and Fuhs Station 7, on August 16-17, was 1.3 mg/L. This suggests little significant change in the cholorphyll values over this 58 year period. However, it must be recalled that the back-calculation for a cholorphyll a value based on the 1920 data is not a precise number, and it is certain that there has been some deterioration in the quality of the lake during this 58 year period. Unfortunately, the exact magnitude of this deterioration is difficult to determine utilizing chlorophyll a changes.

TABLE 32. DIATOMS IN SEDIMENT CORES FROM LAKE GEORGE

PLANKTONIC DIATOMS	BENTHIC DIATOMS
Cyclotella comta-bodanica	Synedra spp.
Cyclotella kutzinghiana	Achnanthes spp.
Cyclotella meneghiniana	Cocconeis spp.
Cyclotella operculata	Eunotia
Cyclotella glomerata-stelligera	Diploneis
Stephanodiscus astrae	Cymbella
Stephanodiscus spp.	Epithemia
Tabellaria fenestrata	Amphora
Tabellaria flocculosa	Gomphonema
Melosira granulata	Gyrosigma
Melosira arenaria	Navicula
Melosira spp.	Nitzschia
Asterionella formosa	Pinnularia
Fragilaria crotonensis	Stauroneis
	Surirella
	Diatoma

Macroalgae

The macroalga, Nitella flexilis, forms extensive beds in Lake George as originally reported by Needham, et al. (1922). The studies of N. flexilis have been largely restricted to the south basin of the lake. Distributions of Nitella populations, their photosynthetic activity, and the influence of certain environmental parameters on the Nitella have been investigated. Densities of Nitella flexilis were generally uniform on the bottom from 7 through 9 m at 35.0 g (dry weight)/m^2, and from 10 through 12 m at 119.5 g/m^2. Photography and morphological analysis of the plants confirms the much greater luxuriance in the deeper water. The growth form of the Nitella and its rather striking delimitation along depth contours illustrate precisely how the environment apparently controls its growth (Stross, 1972, 1974). The standing crop seems to be replaced at least twice each year. There is evidence for both a winter and a summer population of

Nitella. Three types of individual plants were recognized. Old plants contained only dark green or green-brown cells; many of these plants contained segments that were dead or necrotic. New plants were light green and finer textured. A third category consisted of old plants with young or newly generated or light green terminal sections. Most of the observations were made between June and October. Within this interval there clearly is replacement taking place in June and again in September (Stross, 1972). The existence of two distinct replacements annually may be supplemented by partial replacement occurring in the winter season. This also occurred in certain macrophyte populations.

The densest populations of Nitella existed in the depth zone of 10 to 12 meters, and the added biomass was consistent with the observations of the length of the individual plants. In the interval from June through July, crops at 12 m were estimated to be in the range of 73.6 to 117.1 g (dry weight)/m^2. During the same interval, at a depth of 7 to 8 m, biomass ranged from 9.8 to 42.5 g m^2.

Similarly, the fall population was denser in the deeper water, although the difference was less dramatic, possibly owing to location of sampling rather than real increases at the shallower locations. Considering only the Nitella, mean values ranged from 43.8 to 133.0 g/m^2 with some suggestion that the deeper zone was the more productive.

Macrophytes (Boylen and Sheldon, 1973)

Most species of macrophytes are found in the littoral regions of both the north and south basins of Lake George. Table 33 lists those common to the lake, as well as data on their associated dry weights, heights, and depth of maximum abundance.

A comparison was made of the total macrophyte biomass between a heavily developed southern bay (Warner Bay) and a relatively undeveloped northern bay (Hearts Bay) as shown in Table 34. The total biomass was much greater in Warner Bay. These data are also presented graphically for Warner Bay (Figure 35) and Hearts Bay (Figure 36). The maximum macrophyte standing crop in Warner Bay was observed at 3 m in late August and exceeded 200 g dry weight/m^2. The maximum standing crop in Hearts Bay was only 12% that of Warner Bay but also occurred at 3 m depth. Figure 37 shows the mean biomass production for each bay. The two curves were generated by summing the standing crop at the 1, 3, 5, and 7 m depths on each sampling date

TABLE 33. COMMON MACROPHYTE SPECIES FOUND
IN THE LITTORAL ZONE OF LAKE GOERGE, N.Y. *

Species	Average Dry Weight of mature plant[+] Grams	Average Maximum Height of mature plant (cm)	Depth of maximum abundance (meters)
Bidens beckii	.483	56.3	2-7
Chara globularis	.075	12	1
Elatine minima			1
Elodea canadensis	.540	60	1-9
Eriocaulon septangulare	.237	2.8	1
Heteranthera dubia	.947	84	1-3
Isoetes echinospora			1-3
Isoetes macrospora			3-8
Juncus sp.			1
Lobelia dortmanna			1
Myriophylum alterniflorum	.268	51.3	1-3
Myriophyllum tenellum			1
Najas flexilis	.080	24	1-7
Nitella flexilis =			9
Potamogeton amplifolius	2.677	75.7	3
Potamogeton gramineus	.307	84	1-5
Potamogeton perfoliatus	.284	74.5	1-5
Potamogeton praelongus	.836	73.3	5
Potamogeton pusillus	.081	29.3	2-5
Potamogeton robbinsii	.873	69.7	7
Ranunculus longirostris	.154	46	1-3

TABLE 33 (Continued). COMMON MACROPHYTE SPECIES FOUND IN THE LITTORAL ZONE OF LAKE GEORGE, N.Y. *

Species	Average Dry Weight of mature plant+ Grams	Average Maximum Height of mature plant (cm)	Depth of maximum abundance (meters)
Sagittaria sp.	.394	11	1
Utricularia resupinata			1
Vallisneria americana	.536	77.7	1-5
Subularia sp.	.014	6.2	1

* All species collected from 1 m depth or greater. All were submergent.

\+ Plants were collected on 8/30/73. Visual observation suggests that plants collected were smaller than mature plants found earlier in the summer.

= Considered a macroalaga and only listed here for identification purposes.

Ref.: Sheldon and Boylen, 1973.

TABLE 34

Total Macrophyte Biomass at Various Depths in Warner Bay and Hearts Bay [a]

g/m^2 dry wt.

Location	Depth	5/25/73	6/5/73	6/26/73	7/10/73	7/24/73	8/7/73	8/21/73	9/6/73	10/28/73
Warner Bay	1 m	11.7	7.0	26.5	26.4	35.2	122	119	67.5	24.7
	3 m	9.8	36.1	37.0	58.9	76.9	143	206	198	121
	5 m	2.1	.3	15.1	32.1	4.7	14.7	54.6	11.8	30.6
	7 m	11.5	3.5	18.4	15.7	43.5	38.6	50.0	27.0	12.0
	9 m[b]	301	165	64.9	256.0	347.0	179	264	140	213
Hearts Bay	1 m	.3	7.4	3.1	15.8	20.8	12.9	20.2	18.1	19.7
	3 m	1.2	.7	2.4	5.4	26.3	31.7	9.0	.7	0
	5 m	6.1	11.9	.8	3.3	15.6	9.3	1.5	1.2	0
	7 m	.2	.2	3.1	.6	1.0	.5	4.5	0	0
	9 m[b]	.1	.9	1.2	1.2	4.6	0	0	0	0

[a] Total biomass at each station is a summation of dry weight data on plant sections (leaves, roots, stems, rhizomes) as well as sloughing by individual species.

[b] Biomass from 9 m is represented solely by *Nitella flexilis*.

FIGURE 35

MACROPHYTE STANDING CROP BIOMASS DETERMINATIONS IN WARNER BAY

MACROPHYTES WERE COLLECTED AT 1,3,5,7 m. RESULTS ARE EXPRESSED IN TERMS OF g dry wt/$_m$2

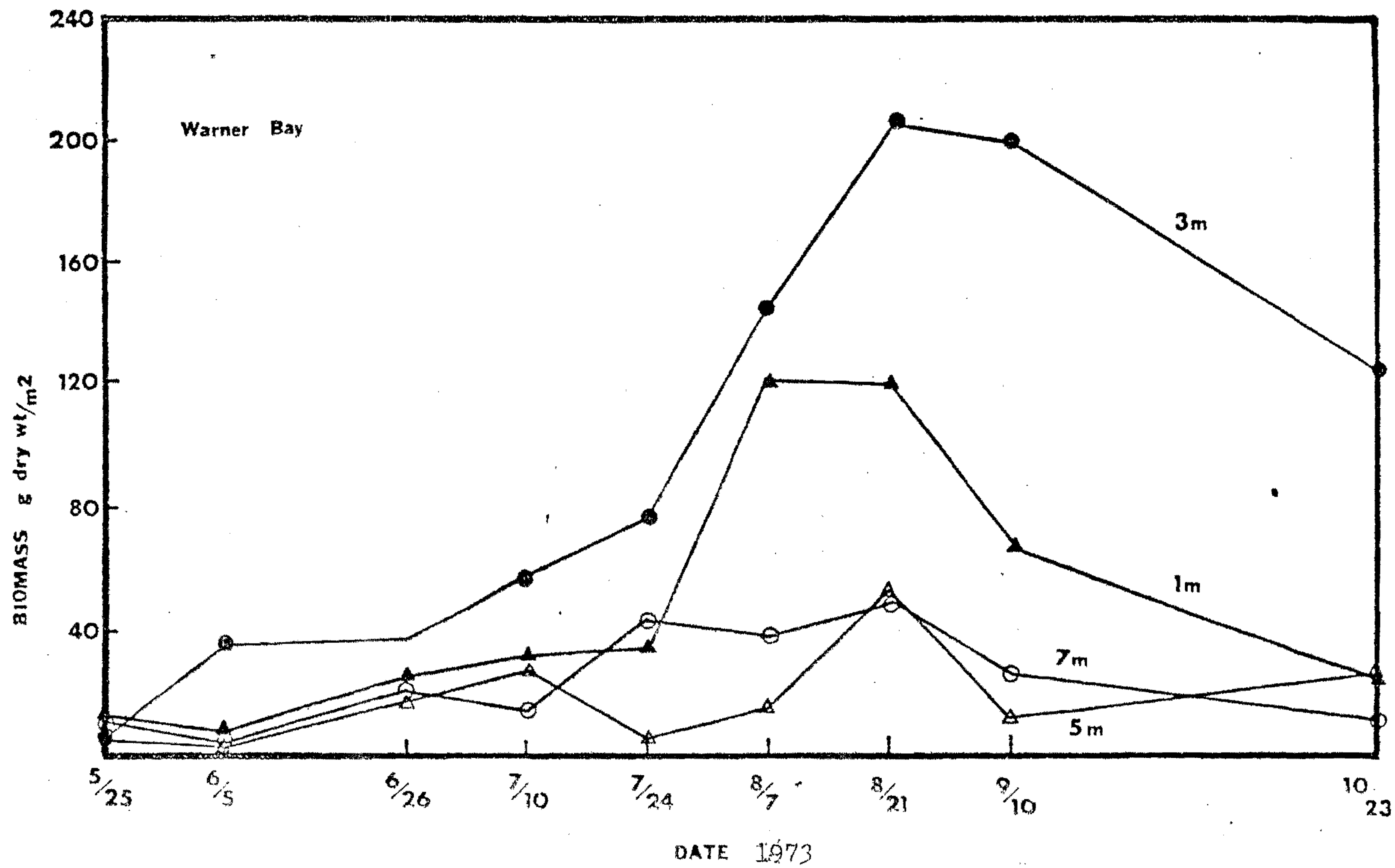


FIGURE 36

MACROPHYTE STANDING CROP BIOMASS DETERMINATIONS IN HEARTS BAY

MACROPHYTES WERE COLLECTED AT 1,3,5,7 m. RESULTS ARE EXPRESSED IN TERMS OF g dry wt/m2

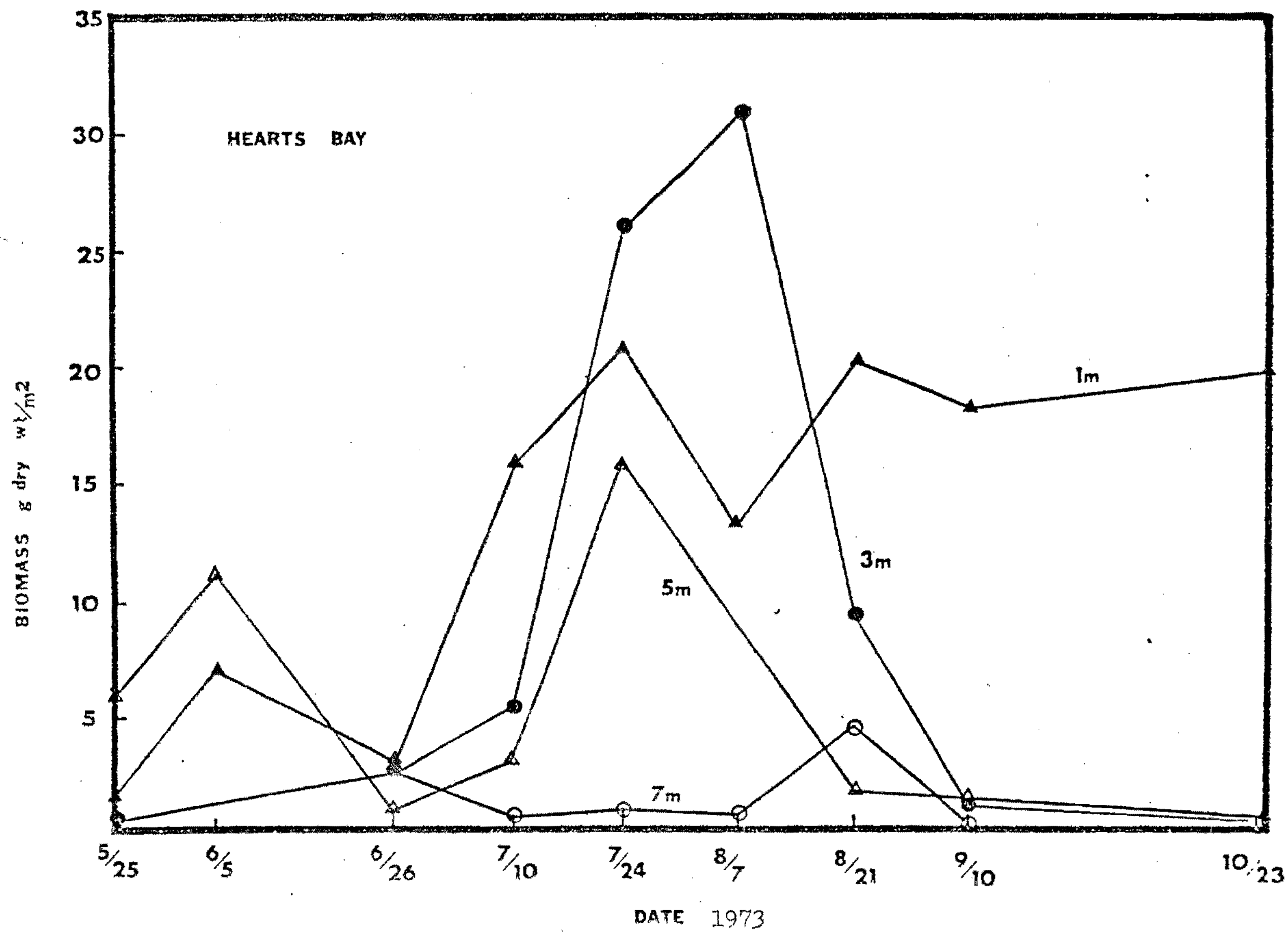
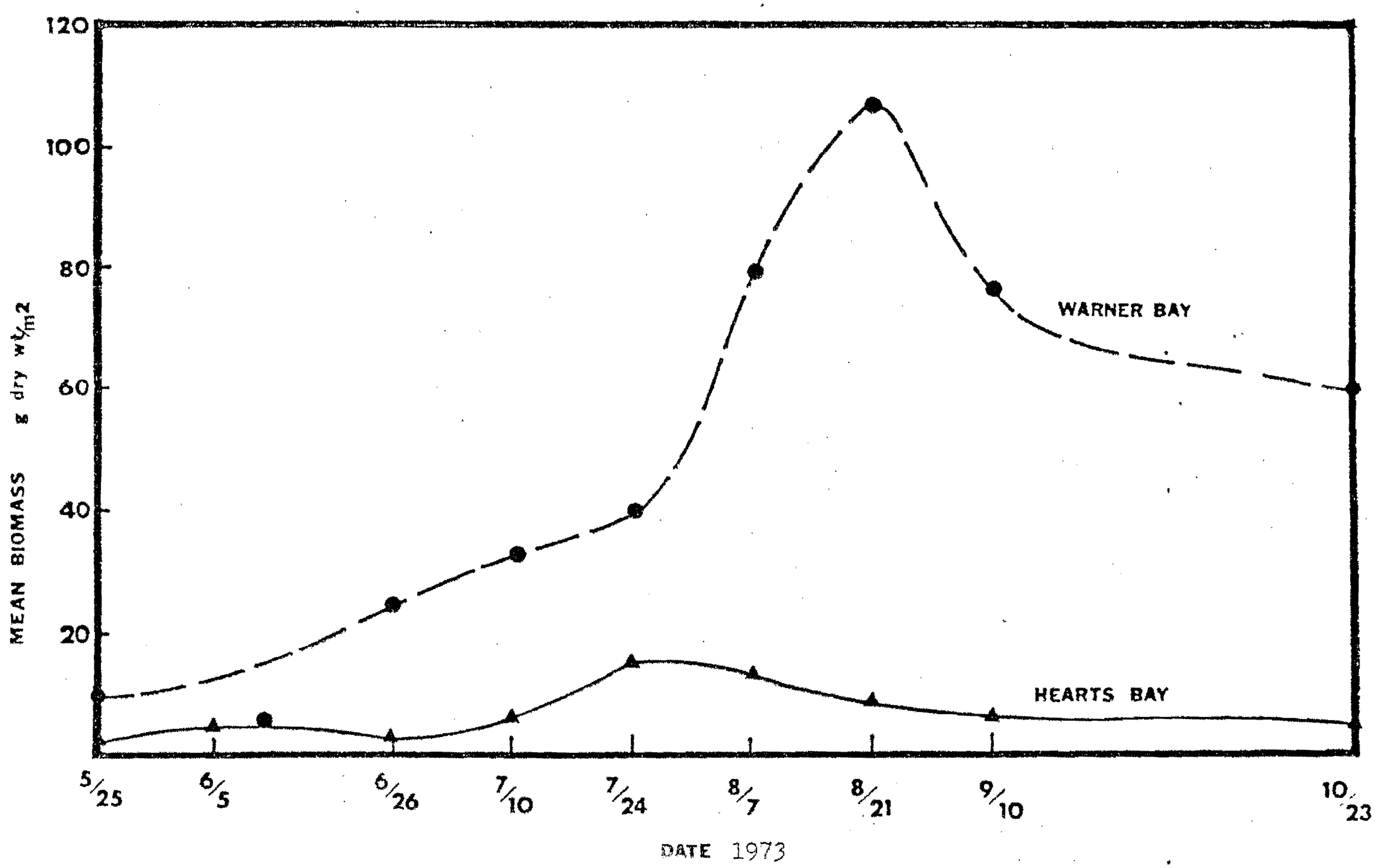


FIGURE 37

MEAN MACROPHYTE BIOMASS MEASUREMENTS FOR WARNER BAY AND HEARTS BAY



and dividing by four. Peak biomass production of all macrophyte species collected occurred in late July in both Hearts Bay and Warner Bay. In general, the macrophytes had a slow growth period in June followed by a rapid growth rate in late July and early August. Many species in Lake George are annuals, over-wintering as buds or rhizomes.

Of the 20 separate species found in Warner Bay certain dominant and co-dominant species were noted at various depths. At 1 m, Vallisneria americana was dominant, followed by Sagittaria sp. At 3 m, V. americana and P. amplifolius were co-dominant, three species, P. praelongus, P. robbinsii, and V. americana exerted dominance at 5 m. P. robbinsii was virtually the only species present at 7 m and N. flexilis, a macroalga, dominated the 9-12 m region. Figures 38 and 39 show the temporal and depth distribution of the biomass of V. americana and P. robbinsii in Warner Bay. The temporal distribution of P. amplifolius, the only macrophyte abundant in both bays, is expressed in Figure 40.
In Hearts Bay, Ultricularia resupinata was dominant at 1 m depth, whereas at other depths there was no dominant macrophyte.

An underwater survey of plant distribution identified over 40 submergent macrophytes. V. americana was the predominant species throughout the lake, although 24 other species were quite common. Fassett (1930) divided aquatic macrophytes into four different life forms: (1) forms with long lax stems and flexous leaves (e.g., Vallisneria species); (2) forms with basal rosettes and and unbranded stems (e.g., Sagittaria species); (3) forms with vegetative stems and horizontal floating leaves (e.g., Potamogeton species); and (4) forms that are rooted underwater, but have photosynthetic parts emergent (e.g., Typha; Nuphar). All these forms in additon to the small, free-floating plants (e.g.,

FIGURE 38

BIOMASS DISTRIBUTION OF _VALLISNERIA AMERICANA_ IN WARNER BAY

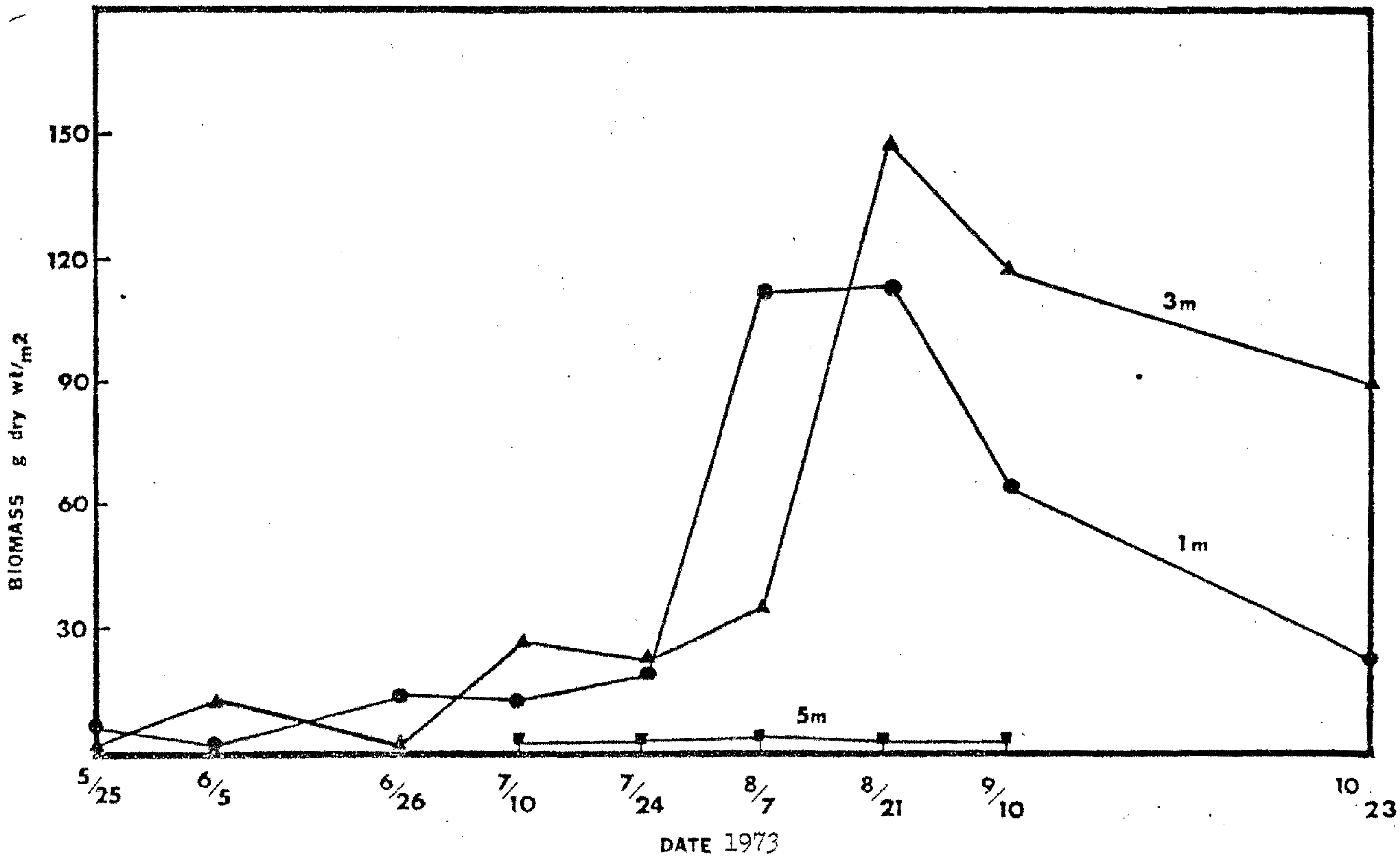


FIGURE 39

BIOMASS DISTRIBUTION OF POTOMOGETON ROBBINSII IN WARNER BAY

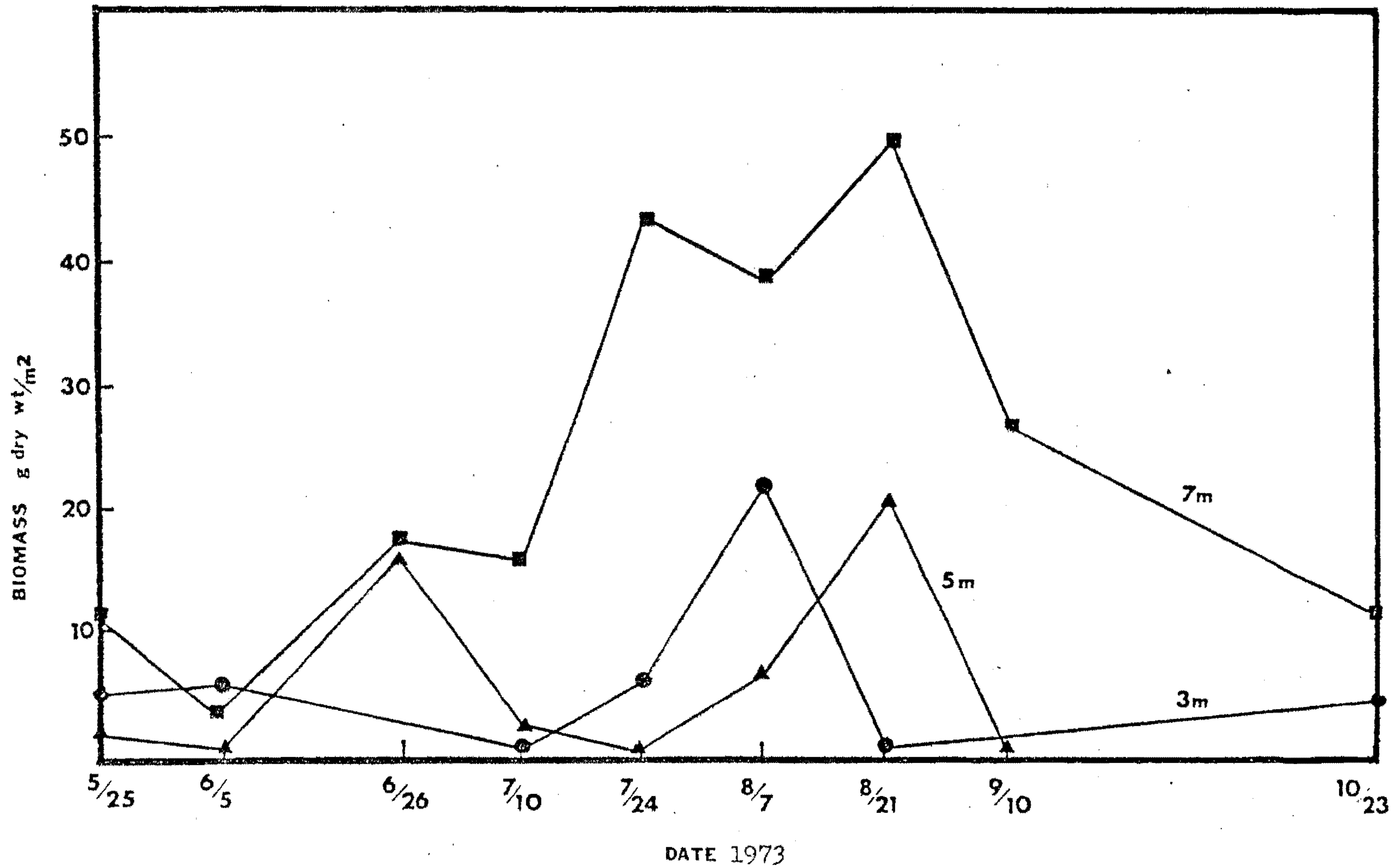
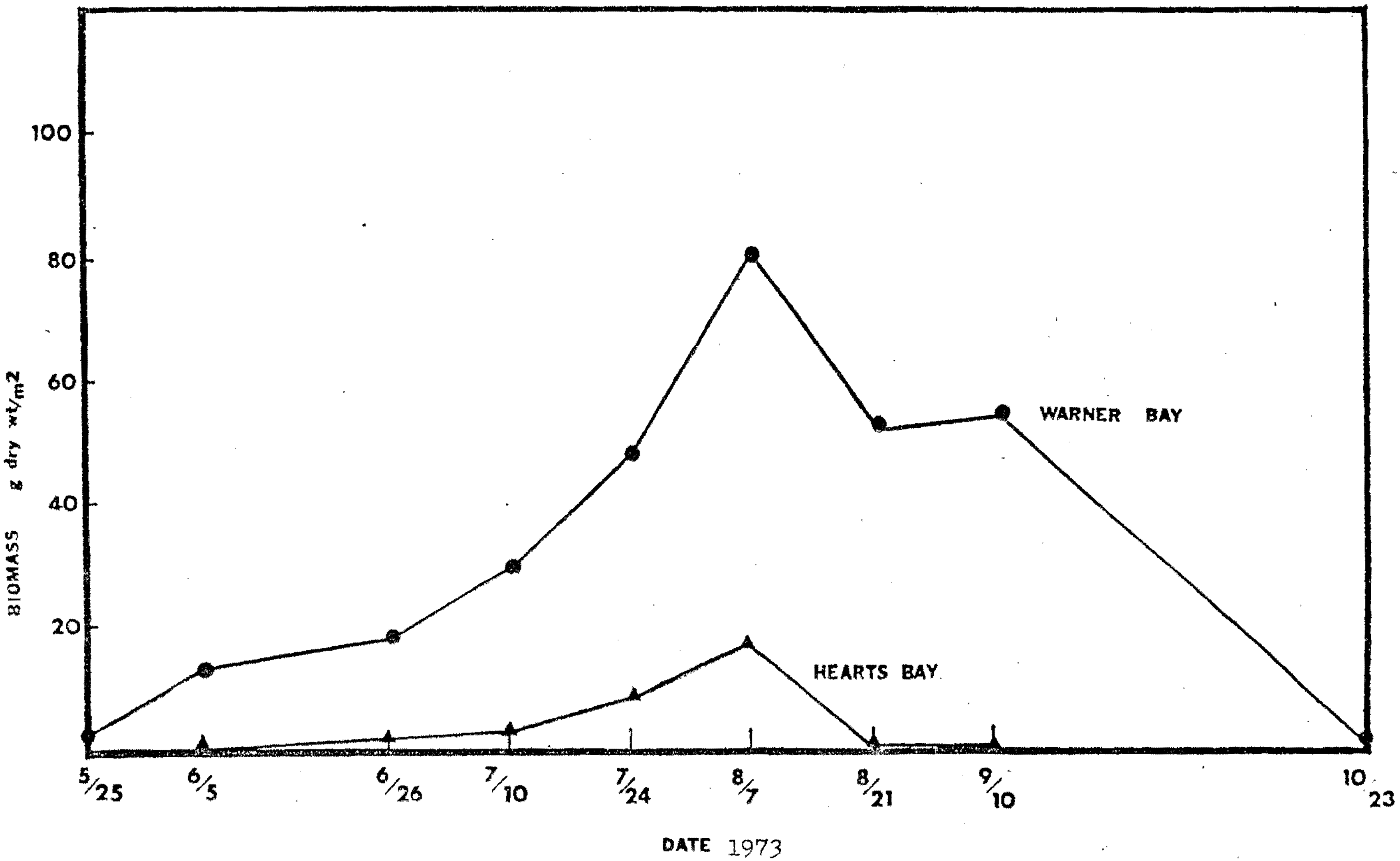


FIGURE 40

BIOMASS DISTRIBUTION OF POTOMOGETON AMPLIFOLIUS IN WARNER BAY AND HEARTS BAY



Lemna: Wolfia) were evident in the littoral areas of Lake George. These investigations at Lake George were keyed to depths of 1 m and greater, neglecting for the most part however, the highly diversified marsh regions.

Growth patterns of the macrophytes in the lake are quite variable. Most of the macrophytes in the southern bays have higher distribution and abundance numbers than those found in the northern bays. There are several exceptions to this pattern, however, notably the high values found near the outlet of Lake George at Ticonderoga. The variation in distribution probably is due to the local influx of nutrients which is greater in the more populated south end of the lake. Another important variable affecting the abundance and types of species present appears to be the lake bottom sediment types.

^{14}C uptake experiments using P. robbinsii have determined photosynthetic rates and their variation with time and temperature (Figures 41 and 42). The temporal rates have a great variation; however, a general trend can be noted with the maximum photosynthetic rate occurring in early August. The photosynthetic rate varies considerably with temperature. The optimum temperature was found to be near 22°C, approximately the maximum summer temperature at the depth from which the P. robbinsii was sampled (7 m). This may indicate the organism's adaptation to its environment, since this maximum temperature also occurs in August coincidental with the maximal temporal photosynthetic rate.

FIGURE 41

TEMPORAL PHOTOSYNTHETIC RATE OF

POTOMOGETON ROBBINSII

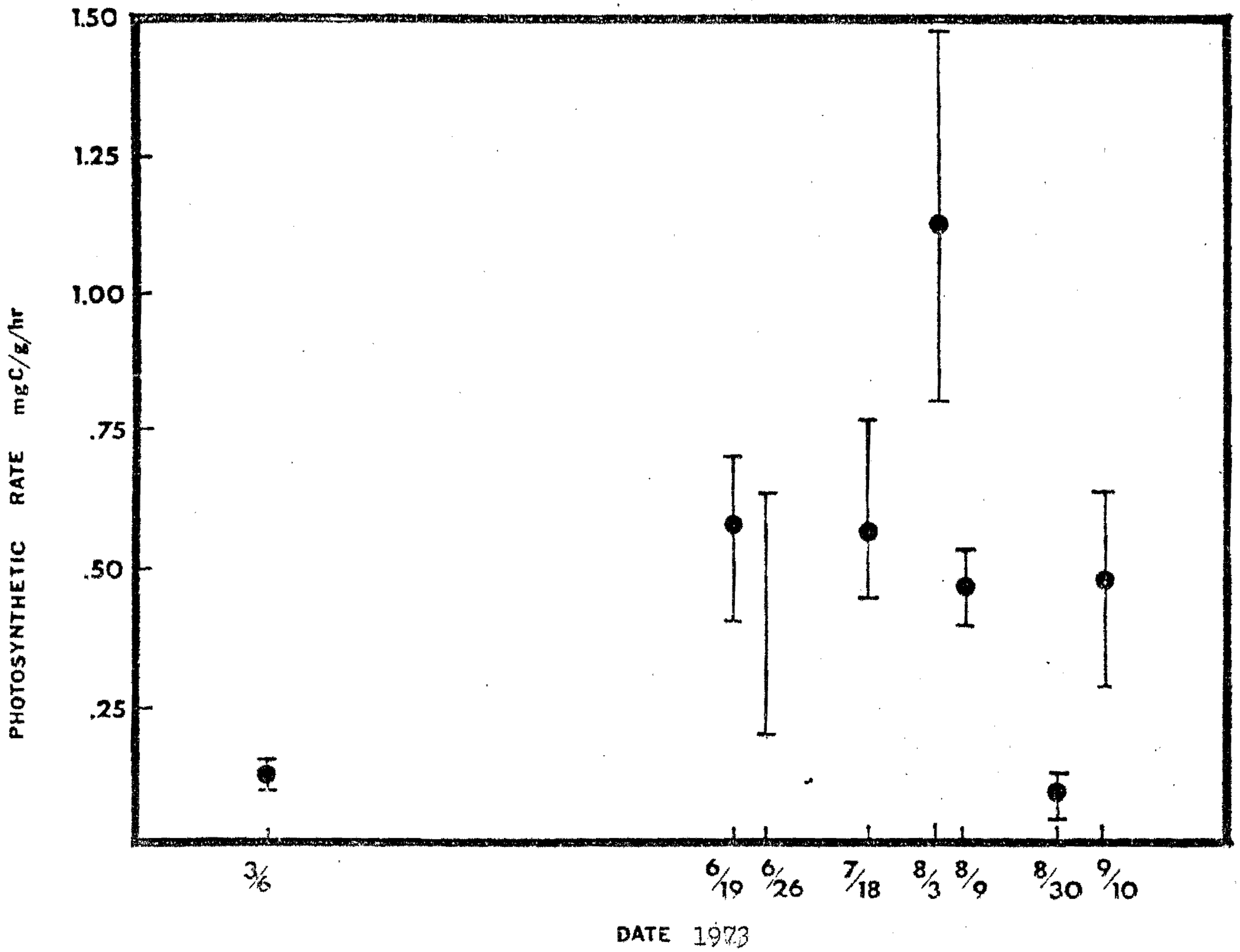
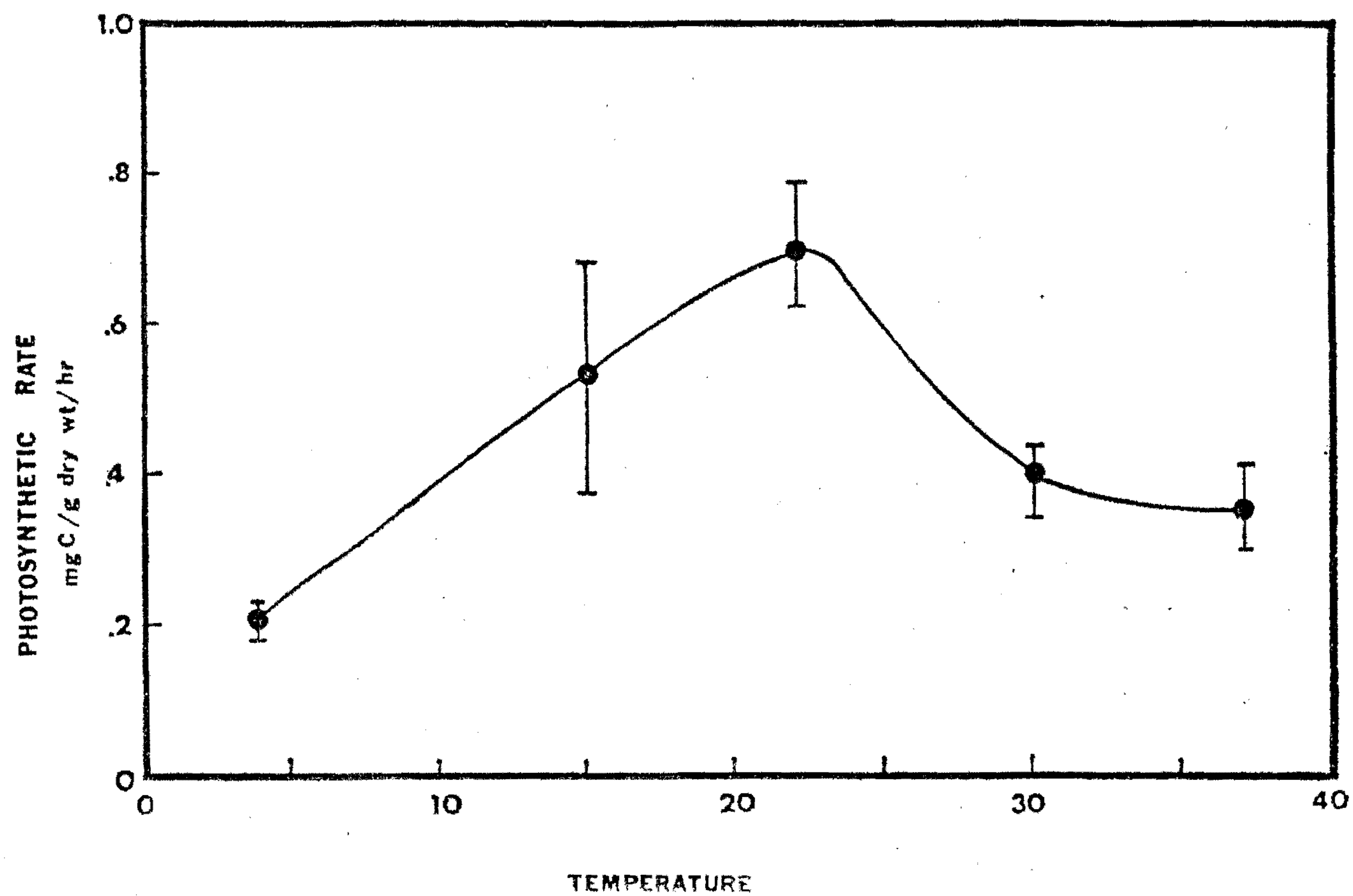


FIGURE 42

VARIATION OF PHOTOSYNTHETIC RATE OF POTOMOGETON ROBBINSII WITH TEMPERATURE

Plants were taken from Warner Bay at 7m on August 9, 1973. Bay temperature was 22 C.



Epiphytes

The role of epiphytes in certain aquatic systems has been studied by some (Allen, 1971; and MacCracken, et al., 1972) and overlooked by many others. Sheldon and Boylen (1975) investigated the contribution to productivity by epiphytic algae in the littoral zone of Lake George and the factors affecting their productivity. They showed that a number of factors were important as regulators of these biota in the lake.

One of the more effective growth controlling factors of these populations was temperature. The optimum growth temperature for the epiphytic algae populations was 30° C while maximum lake water temperature was 24° C. However, it is generally difficult to relate the relative epiphytic algal contributions to littoral zone productivity directly to lake water temperature, location in the lake, or season of the year. Nevertheless, certain data suggest that the increased availability of nutrients can be correlated to epiphyte production, especially at the lake's outlet where a sufficient and constantly available nutrient supply is found.

Initial determinations by these investigators regarding the existence of nutrient limitation showed an inhibitory effect with varying additons of NH_4^+ (0.025 to 0.225 mg N/L); SO_4^{2-} (5 to 50 mg S/L); PO_4^{3-} (0.005 to 0.05 mg P/L); NO_3^- (0.15 to 1.5 mg N/L); SiO_3^{2-} (0.5 to 10 mg Si/L), and with combinations of NO_3^- and PO_4^{3-} (0.15 mg N/L + 0.005 mg P/L to 1.5 mg N/L + 0.5 mg P/l). However, the addition of bicarbonate in concentrations ranging from 2 to 24 mg/100 ml resulted in stimulations of up to 30% (16 mg/100 ml), suggesting carbon limitation for Lake George epiphytes. It was considered that the slight pH rise from 7.4 to 8.3 would not cause this observed increase in photosynthesis rate.

The epiphytes exhibited their maximum photosynthetic activity in mid-summer, with slightly higher average values at the southern basin station. This further confirms the influence of nutrients from increased human activity in the southern basin in governing this photosynthes. The photosynthetic rate for mid-August was found to be 0.6 mg C/m^2 hr. This value of 14.4 mg C/m^2-d is low compared to the value of 258 obtained by Allen (1971) in Lawrence Lake, MI, and very much less than the values of 2,010 obtained in August in eutrophic Saratoga Lake, NY (Tuttle 1974) and 2,300 in eutrophic Lake Wingra, WI (McCracken, et al. 1972).

Although the epiphytes contribute a small amount (~5% of the littoral macrophyte-epiphyte component) of the total lake primary productivity, their role as food for littoral zone grazers is important, and changes in nutrient status or other physical-chemical factors could enhance their role in the overall lake's ecosystem stability. The most common epiphytes observed in Lake George are shown in Table 35.

Zooplankton

In their zooplankton studies, McNaught, et al. (1972) showed that Lake George supports a density of 355 to 1557 animals/m^3 which, based on yearly averages, indicates the capacity to support higher standing crops of cladocerans and copepods than Laurentian Great Lakes. The community competition coefficient ranged from 0.42 to 0.50 from June to August, suggesting that high competition for food and resources by planktonic herbivores is necessary. Apparently, competition is most significant in May at the spring zooplankton pulse, when the competition coefficient, $\alpha = 0.92$. An estimation of α has permitted calculation of the theoretical carrying capacity. Table 36 shows the dominant species of

TABLE 35. Most Common Epiphytes Observed in Lake George

Green algae	Protoderma
	Scenedesmus
	Spirogyra
	Mougeotia
Blue-green algae	Nostoc
	Spirulina
	Oscillatoria
Desmid	Cosmarium
Diatoms	Asterionella formosa
	Navisula sp.
	Synedra sp.
	Fragilaria sp.
	Nitzschia sp.
	Stephanodiscus astrae
	Cocconeis placentula
	Gomphonema acuminatum
	Cymbella cistula

Ref.: Sheldon and Boylen, 1975.

TABLE 36. Dominant Zooplankton Species in Lake George, N.Y.

Cladocerans	Copepods	Rotifer
Bosmina	Cyclops bicuspidatus	
Daphnia galeata	Cyclops scutifer	Asplanchna
Daphnia longiremis	Diaptomus sicilus	
Diaphanosoma leuchtenbirgianium	Diaptomus minutus	
Holopedium gibberum	Mesocyclops edax	
Polyphemus pediculus	Epischura lacustris	
Leptodora kindtii		
Nauplii		

Ref.: McNaught, et al., 1972.

zooplankton found in Lake George. Of the 15 dominant cladocerans and copepods of Lake George, only 9 species ever reached 10% carrying capacity. These include: *Cyclops bicuspidatus*, *C. scutifer*, *Diaptomus minutus*, *Daphnia longiremus*, *Diaphanosoma leuchtenbergianum* and *Leptodora kindtii*. All except *Leptodora* are herbivores.

The copepod genera *Cyclops* and *Diaptomus* accounted for 85% of the total production of crustacean zooplankton in Lake George (Table 37). In an unusual year (1972) *Cyclops bicuspidatus*, likely a predator on young copepods, accounted for more than 43% of the total production of limnoplankton. The cladocerans were less important in Lake George, with *Daphnia* and *Bosmina* responsible for only 15% of total production.

Studies via radioactive labeling (McNaught and Bogdan, 1973) of short term (10 minute) selective grazing by zooplankton on net and nannoplankton and bacteria permitted a measurement of filtering rates of these organisms. On phytoplankton foods, both *Diaptomus* and *Diaphanosoma* preferred nannophytoplankton, whereas *Daphnia* showed no preference. Both *Daphnia* and *Diaphanosoma* preferred bacteria over algae.

Upon analyzing the data on filtering rates (Table 38), two points are immediately obvious: (1) the rather low rates of filtering shown by all the species and (2) especially the 40-50% reduction in filtering observed among the various size classes of *Daphnia* and *Diaphanosoma*. The lower rates, however, may not represent a breakdown in the analytical technique because there are patterns that are consistent within and between days. For example, in both trials, there was the same pattern of filtering rate increase among the size classes of *Daphnia* and *Diaphanosoma*. The large *Sida* (1.56 mm) were the most rapid filterers, and the large *Diaphanosoma* (6.28 mm) and Daphnia (1.12 mm) had almost identical feeding rates. However, *Holopedium* and *Diaptomus* did not show

TABLE 37. Species Dominance in Relation to Total Zooplankton Production in Lake George (1972) [A]

Species	Production number/m^3/day	Relative Production % of total seasonal
Diaptomus sicilis	961	11.3
Diaptomus minutus	2554	29.9
Cyclops bicuspidatus	3737	43.8
Daphnia galeata	714	8.3
Daphnia longiremis	212	2.5
Bosmina spp.	358	4.2
	8536	100.0

A. Species listed comprise 80 percent of total zooplankton production in Lake George.

Ref.: McNaught, et al., 1972.

TABLE 38. Filtering rates on total phytoplankton

Trial 1

Species	size class approx.	filtering rate ml/anim./hr.	# of replicates	# of animals in each vial
Holopedium gibb.	1.00 mm	.34	1.	3.
Sida crystalline	1.56 mm	.73	1.	6.
Diaptomus	.92 mm	.03	3.	30.
Diaptomus	1.47 mm	.31	1.	3.
Diaphanosoma leuch.	1.11 mm	.06	3.	20.
Diaphanosoma leuch.	1.25 mm	.13	3.	11.
Daphnia galeata	.79 mm	.04	2.	25.
Daphnia galeata	1.12 mm	.13	1.	15.
Daphnia galeata	1.45 mm	.25	2.	18.
Daphnia galeata	1.81 mm	.40	2.	11.

Trial 2

Species	size class	filtering rate ml/an/hr.	# of replicates	# of animals in each vial
Holopedium gibb.	1.00 mm	.36	1.	4.
Sida crystalline	1.17 mm	.32	2.	7.
Sida crystalline	1.56 mm	.56	2.	5.
Diaptomus	.92 mm	.02	5.	25.
Diaphanosoma leuch.	1.11 mm	.03	3.	11.
Diaphanosoma leuch.	1.25 mm	.05	5.	11.
Daphnia galeata	.79 mm	.02	2.	20.
Daphnia galeata	1.12 mm	.06	2.	13.
Daphnia galeata	1.45 mm	.13	3.	12.
Daphnia galeata	1.81 mm	.25	2.	8.
Leptodora Kin.	-	0.00	1.	2.
Cyclops sp.	-	0.00	1.	25.
Mesocyclops sp.	-	0.00	1.	10.

this variation.

When examining the filtering rates for each species on a given day, one can try to attribute the filtering rate patterns to two factors: (1) size and (2) competitive ability. The data strongly suggest that larger individuals filter faster than small individuals for Sida, Diaphanosoma, and Daphnia. There is little doubt that size influences filtering ability. However, when one begins to link filtering rate with competitive abilities, present lack of knowledge becomes quite evident. Many models of competition assume that the species with the highest feeding rate on a given resource, "all other factors being equal," will out-compete all other species. It still can not be determined what species is the best competitor in Lake George because data are lacking on the efficiency at which the animals utilize the food they ingest. For example, since filtering rates represent intake of algal cells, and even though Sida has a much higher filtering rate than a Daphnia of equivalent size, and thus is getting more food in a given time, it may be less efficient in converting that food to biomass than the Daphnia. Thus, data on assimilation are needed. Furthermore, remembering that filtering rate is only indirectly measured, it is unknown whether a higher rate indicates faster passage of water through the setae, or higher efficiency of extracting cells from a given volume by the setae.

LaRow (1973), in studying the effect of food concentration on respiration and excretion on three dominant species of zooplankton, showed an increase in total physiological response (TPR) of the plankton with both temperature and food concentration. The Q_{10} values for TPR ($\bar{x}$ Q_{10} for respiration, nitrogen and phosphorus excretion) were inversely related to food concentration (50% Ankistrodesmus and 50% Euglena gracilis at 5×10^5, 5×10^6, and 1×10^7 cells/

liter), i.e., increased food concentration had a slight depressant effect on the TPR of the organism to temperature change (see Tables 39 and 40). The Q_{10} values for TPR were greatest at a food level of 5×10^5 cells/liter (1.80), and least at a food level of 1×10^7 cells/liter (1.66). This food concentration-temperature interaction apparently affected respiration and excretion of the lake's herbivorous zooplankton. Other investigations conducted regarding zooplankton characteristics in Lake George are not presented here because they are unconfirmed.

FISH

Species

Information on the species of fish in Lake George is based primarily on the early studies of Needham, et al (1922) and Greely, et al (1930). A listing of fish species for Lake George (Table 41) was derived from the works of these early investigators and from current information provided by investigations now in progress (personal communications, R. MacWatters and C. George, Fresh-water Institute Gull Bay). A total of 44 species represented by 13 families is listed for Lake George in Table 41. The greatest variety of fish species is in the family cyprinidae (shiners and minnows) and the most important from a sport fishing interest are represented by the families Salmonidae (Lake trout and Atlantic salmon), Centrarchidae (Smallmouth and Largemouth bass) and Esocidae (Northern Pike and Chain Pickerel).

Salmonids

The fisheries management unit, Region 5, New York State Department of Environmental Conservation (D.E.C.) in Warrensburg, N.Y. has a Salmonid management program for Lake George consisting of artificial propagation, coupled with an annual evaluation of salmonid populations and fishermen's yield. The pre-

TABLE 39. Q_{10} values for Respiration, Nitrogen and Phosphorus Excretion. Values were determined by comparing the various physiological responses at 10°C and 20°C for each food level.

Species	Food Level*	Q_{10} Respiration	Q_{10} N Excretion	Q_{10} P Excretion	$\bar{x}$ Q_{10} Total Physiological Response
Cyclops	1	1.58	1.81	1.75	1.71
	2	1.92	1.70	1.64	1.75
	3	1.53	1.59	1.63	1.58
Daphnia	1	2.13	1.70	1.77	1.87
	2	1.41	2.00	1.84	1.75
	3	1.67	1.98	1.77	1.80
Diaptomus	1	4.27	1.76	1.81	1.79
	2	1.81	1.73	1.45	1.66
	3	1.68	1.49	1.54	1.57
$\bar{x}$ All Species	1	1.86	1.76	1.78	1.80
	2	1.71	1.81	1.64	1.72
	3	1.63	1.69	1.67	1.66

* Food Level 1 = 5×10^5 cells/L
2 = 5×10^6 cells/L
3 = 1×10^7 cells/L

TABLE 40. The Effect of Food Concentration on Physiological Response. Values determined by comparing the various physiological responses at two food levels.

Species	Food Levels* Compared	Temp (°C)	% Increase Respiration	% Increase N Excretion	% Increase P Excretion	% Increase All Physiological Responses
Cyclops	1-2	10	10.0	13.9	39.3	21.1
	2-3	10	29.1	30.6	13.7	24.5
	1-2	20	25.7	9.4	34.0	23.0
	2-3	20	11.3	25.9	13.3	16.8
Daphnia	1-2	10	70.6	29.9	15.3	38.6
	2-3	10	4.5	34.2	14.5	17.7
	1-2	20	55.5	39.4	18.1	37.7
	2-3	20	19.7	33.6	11.3	21.5
Diaptomus	1-2	10	67.3	23.2	21.1	37.1
	2-3	10	29.5	26.4	-3.0	17.6
	1-2	20	22.4	21.9	0.0	14.7
	2-3	20	23.1	14.6	3.5	13.7
$\bar{x}$ All Species	1-2	10	49.3	22.3	25.2	32.3
	2-3	10	21.0	30.4	8.4	19.9
	1-2	20	34.5	23.6	17.4	25.2
	2-3	20	18.0	24.7	9.37	17.4

* Food Level 1 = 5×10^5 cells/L
2 = 5×10^6 cells/L
3 = 1×10^7 cells/L

TABLE 41. List of Fishes Common to Lake George

Family and Species	Common Name
Osmeridae	
Osmerus mordax (Mitchill)	Rainbow smelt
Salmonidae	
Coregonus artedii Lesueur	Cisco
Salmo gairdner: Richardson	Rainbow trout
Salmo salar L.	Atlantic salmon
Salmo trutta L.	Brown trout
Salvelinus fontinalis (Mitchill)	Brook trout
Salvelinus namaycush (Walbaum)	Lake trout
Umbridae	
Umbra limi (Kirtland)	Central mudminnow
Catostomidae	
Catostomus commersoni (Lacepede)	White sucker
Cyprinidae	
Exoglossum maxillingua (Lesueur)	Cutlips minnow
Hybognathus nuchalis Agassiz	Silvery minnow
Notemigonus crysoleucas (Mitchill)	Golden shiner
Notropis bifrenatus (Cope	Bridle shiner
Notropis cornutus (Mitchill)	Common shiner
Notropis hudsonius	Spot tail shiner
Notropis rubellus (Agassiz)	Rosyface shiner
Notropis spilopterus (Cope)	Spot fin shiner
Pimephales notatus (Rafinesque)	Bluntnose minnow
Rhinichthys atratulus (Hermann)	Blacknose dace
Rhinichthys cataractae (Valenciennes)	Longnose dace
Semotilus atromaculatus (Mitchill)	Creek chub
Couesius plumbeus (Agassiz)	Lake chub
Semotilus corporalis (Mitchill)	Fallfish

TABLE 41 (Continued). List of Fishes Common to Lake George

Family and Species	Common Name
Ictaluridae	
Ictalurus natalis (Lesueur)	Yellow bullhead
Ictalurus nebulosus (Lesueur)	Brown bullhead
Noturus flavus (Rafinesque)	Stonecat madtom
Noturus gyrinus (Mitchill)	Tadpole madtom
Esocidae	
Esox lucius (L.)	Northern pike
Esox niger (Lesueur)	Chain pickerel
Anguillidae	
Anguilla rostrata (Lesueur)	American eel
Cyprinodontidae	
Fundulus diaphanus (Lesueur)	Banded killifish
Pereidae	
Etheostoma flabellare (Rafinesque)	Fantail darter
Etheostoma nigrum (Rafinesque)	Johnny darter
Perca flavescens (Mitchill)	Yellow perch
Stizostedion vitreum vitreum (Mitchill)	Walleye
Centrarchidae	
Ambloplitus rupestris (Rafinesque)	Rockbass
Lepomis auritus (L.)	Redbreasted sunfish
Lepomis gibbosus (L.)	Pumpkinseed
Micropterus dolomieui (Lacepede)	Smallmouth bass
Micropterus salmoides (Lacepede)	Largemouth bass
Pomoxis nigromaculatus (Lesueur)	Black crappie
Cottidae	
Cottus cognatus (Richardson)	Slimy sculpin
Cottus bairdi Girard	Mottled sculpin
Gasterosteidae	
Culaea inconstans (Kirtland)	Brook stickleback

sent stocking policy for Lake George specifies annual plants of 50,000 yearling Adirondack strain Lake trout Salvelinus namaycush (Walbaum), 50,000 yearling rainbow trout Salmo gairdneri Richardson, and 35,000 spring fingerling landlocked Atlantic salmon Salmo salar Linnaeus.

In 1974 D.E.C. initiated a standardized annual lake trout gill netting survey to evaluate the population status of juvenile lake trout and the Cisco Coregonus artedii Lesueur, a principal forage fish of the lake trout. Deep water gill netting in the north and south basins of Lake George, conducted in he fall of 1974, showed the spawning population in each basin to be significantly different (E. Lantiegne, D.E.C. progress rep't Reg. 5). In the south basin, 4.5 percent of the lake trout netted were less than 21 inches, compared to 46.2 perecent in the north basin. In the south basin, no mature females less than 21 inches were trap netted. In the north basin 20.5 percent of the total catch were mature females less than 21 inches. The new state wide minimum length regulation of 21 inches on lake trout should benefit the north basin spawning population.

D.E.C. has also evaluated the Lake George salmonid population through an angler diary-cooperator program which started in 1964 and was intesified in 1973. Information collected from participating anglers showed a marked decrease in the catch of lake trout from 1973 to 1974. Angler cooperators caught 402 lake trout in 1973 compared to 291 in 1974. (E. Lantienge D.E.C. progress rep't Region 5). Catches of rainbow trout among cooperators increased significantly during the same years: 81 fish (1973) to 239 fish creeled in 1974. Landlocked salmon catches increased from 13 fish (1973) to 118 fish (1974). The increase in salmon creeled was attributed to a fingerling planting which produced Atlantic salmon smolts that grew well.

The lake trout population in Lake George has faced many problems. In the early 1800's, it was reportedly overharvested (Needham et al., 1922). During the 1950's, the chlorinated hydrocarbon D.D.T. decimated the Lake trout in Lake George. Although artificial propagation during the 1960's and 70's has been encouraging, the lack of yearling Adirondack strain lake trout for stocking, the questionable status of the Cisco (principal forage species), and the threat of the overharvest of juvenile lakers taken by ice fisherman raises a serious question as to the fate of this species in Lake George.

Population Estimates

The only documented attempt to estimate fish populations for Lake George is from the work of George, et al (1973). The earlier investigations of Needham et al (1922) and Greely, et al (1930) and Greely (1953) do not include population estimates. The population estimates conducted by George et al (1973) were limited to underwater sampling of the littoral shoreline of Lake George. Table 42 shows fish populations in the littoral region of Lake George.

Approximately five kilometers of shoreline, i.e., 2.4% of the entire perimeter, were surveyed yielding a total of 3,294 fish of ten different species three of which the killifish (*Fundulus diaphanus*), the rainbow trout (*Salmo gairdneri*), and the Johnny darter, (*Etheostoma nigrum*), were observed in small numbers. Five species of the Centrarchidae, the redbreast sunfish (*Lepomis auritus*), the rock bass (*Ambloplites rupestris*), the pumpkinseed (*Lepomis gibbosus*), the smallmouth bass (*Micropterus dolomieui*), and the largemouth bass (*Micropterus salmoides*) constituted a total of 3,164 o4 97% of all fish observed.

Using the shorelength approximation of 209.6 km (Colon, 1971, 1972) and the numbers of each species inventoried per km, it is possible to approximate the total numbers and the biomass of the adult members of the species for the entire lake.

TABLE 42. FISH POPULATIONS IN THE LITTORAL REGION OF LAKE GEORGE, N.Y.

Species	Total Number (N) 15 Sites	Approx. Total (entire shoreline*)	Approx. Biomass (kg)	% Total
Red Breast Sunfish (*Lepomis auritus*)	1,149	48,600	2,576	34.9
Rock Bass (*Ambloplites rupestris*)	905	38,300	2,480	27.5
Pumpkinseed (*Lepomis gibbosus*)	707	29,900	1,582	21.5
Smallmouth Bass (*Micropterus dolomioui*)	400	16,900	1,815	12.1
Yellow Perch (*Perca flavescens*)	85	3,600	313	2.6
Largemouth Bass (*Micropterus salmoides*)	30	1,300		0.9
Northern Pike (*Esox lucius*)	11	500		0.3
Other	7	300		0.2
Total Fish	3,294	147,400		
Total Length of Runs (m)	4,952			
Total Area (m^2)	47,004			
N/1,000 m	9,897			
N/10,000 m^2 (ha)	10,389			

*Using 209.6 km as shoreline length and knowing number of fish species/km.

A total of 1,532 fish were observed over 2,672 meters of western shore and 1,762 fish were observed over 2,280 meters of eastern shore to produce a figure of 573 fish/km and 773 fish/km, respectively. A total of 1,402 fish were observed over 21,150 meters of shoreline for the southern basin, and 1,335 fish/2,252 meters for the northern basin, giving a figure of 652 fish/km and 593 fish/km for the southern and northern basins respectively.

Numbers of fish/km range from a low of 360 at Orcutt Bay on the western side of the lake, to a high of 1,640 fish along the heavily developed frontage of the western shore of Warner Bay on the eastern side, both in the southern basin. Huddle Bay on the west side of the south basin and the open bay north of Anthony's Nose on the east side of the north basin also yielded few fish. Other high yielding sites were French Point and Paradise Bay in the Narrows, and the site north of Racket Island the east side of the north basin.

Focusing on the four species which are best evaluated in the study (red-breast sunfish, rock bass, pumpkinseed, smallmouth bass), it is possible to approximate aggregate minimal numbers of 133,700 adult and sub-adult individuals weighing about 8.45 metric tons. Assuming a lake perimeter of 210 km, this means a minimum of about 0.64 fishes per meter of shoreline. Assuming that the populations are restricted to a 10 m wide band, the density of the four species of fish is 0.064 per square meter or 640 per ha. If the biomass density is calculated for the entire lake (i.e., 114 km^2), it is about 4 g (wet weight) per square meter.

Given their distribution in the demersal section of the euphotic zone, the overall role and importance of the centrarchids in the regulating of energy and substance in Lake George seems great, but the focus in both time and space of such action is highly seasonal. Actively feeding adult populations are dispersed in the littoral zone during the spawning periods while, during the winter, food consumption drops greatly and fish collect into schools which range into deeper water. Immature individuals are usually tied to areas providing cover. The amount and kind of food entering the diet must be expected to vary greatly within each species. It seems clear, however, that adult and sub-adult individuals constitute most of the biomass and channelling influence present.

Benthic Macroinvertebrates

Needham et al, (1922) discussed the importance of various species of Crustaceans, Diptera, Trichoptera, Gastropoda, and Ephemeroptera in the diet of the fishes of Lake George. Of special consideration was the role played by two species of burrowing mayflies (Ephemeroptera), *Ephemera varia* and *Hexagenia bilineata*. *E. varia*, the smaller of the two species, abounded in the shallow cross channels near the islands of the Narrows emerging in late June. *Hexagenia bilineata*, a larger species, was more common in the deeper beds of the central basin, emerging in early July. The time of emergence of these two species was a time of feasting for most of the fishes of the Lake. (Needham et al. 1922) More recent studies by Henningson (1973) revealed a diverse benthic fauna in several selected smapling sites in Lake George. Henningson (1973) sampled macroinvertebrates in selected sites in the north and south basins of Lake George. The sampling sites were located at Smith bay (2 stations), Dunham Bay (3 stations) and Echo Bay (2 stations). A total of 108 taxa were identified, 45 of which were common to all of the bay sites sampled. Benthic organisms were found to belong to the following groups: *Coelenterata*, *Turbellaria*, *Odonata*, *Gastropoda*, among others. Qualitatively, the distribution of organisms varied considerably from month to month in the three bays studied. Quantitatively the densest population (12,150 organisms/m^2) was found at Smith Bay (North basin) in May 1972. The least dense population (862 organisms/m^2) was at Dunham Bay in the south basin.

The total poulation densities of macroinvertebrates appeared to peak in May (Echo Bay) or early June (Smith and Dunham Bays) and drop sharply in late June or July. A gradual increase in numbers appeared by August and September at all stations. By the end of June, larval stages of immature aquatic insects belonging to the groups Ephemeroptera, Trichoptera, Neuroptera, and Odonata had virtually disappeared.

In September, the presence of trichopteran larvae became evident in most bays. Dipteran larvae were the dominant macroinvertebrate found in the lake with significant variation in individual genera expressing dominance on a monthly basis. In the deeper water stations investigated, Tanytarsus were especially common in comparison with Oligochaetes and Gastropods which were found in high numbers in shallow water stations.

Diversity indices ($\bar{d}$) were developed for numerical comparisons of the population. Values ranged from 1.42 at Smith Bay in late June to 4.15 at Dunham Bay in July. The $\bar{d}$ values showed considerable fluctuations, especially throughout the warmer periods of June, July and August. Generally, however, the values were greater than 2.5. The average $\bar{d}$ values for the bays as a whole are Dunham Bay, 3.075; Echo Bay, 2.976; and Smith Bay, 2.736. Only Smith Bay and Dunham Bay 1 had $\bar{d}$ values significantly less than 3.0, the theoretical value above which water might be considered "unpolluted."

Decomposers

Microorganisms actively decompose dissolved and particulate organic matter throughout the year in Lake George. The rates at which microbial decomposition occurs depend upon the chemical nature of the organic substrates, the biomass of microorganisms, and several other environmental variables, the most important of which is temperature. In the water column, most of the microorganisms associate with fine particulate organic matter. From 100 to 600 colonized particles are found per ml of lake water. The level of suspended colonized particles, in general, increases in the near shore areas and near the sediment. Lake George has from 10^7 to 10^8 bacterial cells per mg of sediment (dry weight basis). A range of 10^8 to 10^9 is found per mg dry weight of decomposing aquatic plant material, and from 10^9 to 10^{10} per mg allochtonous particulates (dry) brought in from streams.

Although there are innumerable species of decomposing microorganisms in Lake George, certain dominant bacteria are widespread and consistently distributed throughout the northern and southern basins, both in the water column and in the sediment. They are: *Achromobacter*, *Aeromonas*, *Arthobacter*, *Cellulomonas*, *Corynebacterium*, *Jurthea*, *Proteus* and *Pseudomonas*.

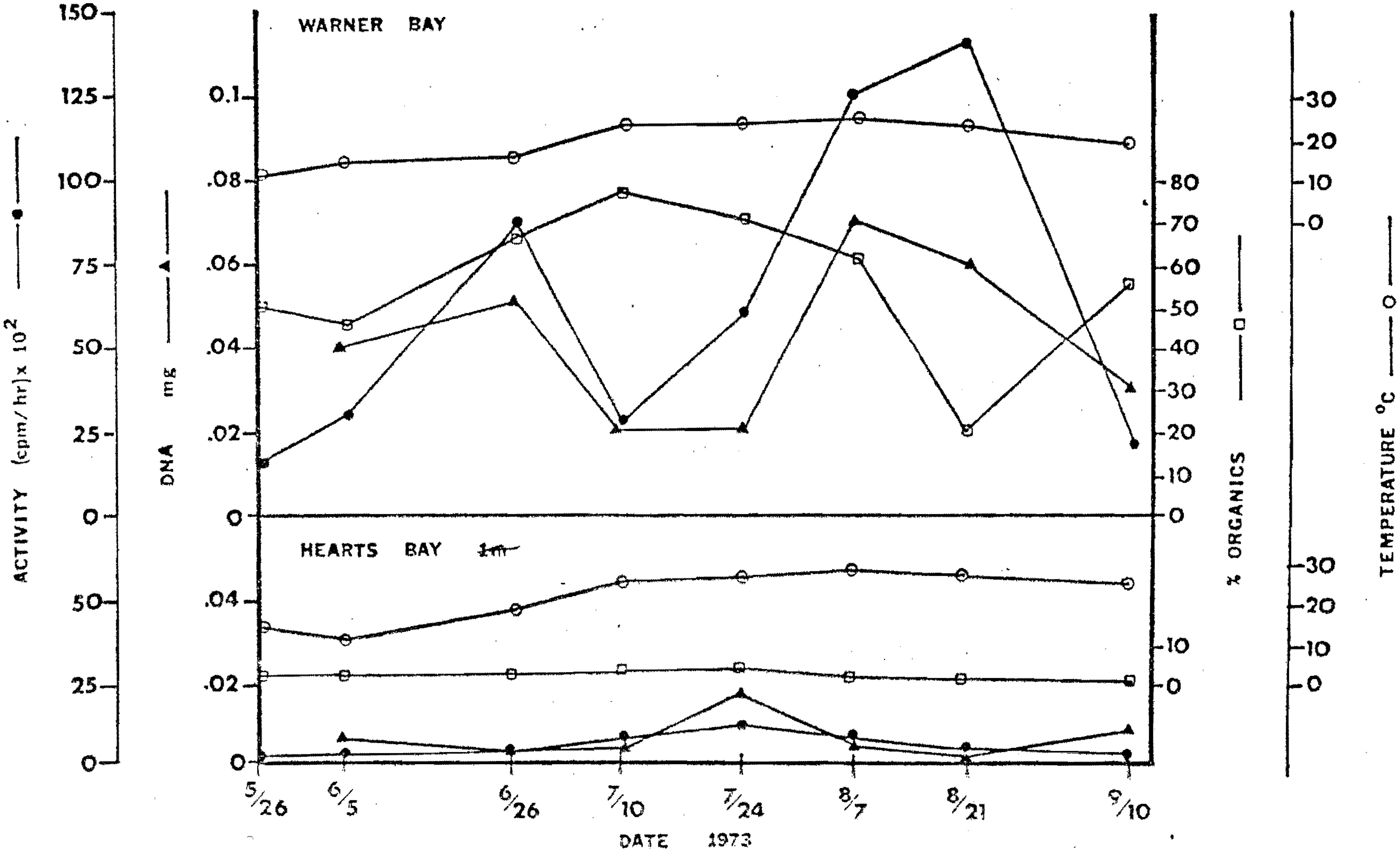
In general, the microorganisms that dominate the microbial population in the lake are small. A good estimate for an average cell weight of these organisms is 0.029 picogram (pg). These cells contain on the average 2×10^{-4} pg deoxyribonucleic acid (DNA).

Extensive determinations of biomass in the sediment have been done by estimating the DNA content of the sediment (Clesceri and Dazé, 1975). During the growing season DNA levels are highly correlated with activity measurements, as measured by a labeled organic carbon uptake technique (Clesceri, 1972). This is seen in Warner Bay, which is heavily developed and receives input from an adjacent marshland. Comparison with Hearts Bay demonstrates the influence of enrichment of Warner bay with allochthonous material (Figure 43).

Activity of the decomposing microorganisms is the important measurement with respect to the conversion of organic matter to materials that can re-enter the food web either through remineralization or as microbial cells. The activity, or metabolic rate, of the decomposing microorganisms is a complicated

FIGURE 43

TEMPORAL VARIATIONS OF THE PERCENT ORGANICS, DNA LEVEL, TEMPERATURE AND MICROBIAL ACTIVITY AS MEASURED BY THE UPTAKE OF ^{14}C-GLUCOSE BY SEDIMENT AT 1m DEPTH (Clesceri and Dazé 1973)



function and shows different dependencies as the growing season progresses (Clesceri and Dazé, 1973). There is roughly a hyperbolic relationship between activity and temperature, with a maximum between 25 and 30° C for samples withdrawn from a 15° C environment as shown in Table 43.

TABLE 43. Influence of Temperature on Sediment Activity

Temperature (° C)	Uptake (cpm/hr)	Uptake (cpm/mg o.w.)*
4	26172	3347
10	78691	10063
15	91667	11722
25	156421	20003
30	158797	20307

* o.w. = organic weight

As the growing season progresses, however, this simple relationship is complicated by the quantity and chemical quality of the organic material available for decomposition (see Table 44). This is most dramatic when the activity is related to DNA.

Microbial activity was also studied by measuring the rates of decomposition of several polymers of plant origin. These were found to be fairly high. Cellulose, lignin and pectin were studied; the rates varied reflecting the season, the source and the temperature of the sediment. Most rapid decomposition occurred at the highest temperature achieved, in sediment associated with the macrophyte beds, and where there was a continual input of highly biodegradable material through the sloughing of perennial plants. Under these conditions, 80% of the cellulose can be degraded in less than 2 weeks. As in many north temperate lakes, however, the major input of organics occurs when water

TABLE 44. Seasonal Variation in Sediment Activity

Temperature (° C)	Date 1973	Uptake (cpm/hr)	Uptake (cpm/mg o.w.)	Uptake (cpm/mg DNA)
11.0	6/26	15305	212	21556
18.0	7/10	147193	1978	91995
20.0	7/24	155245	1842	119419
19.0	8/7	147639	209	268434
21.5	8/21	112381	1257	178382
21.8	9/10	12449	123	9650

o.w. = organic weight

Ref.: Clesceri and Dazé, 1973.

temperatures are less than 15° C (compared to the maximum temperature for surface water in Lake George of 24° C). This situation limits the rate of organic decomposition and remineralization, thus providing for a more regulated decomposition process over a longer period of time.

Table 45 shows decomposition, under winter conditions, in the field (Boylen, et al., 1975). Although the decomposition rate is slower than that achieved at 24° C, the rate is substantial, and illustrates the continual microbiological activity observed throughout the year.

The remineralization accompanying organic decomposition is not well understood. It appears that no remineralization of N and P occurs during periods of active microbial growth, i.e., the N and P are conserved within the microbial biomass. Under these conditions the ratio of C to N and P continually decreases in the particulate organic - microorganism or "detrital" complex. As the readily degradable material becomes exhausted, release of P and N is observed, since it is then in excess supply for the small amount of biomass being synthesized.

In examining the concentration of inorganic nutrients in the interstitial water of sediment cores, a definite gradient appears. The concentration of inorganic nutrients in the upper 3 in (7.6 cm) of the sediment water is roughly ten times the concentration observed in the overlying water as demonstrated with data from Hearts Bay and Warner Bay at 9 m depth (Table 46).

The release of nutrients from these interstitial waters occurs via macrophyte root assimilation, diffusion, and periodic mixing. The depth of mixing is probably not very great and release seems to be accompanied by sorption by the flocculent layer (work in progress), suggesting that the influence on phytoplankton of nutrient regeneration with in the sediments is minimal.

TABLE 45. Decomposition of Natural Polymers in Sediment

Date	Temperature (^{o} C)	Cellulose (g.o.w.)	Pectin (g.o.w.)	Lignin (g.o.w.)
1/9*	3.0	100.0	7.9	3.2
3/3*	4.0	49.7	12.2	4.9
4/8*	4.0	31.2	6.2	3.0
5/1	8.0	15.3	2.8	0.9
5/15	10.0	10.2	1.8	-

* Ice Cover

** mg/g dry organic wt. of sediment

Ref.: Boylen, et al., 1975.

TABLE 46. Comparision Between Column Water and Interstitial Water Chemistry *

Interstitial Water **	pH	NH_3-N (mg/L)	Kjeldahl-N (mg/L)	Total P (mg/L)
Warner Bay 9 M	6.9	0.770	1.01	0.196
Hearts Bay 9 M	6.8	0.220	0.635	0.057
Column Water (from half depth)				
Warner Bay 9 M	7.0	0.046	0.310	0.006
Hearts Bay 9 M	7.3	0.027	0.325	0.005

*from 6/17/75

**Top 3 in (7.6 cm) of sediment

Ref.: Boylen et al., 1975

The role of microorganisms as a food source in detrital food web dynamics is postulated as a significant route whereby material is moved out of the sediment.

SUMMARY

Lake George is presently an oligotrophic lake bordering on mesotrophy. It is a long narrow lake created by the last glacier. The area is presently a tourist attraction, primarily due to the clear, deep waters of the lake. The lake is renowned for the clarity of the water and is frequented by divers who study the bottom of the lake under natural light.

The lake is receiving stresses from the populated areas at the south end of the lake. Here various recreational and commercial interests have attracted many tourists with the resultant accumulation of tourist attractions such as hotels, motels, and restaurants. Lake sports are conducted on the waters including such activities as swimming, fishing and boating. Lake George provides the water supply for the Village and Town of Lake George and the Village of Ticonderoga with only chlorination prior to distribution. In addition, many homeowners surrounding the lake use the water directly from the lake with no treatment whatsoever. This confirms the purity of the waters within the lake since there have been no known outbreaks of disease caused by drinking the water directly from the lake. Numerous efforts are being made to preserve the quality of the water of Lake George.

Whereas recent studies have been conducted in order to evaluate the quality of the waters within the lake, there are few historical records relating specifically to water quality. Therefore, it is difficult to determine any significant deterioration in water quality and, in particular, the rate of any such deterioration. The quality of the water is definitely poorer in the south basin where the greatest population exists. The quality of the water in the north basin is measurably superior and less subject to stress. Inasmuch as the lake flows from south to north, there is concern that eventually the poorer quality waters from the south basin will reach the north basin, thereby deteri-

orating the quality of the water in the north basin.

The quality of the water within Lake George is still very high and programs to preserve this high quality should be conducted. Thus, every effort possible should be made to prevent the input of nutrients, particularly phosphorus to Lake George, including sewering certain areas and preventing development of other areas. Planning or zoning ordinances should be instituted to facilitate orderly development that is in consonance with the water quality requirements of the lake. Future concerns may include limiting the number of boats utilizing the lake. These and other factors must be faced now in order to preserve the high quality of Lake George.

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