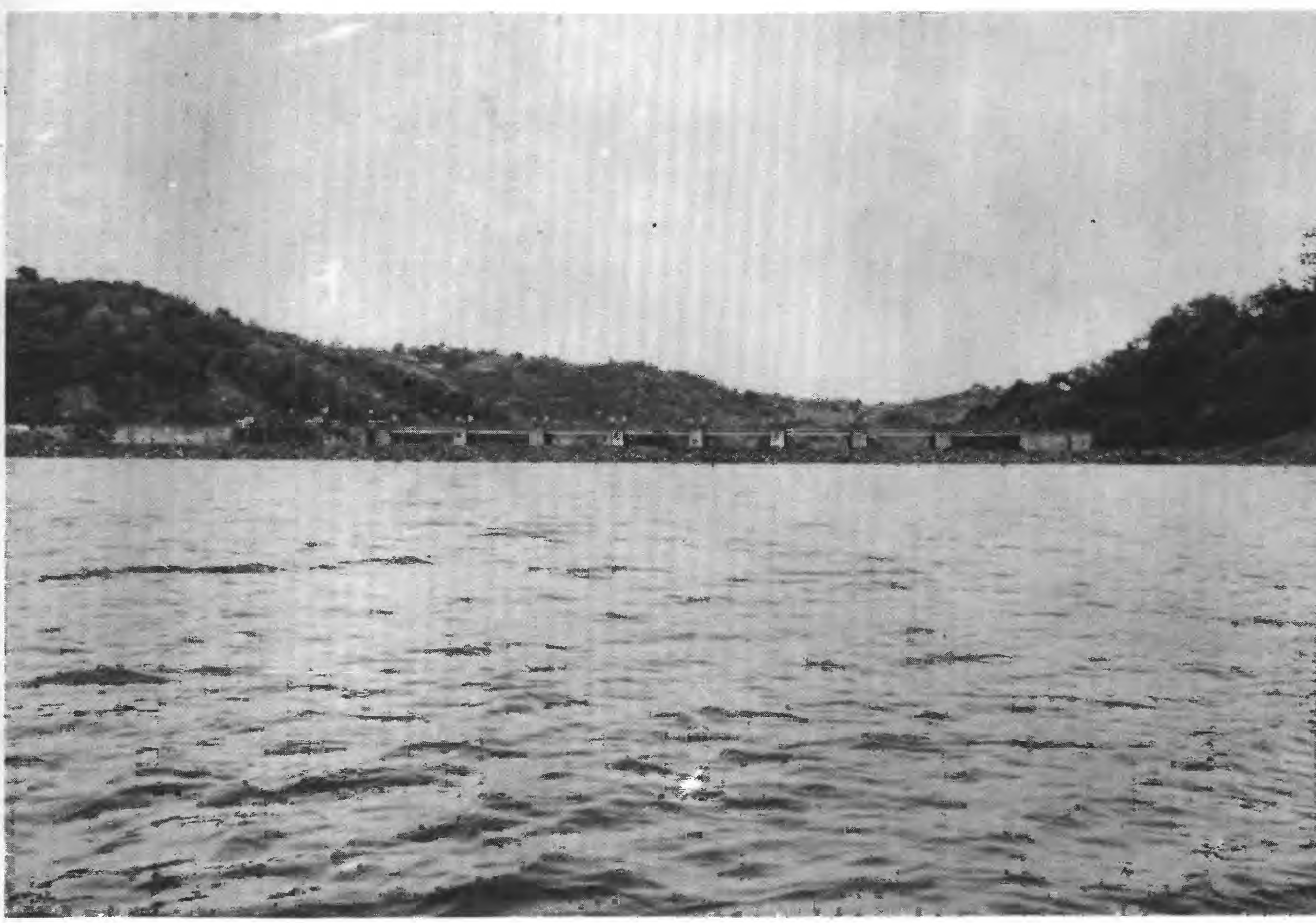
LIMNOLOGY OF LAGO LOIZA, PUERTO RICO

U.S. GEOLOGICAL SURVEY
Water Resources Investigations 79-97



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16. Abstracts

The principal chemical, physical and biological characteristics of Lago Loíza, Puerto Rico, and its main tributaries were studied from 1973-74. The lake supplies an average of 300,000 cubic meters per day of water to metropolitan San Juan. Flows from Río Grande de Loíza and Río Gurabo contribute 83.0 percent of the water, 67.4 percent of the nitrogen, and 65.7 percent of the phosphorus to the lake. About 31 percent of the nitrogen and 45 percent of the phosphorus were retained in the lake, which has a mean flushing rate of 19 times per year. The lake's capacity declines at a rate of about 1.9 percent per year and is about 14.9 million cubic meters. Sewage inputs to the lake's tributaries average 18,560 cubic meters per day. Fecal coliform bacteria in numbers ranging from 100 to 6,700,000 were recorded throughout the tributaries and the lake. In the lake the dissolved oxygen concentration is less than 5.0 milligrams per liter below the 1.5-meter depth. Lago Loíza is a hypereutrophic lake, with an average total nitrogen concentration of 1.7 milligrams per liter and 0.33 milligrams per liter of total phosphorus.

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

TABLES--Continued

GLOSSARY

Alga, algae (n), algal (adj). A group of plants, mostly aquatic, single-celled, colonial, or multicelled, containing chlorophyll and lacking roots, stems and leaves.

Algal bloom (n). A large number of a particular algal species, often amounting to 0.5 to 1 million cells per liter.

Anaerobe (n), anaerobic (adj). An organism living or growing in the absence of free oxygen.

Aquatic (adj). Pertaining to water; aquatic organisms, such as phytoplankton or fish, live in or on water.

Average flow (n). The average yearly discharge at a particular station, obtained from the sum of the annual total discharges of n years divided by the same number of years.

Bacterium, bacteria (n), bacterial (adj). Microscopic unicellular organisms, typically spherical, rod-like, or spiral and thread-like in shape, often clumped into colonies. Some bacteria cause disease, others perform an essential role in the recycling of materials, for example, by decomposing organic matter into a form available for reuse by plants.

Biochemical oxygen demand (BOD) (n). The amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. BOD-5 is a 5-day determination of the oxygen requirement for a known volume of water.

Biology (n), biological (adj). The science or study of organisms.

Bloom (n). See Algal bloom.

Carnivore (n). An organism that obtains its nourishment by consuming other animals; includes many fishes and aquatic insects.

Clinograde (n). The stratification curve of temperature or of a chemical substance in water that exhibits a sloping profile from the surface downward into deeper water.

Coliform bacteria (n). A particular group of bacteria used as indicators of possible sewage pollution. They are formally characterized as aerobic, and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C.

Convective (adj). Flow originated by heat differentials. Climatologically it implies precipitation which originates when warm air rises against the windward side of a mountain, and upon contact with the colder upper layers.

Cultural eutrophication (n). The acceleration of the natural process of nutrient enrichment in a lake as a result of man's activities.

Detritus (n). Fragmented material of inorganic or organic origin.

Diatom (n). A unicellular or colonial alga having a siliceous shell.

Diel (adj). Relating to a 24-hour period that usually includes a day and the adjoining night.

Diurnal (adj). Relating to daytime or something recurring every day, often used as a synonym for diel.

Diversity (n). The abundance in numbers of species in a specified location.

Drainage basin (n). A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams.

Ecology (n), ecologic(al) (adj). The science or study of the relation of organisms or groups of organisms to their environment.

Ecosystem (n). The community of plants and animals interacting together with the physical and chemical environment.

Environment (n). The sum of all the external physical, chemical, and biological conditions and influences that affect the life and development of an organism.

Epilimnion (n). The upper, relatively warm, circulating zone of water in a thermally stratified lake.

Euphotic zone (n). That part of the aquatic environment in which the light is sufficient for photosynthesis; commonly considered to be that part of a water body in which the intensity of underwater light equals or exceeds 1 percent of the intensity of surface light.

Eutrophication (n), eutrophic (adj). Enrichment of water, a natural process that may be accelerated by the activities of man; pertaining to waters in which primary production is high as a consequence of a large supply of available nutrients. See also Oligotrophic.

Evapotranspiration (n). Water withdrawal from the soil, a body of water, etc., by evaporation and plant transpiration.

Fecal coliform bacteria (n). That part of the coliform group that is present in the gut or the feces of warmblooded animals; they are indicators of possible sewage pollution.

Fecal streptococcal bacteria (n). A particular group of bacteria found in the gut of warmblooded animals; their presence in natural waters is considered to verify fecal pollution. They are formally characterized as gram-positive, cocci bacteria which are capable of growth in brain-heart infusion broth either at 45°C and 10°C (the enterococci species) or at 45°C only (*Streptococcus bovis* and *S. equinus*).

Flushing rate (n). The ratio between the annual discharge into a lake (or other water body) and the lake volume.

Genus, genera (n), generic (adj). The taxonomic categories below family, consisting of species; the first part of the scientific name of organisms. See also Taxonomy.

Gross primary productivity (n). The total rate at which organic matter is formed by photosynthesis, including the organic matter used up in respiration within the period of measurement. The term is synonymous with gross primary production, total photosynthesis, and total assimilation.

Habitat (n). The place where an organism lives.

Herbicide (n). Chemical or a mixture of chemicals intended to control or destroy vegetation.

Hypolimnion (n). The lower, relatively cold, noncirculating water zone in a thermally stratified lake.

Limnology (n). The science or study of inland waters; the ecology of inland waters.

Macrophyte (n). Large plants that can be seen without magnification; includes mosses and seed plants.

Mean annual flow (n). The average daily discharge at a particular station, obtained from the sum of the daily discharges in a year divided by the number of days in the same year.

Mean depth (n). The volume of the lake divided by its area.

Metabolism (n). The chemical processes of living cells by which energy is derived and material is assimilated.

Net community productivity (n). The rate of storage of organic matter not used by the organisms in the environmental area under study during the period of measurement.

Nutrient (n). Any chemical element, ion, or compound that is required by an organism for the continuation of growth, for reproduction, and for other life processes.

Pesticide (n). Any substance used to kill plants, insects, algae, fungi, and other organisms; includes herbicides, insecticides, algalcides, fungicides, and other substances.

pH The negative logarithm of the hydrogen-ion concentration, expressed as a number from 0 to 14. A pH of 7 is neutral, a pH of less than 7 is acidic, and a pH of greater than 7 is basic.

Photosynthesis (n), photosynthetic (adj). A biochemical sysnthesis of carbohydrates from water and carbon dioxide in the chlorophyll-containing tissues of plants in the presence of light.

Phytoplankton (n), phytoplanktonic (adj). The plant part of the plankton.

Plankter (n). An individual planktonic organism.

Plankton (n), planktonic (adj). The community of suspended or floating organisms which drift passively with water currents.

Pollution (n). ". . . an undesirable change in the physical, chemical, or biological characteristics of our air, land, and water that may or will harmfully affect human life or that of other desirable species, our industrial process, living conditions, and cultural assets; or that may or will waste or deteriorate our raw material resources." National Research Council, Committee on Pollution, 1966, p. 3).

Population (n). A group of interacting and interbreeding individuals of the same type living in a common habitat and having little reproductive contact with other groups of the same species.

Primary productivity (n). The rate at which radiant energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form of organic substances which can be used as food materials (Odum, 1971, p. 43). See also Gross primary productivity, Net community productivity, and Secondary productivity.

Production (n). The total amount of living matter produced in an area per unit time regardless of the fate of the living matter.

Respiration (n). A life process in which carbon compounds are oxidized to carbon dioxide and water and the liberated energy is used in metabolic processes.

Sample (n). A small separated part of something that is representative of the whole.

Secchi disk (n). A circular metal plate, 20 centimeters in diameter, the upper surface of which is divided into four equal quadrants painted black and white. Variations in size and painted only in white are used. The disk is lowered into the water and the depth at which it is no longer visible is denominated as the "secchi disk transparency."

Sediment (n). Fragmental material, both mineral and organic, that is in suspension or is being transported by the water mass or has been deposited on the bottom of the aquatic environment.

Species (n, sing. and pl.). The basic unit for the classification of organisms; the taxonomic category below genus, and the second part of the scientific name of an organism. See also Taxonomy. The biological concept of species, in contrast to the purely taxonomic concept, has been defined by Mayr (1940) as ". . . a group of actually or potentially interbreeding organisms reproductively isolated from other such groups of interbreeding organisms."

Specific conductance (n). Specific conductance measures the ability of a solution to conduct an electric current. Its value increases with increasing concentration of ions in solution. Thus, its value may be related to the concentration of dissolved solids. Unpolluted streams in Puerto Rico seldom exceed a specific conductance value of 400 μmho per centimeter.

Suspended sediment (n). Fragmental material, both mineral and organic, that is maintained in suspension in water by the upward components of turbulence and currents or by colloidal suspension.

Taxonomy (n). The division of biology concerned with the classification and naming of organisms; synonymous with systematic biology. The classification of organisms is based upon a hierarchal scheme beginning with the species at the base. The higher the classification level, the fewer features the organisms have in common. See also Species. As an example, the taxonomy of the common stonefly, Pteronarcys californica is as follows:

Kingdom	Animal
Phylum	Arthropoda
Class	Insecta
Order	Plecoptera
Family	Pteronarcidae
Genus	Pteronarcys
Species	californica
Scientific name	Pteronarcys californica

Thermal stratification (n). A temperature distribution characteristic of many lakes in which the water is separated into three horizontal layers: a warm epilimnion at the surface, a metalimnion in which the temperature gradient is steep, and a cold hypolimnion at the bottom.

Trophic level (n). A scheme of categorizing organisms by the way they obtain food from primary producers or organic detritus involving the same number of intermediate steps.

Tuff (n). Volcanic ash usually more or less stratified in various states of consolidation.

Water quality (n). Kinds and amounts of matter dissolved and suspended in natural waters, the physical characteristics of the waters, and the ecological relationships between aquatic organisms and the environment.

Zooplankton (n), zooplanktonic (adj). The animal part of the plankton.

The following conversion factors for the terms used in this report are for those readers who prefer to use inch-pound rather than the International System (SI) of units:

Divide SI unit	by	to obtain inch-pound unit
	Length	
millimeter (mm)	25.40	inch (in)
meter (m)	0.3048	feet (ft)
kilometer (km)	1.609	mile (mi)
	Area	
square meter (m^2)	0.0929	square feet (ft^2)
square kilometer (km^2)	2.590	square mile (mi^2)
hectare (ha)	2.471	acre
	Volume	
cubic meter (m^3)	0.02832	cubic feet (ft^3)
	Weight	
gram (g)	28.35	ounce (oz)
kilogram (kg)	2.2046	pound (lb)
metric ton	0.9072	ton (t)
	Flow	
cubic meters per second (m^3/s)	0.02832	cubic feet per second (ft^3/s)
cubic meters per second (m^3/s)	0.04381	million gallons per day (Mgal/d)

LIMNOLOGY OF LAGO LOIZA, PUERTO RICO

by

Ferdinand Quiñones-Márquez

ABSTRACT

A comprehensive study of the limnology of Lago Loíza, Puerto Rico, and its main tributaries was conducted from 1973-75. A sedimentation-capacity survey of the lake was included in the study.

At a water-surface elevation of 39.78 meters above mean sea level, Lago Loíza has an effective surface area of about 242.5 hectares, a mean depth of 6.1 meters and a maximum depth of 17.2 meters. The lake supplies an average of 300,000 cubic meters of water per day to the metropolitan San Juan area. During the drought of 1974, the water level in the lake declined 5.1 meters and pumpage to 200,000 cubic meters per day.

During the period from November 1973 to October 1974, a total of 279.7 million cubic meters of water flowed into Lago Loíza. The Río Grande de Loíza contributed 49.7 percent while Río Gurabo contributed 34.6 percent. The floods of October 1974 contributed 37.0 percent of the total. The lake's mean flushing rate is about 19 times per year, although it may be flushed several times during one flood.

The lake's present capacity is about 14.9 million cubic meters. The sedimentation rate is about 1.9 percent per year. Estimated potential usable life of the reservoir is about 40 years. The bottom sediments are from 60 to 90 percent clay, with 10 to 12 percent organic matter, containing an average of 0.18 percent nitrogen, and 0.09 percent phosphorus.

Streams flowing into Lago Loíza receive an average of 18,560 cubic meters per day of partially treated sewage. The sewage contributes fecal coliform bacteria in concentrations ranging from 2,000 to 4,300,000 in Río Caguitas, 2,700 to 6,700,000 in Río Bairoa, 100 to 60,000 in Río Grande de Loíza, and 200 to 17,000 in Río Gurabo (colonies per 100 milliliters of sample). In the lake, bacteria concentrations decrease downstream averaging about 200 colonies per 100 milliliters at the damsite. However, during periods of high flow, fecal coliform bacteria concentrations from storm runoff average 9,000 colonies per 100 milliliters at the damsite.

Nonpoint sources and sewage treatment plants contributed 564.1 metric tons of nitrogen and 128.3 of phosphorus to Lago Loíza during a 12-month period. Río Grande de Loíza contributed 31.7 percent of the nitrogen and 31.9 percent of the phosphorus, while Río Gurabo contributed 35.6 percent of the nitrogen and 24.9 percent of the phosphorus. The average concentration of nitrogen

throughout the lake was 1.7 milligrams per liter, while phosphorus averaged 0.33 milligrams per liter. The lake retained about 31 percent of the nitrogen and about 45 percent of the phosphorus inputs.

The dissolved-oxygen concentration in the lake's water column did not exceed 5.0 milligrams per liter below a depth of 1.5 meters, except after intense storms. Below the 5.0-meter depth, the dissolved-oxygen concentration does not exceed 1.0 milligram per liter.

There was no significant thermal stratification in the lake's water column. Temperatures ranged seasonally from 24 to 31 degrees Celsius, and vertically a maximum of 6 degrees during September 1974.

Anacystis spp., *Cyclotella* spp., and *Melosira* spp. are the dominant phytoplankton in the lake. Cell concentrations averaged 10,000 cells per milliliter. Zooplankton numbers ranged from 200,000 to 3,700,000 per cubic meter. *Macrocyclops* spp. was the dominant zooplankton. Gross primary productivity ranged from 0.31 to 0.41 grams per cubic meter per hour of carbon.

Water hyacinths (Eichornia crassippes), enhanced by nutrients in the lake, are the dominant aquatic plants. Two species of tilapia fish (Tilapia mossambica and Tilapia vendalli) constituted more than 62 percent of the species identified by another investigator.

INTRODUCTION

Lago Loíza is the principal source of water to the metropolitan area of San Juan, Puerto Rico. The reservoir supplies about 300,000 m^3/d for both domestic and industrial users in the metropolitan area. In 1974, this was about 58 percent of the total water used in the city.

Several surveys conducted by the Puerto Rico Aqueduct and Sewer Authority (PRASA), as well as by other Commonwealth of Puerto Rico agencies, have shown that the reservoir and its tributaries are contaminated by domestic and industrial pollutants. Sewage and nutrients from both point and nonpoint sources are the principal contaminants. These surveys have been limited in scope.

In cooperation with the Environmental Quality Board of Puerto Rico, a comprehensive study of the reservoir and its tributaries was started in 1973 by the U.S. Geological Survey. The study, completed in 1975, was conducted as part of the cooperative water-resources investigations program between the Commonwealth of Puerto Rico and the U.S. Geological Survey.

Purpose and Scope

The principal objectives of the study were as follows:

1. To determine the existing water-quality conditions in Lago Loíza as reflected by the principal chemical, physical, biological and bacteriological characteristics in the lake and its tributaries.

2. To estimate the reservoir's water budget during the study period, including the contributions from the tributaries and other sources.

3. Estimation of the reservoir's overall nitrogen and phosphorus budget, including the principal sources and sinks of these nutrients.

4. Definition of the sedimentation rate in the reservoir.

Most of the data for the study were collected from five streamflow and water-quality sampling stations established at the main tributaries (fig. 1) and seven water-quality sampling stations in the lake (fig. 2) that are listed in table 1. At the damsite, a water-quality sampling station (0590) was also established (fig. 1) and flows were obtained from discharge records maintained by PRASA (Puerto Rico Aqueduct and Sewer Authority). Information relative to the fish populations in the lake was supplied by Mr. Tom Schultes, Aquatic Biologist, from the Puerto Rico Department of Natural Resources.

At the stations within the lake, water samples were collected on a monthly basis for the determination of common ions and nutrients. Vertical profiles of dissolved oxygen, temperature, and specific conductance were also determined during each visit. After January 1974, samples of phytoplankton and zooplankton were collected from stations 5, 6, and 7. One sample was collected at stations 1 through 7 for the determination of selected metals in water and bottom sediments. Determinations of pesticides in water and bottom sediment samples collected at stations 4 and 7 were also made once during the study.

The data shown in some sections of the report (evaporation, streamflow, storage, and so forth) include periods prior to or after the dates used for water or nutrient budget calculations. This is a result of the different time frames for which data either were available or were collected for different parameters. Only the data from November 1973 to October 1974 were used in the water and nutrient budget calculations.

Methods, Procedures, and Sampling Network

Chemical analyses of the samples collected were made at the U.S. Geological Survey Atlanta Central Laboratory in Doraville, Ga. Methods described by Skougstad and others (1979) and the American Public Health Association and others (1971) were used in the analyses. Phytoplankton analyses were also made at the Doraville laboratory. Zooplankton identification and numbers were

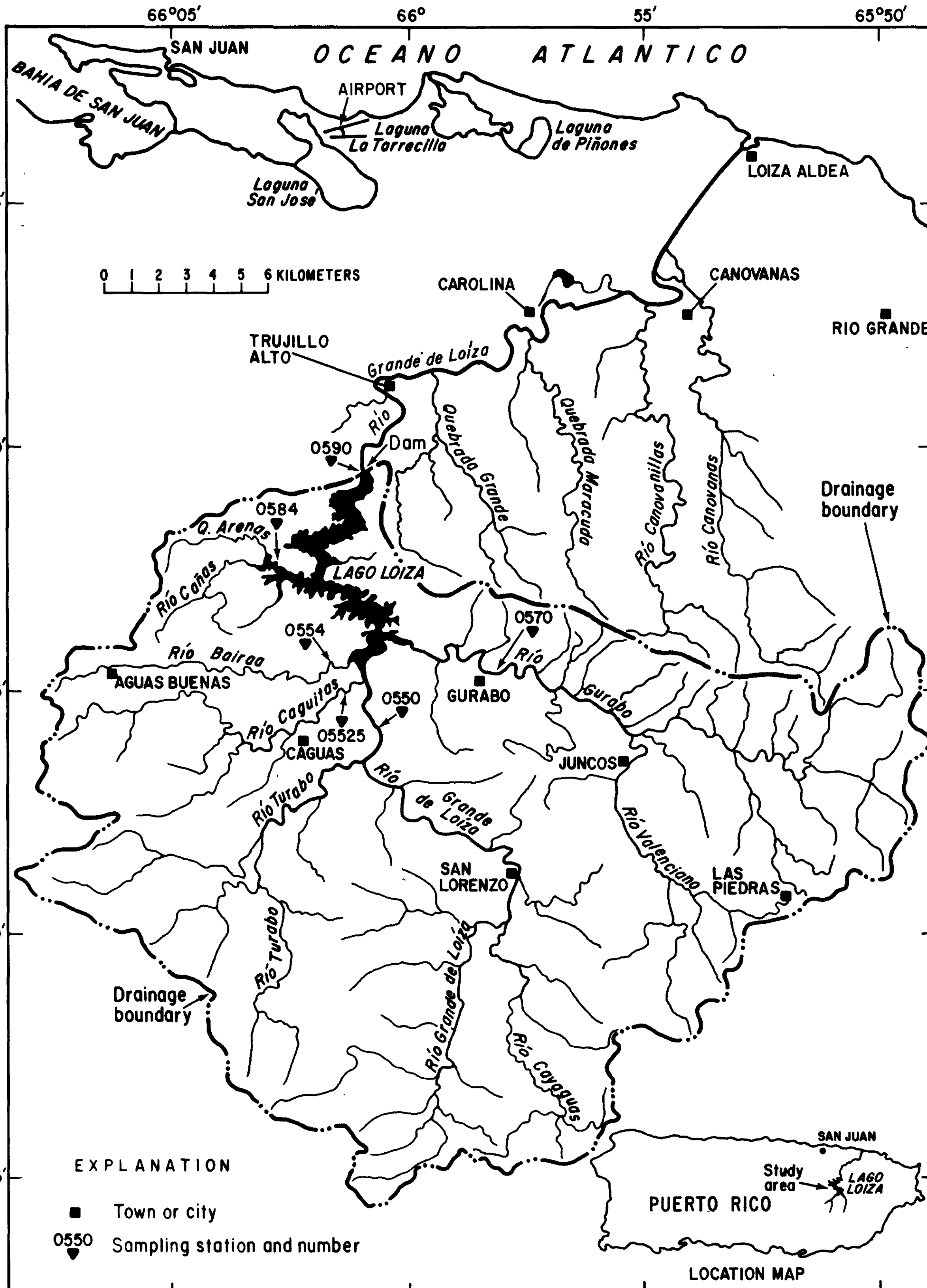

Figure 1.--Study area and sampling stations at the main tributaries and outflow of Lago Loíza.

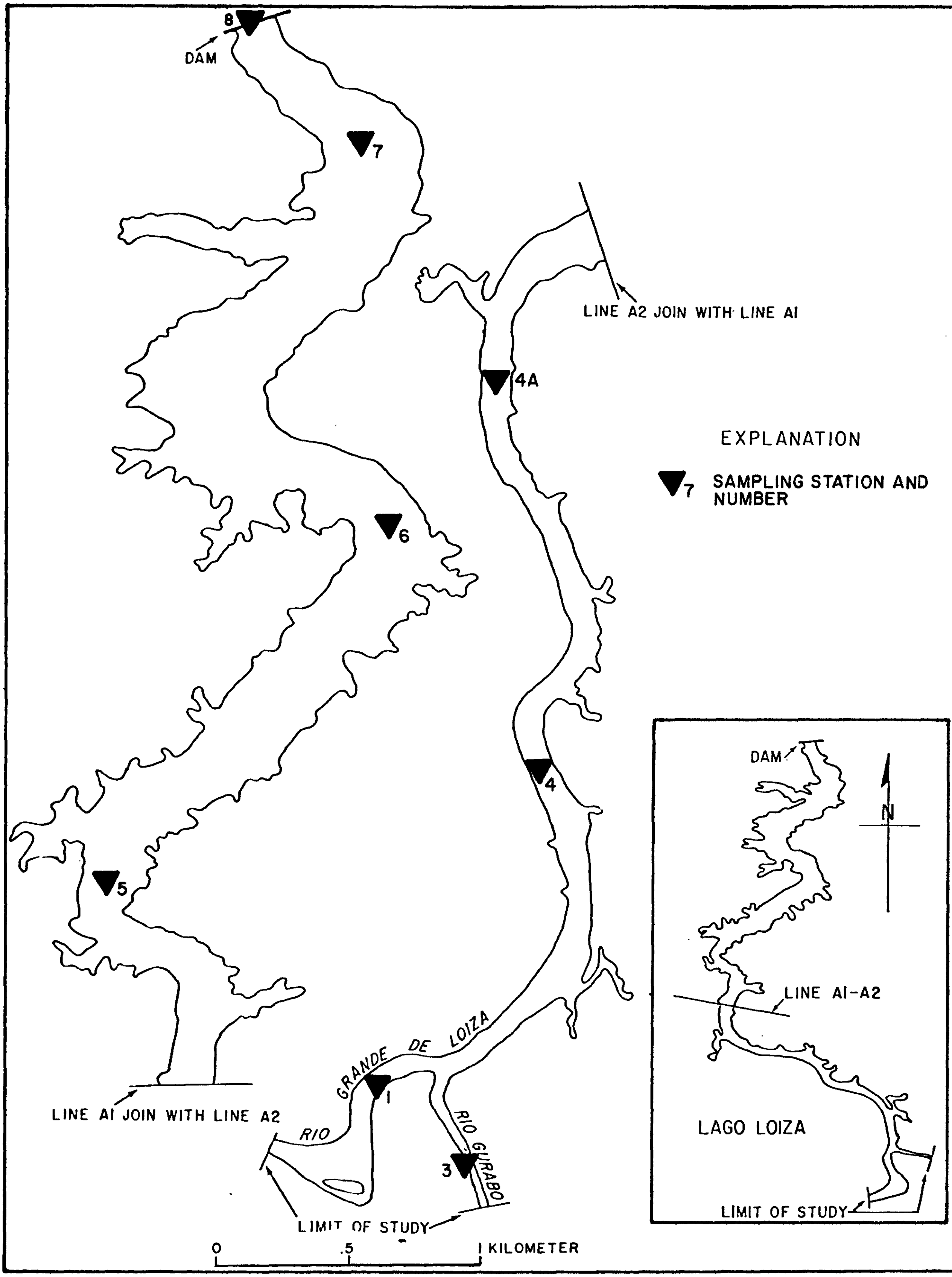

Figure 2.--Main body of Lago Loíza showing sampling stations.

Table 1.--Stream gaging and water-quality sampling stations.

Station no.	Name	Latitude	Longitude	Drainage area (km^2)
50 0550 00	Río Grande de Loíza at Caguas	18°14'35"	66°00'35"	232.6
0552 50	Río Caguitas at Hwy 30 at Caguas	18°15'11"	66°01'26"	36.5
0550 80	Río Grande de Loíza above Lago Loíza (Lago Loíza station 1)	18°16'20"	66°00'35"	--
0554 00	Río Bairoa near Caguas	18°15'28"	66°02'13"	14.0
0570 00	Río Gurabo at Gurabo	18°15'30"	65°58'05"	156.0
0570 50	Río Gurabo above Lago Loíza (Lago Loíza station 3)	18°16'21"	66°00'17"	--
0575 00	Lago Loíza station 4	18°16'51"	66°00'35"	--
* --	Lago Loíza station 4A	--	--	--
0584 00	Río Cañas above Lago Loíza	18°17'34"	66°02'33"	20.2
0586 00	Lago Loíza station 5	18°18'07"	66°01'47	--
0587 00	Lago Loíza station 6	18°18'48"	66°00'59"	--
0588 00	Lago Loíza station 7	18°19'29"	66°00'47"	--
0590 00	Lago Loíza at damsite	18°19'49"	66°01'00"	538.2

*Only miscellaneous measurements made at this site determined in the Caribbean District facilities. Methods described by Slack and others (1973) were used in the biological analyses.

Two diurnal studies to determine community primary productivity were conducted during March and July 1974. Diurnal fluctuations in the plankton populations were observed during these studies, along with measurements of dissolved oxygen and pH. Methods described by Slack and others (1973) were applied during the fieldwork and sample analyses.

A bathymetric study of the lake was conducted during March 1974. A fathometer coupled to an Ott current meter mounted on a boat was used to measure depths and distances (Smoot and Novak, 1972). Bearings were maintained with a compass and the use of land controls. Data from the bathymetric study were used for computations of the lake capacity (Eakin and Brown, 1939; and Heinemann and Dvorak, 1970). Concurrent with the bathymetric study, samples of bottom sediments were collected from about 50 stations throughout the lake. Determination of particle size and percent loss on ignition were made for each sample. Methods described by Guy (1969), were used for the analyses of the samples.

The author thanks Mr. Juan Carvajal Zamora, Microbiologist, from the Puerto Rico Department of Natural Resources and Luis A. Fusté, Hydrologic Technician, for their assistance in the biological work involved in this project.

Continuous recording gaging stations to determine water-level fluctuations were established at Ríos Caguitas, Bairoa, and Cañas. These supplemented similar existing gaging stations at Río Gurabo and Río Grande de Loíza. Samples were collected for chemical, physical, biochemical, and bacteriological analyses at these stations on a monthly or more frequent basis. Discharge measurements were made concurrent with the sampling. Discharge ratings for the stations at Ríos Caguitas, Bairoa, and Cañas were developed on the basis of these measurements. Discharge ratings for the existing stations at Río Gurabo and Río Grande de Loíza were developed previously.

The amount of water pumped from the reservoir was obtained from daily records collected by the Puerto Rico Aqueduct and Sewer Authority at the damsite pumphouse. Cocurrent with the monthly sampling and measurements at the main tributaries, chemical and physical analyses were made from samples collected at the pumphouse.

Precipitation and evaporation data were obtained from existing stations operated by the National Oceanographic and Atmospheric Administration at San Lorenzo, Gurabo, and the Lago Loíza damsite. At the damsite, precipitation samples for chemical analyses were collected by a hired observer. The samples were collected from an open collector and no corrections for dry fallout were applied.

Class "A" weather station evaporation data collected at the Gurabo substation were assumed to be representative of the drainage area. A 0.80 coefficient was applied to the pan-evaporation data to estimate lake evapotranspiration (Pruitt, 1966).

LAKE AND BASIN CHARACTERISTICS

Lago Loíza is located in the municipalities of Trujillo Alto, Caguas and Gurabo, about 12 km southeast of San Juan International Airport and about 9 km northeast of Caguas. The Río Grande de Loíza, one of the largest streams in Puerto Rico, was impounded by a dam built in 1953, creating Lago Loíza. The dam is located about 22 km upstream from the river mouth (fig. 1). Design characteristics of the dam are shown in table 2.

The original surface area of Lago Loíza was about 300 ha. This area included an embayment of the Río Cañas, which no longer constitutes an effective storage area due to sedimentation and plant growth. Substantial areas in the Loíza and Gurabo rivers do not provide effective storage capacity, but were included in the original estimates. For the purpose of this report, an effective surface area of 242.5 ha will be used. The surface area used in this report is illustrated in figure 2.

A bathymetric map of the lake (fig. 3) shows a maximum depth of 17.2 m in the vicinity of the damsite. An irregular bottom surface reflects the rugged terrain where the reservoir is located. Several concrete structures, mostly houses that were covered by the impounded water, are still present. During the drought of 1974, a part of a house (fig. 4) was exposed as the water level declined to a minimum elevation of about 35 m (from a maximum of about 40 m). The lake is relatively deep throughout its entire length with an average depth of 6.1 m. The principal physical characteristics of the lake are summarized in table 3.

The total drainage area is about 538 km^2 at the damsite. The sum of the drainage areas of the tributaries listed in table 1 is about 459 km^2. The area adjacent to the lake and the surrounding slopes drain about 79 km^2. The combined drainage area at the damsite represents the largest basin under impoundment in Puerto Rico.

The basin is characterized by its rugged terrain. The Sierra Luquillo on the northeast, and the Sierra de Cayey to the southeast provide the boundaries to the mountainous upper basin. The geology of the basin is dominated by several main features. Plutonic rocks, largely granodiorite and quartz diorite are the primary formations in the Río Grande de Loíza basin. Volcanic rocks, mostly lava and tuff, as well as extensive alluvial deposits are present in the Río Gurabo basin. The geology of the area is described in detail by Briggs and Akers (1965).

Most of the land in the upper basin is used for pastures. The Puerto Rico Department of Natural Resources estimates that about 60 percent of the basin is

Table 2.--Characteristics of Lago Loíza and structures.*

Total length - 210 meters
Crest elevation of spillway - 31.0 meters (gates open)
Length of spillway - 95.1 meters
Discharge gate - 8 (operated by electric hoists)
Maximum design discharge of spillway - 8,840 cubic meters per second at 44.0-meter elevation
Effective storage elevations - 28.0 to 40.1 meters
Dead storage elevations - 15.2 to 28.0 meters
Water service intakes - 2 (1.2-meter diameter pipes)
Power service intakes - 3 (1.6-meter diameter pipes)
Power generating capacity - 3,000 kilowatts

*Data modified from Hunt (1975) and P.R. Aqueduct and Sewer Authority

Table 3.--Physical characteristics of Lago Loíza (reference water-surface elevation of 39.78 meters above mean sea level).

Surface area (A)	242.5 hectares
Original capacity (v)	26.8×10^6 cubic meters
Present capacity (v[1])	14.9×10^6 cubic meters
Maximum depth (dm)	17.2 meters
Mean depth (d)	6.1 meters

[1]Based on capacity computations in this report

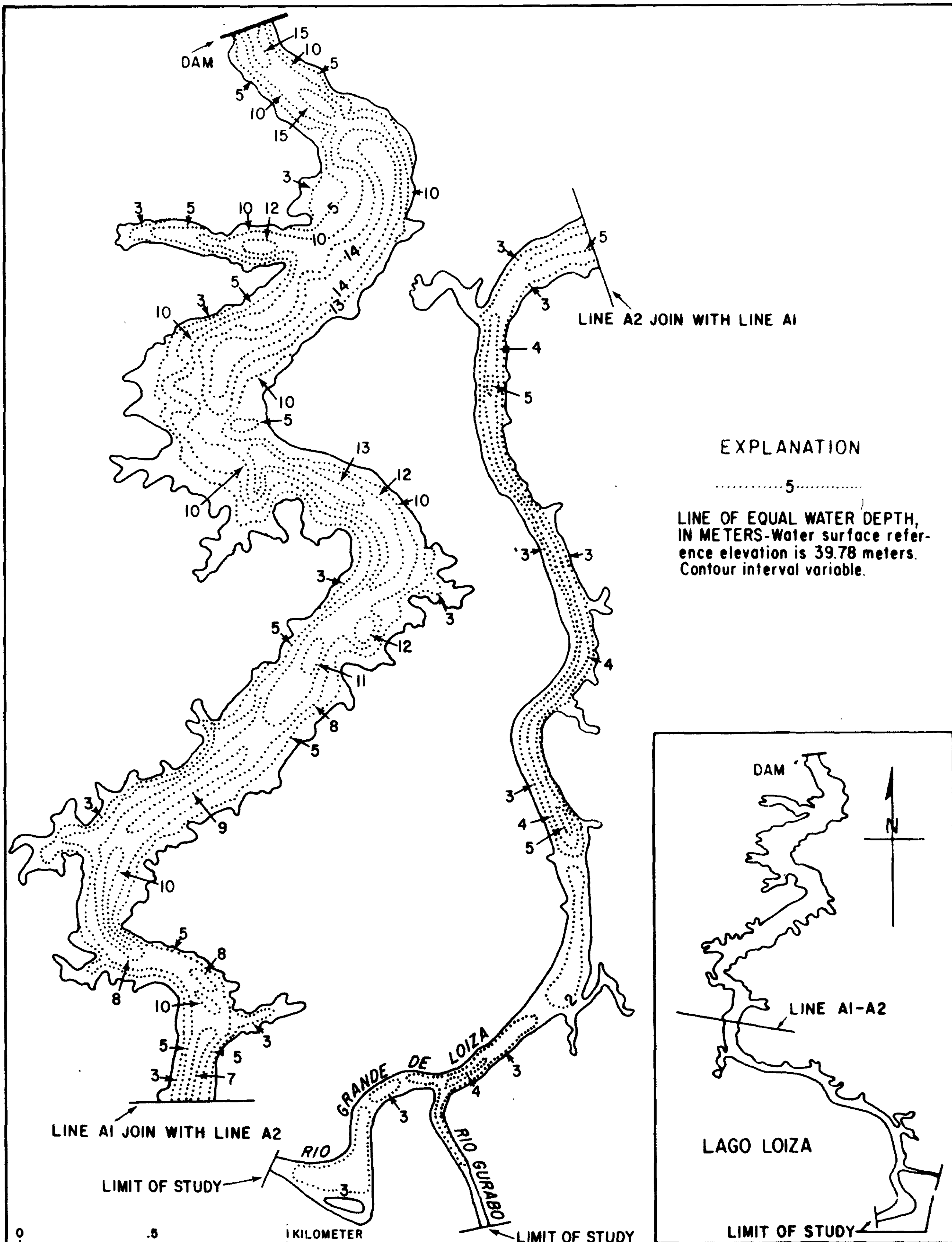

Figure 3.--Generalized bathymetric map of Lago Loíza.

Figure 4.--Old house exposed in Lago Loíza during the 1974 drought.

used for improved and unimproved pastureland. Forests cover about 20 percent of the area, while nearly 11 percent of the land is cultivated (sugarcane accounts for about 5 percent of the total basin area). The remaining 9 percent of the basin includes urban developments and water.

The basin has a total population of about 300,000 (1970 census). Caguas is the largest city with a population of about 100,000, followed by several smaller towns with less than 10,000 inhabitants. Most of the population live in rural communities or in houses scattered throughout the rural area.

Livestock and poultry production are the principal industries in the basin. Although there are no feedlots as such, large numbers of cattle are grouped in relatively small farms. The Puerto Rico Department of Agriculture estimates that about 80 percent of the total income in the basin is derived from the cattle and poultry industries.

Less than half of the population in the basin lives in urban communities. Most of the domestic wastes from urban areas are collected and transported to sewage treatment plants. The treatment plants, operated by PRASA, discharge about 18,600 m^3/d of treated sewage into the streams in the basin. The plant's location, effluent, volume, and other characteristics are summarized in table 4. The treatment of the wastes is mostly primary with low efficiencies in the percent reduction of BOD-5. The report by the Production Division of PRASA (Font and others, 1972) indicated that efficiencies ranged from 48 to 95 percent. However, these efficiencies are under optimal operational conditions. The plants are generally overloaded and partially treated or even raw wastes are discharged into the streams. The construction in the near future of a regional sewage treatment plant providing at least secondary treatment should help to alleviate this condition.

The domestic wastes from both urban and rural communities contribute a variety of organisms and substances that eventually affect the quality of the water in the basin and lake. Porcella and others (1974) report that mean per capita wastes from humans are 10.8 g/d (grams per day) of nitrogen (N) and 2.2 g/d of phosphorus (P). Detergents in domestic sewage account for about 50 percent of the per capita phosphorus. Whether these nitrogen and phosphorus loading rates apply to Puerto Rico and the Loíza basin is not known. Sodium, chloride, sulfate, and other ions are also present in greater than ambient levels in domestic sewage.

Most of the industrial effluent in the basin is derived from agricultural activities. Prior to 1972, a sugar mill located near Juncos contributed large amounts of wastes that were discharged into the Río Valenciano, a tributary of the Río Gurabo. Details of the waste loads and effects on the river during a survey conducted by PRASA are discussed by Font and others (1972).

Sand extraction is an important industrial activity in the basin that affects the quality of the water in the rivers and the lake. More than 15 permits for sand extraction in the river beds, flood plains, and nearby

Table 4.--Sewage treatment plants discharging into the Lago Loíza tributaries.

Plant location	Type*	Capacity, m^3/d	Effluent, m^3/d	BOD-5 removal, in percent	Solids removal, in percent
Aguas Buenas	2	570	730	48	66
Caguas	2	12,600	13,250	67	80
Gurabo	1	2,270	1,070	95	88
San Lorenzo	2	2,380	1,640	82	84
Juncos	2	1,510	1,480	70	77
Las Piedras	5	230	390	29	26

*Type

1 Activated sludge

2 Trickling filter

5 Imhoff tank

(Data from the Puerto Rico Aqueduct and Sewer Authority 1973-74 Annual Report. Data represent yearly averages.)

hills in the basin have been issued by the Department of Natural Resources. In the process of sand extraction, large amounts of sediment are suspended. This sediment is transported into the lake, increasing turbidity and decreasing storage capacity. Nutrients, organic compounds, and other substances are released from the sediments and made available to algae in the rivers and the lake.

BASIN HYDROLOGY

Precipitation

Mean annual precipitation over the Loíza basin ranges from 1,600 mm in the Caguas area to 2,540 mm in the Sierra de Luquillo area in the eastern part of the basin (Colón, 1970). Monthly totals during the study period at the damsite (Trujillo Alto), Gurabo, and San Lorenzo are shown in figure 5. From November 1973 to October 1974, 1,209 mm of rainfall was recorded at the damsite, whereas 1,175 and 1,375 mm was recorded at Gurabo and San Lorenzo, respectively. The average of the three stations was 1,253 mm, indicating a relatively minor variation in precipitation throughout the basin other than the mountainous area. As a result of a severe drought, the 1973-74 precipitation over the basin was about 30 percent less than the average precipitation.

Precipitation over the basin is characterized by intense storms during the rainy season (August to December) and extended dry periods during the spring and summer. Orographic factors and seasonal weather patterns result in the extreme variations in precipitation between the mountainous and lower part of the basin.

Precipitation on Lago Loíza was estimated as the average between the Trujillo Alto (damsite) and Gurabo substation gages (fig. 5). For the period of study a total of 1,192 mm of rainfall was estimated to have fallen on the lake. Total volume of water contributed from direct rainfall to Lago Loíza was estimated as 2.88×10^6 m^3.

Streamflow

Streamflow in the Loíza basin is characterized by seasonal fluctuations. The flow declines dramatically during the dry season (January through July). Convective storms during May and June may produce sizable floods that reduce or change the normal decline in runoff. During the rainy season (from August to December), storms throughout the Caribbean generate abundant precipitation that produces most of the yearly runoff. The main tributaries, Río Grande de Loíza and Río Gurabo, fluctuate through a greater range of discharge than other streams in the basin. Streamflow in Ríos Caguitas, Bairoa and Cañas fluctuates over a relatively smaller range because of the year-round inflow of domestic and industrial discharges. Mean monthly discharges at the tributaries are shown in figure 6.

The total discharges from the tributaries to Lago Loíza during the water-budget study period (November 1, 1973, to October 31, 1974) are shown in table 5. The table also shows the mean monthly minimum and the average flow for Río Grande de Loíza and Río Gurabo (15 years of record).

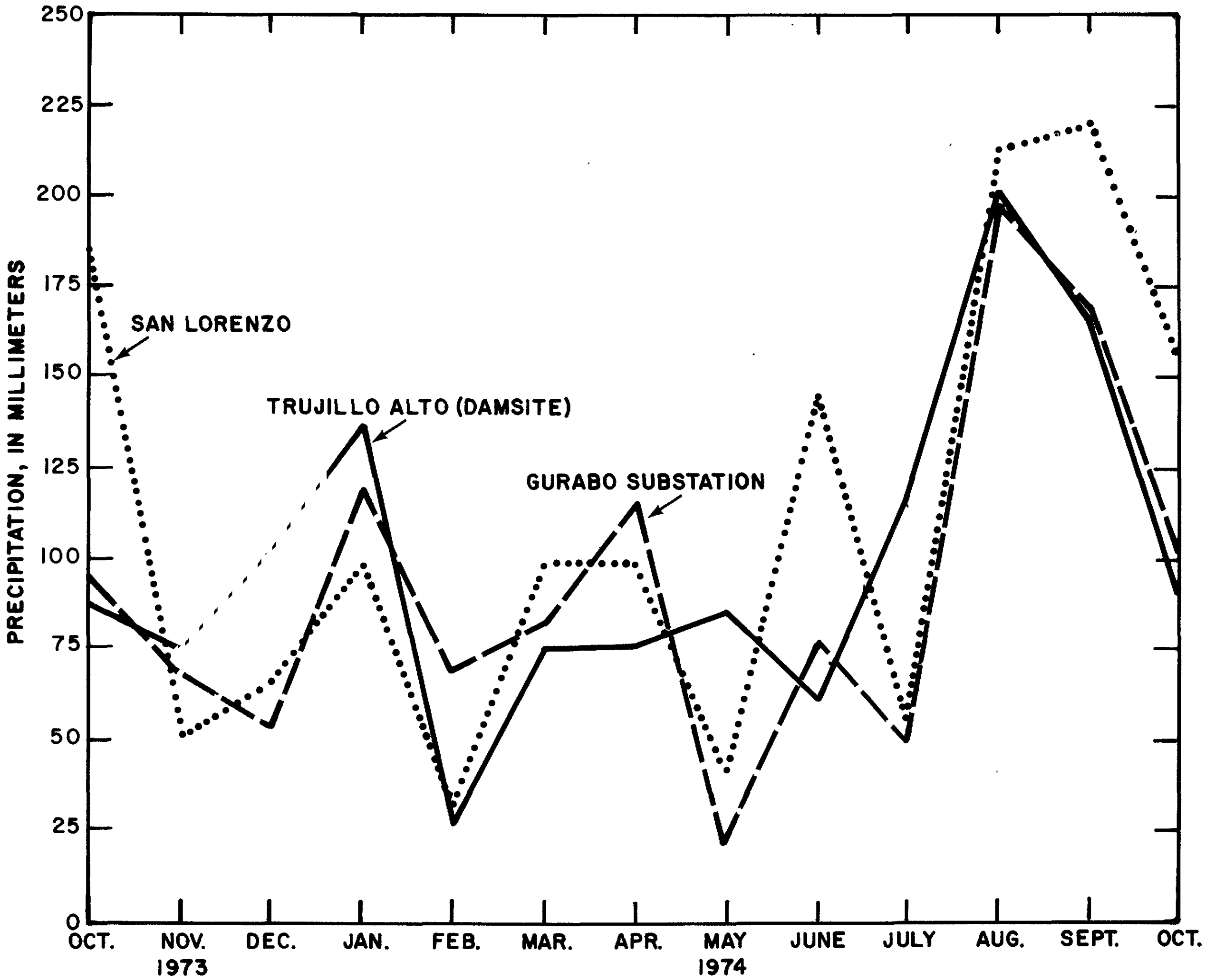

Figure 5.--Monthly precipitation at selected stations in the Loíza basin October 1973 to October 1974.

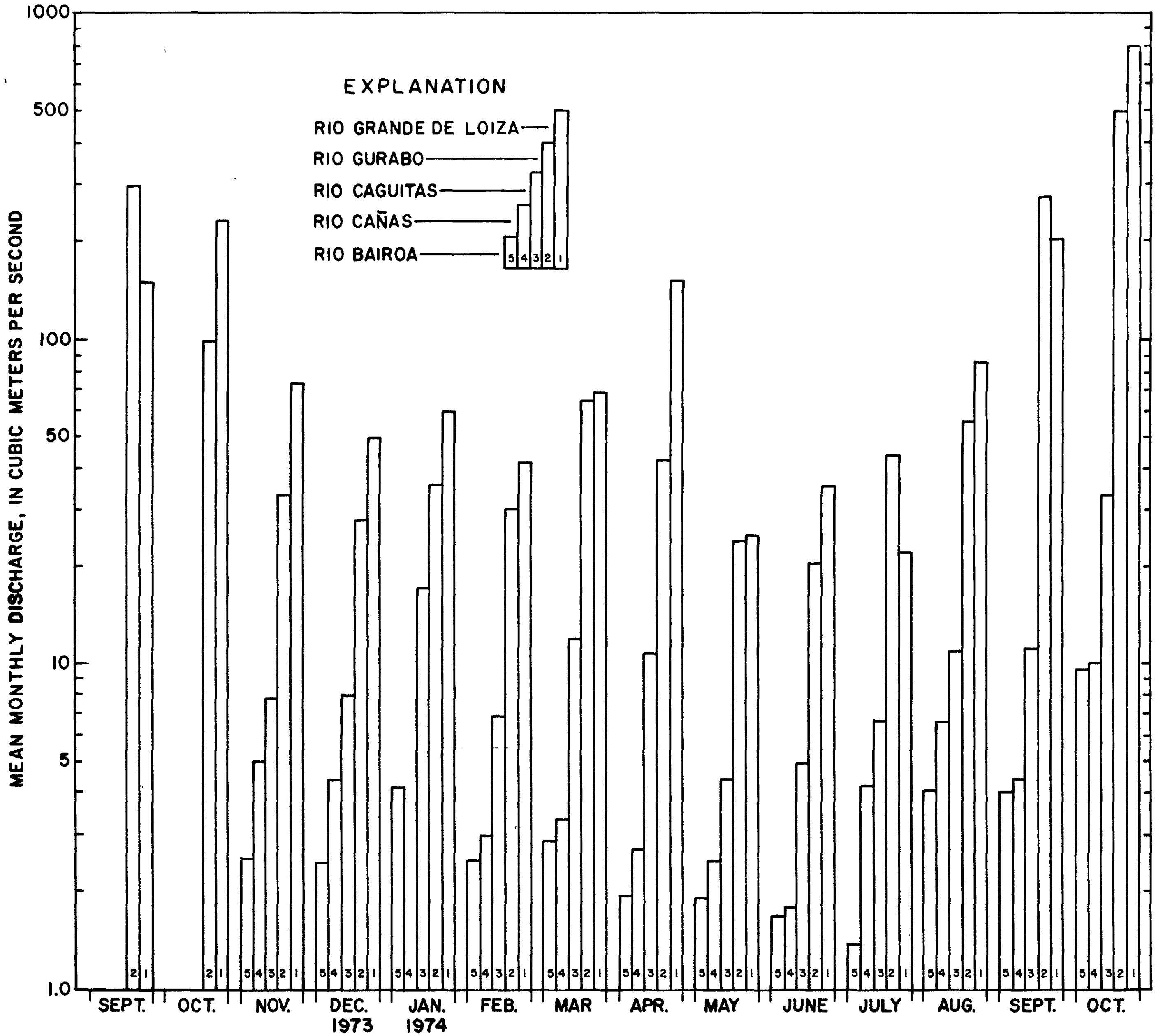

Figure 6.--Mean monthly discharge at the principal tributaries to Lago Loíza, September 1973 to October 1974.

Table 5.--Total water discharged from the principal tributaries to Lago Loíza and other statistics for Río Grande de Loíza and Río Gurabo, November 1, 1973, to October 31, 1974.

Station no.	Tributary	Total discharge, $m^3 x 10^6$	Mean monthly minimum, m^3/s	Average discharge, m^3/s*
50 0550 00	Río Grande de Loíza	139.1	22.0	6.1
0570 00	Río Gurabo	96.7	20.0	3.6
0552 50	Río Caguitas	13.1	4.5	--
0584 00	Río Cañas	4.7	1.9	--
0554 00	Río Bairoa	3.6	1.3	--
	Total	257.2		

*15 years of record

Note: The data for Río Gurabo reflect water pumped from Río Blanco to Río Gurabo by PRASA to augment the flow to Lago Loíza. The pumpage is intermittent and there are no records to determine the volume of water pumped to Río Gurabo.

Other Surface Runoff

The drainage area of the watershed at the damsite is almost 79 km^2 more than the combined drainage areas at the gaging stations shown in figure 1. The surface runoff from this ungaged area was estimated on the basis of the precipitation over the area and a modification of Thornthwaite's climatological index procedure (López and Giusti, written commun., 1967). A total volume of $19x10^6$ m^3 was computed as the surface runoff from the ungaged area.

Evapotranspiration

Data to estimate the ET (evapotranspiration) from Lago Loíza were obtained from a class "A" evaporation pan located at the Gurabo Experimental Substation (fig. 7). An evaporation pan located in the vicinity of the dam was vandalized on several occasions and the assumption was made that pan evaporation at the Gurabo Substation was approximately equal to that at the lake. A further assumption in the estimate was that the lake surface area did not change. Although the level in the reservoir declined 5.1 m during the year, the change in surface area due to the change in stage is probably a small percentage of the total lake surface area. A pan-to-ET coefficient of 0.80 was used in the computation (Colón, 1970). The total evapotranspiration from the lake surface of $2.425x10^6$ m^2 was estimated to be 1.33 m. This was equivalent to an estimated volume of $3.27x10^6$ m^3 during the water-budget study period (November 1, 1973 to October 31, 1974).

Changes in Storage in Lago Loíza

Water is pumped from Lago Loíza by four electric pumps on the downstream side of the dam structure, rated at 0.88 m^3/s each. During the study period a total of $108x10^6$ m^3 was pumped to the San Juan metropolitan area. Daily pumpage averaged 300,000 m^3/d and ranged from 200,000 to 340,000 m^3/d. At the peak of the drought in July 1974, the daily pumpage averaged 245,000 m^3/d.

The water surface during the study period declined from an elevation of 40.14 m on March 6, 1974, to 35.04 m on July 28, 1974. In terms of volume stored (based on original lake capacity computations), the amount of water in the lake declined from $25.0x10^6$ m^3 (maximum storage) to a low of $12.7x10^6$ m^3 (about 51 percent of the maximum storage). The fluctuation in the volume of water in Lago Loíza during the study period is shown in figure 8. Data from the reservoir daily storage table showed that from August 29 to August 30, 1974, the volume of water in Lago Loíza increased from $16.9x10^6$ to $23.1x10^6$ m^3. A total of $6.2x10^6$ m^3, or an average of 72 m^3/s flowed into the lake during the 24-hour period.

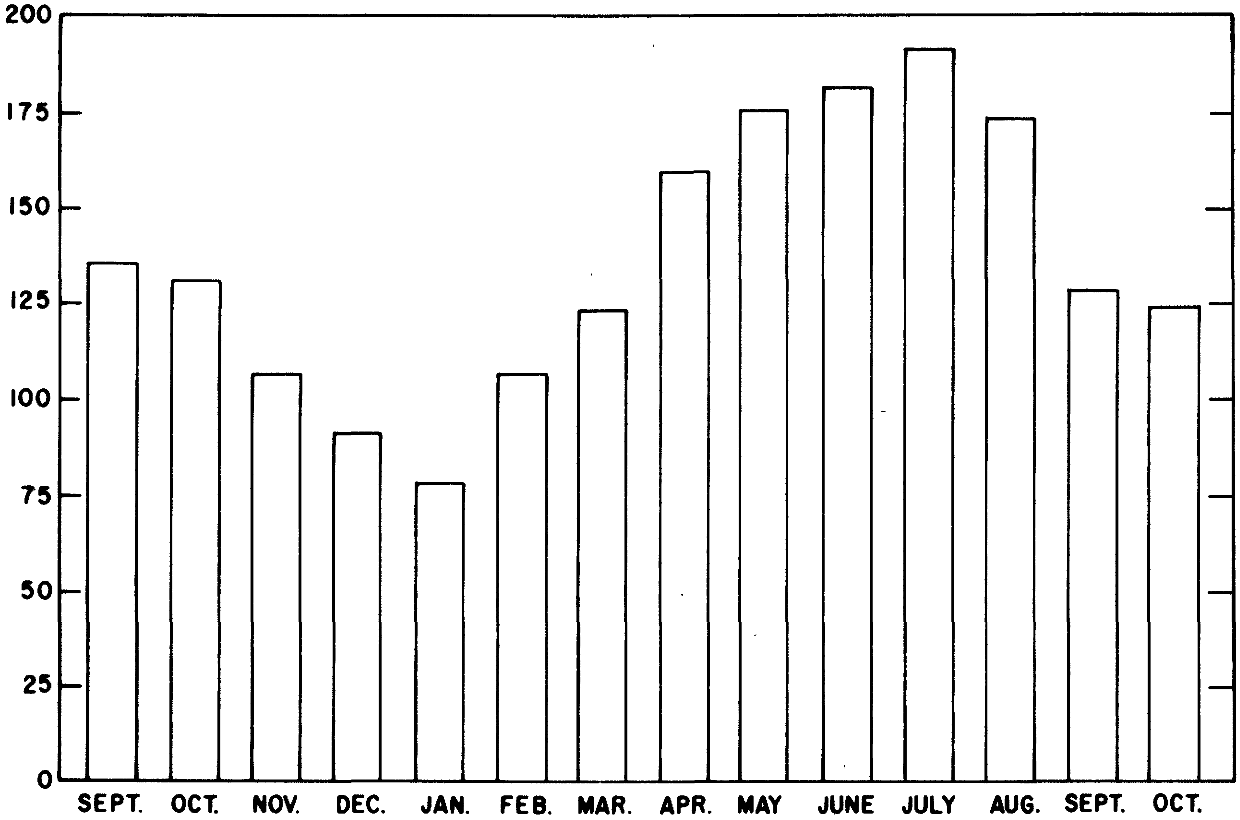

Figure 7.--Monthly class "A" pan evaporation at the Gurabo Agricultural Substation, September 1973 to November 1974 (National Weather Service Records).

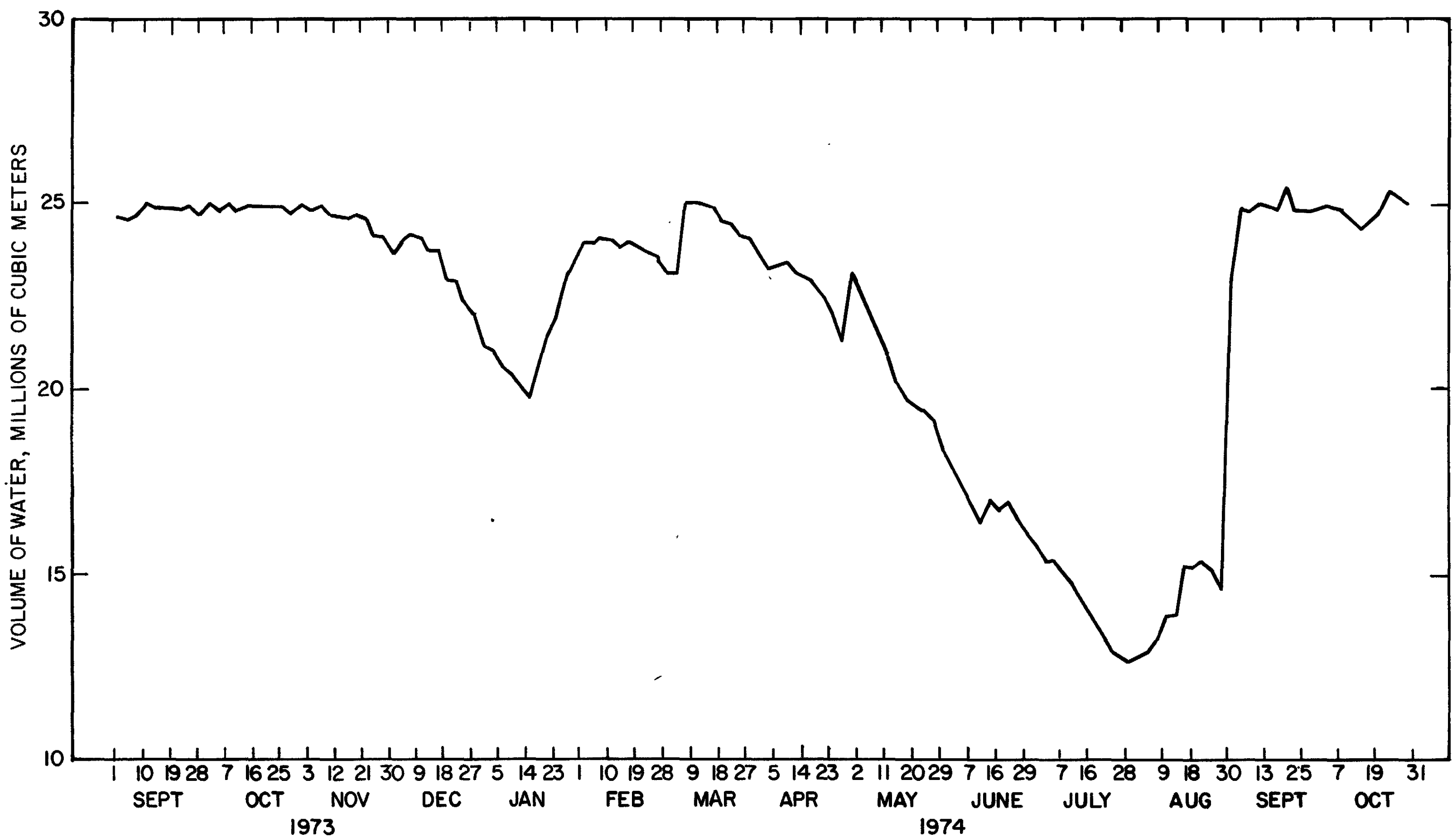

Figure 8.--Fluctuation in the volume of water in Lago Loíza from September 1973 to October 1974 (data from Puerto Rico Aqueduct and Sewer Authority).

Water Budget of Lago Loíza

The water budget of Lago Loíza for the period from November 1, 1973, to October 31, 1974, is summarized in figure 9. This is not the ideal cycle for a water-budget analysis in Puerto Rico as it overlaps two rainy seasons in consecutive years. However, the records available for some of the tributaries included only the indicated period. Symbols used in figure 9 are based on concepts described by H. T. Odum (1971).

A total of 279.7×10^6 m^3 was discharged into Lago Loíza during the period studied. This indicates the magnitude of some of the storm events during the rainy season and the changes these events may induce in the lake. The five tributaries contributed 257.2×10^6 m^3, or 92 percent of the total. Río Grande de Loíza and Río Gurabo, the two main tributaries, contributed about 49 and 34 percent of the volume, respectively. During October 1974 the combined discharge from these two tributaries was about 37 percent of the total inflow to the lake.

Pumpage from the reservoir to metropolitan San Juan was about 103×10^6 m^3, or about 39 percent of the total water that flowed into Lago Loíza during the water-budget period. It was assumed that other than evapotranspiration losses (1.2 percent), spills and seepages accounted for the remaining outflow (about 60 percent).

The overall water budget may be used to estimate the lake's flushing rate during the study period. Because the flushing rate may be an indicator of the lake's ability to receive nutrients in concentrations exceeding those concentrations described as critical, a long-term estimate of this parameter may be valuable. The streamflow records from 1960 to 1972 at Río Grande de Loíza and Río Gurabo can be used to estimate a long-term average flushing rate for Lago Loíza.

In order to adjust the available discharge records from Río Grande de Loíza and Río Gurabo, the assumption was made that their contribution to the lake from 1960-72 was proportional to the contribution during the study period. The discharge records were augmented on a drainage area basis. The lake's capacity was decreased in proportion to the number of years since its construction and the original and present capacities (described in another section of the report).

The discharge data and computations are summarized in table 6. The estimated flushing rates range from 4.3 times per year (1967) to 44.0 times per year (1970). The mean value is 19.5 times per year. Although the average flushing by volume is 19.5 times per year, the frequency of flushing may be less. One storm in the basin could contribute enough water to flush the lake several times. This happened during the 1974 floods when enough water was discharged.during the October flood to flush the lake about seven times. For the study period, using the data in figure 9, a flushing rate of 19 times per year was computed.

Table 6.--Water-discharge records for Río Grande de Loíza at Caguas and Río Gurabo at Gurabo, and estimated flushing rates for Lago Loíza.

Year	Río Grande de Loíza	Río Gurabo	Total	Drainage area, adjusted	Lake capacity	Flushing rate, times per year
	Million cubic meters per year					
1960	324.9	239.2	564.1	670.0	22.0	30.4
1961	266.0	121.4	387.1	452.9	21.0	21.6
1962	230.3	104.4	334.1	391.6	21.0	18.6
1963	133.9	57.3	191.2	223.7	20.0	11.2
1964	143.7	58.9	202.6	237.0	20.0	11.8
1965	232.1	139.2	371.3	434.4	19.0	22.9
1966	158.9	87.9	246.8	288.8	19.0	15.2
1967	47.7	19.0	66.7	78.0	18.0	4.3
1968	105.3	56.8	162.1	189.6	18.0	10.5
1969	279.4	195.4	474.8	555.5	17.0	32.7
1970	376.6	263.2	639.8	748.6	17.0	44.0
1971	138.3	78.4	216.7	253.5	16.0	15.8
1972	143.7	52.7	196.4	229.8	16.0	14.4
						Mean value 19.5

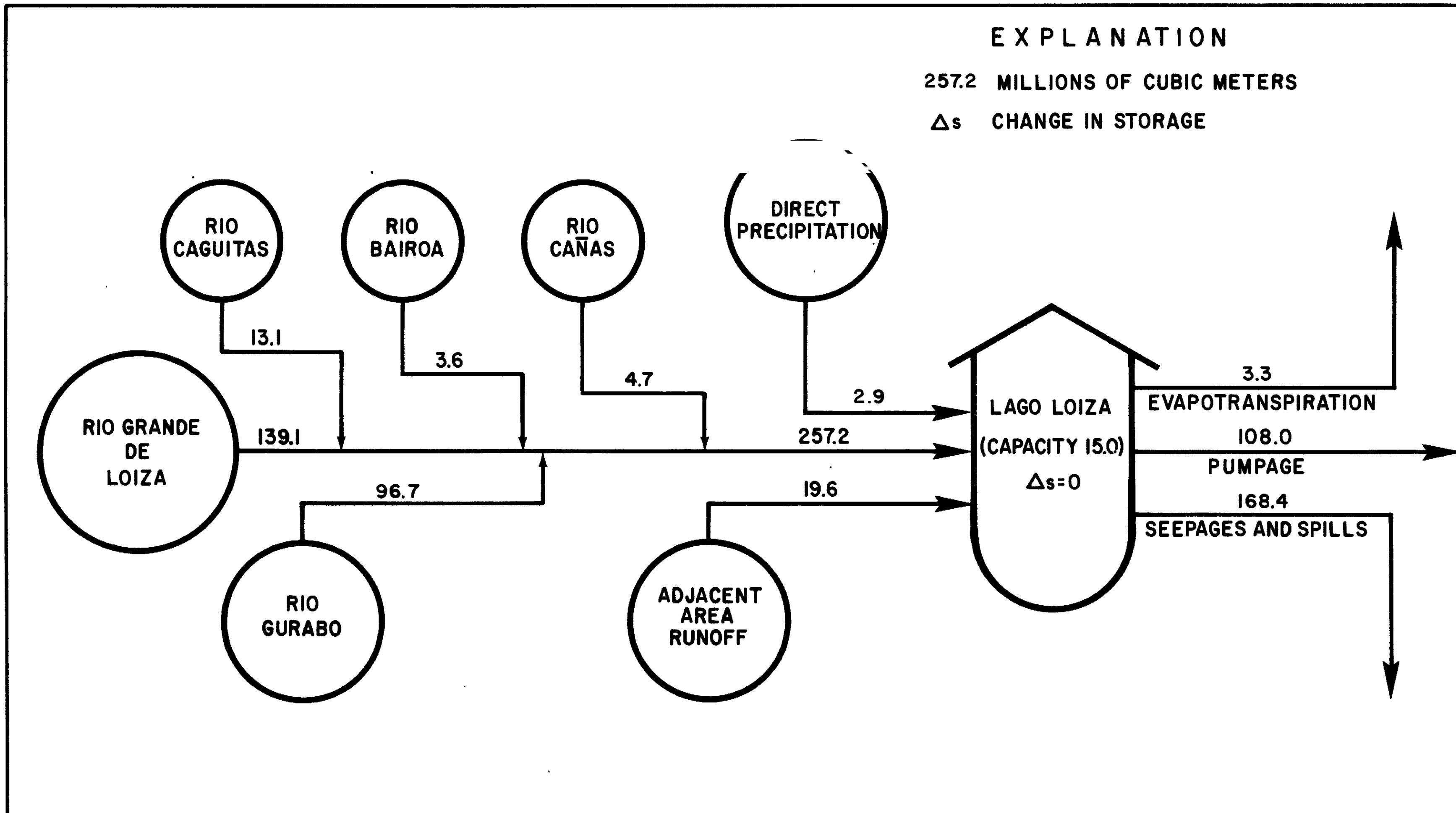

Figure 9.--Water budget of Lago Loíza, November 1973 to October 1974.

If the flushing rate of about 19 times per year is representative of Lago Loíza and other reservoirs in Puerto Rico, this may be one of the most important factors in their overall water-quality condition. The periodic flushing of the lake probably helps to improve the quality of the water by the introduction of water with a higher dissolved oxygen content and lower concentrations of bacteria and organic matter. On the other hand, large amounts of sediment, pesticides, nutrients, and various chemicals are probably transported into the lake during high-flow periods.

SEDIMENTS

Transport and Sedimentation Rates

The transport and consequent deposition of sediment into Lago Loíza is one of the most important problems in the lake. The sediments that are deposited reduce the usable capacity of the lake, thereby decreasing the economic and social value of the lake to the metropolitan area. Both suspended and deposited sediments interact with the different communities in the lake, affecting their life cycles. Suspended sediments in large concentrations reduce transparency and visibility for fish and other organisms, interfering with their ability to compete for survival. The larger particles cover areas that constitute specific niches for bottom dwellers and that are spawning grounds for many species of fish. Other plant and animal communities in the lake may be affected by increased turbidity.

Little is known about the sediment transport characteristics in the Loíza basin. Logistics and site location problems curtailed data collection for this part of the investigation. On the Río Grande de Loíza, samplers cannot be installed or samples collected without undue safety risks. Except for the samples collected August 30, 1974, all the other data pertain to low-flow conditions. Haire (1972) collected a sample at Río Gurabo at Gurabo during the 1970 floods. The mean suspended-sediment concentration was 1,600 mg/L, while the discharge was 665 m^3/s. A particle-size analysis of a sample collected during the flood indicated that only about 15 percent of the sediment in suspension was sand. Miscellaneous data from previous years at both Río Gurabo and Río Grande de Loíza are also available (U.S. Geological Survey, 1975).

Miscellaneous samples of suspended sediment (about monthly) were collected during periods of low flow and low sediment transport (table 7). Only the sample collected on August 30, 1974, reflects higher than base flows. A flow of 37 m^3/s was measured on the Río Grande de Loíza at Caguas at the time the suspended-sediment concentration of 1,630 mg/L was recorded. This is still a low discharge when compared to the maximum instantaneous peak of 102 m^3/s recorded during the storm. Most of the suspended-sediment discharges occur during the rising stages of a flood. As the sample was collected during the falling stage of the flood, it is probable that much higher sediment concentrations are characteristic of the measured flow. The bedload portion of the transported sediment is unknown.

Table 7.--Seasonal fluctuation in the concentration of suspended sediment at the main tributaries and outflow of Lago Loíza (in milligrams per liter).

DATE	STATION Río Grande de Loíza at Caguas 0550	Río Gurabo nr Gurabo 0570	Río Caguitas nr Caguas 0552 50	Río Bairoa nr Caguas 0554	Río Cañas at Lago Loíza 0584	Lago Loíza at damsite 0590
1973						
11-16	437		5	34	405	--
11-30	--		60	27	40	--
12-07	60	49	38	71	244	--
12-13	--	46	--	--	--	3
12-19	198	41	9	38	--	--
1974						
01-08	260	24	93	24	97	3
01-18	--	202	34	108	3,820	--
02-14	278	252	34	389	31	4
02-28	162	98	182	187	149	1
03-07	149	503	104	143	752	137
03-15	303	130	216	132	185	141
03-20	--	55	--	--	--	--
03-25	250	87	--	--	--	--
04-19	--	--	--	18	64	4
05-08	170	265	155	93	177	124
05-20	147	478	--	131	94	117
06-06	--	201	300	76	101	110
06-27	--	--	--	--	--	70
07-01	125	--	168	51	73	--
07-19	218	1,350	173	114	143	120
08-01	71	2,980	--	74	248	66
08-07	--	--	--	--	--	90
08-15	529	--	202	--	--	53
08-28	110	7,680	--	--	--	--
08-30	1,630	1,350	1,070	2,440	3,040	36
10-02	445	1,294	86	54	79	118
10-24	--	214	--	--	--	--

Size analyses of a sample collected from the bottom deposits at the Río Grande de Loíza station are shown in table 8. The data indicate that about 70 percent of the bottom material was sand and gravel (greater than 0.062 mm), while 30 percent were silts and clays. This suggests that most of the bedload transported by the Río Grande de Loíza into the lake consists of sand and gravel. Miscellaneous suspended-sediment concentrations of samples collected at the Río Gurabo are also shown in table 7. All samples were collected during periods of low flow except for the one collected on August 30, 1974. The increase in the suspended-sediment concentration after January 1974 apparently was the result of a sand and gravel extraction operation upstream from the station. During the drought, when the flows were minimal, the suspended-sediment concentration increased to 7,680 mg/L. There were not enough data to estimate the total suspended-sediment or bedload discharge from the Río Gurabo into Lago Loíza. Size analyses at the station (table 8) indicate that only about 2.5 percent of the bed material was sand, while about 35 percent were silts and the remaining 62.5 percent were clays.

Miscellaneous suspended-sediment measurements at Río Caguitas at Caguas are also shown in table 7. Except for the sample of August 30, 1974, the samples were collected during low-flow periods. The increase in concentration after February 14, 1974, probably was due to construction activities upstream from the gage where the natural channel of the river was being widened as a flood-control measure.

Suspended-sediment measurements at the Río Cañas are also shown in table 7. At the time of the study a highway was under construction about 0.5 km upstream from the gage. Low-flow suspended-sediment concentrations probably are best represented by an average of about 80 mg/L. The suspended-sediment contribution from the Río Cañas to Lago Loíza probably is a small percentage of the total from the basin. On an area-yield basis of comparison it is probably less than 5 percent.

Suspended sediment transported into Lago Loíza deposits rapidly downstream from the junction of the Río Gurabo and the Río Grande de Loíza. Suspended-sediment samples were collected throughout the lake during periods of low flow and after storm events. The results of the analyses are shown in figure 10. Stations refer to figure 2. In each case shown in figure 10, most of the suspended sediment deposited before reaching station 5.

An indirect estimation of the total sediment input to Lago Loíza during the period of study was calculated. If the present capacity of the lake is compared with prior determinations, the loss in capacity may be assumed to be equal to the sediment deposited.

Hunt (1975) conducted a detailed survey of the sedimentation of Lago Loíza. The survey was based on a determination of the capacity of the reservoir at the time of the study (1971). A comparison was made with a similar study conducted by Guzmán (1963), and the loss in capacity was assumed to be equal to the

Table 8.--Size analyses of the bed material at Río Grande de Loíza near Caguas and Río Gurabo at Gurabo (December 2, 1974).

	Percent finer than									
	SAND					SILT			CLAY	
Size, millimeters	1.0	0.50	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002
Río Grande de Loíza	81.1	58.7	40.4	31.4	30.0	29.5	26.8	20.4	13.6	8.8
Río Gurabo	99.5	99.3	99.1	98.9	97.5	97.3	94.4	82.3	62.6	43.6

Table 9.--Comparisons of sedimentation surveys in Lago Loíza.

Investgation and date	Initial volume, 10^6 m^3	Number of transects	Survey volume calcul. 10^6 m^3	Percent loss capacity	Sedimentation rate, percent per year	Usable life of lake, years
Guzmán (1963)	26.8	26	23.1	13.8	1.4	58
Hunt (1971)	26.8	26	19.3	28.0	1.5	48
Quiñones (1974)	26.8	56	14.9	44.4	2.1	27
Do	24.6	56	14.9	39.4	1.9	32
Do	26.8	26	16.6	38.0	1.8	35
Do	24.6	26	16.6	32.5	1.5	45

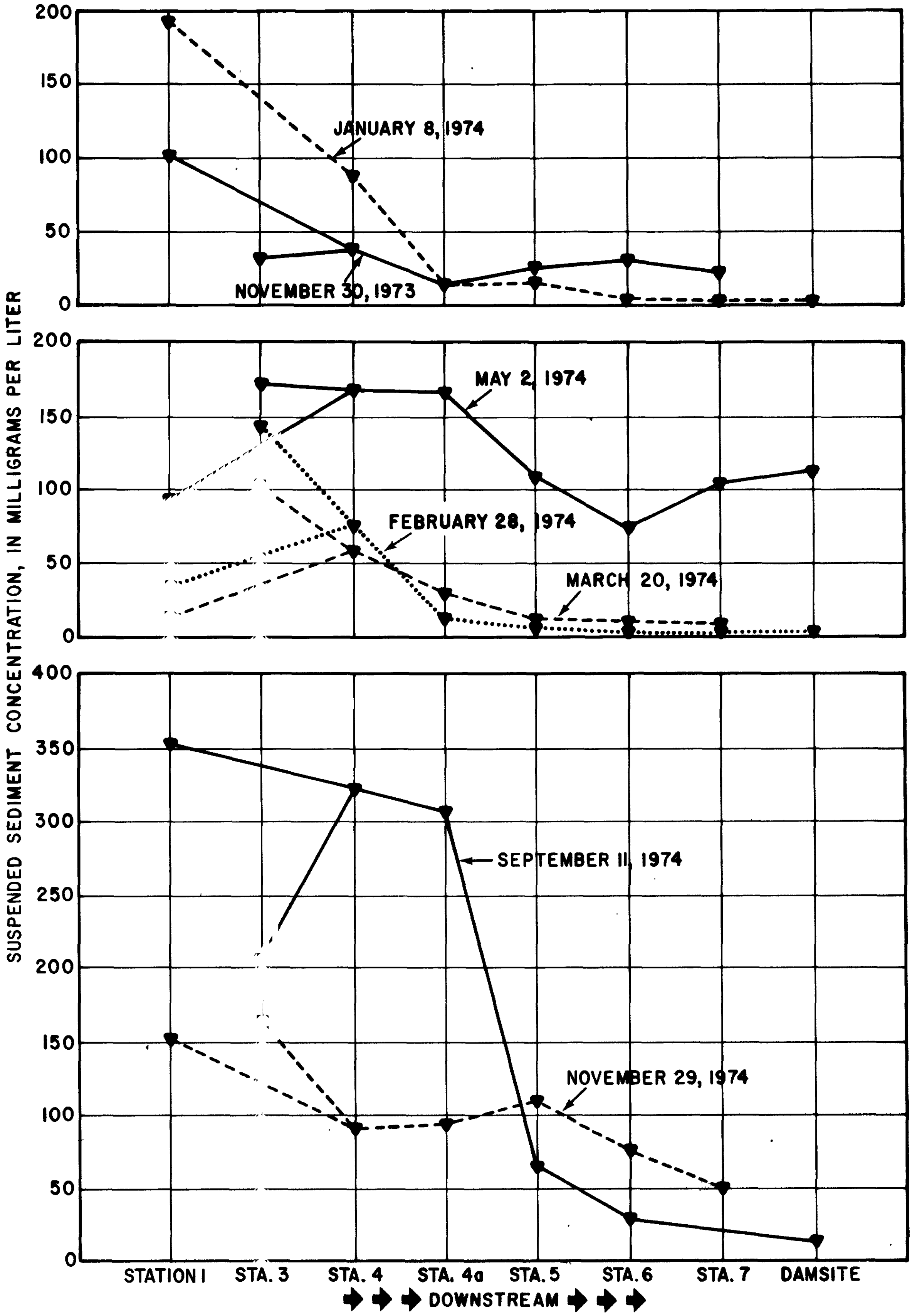

Figure 10.--Suspended sediment concentrations in Lago Loíza.

volume of sediment deposited in the lake. Hunt estimated that about 304,800 metric tons of sediment is deposited yearly in the lake. This is equivalent to an average yearly loss of about 1.5 percent of the original capacity.

A survey similar to the ones conducted by Guzmân and Hunt was completed during this study. Both Guzmân and Hunt utilized about 26 transects throughout the lake. These included 5 into several of the embayments. In this study a total of 56 transects were utilized, including 6 into the principal embayments (fig. 11). It is probable that more transects would give a more accurate determination of the actual capacity of the lake. Hunt indicates that the original capacity of Lago Loîza was computed on the basis of the study by Guzmân in 1963, utilizing the 26 transects that were surveyed by Guzmân.

The original capacity of Lago Loîza is reported by Hunt to be about 26.8×10^6 m^3 at a stage of 40.1 m. However, Arnow and Crooks (1960) reported an original capacity of about 24.6×10^6 m^3. Hunt also indicated that Guzmân, in a supplement to his 1963 survey, reported an original capacity of 24.6×10^6 m^3, in agreement with Arnow and Crooks.

Hunt, utilizing the initial capacity of 26.8×10^6 m^3, estimated the loss in capacity in the lake at about 1.5 percent per year. The actual capacity of the lake, on the basis of the survey conducted during this study was computed as about 14.9×10^6 m^3. If Hunt's initial capacity is considered, the actual loss is about 11.9×10^6 m^3, or about 44.4 percent of the original capacity. This is equivalent to an annual loss rate of about 2.1 percent. However, if it is assumed that the initial capacity of 24.6×10^6 m^3 reported by Arnow and Crooks is more accurate, the actual loss in capacity is about 9.7×10^6 m^3, or about 39.4 percent of the original capacity. This is equivalent to an annual rate of loss of about 1.9 percent.

To provide an additional basis for comparison, the present (1974) capacity of the lake was computed utilizing transects similar to those utilized by Hunt and Guzmân. The present (1974) capacity was computed at about 16.6×10^6 m^3. The loss in capacity would be 10.2×10^6 m^3 utilizing Hunt's original capacity, and 8.0×10^6 m^3 using Arnow and Crooks' estimate. This is equivalent to losses of 38.0 percent and 32.5 percent, respectively, of the original capacities. The annual rates of loss in capacity would be 1.8 and 1.5 percent, respectively.

These comparisons show that unless the original capacity of Lago Loîza is computed accurately, determinations of the loss in capacity and rates of loss will be only approximations. Applying Hunt's original capacity (26.8×10^6 m^3), rate of loss (1.5 percent), and present (1974) capacity (16.6×10^6 m^3), the remaining life of the lake is estimated at about 45 years. If the lesser original capacity reported by Arnow and Crooks is used (24.6×10^6 m^3), with an annual rate of loss of 2.0 percent and an actual capacity of 14.9×10^6 m^3 (survey computations), the potential usable life of the lake is about 30 years. These computations as well as Guzman's and Hunt's surveys, are summarized in table 9. Although the difference between the computations is significant,

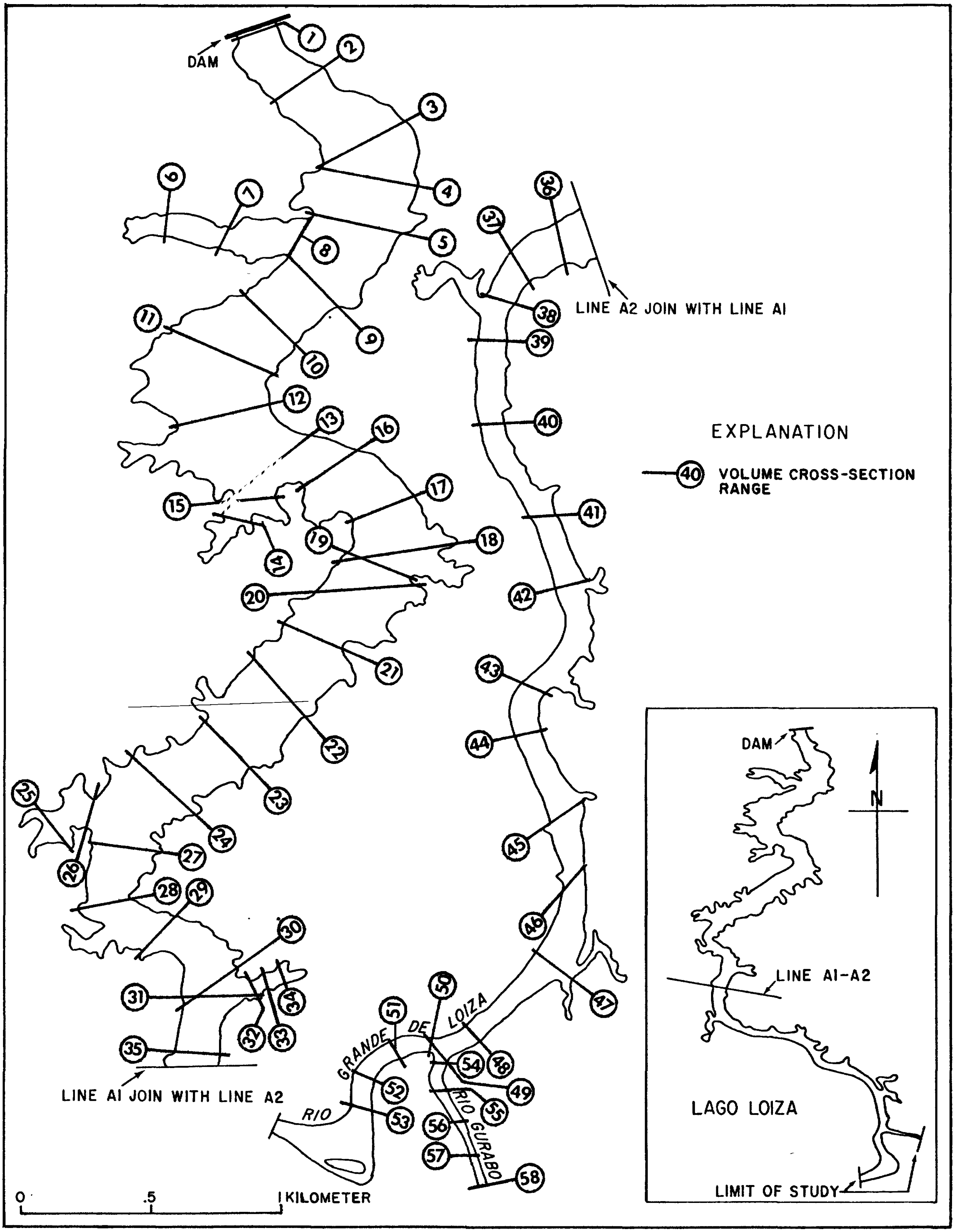

Figure 11.--Cross-section ranges used for volume computations in Lago Loíza.

it still indicates the gravity of the problem. Unless drastic measures are implemented to reduce the sedimentation rate, or the lake is dredged, its maximum potential usable life is from 30 to 45 years.

Chemical Composition and Size Distribution

The bottom deposits in any aquatic system constitute a sink, or storage area, for many of the chemical and physical components of the system. Components may be stored nearly permanently, or temporarily, depending on a series of interacting factors. Deep lakes constitute almost permanent storage areas. Shallower lakes are subject to physical interactions, such as wind and diffusion, as well as chemical and biological reactions, mainly oxidation of insoluble inorganic compounds into soluble components and bottom dwellers that recycle nutrients. In shallow lakes recycling of many components, nutrients in particular, constitutes an important aspect of the stability of the system (Stumm and Leckie, 1970).

The chemical analyses of samples from the bottom deposits in Lago Loíza included determinations of the most important parameters related to the quality of the water, major nutrients, insecticides, and selected heavy metals.

Analyses of organic carbon, total nitrogen, and total phosphorus are shown in table 10. Organic carbon in the bottom sediments ranges from 0.3 to 1.4 percent by weight. Except for stations 3 and 7 there is a general decrease in the amount of organic carbon downstream toward the damsite. The higher percentages at the upstream stations probably are due to the direct inflow from the main tributaries. In the lake proper, several factors may interact to reduce the amount of organic carbon. Oxidation of the carbon loads from the tributaries takes place as the bottom deposits are moved downstream. Movement toward the damsite may be limited by deposition in deep holes and low velocities.

Table 10.--Organic carbon, nitrogen and phosphorus concentrations in the bottom sediments of Lago Loíza (March 20, 1974).

Station	Organic carbon (grams per kilogram)	Total nitrogen, N (milligrams per kilogram)	Total phosphorus, P (milligrams per kilogram)
1	9.9	1,510	980
3	14	1,770	690
4	9.5	1,820	1,100
5	6.8	1,910	1,000
6	3.1	1,960	840
7	6.0	1,920	840

There are no similar analyses in lakes in Puerto Rico which could be compared with the data shown in table 10. Kemp and others (1972) in a study of the Great Lakes, reported percentages of organic carbon in sediments ranging from 1.6 to 5.0. They suggested that high organic loadings to the lakes were the principal reason for the high organic carbon percentages in the sediments.

The amount of total nitrogen in the bottom deposits in Lago Loíza increases in a downstream direction toward the damsite. Values range from about 0.15 to nearly 0.20 percent by weight. Phosphorus, although present in amounts ranging from 0.07 to 0.11 percent by weight, does not follow the same pattern of increasing concentrations in more downstream samples. Nitrogen and phosphorus in the sediments enter the lake principally from the Ríos Grande de Loíza and Gurabo. Particulate matter containing nitrogen and phosphorus is transported as suspended sediment. In addition, productivity in the lake contributes organic loadings of nitrogen and phosphorus, through biological death and decay which eventually may be incorporated in the sediments. If the values reported for nitrogen and phosphorus from the samples of sediments in Lago Loíza are representative throughout the lake, these constitute a large pool of nutrients. The availability of these to the plant life in the lake will be discussed in a later section of the report.

Concentrations of selected metals in the bottom sediments in Lago Loíza are shown in table 11. None of the toxic heavy metals are present in concentrations which, if released to the water, would exceed maximum permissible concentrations. Mercury is present downstream from station 4 in concentrations averaging 0.20 ug/kg. If this concentration is representative of the sediments throughout the lower portion of the lake, a large amount of mercury is stored in the sediments. Mercury in the sediments may be recycled by benthic organisms in their tissue in concentrations many times that found in the sediments (Committee on Water Quality Criteria, 1974). Mercury may be transformed and recycled to the water upon the death of the organisms, or it may be concentrated in the next trophic level of the food chain. Monitoring of the bottom sediments for mercury should be continued to determine whether the reported concentrations increase or decrease.

The concentrations of iron and manganese in the sediments are the highest detected of the metals sampled. These high concentrations are probably related to the interaction of these metals with phosphorus, which is precipitated as ferric, ferrous, and manganous phosphates. The activity of these compounds under anaerobic conditions promotes the recycling of phosphorus to the water.

Determinations of insecticides in the bottom sediments in Lago Loíza included the principal chlorinated hydrocarbon and organophosphoric series (table 12). Low concentrations of chlordane, DDD, and dieldrin were detected in the samples from stations 4 and 7. Chlordane, one of the chlorinated-hydrocarbon insecticides, has a very low solubility in water but may be absorbed in soils (Gould, 1966). DDD, one of the members of the DDT family, is present throughout the environment. Concentrations in the sediments in Lago Loíza are much lower than those reported by the American Chemical Society

Table 11.--Concentrations of selected metals in bottom sediment at Lago Loíza, April 4, 1974 (micrograms per kilogram).

METAL	STATION					
	1	3	4	5	6	7
Arsenic (As)	2	2	2	1	1	1
Cadmium (Cd)	6	6	9	4	2	0
Chromium (Cr)	12	10	14	9	9	9
Cobalt (Co)	20	30	30	20	20	20
Copper (Cu)	48	71	48	65	63	49
Iron (Fe)	11,000	15,000	18,000	14,000	15,000	14,000
Lead (Pb)	40	0	20	30	20	20
Manganese(Mn)	900	1,400	1,200	1,700	1,800	1,700
Mercury (Hg)	0	0	.10	.30	.20	.20
Selenium (Se)	0	0	0	0	0	0
Zinc (Zn)	82	80	90	66	66	0

in soils (1969). Dieldrin, the oxidation product of aldrin, is very persistent in soils, with a half life of about 3 years (Sanborn, 1974). Dieldrin is concentrated by several species of fish, and although concentrations in the sediments are low, concentrations in the food chain may constitute a hazard to higher trophic levels. Although insecticides in the bottom sediments are present in relatively low concentrations, their persistence and the possibility of biological magnification through the food chain in Lago Loíza make further studies advisable to determine their ultimate effect.

Table 12.--Concentrations of insecticides and PCB's in bottom deposits in Lago Loíza, April 4, 1974 (micrograms per kilogram).

	Station 4	Station 7
Aldrin	0	0
Chlordane	5	0
DDD	0.5	0.5
DDE	0	0
DDT	0	0
Dieldrin	1.6	1.7
Endrin	0	0
Heptachlor	0	0
Heptachlor epoxide	0	0
Lindane	0	0
Toxaphene	0	0
PCB	0	0

Samples from the bottom deposits were also collected to determine the amount of loss upon ignition at 475°C, a measure of the organic content of the sediments (Tuenhofel and Tyler, 1941). The highest percentages of organic matter in the sediments (10 to 12 percent) are found in the main body of the lake, downstream from station 5 toward station 7 (fig. 12). The area in the vicinity of station 4, where the lowest percentages of organic matter appear to be present, was the site of a short-lived sand extraction operation. The areas where the higher percentages of organic matter are present are the deepest parts of the lake. Aquatic plants, mostly water hyacinths (Eichornia crassipes) abound in these areas. Organic matter from these and other decaying plants is deposited on the bottom.

The percent-composition of sands, silts and clays in the bottom deposits in Lago Loíza were determined from particle-size analyses. Sands include particles with diameters ranging from 0.625 to 1.0 mm, graded from very fine to coarse sand. Silts include particles with a diameter ranging from 0.004 to 0.625 mm, while clays include all those particles with a mean diameter smaller than 0.004 mm (Guy, 1969).

The bottom sediments in Lago Loíza are mostly silts and clays, (figs. 13-15). Sands constitute a small percentage of the sampled sediments. The amount of sand (fig. 13) did not exceed 15 percent in any of the samples collected. Only in the area of the sand extraction operation and a small embayment near station 5, did the amount of sand exceed 10 percent of the bottom sediments. Throughout most of the lake the amount of sand was less than 5 percent. Most of the sand is apparently deposited upstream from station 4.

The percentage of silt in the bottom deposits in Lago Loíza decreases downstream toward the damsite. The data in figure 14 suggest that the Río Gurabo contributes the highest load of silt to the lake. Only in the Río Gurabo reach and downstream from its junction with the Río Grande de Loíza does the silt exceed 60 percent of the sediments. As the water moves downstream toward station 6, the silt in suspension settles. In the bottom deposits it constitutes from 30 to 60 percent of the total material. In the lower part of the lake, the amount of silt remaining in suspension is relatively low and accounts for less than 30 percent of the bottom sediments.

Clay constitutes the bulk of the bottom sediments in Lago Loíza. In general, the percent of clay increases downstream toward the damsite, ranging from 60 to 90 percent of the bottom sediments throughout most of the area from station 5 to the dam. The data in figure 15 suggest that the Río Grande de Loíza contributes most of the clay particles to the lake. Bottom deposits in the Río Gurabo reach contain the lowest percentages of clay. The area where sand was extracted also shows a relatively low percentage of clay. In the process of sand extraction, clay was also removed.

The general characteristics of the bottom sediments in Lago Loíza and the high sedimentation rates are an indication of the poor soil conservation

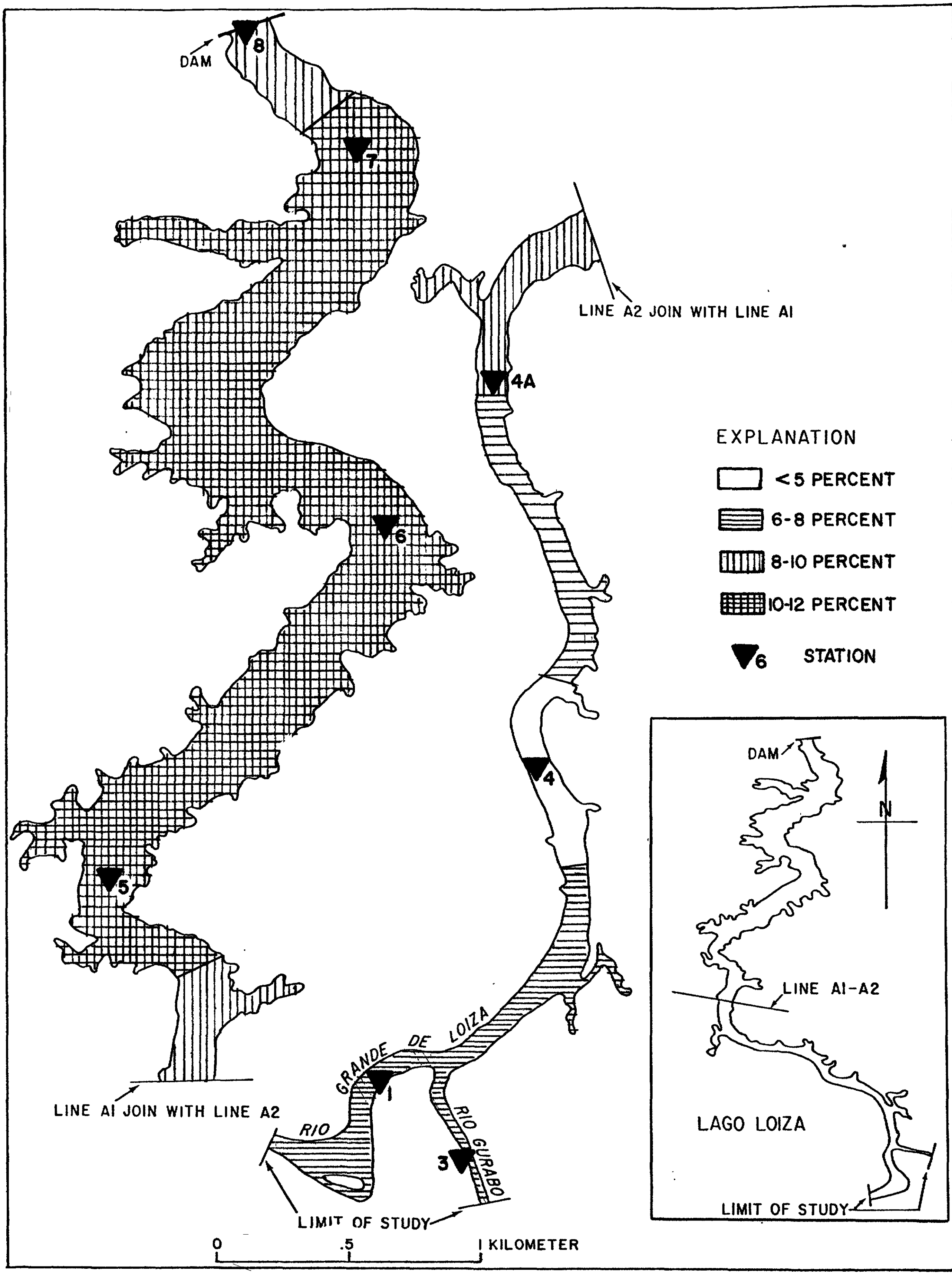

Figure 12.--Organic material in the bottom sediments in Lago Loíza.

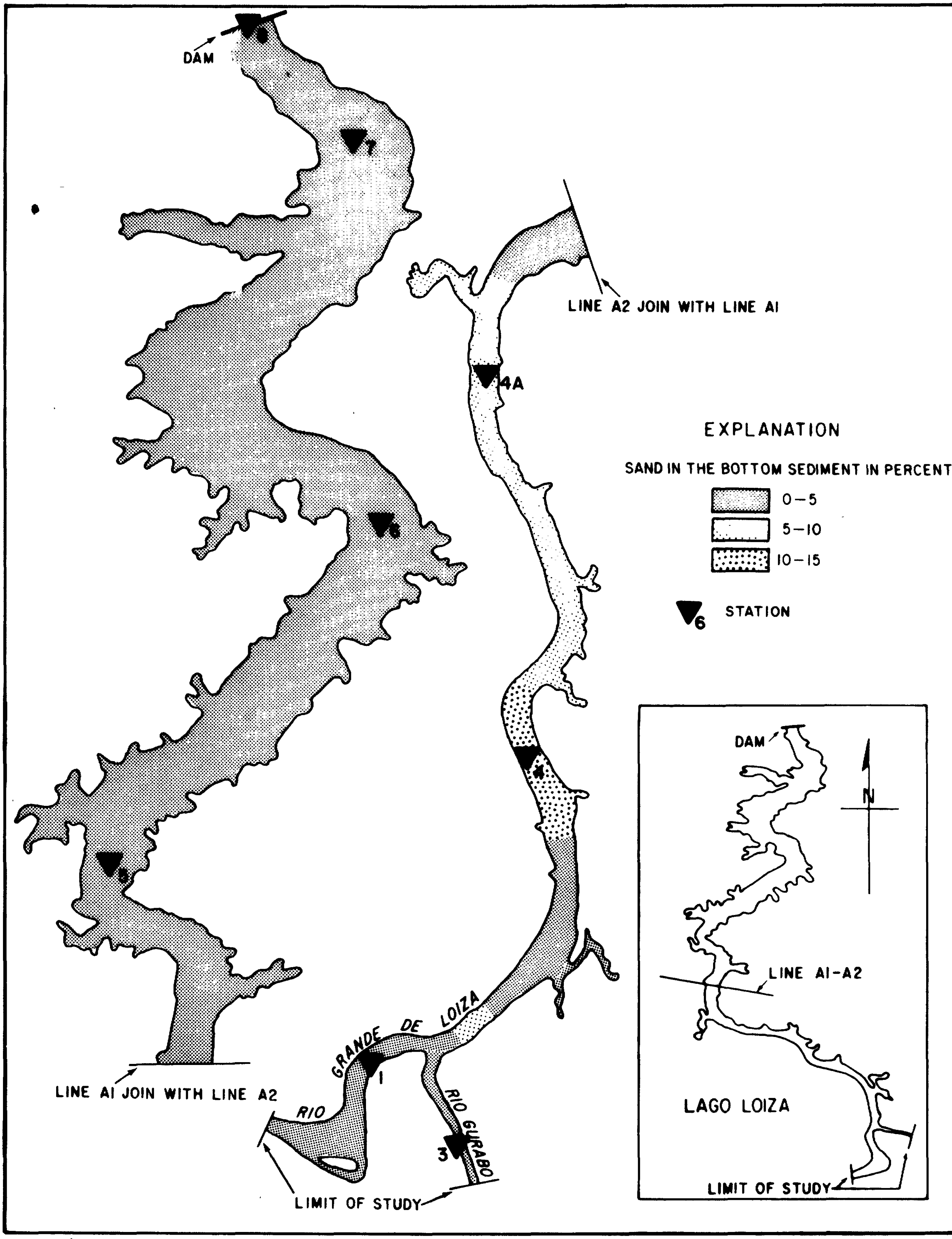

Figure 13.--Percentage of sand in the bottom sediments in Lago Loíza.

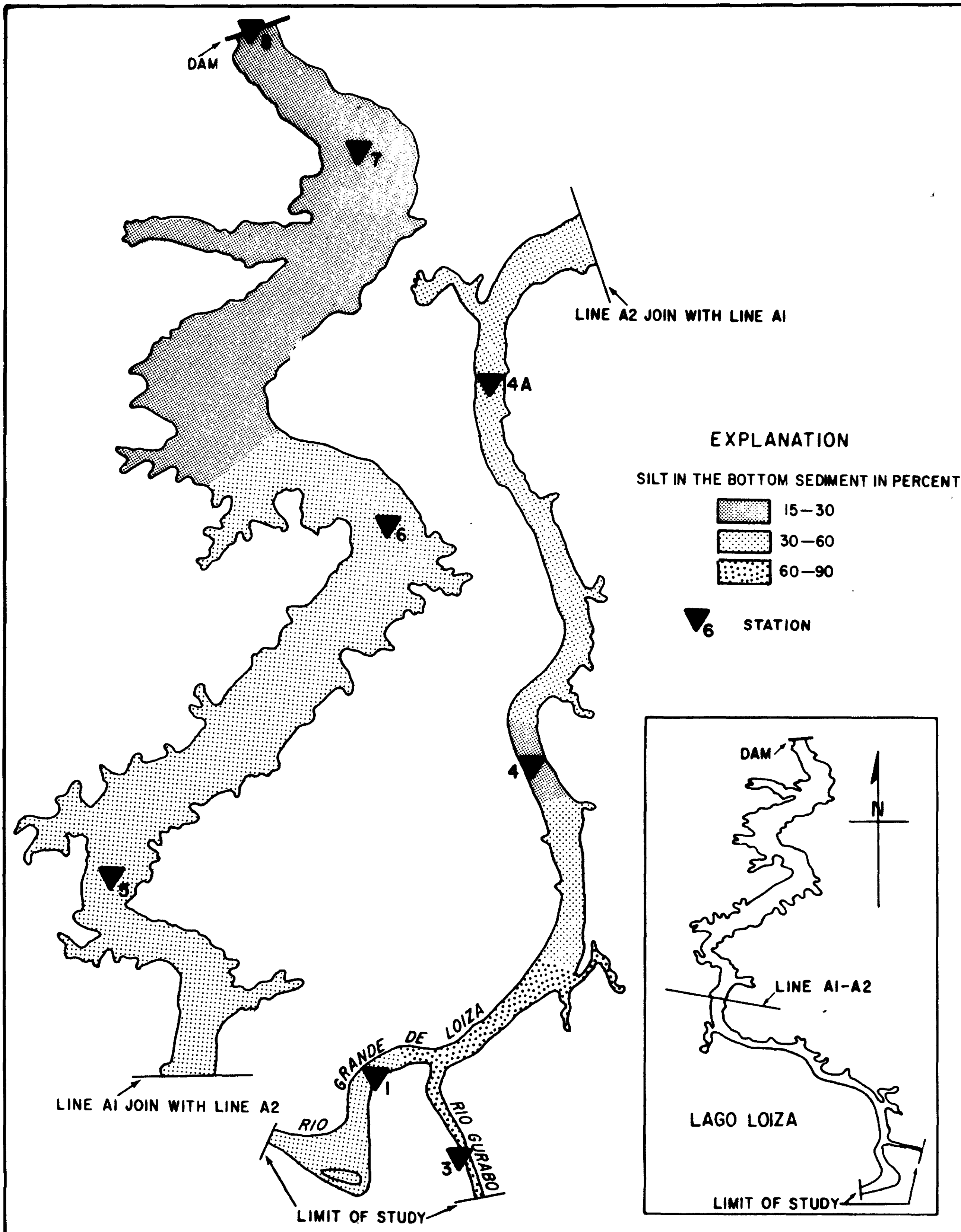

Figure 14.--Percentage of silt in the bottom sediments in Lago Loíza.

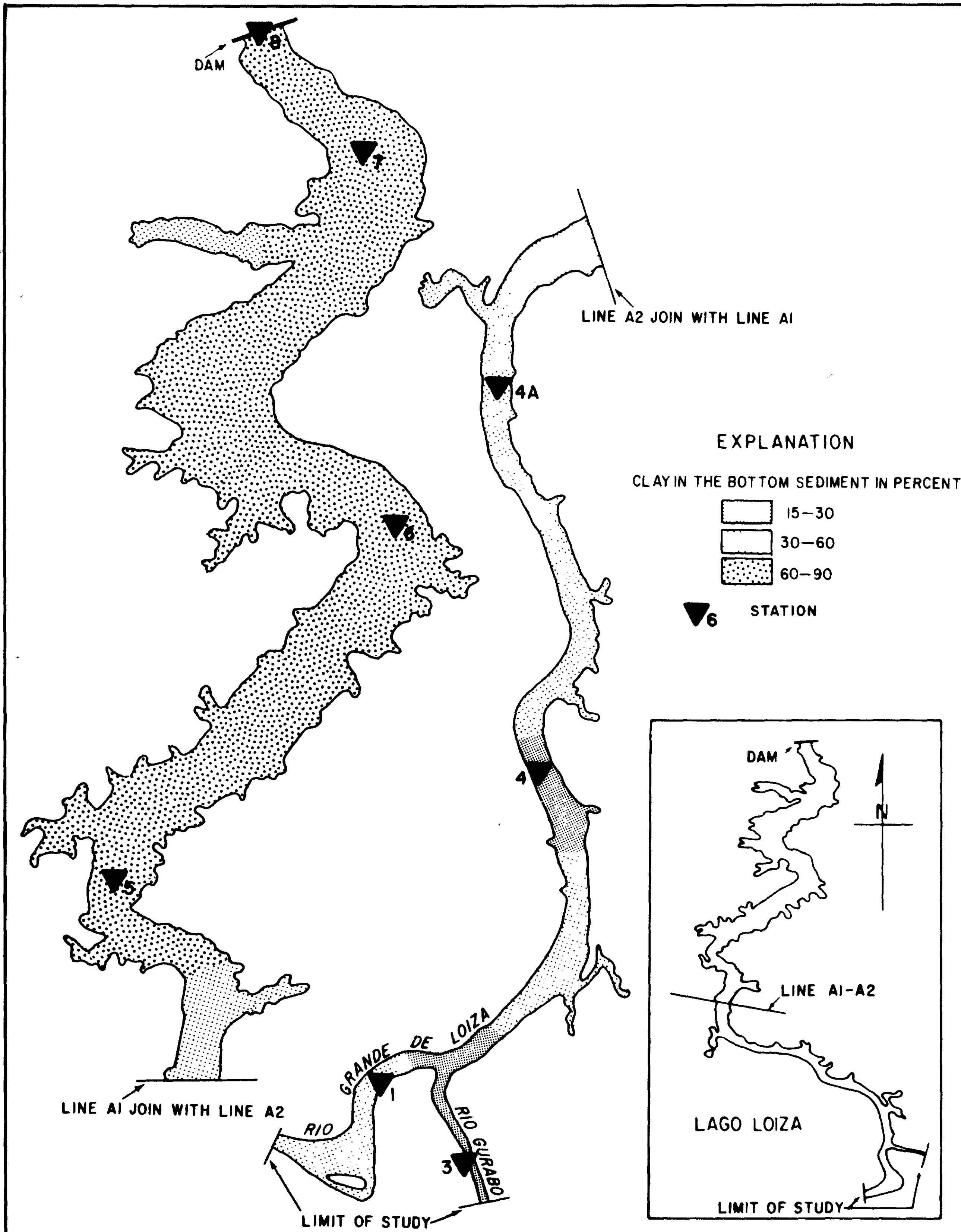

Figure 15.--Percentage of clay in the bottom sediments in Lago Loíza.

practices in the watershed. The soils in the upper basin are mostly associations of clays and loams (Hunt, oral commun., 1975). Most of the area is rugged mountainous terrain, with slopes averaging 32 percent. About 28.5 percent of the land has slopes of more than 50 percent. The steep slopes promote rapid erosion and high sediment transport and deposition rates. Urban developments where all the cover is removed and the soils are exposed to weathering are a contributing factor in the sedimentation process.

CHEMICAL, PHYSICAL, BIOCHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF THE MAIN TRIBUTARIES TO LAGO LOIZA

The principal characteristics that define the quality of the waters both in the tributaries and in Lago Loíza are directly related to drainage and cultural activities in the basin. The quality of the water in the lake is representative of the inflows from the tributaries. The determination of the quality of the water in the tributaries is essential in understanding the lake's characteristics. A multitude of parameters may be used to define the chemical, physical, biochemical, and bacteriological characteristics in the tributaries.

Each of the parameters investigated, either independently or in association with others, represents specific water-quality characteristics of interest to the water-data users. The interpretation of these characteristics may be general or specific, depending on the range of measurements, previous knowledge at the site, and reference values obtained from other sites or from formalized water-quality standards.

The common ions (calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and fluoride) may be used to indicate several water-quality characteristics related either to natural conditions (geology, cover, and so forth) or cultural activities (land use, effluents, and so forth). As examples of these, calcium and magnesium which provide most of the "hardness" in water may be related to the geology of the basin as they are major constituents in dioritic-type rocks. Sodium and chloride are usually present in sewage in higher concentrations than in natural waters. Human consumption of table salt is a source of these ions in sewage. Sulfates occur in natural waters as a result of the decomposition of rocks and minerals, such as igneous rocks and calcium sulfate (gypsum). In sewage, sulfate concentrations are higher than in natural waters as a result of decomposition of organic matter rich in sulfur. An overall analysis of the concentration of the common ion can give an insight into the water-quality problems in a basin (Hem, 1970).

The concentration of the principal common ions in the main tributaries to Lago Loíza and at stations 5, 6, and 7 in the lake are summarized in table 13. The table shows maximum, minimum and mean values (except pH, for which the median is shown) with the purpose of providing a comparison between sites. At least 12 samples are represented for each site. Reference to each site will be made in the particular section dealing with the tributaries or the lake.

Table 13.--Maximum, minimum and mean values (median for pH) for the principal chemical and physical characteristics of the main tributaries and stations 5, 6, and 7 in Lago Loíza. All analyses in milligrams per liter, except for Manganese and Iron (in micrograms per liter), pH (units), temperature (degrees Celsius) and specific conductance (micromhos per centimenter at 25°C).

	Calcium (Ca^{++})			Magnesium (Mg^{++})			Sodium (Na^{+})			Potassium (K^{+})			Silica (SiO_2)			Manganese (Mn^{++})			Iron ($Fe^{+2,+3}$)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Río Grande de Loíza nr Caguas	23	10	19	9.5	6.2	7.2	25	10	22	3.0	2.0	2.5	34	13	28	900	0	--	220	0	--
Río Gurabo nr Gurabo	25	10	20	10	5.0	--	25	15	22	5.5	2.5	4.1	30	15	27	--	--	--	110	0	--
Río Caguitas nr Caguas	55	30	48	18	7.0	15	63	10	46	9.0	3.5	5.9	--	--	--	1300	100	--	130	0	--
Río Bairoa nr Caguas	50	10	35	15	5.0	14	42	15	34	9.7	5.5	7.2	--	--	--	400	0	--	1050	0	--
Río Cañas nr Caguas	120	10	36	21	6.0	9.0	25	12	18	2.7	2.0	2.5	--	--	--	180	0	--	2600	0	--
Lago Loíza station 5	25	19	23	10	7.1	8.6	33	21	26	5.0	3.5	4.1	31	24	25	530	0	--	85	0	--
Lago Loíza station 6	23	18	21	10	6.6	8.4	30	20	25	5.5	3.6	4.2	30	22	27	200	0	--	150	0	--
Lago Loíza station 7	26	18	21	10	6.9	8.5	30	19	25	5.1	3.5	4.1	30	21	26	90	0	--	100	0	--

Note: mean values represent average of at least 12 samples collected from September 1973 to October 1974.

Table 13.--Maximum, minimum and mean values (median for pH) for the principal chemical and physical characteristics of the main tributaries and stations 5, 6, and 7 in Lago Loíza.--Continued.

	Chloride (Cl^-)			Sulfate ($SO_4^=$)			Bicarbonate (HCO_3)			Fluoride (F^-)			Specific conductance			Temperature (°C)			pH *		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Río Grande de Loíza nr Caguas	48	10	23	21	10	16	100	26	78	0.5	0	0.2	410	130	241	30	24	27	7.7	6.6	7.2
Río Gurabo nr Gurabo	28	15	22	19	10	15	120	30	95	.5	.1	.2	400	250	307	29	24	27	7.8	7.0	7.1
Río Caguitas nr Caguas	80	20	49	70	35	51	250	50	175	1.1	.2	.4	800	200	532	29	24	27	7.6	6.9	7.1
Río Bairoa nr Caguas	58	20	42	35	10	25	260	50	188	2.3	.2	.5	700	200	471	27	21	25	7.6	6.9	7.1
Río Cañas nr Caguas	28	13	20	20	12	15	150	25	125	.4	0	.2	350	150	300	34	24	27	9.4	8.0	7.6
Lago Loíza station 5	30	21	25	23	16	18	125	85	104	.5	.1	.3	400	275	318	30	25	27	7.5	7.0	7.1
Lago Loíza station 6	28	21	24	22	15	18	120	85	94	.4	.1	.3	380	255	302	29	25	27	7.7	7.1	7.3
Lago Loíza station 7	30	20	24	20	15	17	125	90	107	.5	.1	.3	380	240	300	29	24	27	7.9	7.2	7.3

*Median values

Metals, in particular those designated as "heavy metals," are introduced in the environment in excess of the natural concentrations from industrial, agricultural and domestic effluents. As examples, mercury is widely used in the wood preservative industry; nickel, cadmium and chromium in the electroplating industry; lead was used extensively in the paint industry and it continues to leach into the environment from existing residues of lead-based paints. Most of these metals are extremely toxic to human beings and animals, even at very low concentrations. A scan of some of the metals of interest from samples collected at the tributaries and the lake is summarized in table 14. Reference to this table will be made in pertinent parts of this section.

The pesticides constitute one of the most important group of compounds from the environmental point of view. The persistence in the environment of some of these compounds, mostly the organic insecticides, and their effect on human beings and animals are discussed in depth by Gould (1966, 1972), among others. Their presence or absence is a definite indicator of the quality of the waters.

Nutrients include a large number of elements and compounds which are essential to plant life (Hutchinson, 1973). Among those listed by Greeson (1971), it is commonly accepted that nitrogen and phosphorus are the most important. Nutrients induce the process of eutrophication, or enrichment of natural waters. Great increases in the concentration of some nutrients may lead to an increase in the process of photosynthesis. Although nutrients are naturally present in water, their concentrations are usually low and eutrophication normally does not occur. Industrial, agricultural and domestic discharges in a basin that contribute large amounts of nitrogen and phosphorus, will in turn accelerate the eutrophication process. Relative values as to what constitutes initial concentrations of the principal nutrients have been developed by Sawyer (1947), Vollenweider (1968), and Brezonik and Shannon (1971), among others. These values may be used as a reference to which concentrations in the Loíza basin may be compared. Other factors, such as depth and turnover rate, have been shown by Vollenweider (1968) and Dillon (1975) to allow lakes to tolerate higher loading rates of nutrients. Lakes with a high turnover rate, such as Lago Loíza, tolerate higher loadings of nitrogen and phosphorus before the eutrophication effects are visible.

Bacteriological conditions are an important indicator of the sanitary quality of waters. Among bacteria, the coliform group is the most widely used indicator of sanitary conditions. The presence of pathogenic organisms such as Salmonella is inferred when high concentrations of some of the components of the coliform group are present in water (Committee on Water Quality Criteria, 1974). Reference levels for maximum permissible concentrations of bacteria for recreation and fishing purposes have been defined at the national level only for the fecal coliform group (Committee on Water Quality Criteria, 1972). However, most of the states have established limits of 20,000 colonies/100 mL of total coliforms and 200 to 500 colonies/100 mL of fecal coliforms. Comparisons with these or other local standards may give an idea of the sanitary quality of the waters.

Table 14.--Average concentrations of selected metals at the main tributaries and outflow of Lago Loíza* (micrograms per liter).

STATION	Cadmium (Cd)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Nickel (Ni)	Zinc (Zn)
Río Grande de Loíza at Caguas (0550)	1	14,000	28	375	4	20
Río Gurabo near Gurabo (0570)	2	4,300	20	330	18	10
Río Caguitas at Highway 30 near Caguas (05525)	1	--	28	500	--	80
Río Bairoa near Caguas (0554)	1	1,500	32	220	22	80
Río Cañas above Lago Loíza (0584)	1	2,600	22	180	16	10
Lago Loíza at damsite (0590)	1	190	13	60	39	10

*Samples collected on April 10 and August 15, 1973.

The ratio of the fecal coliform to the fecal streptococcus concentration provides an indicator of the possible source of fecal matter in waters. Ratios much higher than 1.0 indicate human sources, while ratios much less than 1.0 indicate nonhuman sources such as cattle or poultry (Geldreich, 1967).

Bacteriological characteristics, as well as the other parameters described in the previous paragraphs for the main tributaries to Lago Loíza are discussed below. The overall impact of each tributary in the lake will be treated in a separate section.

Río Grande de Loíza at Caguas

Río Grande de Loíza is the main tributary to Lago Loíza. At the gaging station 0550 (fig. 1), the drainage area (232.6 km^2) exceeds the combined drainage of all the other tributaries monitored. The river flows from the Sierra de Cayey, draining mostly agricultural and pastureland. Effluents from the local sewage treatment plant are discharged into the river at San Lorenzo. Río Turabo is the principal tributary of Río Grande de Loíza, but no independent samples were collected from this source. Font (1972) reported median values in Río Turabo at Caguas of 8.0 mg/L for dissolved oxygen, 4.1 mg/L for biochemical-oxygen demand, and 75,000 organisms/100 mL for total coliforms (Most Probable Number, MPN).

The mean values shown in table 13 indicate that bicarbonate, silica, chloride, sodium and calcium are the principal ions in the waters in Río Grande de Loíza. The maximum and minimum values correspond to samples collected during low and high flows, respectively. On a time basis, concentrations of the principal ions increased as the drought progressed into August 1974, at which time considerable dilution was produced by high flows.

The average concentration of selected metals in Río Grande de Loíza (table 14) is representative of other streams throughout Puerto Rico (Quiñones and others, 1975). The samples were collected after intense storms in excess of 50 mm in the basin. The data for Río Grande de Loíza show a significant amount of iron in suspension and solution, with smaller amounts of manganese and other metals. The lower concentrations at the damsite indicate that most of the iron and other metals contributed by Río Grande de Loíza and the other tributaries precipitate in the lake.

The seasonal fluctuation of the principal nitrogen and phosphorus forms in Río Grande de Loíza are shown in figure 16. Dissolved oxygen concentrations and biochemical oxygen demands are also shown. Among the nitrogen forms, organic and ammonium nitrogen represent about 50 percent of the total nitrogen. Nitrite concentrations average less than 0.05 mg/L, while nitrate comprises the remaining nitrogen in the total computations. The high concentrations of organic and ammonium nitrogen indicate that sewage is one of the sources of nutrients to Río Grande de Loíza.

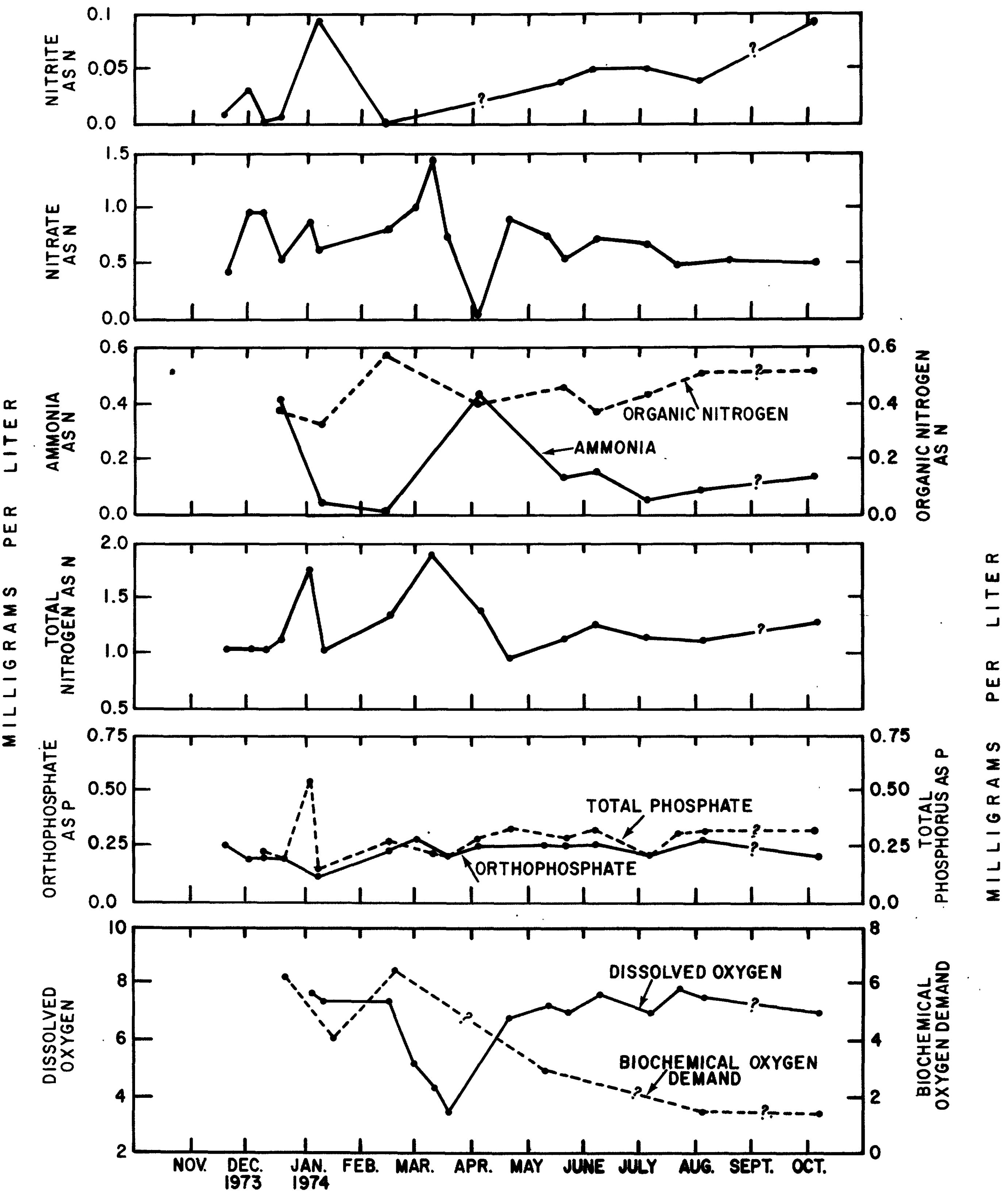

Figure 16.--Seasonal fluctuation in the concentration of nitrogen and phosphorus forms, dissolved-oxygen and biochemical-oxygen demand in Río Grande de Loíza at Caguas.

The total phosphorus concentration in the Río Grande de Loíza during the study period averaged 0.28 mg/L. The phosphorus concentration increased significantly from 0.15 mg/L in December 1973 to 0.35 mg/L during January, and remained nearly constant through the end of the study. Virtually all the phosphorus was inorganic orthophosphate ($PO_4^{\equiv}$). It was observed that for both phosphorus and nitrogen, their concentrations in the Río Grande de Loíza changed very little as the flows increased after the drought.

Biochemical-oxygen demand (BOD-5) in the Río Grande de Loíza ranged from 1.4 to 6.2 mg/L. This indicates that a low level of organic material and few reduced inorganic compounds are present in the water. The dissolved-oxygen (DO) concentration ranged from 3.5 to 7.9 mg/L. The DO concentration decreased steadily through the drought as shown in figure 16. The decrease correlates with the increases in the total nitrogen loads and biochemical-oxygen demands, indicating an increase in the proportion of wasteload to the streamflow.

The numbers of bacteria of the coliform group in the samples collected at Río Grande de Loíza usually exceeded the recommended maximum standards for recreational or any other purposes. The analyses are shown in table 15, where fecal coliform (FC) to fecal streptococcus (FS) ratios are also shown. The FC/FS ratios suggest mostly human sources of fecal contamination during the January and May samples, with more influence from nonhuman sources in August and October. The maximum concentrations were determined from samples collected during relatively high flows after the September 30, 1974 flood. This was a common occurrence for all the stations sampled in the basin and lake. The excessive runoff probably helped to wash human and animal wastes from non-sewered facilities into the rivers. Storm runoff from combined sewers may have reduced the retention time of wastes in several facilites, decreasing the efficiency of the treatment provided.

Río Gurabo at Gurabo

The Río Gurabo is the second most important tributary to Lago Loíza. The Río Gurabo flows from the southern slope of Sierra de Luquillo through several rural communities (Caimito, El Mango, and others) toward the town of Juncos. Near Juncos, its flow is augmented by the Río Valenciano, a major tributary of the upper basin. The Río Valenciano flows through most of the urban area of Juncos and receives domestic effluents, including partially treated sewage from the local treatment plant (table 4). Downstream from the treatment plant, Font (1972) reported a median dissolved-oxygen concentration of 4.1 mg/L, a median BOD-5 of 6.5 mg/L and a median coliform index (MPN) of 2,060,000 organisms/100 mL.

Further downstream, partially treated sewage from the town of Gurabo is discharged into the river. Below the treatment plant outfall, Font (1972) reported a median value of dissolved oxygen of 2.5 mg/L, a median BOD-5 of 8.3 mg/L, and a median coliform index (MPN) of 230,000 organisms/100 mL. At the time of the study by Font, the Juncos sugar mill was still in operation. The low dissolved-oxygen values and relatively high BOD-5 probably reflect some of the effects of the wastes discharged from the mill into the river as reported by Font.

Table 15.--Bacteria analyses in Río Grande de Loíza at Caguas (colonies per 100 milliliters of sample).

Date	Total coliforms	Fecal coliforms	Fecal streptococci	Fecal coliforms/ fecal streptococci*
Dec. 20, 1973	38,000	1,900	--	--
Jan. 8, 1974	6,100	2,500	1,300	1.9
Feb. 14, 1974	11,000	--	800	--
May 8, 1974	5,800	900	190	4.7
June 6, 1974	16,000	14,800	--	--
July 2, 1974	5,900	1,270	--	--
Aug. 1, 1974	3,000	100	800	0.12
Oct. 1, 1974	192,000	60,000	61,000	0.98

*Fecal coliform to fecal streptococci ratio

The waters in Río Gurabo are very similar to those in the Río Grande de Loíza. The data in table 13 show that mean values of most of the chemical and physical parameters monitored for both stations are nearly equal. The concentration of dissolved solids in Río Gurabo, as indicated from the specific conductance values, is slightly higher than in Río Grande de Loíza. This may be a result of the geology of the area or larger amounts of untreated sewage discharged into Río Gurabo as compared with Río Grande de Loíza. Seasonally, the concentration of most of the ions in Río Gurabo declined as the drought progressed. This is probably the result of the effects of the pumpage from Río Blanco, mentioned previously. Waters from Río Blanco drain the southern slopes of the Luquillo rain forest and are low in dissolved solids (U.S. Geological Survey, 1975). Typical specific conductance values in Río Blanco do not exceed 175 micromhos per centimeter at 25°C. Water pumped from Río Blanco to Río Gurabo during the drought diluted the ions in the Río Gurabo.

The concentrations of selected metals in Río Gurabo (table 14) are in general slightly lower than in Río Grande de Loíza. Nickel concentrations are several times higher in Río Gurabo but still do not exceed values recommended as critical for water-supply purposes (Committee on Water Quality Criteria, 1974).

Nitrate (NO_3^-) is the principal nutrient in Río Gurabo. The data in figure 17, where the seasonal fluctuation of the concentration of the principal nutrients, dissolved oxygen and BOD-5 in Río Gurabo are shown, indicate that nitrate concentrations range from 0.8 to 2.5 mg/L, averaging about 1.5 mg/L. The total nitrogen concentrations ranged from 1.8 to 6.0 mg/L, and averaged 2.5 mg/L. On the average, nitrates were about 60 percent of the total nitrogen samples collected. Both the nitrate and total nitrogen average concentrations in Río Gurabo were about twice the averages in Río Grande de Loíza. The organic and ammonia nitrogen concentrations averaged about 0.20 and 0.10 mg/L, respectively. These were about one-half the average values observed in Río Grande de Loíza. The distribution of the nitrogen forms in Río Gurabo is characteristic of treated sewage which has been oxidized. Because the sewage treatment plants in Juncos and Gurabo discharge effluents that are only partially treated, one would expect that the organic and ammonia species would be a higher percentage of the total. This suggests that other sources, perhaps agricultural runoff, may account for some of the nitrates in the river.

The total phosphorus concentration through July 1974 in Río Gurabo averaged about 0.35 mg/L. Samples collected thereafter averaged 0.9 mg/L. The orthophosphates ($PO_4^=$) remained nearly unchanged, averaging about 0.25 mg/L. Seasonal agricultural activities in the basin were probably the main cause of the increased loads of organic phosphates after July 1974.

Biochemical oxygen demands in Río Gurabo ranged from 0.8 to 7.4 mg/L. Only a limited number of samples were collected and it is probable that during May 1974, when the dissolved oxygen declined to about 3.2 mg/L (fig. 17), the BOD-5 was much higher. Most of the time, the dissolved-oxygen concentrations in Río Gurabo were higher than 6.0 mg/L, indicating a relatively low organic loading.

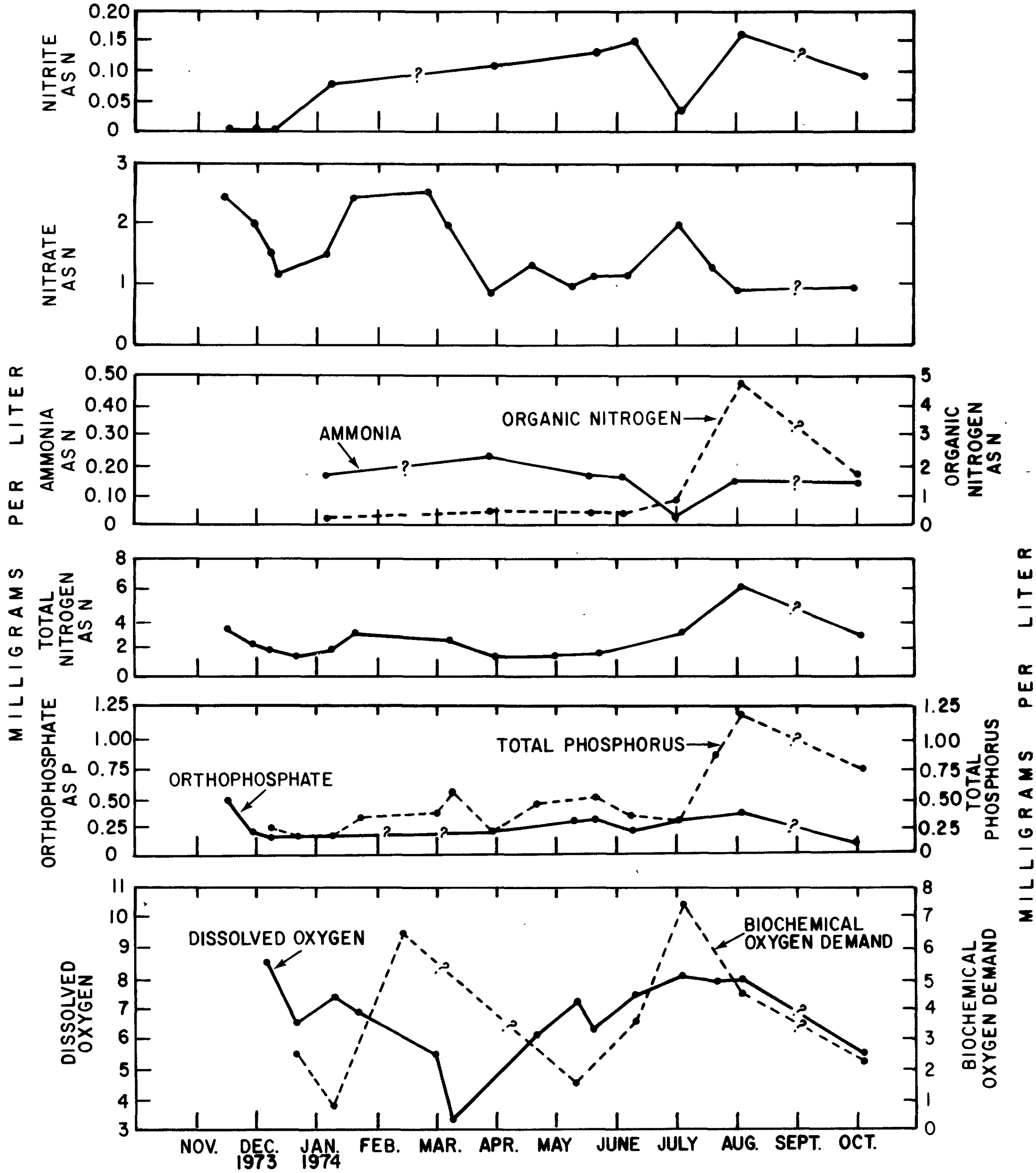

Figure 17.--Seasonal fluctuation in the concentration of nitrogen and phosphorus forms, dissolved-oxygen and biochemical-oxygen demand in Río Gurabo near Gurabo.

The coliform bacteria populations in Río Gurabo were slightly lower than in Río Grande de Loíza. Results of samples collected during the study period are given in table 16. Fecal coliform to fecal streptococci ratios (FC/FS) indicate that human wastes are the primary source of bacteria in Río Gurabo. As in Río Grande de Loíza, the highest number of bacteria were found in samples collected after the flood of September 30-31, 1974. The data from both streams clearly indicate that during storms, nonpoint sources throughout the basin contribute more bacteria to the streams than point sources. This is an important consideration for future plans to improve the sanitary quality of the waters in the basin by providing additional and more efficient treatment to effluents and other point sources. It may be that the additional treatment to point sources may not provide significant improvement in the overall water quality.

Río Caguitas at Caguas

The Río Caguitas is a tributary of the Río Grande de Loíza, flowing into it about 1 km below the Río Grande de Loíza station at Caguas (station 0550, fig. 1). It flows from the area of Cañabón west of Caguas. North of Bairoa, urbanization about 1 km upstream from Highway 30, the effluent from the Caguas sewage treatment plant is discharged into the river. PRASA, in its 1973-74 operations report, indicates that about 13,250 m^3/d of treated sewage is discharged by the plant. The treatment plant, of the trickling filter type (table 4), discharges nearly raw sewage into the river during periods of critical overloading. Font (1972) reported that samples collected below the effluent discharge point contained a median DO of 2.2 mg/L, median BOD-5 of 16 mg/L, and a median coliform index (MPN) of 17,000,000 organisms/100 mL. The Río Caguitas probably is the most contaminated river in the watershed and the quality of its water ranks among the worst in Puerto Rico.

The discharges from the sewage treatment plant into Río Caguitas are reflected in most of the parameters monitored. The average concentrations of all the common ions (table 13) are much higher than those at Río Gurabo and Río Grande de Loíza. The average specific conductance in Río Caguitas indicates that there are nearly twice as many ions in solution as in either of the other streams. The individual samples show sharp changes in concentration from one month to the next, indicating intermittent changes in the amount of effluent discharged into the river.

The concentration of the principal nutrients in Río Caguitas is also typical of streams receiving sewage inputs. The data in figure 18 show erratic seasonal changes from sample to sample but with overall high concentrations of the most important nutrients as compared with other streams in the basin. The total nitrogen concentration during the study period averaged 5.0 mg/L. Organic nitrogen and ammonia were the principal nitrogen forms detected except during December 1973 and July 1974 when inorganic nitrogen, mostly nitrites, were the principal forms. There are no indications as to what may have caused a greater concentration of the more oxidized nitrogen forms.

Table 16.--Bacteria analyses in Río Gurabo at Gurabo (colonies per 100 milliliters of sample).

Date	Total coliforms	Fecal coliforms	Fecal strep-tococci	Fecal coliforms/ fecal streptococci*
Dec. 20, 1973	18,000	1,100	--	--
Jan. 8, 1974	3,400	200	700	0.3
Feb. 14, 1974	16,000	--	1,000	--
May 8, 1974	14,000	1,400	580	2.4
June 6, 1974	15,000	4,300	580	7.4
July 2, 1974	5,000	1,700	730	2.3
Aug. 1, 1974	4,000	2,800	1,500	1.9
Oct. 1, 1974	66,000	17,000	3,500	4.9

*Fecal coliform to fecal streptococci ratio

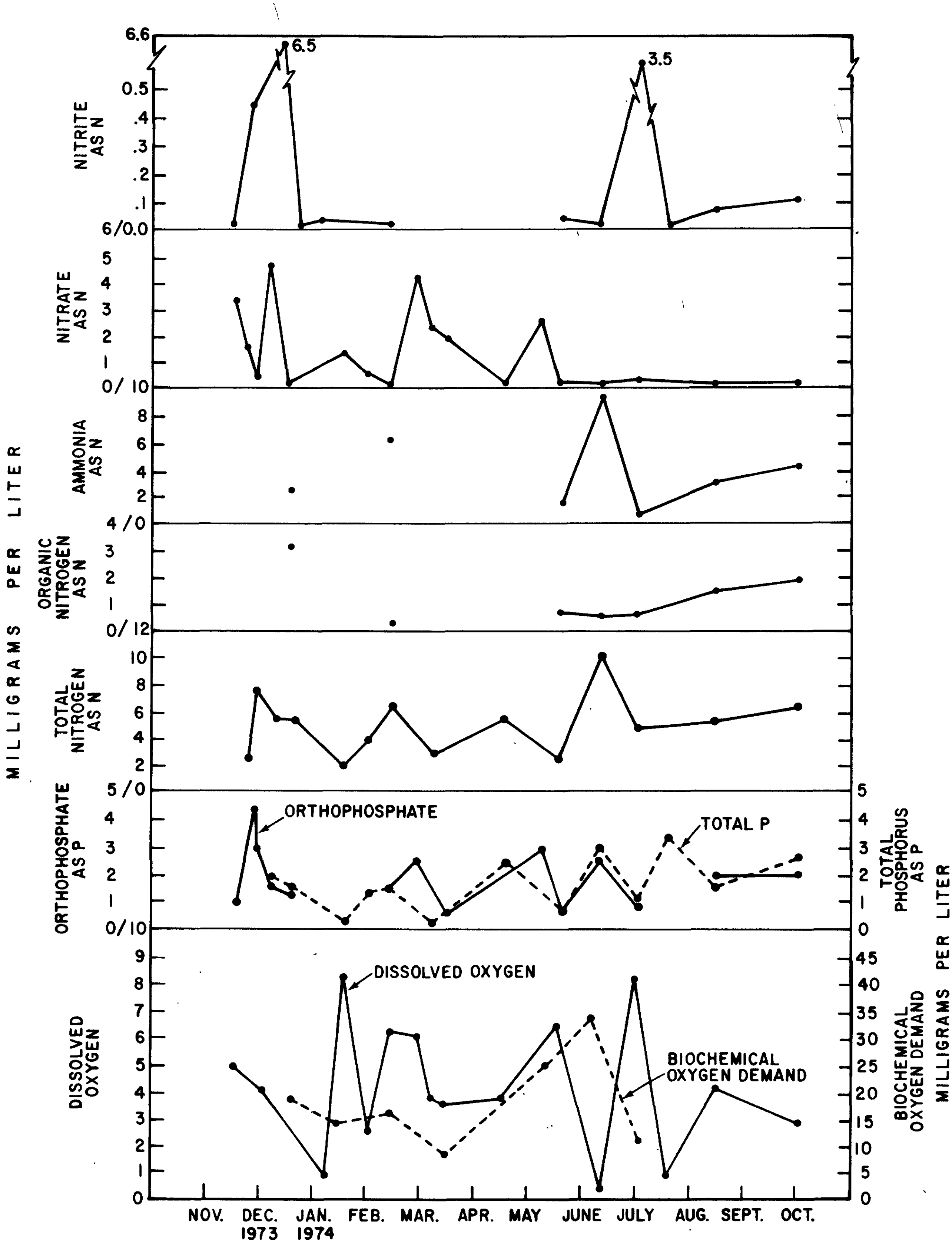

Figure 18.--Seasonal fluctuation in the concentration of nitrogen and phosphorus forms, dissolved oxygen and biochemical oxygen demand in Río Caguitas at Highway 30 near Caguas.

The total phosphorus concentration in Río Caguitas ranged from 0.2 to 4.5 mg/L, averaging about 1.7 mg/L. Nearly all the phosphorus was present as orthophosphate.

The dissolved-oxygen concentration and the biochemical-oxygen demand in Río Caguitas are also characteristic of streams receiving partially treated sewage. The DO concentrations ranged from 0.4 to 8.2 mg/L, averaging 4.2 mg/L In only two samples (January 16 and July 1, 1974), were the DO concentrations near saturation values. The BOD-5 values averaged 19 mg/L, ranging from 8 to 34 mg/L.

The bacteriological analyses from Río Caguitas provide an additional confirmation of the poor water-quality conditions in the stream. The results, shown in table 17, are among the highest recorded in Puerto Rico and confirm the findings of Font (1972) about the sanitary quality of the waters in Río Caguitas. The fecal coliform to fecal streptococci ratios clearly indicate that bacterial contamination in Río Caguitas is primarily of human origin.

Río Bairoa near Caguas

The Río Bairoa flows from the hills west of the town of Aguas Buenas through Bairoa urbanization in southern Caguas, and into the Río Grande de Loíza. About 730 m^3/d of partially treated sewage is discharged into Río Bairoa from the Aguas Buenas treatment plant. In addition, untreated sewage from Las Carolinas community is also discharged into the river. Median dissolved oxygen, BOD-5 and coliform MPN index values of 3.2 mg/L, 8.3 mg/L, and 230,000 organisms/100 mL, respectively, were reported by Font (1972) from samples collected at the bridge on Highway 1 near Caguas (station 0554, fig. 1).

Water-quality conditions in Río Bairoa are very similar to those in Río Caguitas. The water is characterized by relatively high concentrations of most of the common ions (table 13). With the exception of sulfates, mean concentrations of most of the inorganic ions in Río Bairoa are nearly equal to those in Río Caguitas. The concentrations of metals (table 14) are typical of other streams in the basin.

The concentration of the principal nutrients in Río Bairoa is also typical of streams receiving sewage discharges. The data in figure 19 show that total nitrogen concentration ranged from 1.0 to 31 mg/L and total phosphorus concentrations ranged from 1.5 to 9.0 mg/L through May 1974. From June to August 1974 the concentration of both nutrients declined to less than 2.0 mg/L. Improvments in the Aguas Buenas sewage treatment plant and dilution due to storm runoff may account for the reduction in the nutrients' concentration. Samples collected during October 1974 indicated that some of the dilution effects were no longer evident and concentrations as great as 4 mg/L were detected. The dissolved-oxygen and biochemical-oxygen demand seasonal changes, also shown in figure 19, provide additional evidence of the improvement in the overall water quality in Río Bairoa after June 1974. After declining to less than 1.0 mg/L during the May 1974 sampling, DO concentrations were near saturation thereafter. Biochemical-oxygen demands declined accordingly.

Table 17.--Bacteria analyses in Río Caguitas at Highway 30 near Caguas (colonies per 100 milliliters of sample).

Date	Total coliforms	Fecal coliforms	Fecal streptococci	Fecal coliforms/ fecal streptococci*
Dec. 20, 1973	5,000,000	700,000	48,000	14.6
Jan. 8, 1974	10,300,000	4,300,000	270,000	15.9
Feb. 14, 1974	6,500,000	--	20,000	--
May 8, 1974	60,000	2,000	1,000	2.0
June 6, 1974	--	1,090,000	119,000	9.2
July 2, 1974	68,000	17,000	1,700	10.0
Aug 1, 1974	2,500,000	390,000	146,000	2.7
Oct. 1, 1974	8,000,000	1,300,000	1,060,000	1.2

*Fecal coliform to fecal streptococci ratio

Table 18.--Bacteria analyses in Río Bairoa near Caguas (colonies per 100 milliliters of sample).

Date	Total coliforms	Fecal coliforms	Fecal streptococci	Fecal coliforms/ fecal streptococci*
Dec. 20, 1973	79,000	5,500	--	--
Jan. 8, 1974	12,000,000	6,700,000	440,000	15.2
Feb. 14, 1974	15,000,000	--	340,000	--
May 8, 1974	5,600,000	900,000	710,000	1.3
June 6, 1974	220,000	56,000	4,000	14.0
July 2, 1974	11,000	2,700	970	2.8
Aug. 1, 1974	240,000	68,000	2,900	23.4
Oct. 1, 1974	8,000,000	2,300,000	770,000	3.0

*Fecal coliform to fecal streptococci ratio

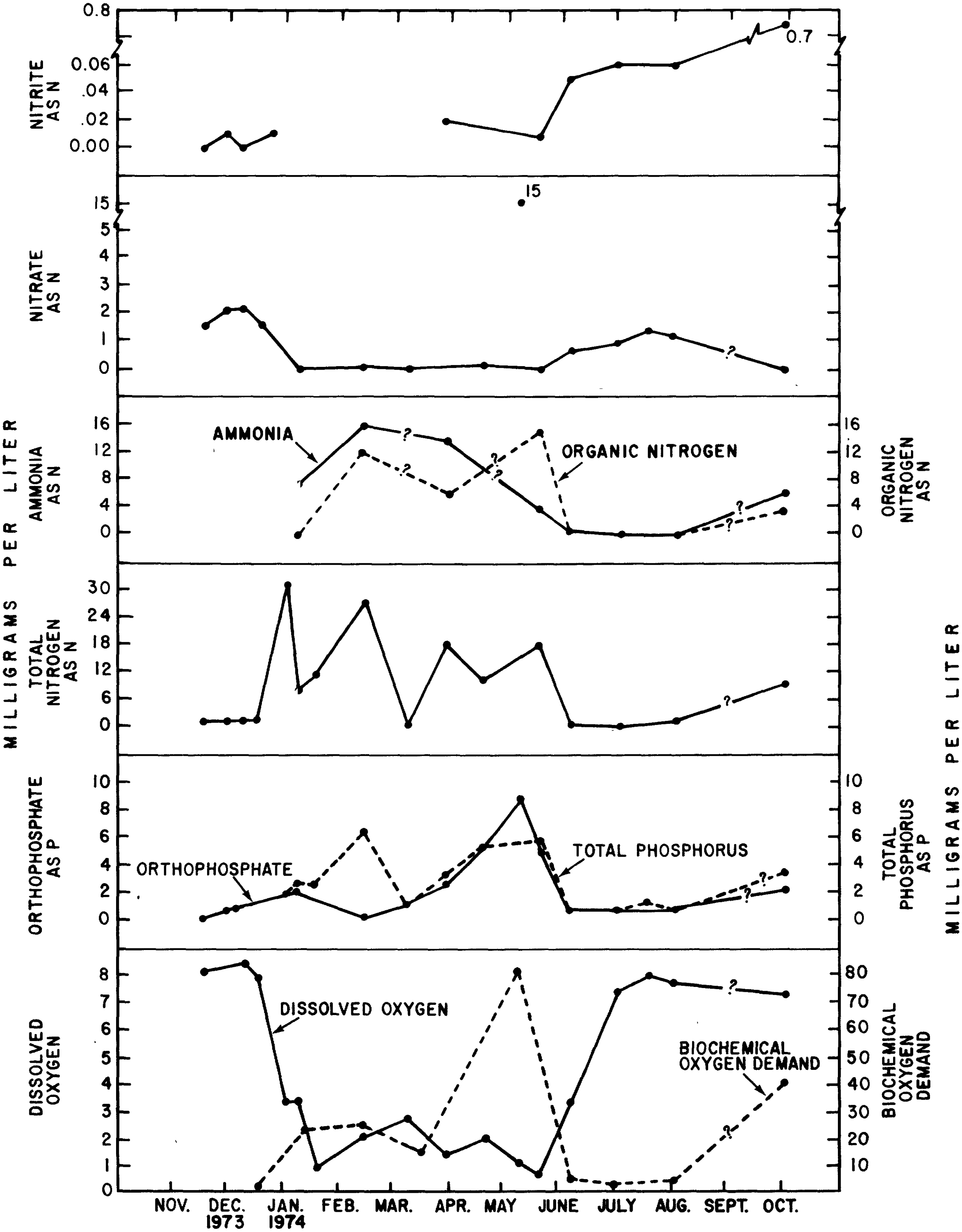

Figure 19.--Seasonal fluctuation in the concentration of nitrogen and phosphorus forms, dissolved oxygen and biochemical oxygen demand in Río Bairoa near Caguas.

The concentrations of bacteria in Río Bairoa were at times even higher than those recorded at Río Caguitas. The analyses, shown in table 18, reflect sanitary conditions similar to those in Río Caguitas. The samples of January and February 1974 represent conditions typical of raw sewage. The input of these two streams into Lago Loíza represents the most significant sanitary problem in the basin.

Río Cañas above Lago Loíza

The Río Cañas flows directly into Lago Loíza from the hills west of Highway 1. The Río Cañas has a major tributary, Quebrada Arenas, which contributes as much flow as the Río Cañas itself. The river has a drainage area of 20.2 km^2 almost totally nonurban, although there are several rural communities in the basin (Quebrada Arenas, La Changa, Río Cañas). The gaging and sampling stations were located about 0.7 km upstream from Lago Loíza (station 0584, fig. 1).

Chemical, physical and bacteriological conditions of the waters in the Río Cañas are the most favorable among the rivers included in the study. Font (1972) reported median DO, BOD-5, and total coliform MPN index of 8.0 mg/L, 6.6 mg/L, and 43,000 organisms/100 mL, respectively. Conditions have not changed significantly since that time.

Waters in the Río Cañas are of the calcium-bicarbonate type. The data in table 13 show that chloride, sodium and sulfate follow in order of abundance. Seasonally, the concentrations of most of the inorganic ions in Río Cañas are affected by industrial wastes discharged about 500 meters upstream from the sampling site. The range of pH values (7.0 to 9.4) and the median value of 7.6 indicate that the wastes are more alkaline than in the other streams. Upstream from the plant, pH values are in the vicinity of 7.0 units. Higher than normal temperatures were also recorded during periods when the wastes were evident near the sampling station (table 13). The wastes do not increase the concentration of any of the metals monitored. The analyses shown in table 14 were representative of other streams in the basin.

The concentration of the principal nutrients in Río Cañas is relatively low compared with other streams in the basin (fig. 20). Total nitrogen and total phosphorus concentrations averaged 0.81 mg/L and 0.14 mg/L, respectively. Nitrate is the principal nitrogen form, while most of the phosphorus is present as the orthophosphate ion.

The dissolved oxygen and biochemical oxygen demand also indicate that the quality of the waters in the Río Cañas is the best among the tributaries monitored. Except during March 1974, when an oxygen sag is evident from the data in figure 20, DO values exceeded 7.0 mg/L. The reasons for the sag are not evident because the BOD values during the study year averaged 1.7 mg/L, indicating that organic loads into Río Cañas are minor.

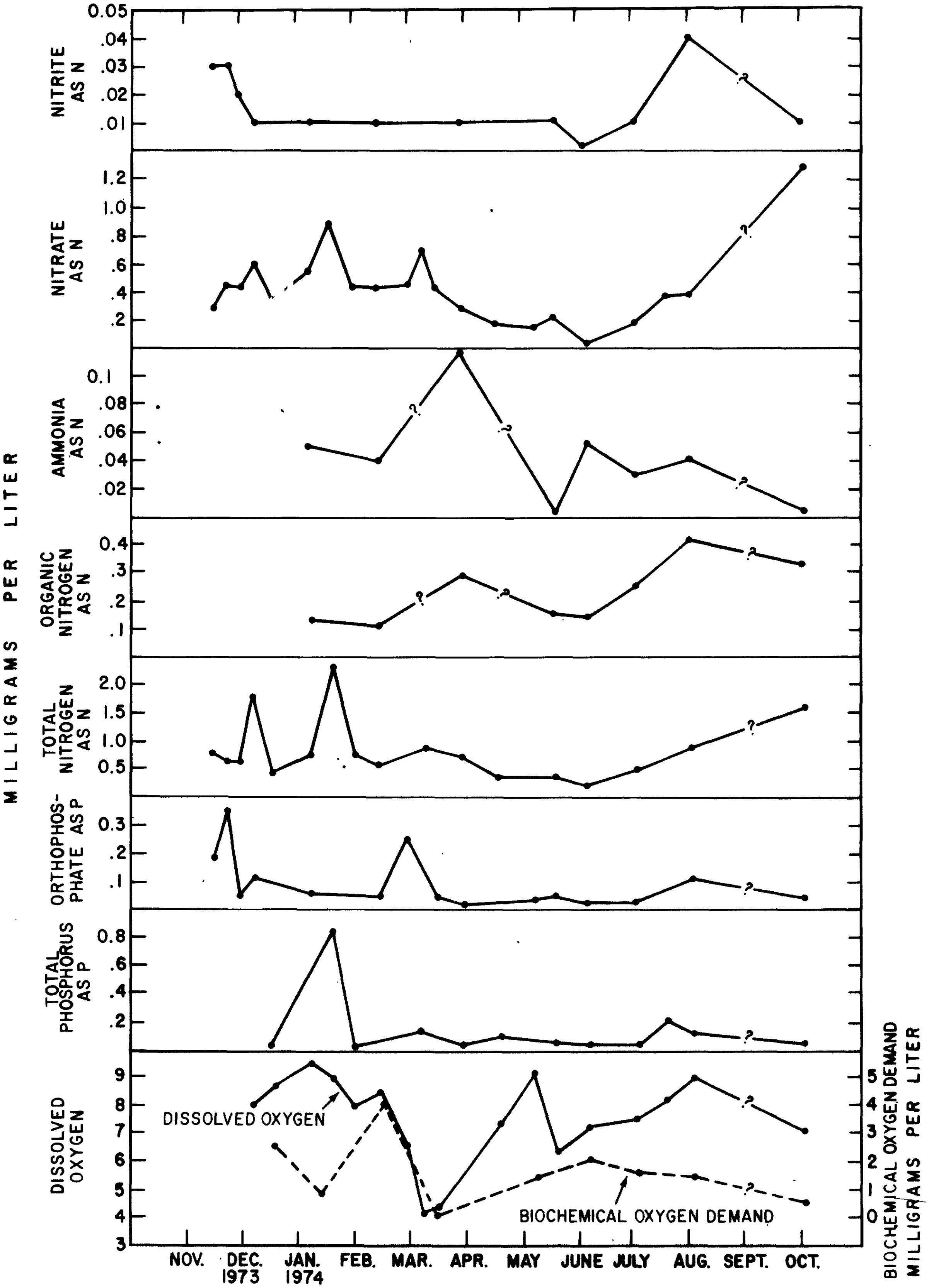

Figure 20.--Seasonal fluctuation in the concentration of nitrogen and phosphorus forms, dissolved oxygen and biochemical oxygen demand in Río Cañas above Lago Loíza.

Bacteriological analyses in Río Cañas (table 19) indicate intermittent inputs of sewage, but probably in amounts much less than at Río Caguitas and Río Bairoa. Although bacteriological conditions in Río Cañas are the best among the streams monitored in the basin, concentrations still exceed recommended standards most of the time. Fecal coliform to fecal streptococci ratios indicate that human fecal matter is the primary source of bacteria in Río Cañas. Field observations help to corroborate this finding, as most of the area drained by Río Cañas consists of unsewered single units with rustic disposal facilities.

CHEMICAL, PHYSICAL AND BACTERIOLOGICAL CHARACTERISTICS IN LAGO LOIZA

The water-quality characteristics of Lago Loíza are primarily affected by the proportional contributions from the tributaries. Seasonal and downstream fluctuations are also important factors that need to be considered. The waters from the tributaries, as shown in the previous section, can be divided into three groups. Flows from the Río Grande de Loíza and Río Gurabo are very similar in most of the parameters monitored. These waters may be classified as of "moderate" quality, with high concentrations of nutrients. Their effect on the lake is fundamental, as these two streams contribute most of the inflows. Río Caguitas and Río Bairoa exhibit similar characteristics and may be classified as of "poor" quality. Extremely high bacteria populations and nutrient concentrations are typical of these streams. Their effect on the lake is secondary in terms of volume but important in terms of quality. Finally, the waters from Río Cañas are of "good" quality with a minor effect on the lake.

The data collected at stations 5, 6, and 7 (fig. 2) in Lago Loíza were assumed to be representative of the entire lake. Occasionally, station 7 was used as an index station as it probably is more representative of the water being pumped to the metropolitan area.

Common Ions and Physical Characteristics

The concentration of most of the common ions in Lago Loíza does not change significantly from the headwaters to the damsite. The average concentrations listed in table 13 show that concentrations at station 5 are only slightly higher than at the other downstream stations. For practical purposes, any one station in the lake may be representative of the others (in terms of the parameters in table 13).

Except during very low flows, the waters throughout the lake represent the combined inputs from Río Grande de Loíza and Río Gurabo. Comparison of the mean values in table 13 for these two streams and the lake stations shows no significant differences. Seasonally, the impact of the smaller tributaries is more important during drought periods. Typical of this effect is the seasonal change in the concentration of sodium. During December 1973, the sodium concentration in the lake stations averaged 22 mg/L. As the drought progressed, it increased to a peak of 30 mg/L in July 1974. After the rains in late August

Table 19.--Bacteria analyses in Río Cañas above Lago Loíza (colonies per 100 milliliters of sample).

Date	Total coliforms	Fecal coliforms	Fecal streptococci	Fecal coliforms/ fecal streptococci*
Dec. 20, 1973	11,300	400	--	--
Jan. 8, 1974	3,500	2,800	300	9.3
Feb. 14, 1974	5,000	--	400	--
May 8, 1974	16,000	2,400	820	2.9
June 6, 1974	80,000	4,700	1,700	2.8
July 2, 1974	9,500	1,280	470	2.7
Aug. 1, 1974	40,000	12,000	3,500	3.4
Oct. 1, 1974	29,000	2,700	3,900	0.7

*Fecal coliform to fecal streptococci ratio

and September 1974, the average declined to 21 mg/L. The increases during the low-flow period were, probably due to higher concentrations in the flows from Río Caguitas and Río Bairoa, at a time when the overall flow input to the lake had declined dramatically. Although the flows in Río Caguitas and Río Bairoa had also declined, the relative reduction was proportionately much less than at Río Grande de Loíza and Río Gurabo. The discharge of sewage into the smaller streams maintained a more constant flow.

The mean specific conductance throughout Lago Loíza was 249 umho/cm (micromhos per centimeter) ranging from 240 to 400 umho/cm. Conductance values at station 5 departed from values at stations 6 and 7, which were very similar. Seasonally, the specific conductance followed the pattern of increasing during the drought in a manner similar to that discussed for most of the other ions. During periods of low flow, ground waters contribute most of the flow in the streams. Ground waters in Puerto Rico usually have a much higher specific conductance than surface waters (Bogart and others, 1964). As previously indicated, waters receiving effluents from sewage treatment plants also have a conductance higher than natural waters. A combination of both of these factors (ground-water contributions and sewage effluents) probably caused the increase in the specific conductance.

The pH at 1.0-m depth in Lago Loíza ranged from 7.0 to 7.9 units, with a median of 7.2. Seasonally, there were no significant changes in the pH.

Selected Metals and Pesticides

The importance of metals in the environment was discussed in a previous section. The role of Lago Loíza as the principal water-supply source to metropolitan San Juan makes it even more important to monitor the concentration of selected metals in its waters, particularly "heavy" metals. The same principles apply to the monitoring of pesticides and their derivatives. The limitation of funds during the study precluded a more detailed monitoring of both heavy metals and pesticides in the waters in Lago Loíza.

The concentration of selected metals in samples collected March 20, 1974 (table 20), are typical of other streams throughout Puerto Rico (Quiñones and others, 1975). None of the metals detected exceeded recommended standards for public water-supply purposes.

The concentrations of pesticides in Lago Loíza were monitored at stations 4 and 7 (table 21). These stations represent most of the combined inflow and outflow of the lake. Only very minor amounts of dieldrin and diazinon were detected. Dieldrin is a very persistent insecticide with a soil half-life of about 3 years (Sanborn, 1974). Its water solubility has been reported as 0.25 mg/L (Gould, 1966). The 0.01 ug/L of dieldrin observed at station 4 is much below its maximum solubility and near the detection limits of the analytical methods. Although this concentration is very low, it is possible that dieldrin could be concentrated in aquatic organisms in the lake.

Table 20.--Concentrations of selected metals in waters at Lago Loíza, March 20, 1974. (See figure 2 for station locations; concentrations in micrograms per liter.)

METAL	STATION						
	1	3	4	5	6	7	Outflow at damsite
Cadmium (Cd)	0	0	1	0	1	3	1
Copper (Cu)	4	12	6	0	5	--	--
Lead (Pb)	7	8	4	2	13	0	13
Nickel (Ni)	6	6	9	6	9	14	--
Selenium (Se)	3	5	9	2	0	--	--
Strontium (Sr)	140	140	100	100	100	100	--
Zinc (Zn)	70	70	70	60	70	20	10

Table 21.--Concentration of selected pesticides and polychlorinated biphenyls in Lago Loíza, March 20, 1974 (micrograms per liter).

	Station 4	Station 7
Aldrin	0	0
Chlordane	0	0
DDD	0	0
DDE	0	0
DDT	0	0
Dieldrin	0.01	0
Endrin	0	0
Heptachlor	0	0
Heptachlor epoxide	0	0
Lindane	0	0
Methyl parathion	0	0
PCB*	0	0
Diazinon	0.05	0.02
Malathion	0	0
Parathion	0	0
2,4-D	0	0
Silvex	0	0
2,4,5-T	0	0

*Polychlorinated biphenyls

Sanborn (1974) reported concentration factors of 115,000, 7,500 and 6,100 in snails, algae, and fish, respectively. The fate of dieldrin or other pesticides in food chains in Lago Loíza was not investigated.

Diazinon is one of the commonly used organophosphate insecticides. Like others in the organophosphoric group, diazinon is readily metabolized into elementary materials. Sethunathan (1972) reported that diazinon persists for about 15 days in flooded soils. This suggests that the presence of diazinon is indicative of recent application. When properly applied, diazinon does not constitute an environmental problem. The concentrations of diazinon in the water in Lago Loíza are very low and do not create a health hazard.

Bacteria

The number of bacteria of the coliform group in Lago Loíza exceeds the recommended standards for contact sports and all other purposes nearly fifty percent of the time. Total bacterial concentration is affected seasonally by several factors. Results of samples collected during the study period at stations 5, 6, and 7 are shown in figure 21. During periods of high flows into the lake, storm runoff contributes large numbers of bacteria. Typical of these are the samples collected after the floods of late August and September 1974. During periods of low flow, input from the Río Caguitas and Río Bairoa may also contribute a high concentration of bacteria. Their effect on the lake stations depends on the proportional flow from the less contaminated Río Grande de Loíza and Río Gurabo.

During low-flow periods, the bacteria in the lake decrease rapidly in a downstream direction. Typical downstream concentrations are shown in figure 22. Although some decrease occurs during high flows, it is not as effective as during low flows. If a storm flushes the entire lake as during the August-September 1974 floods, comparatively high concentrations of bacteria are transported downstream toward the damsite. The retention time of the water in the lake is a key factor in the concentration of bacteria at the damsite.

Dissolved Oxygen

The concentration of dissolved oxygen (DO) is one of the most studied and important parameters in lake waters. Oxygen determinations provide an insight into the chemical and biological interactions in a lake.

The solubility of oxygen in water is partially regulated by the atmospheric pressure and the temperature. It is directly proportional to the partial pressure in the gas phase and decreases nonlinearly with increasing temperature.

The concentration of oxygen in lake waters is influenced by several factors. Oxygenation by wind turbulance on the water surface is an important factor. Biological activity by algae produces oxygen which may be retained in the water. Consumers such as fish and zooplankton utilize some of the available oxygen. Organic matter is oxidized by bacteria, exerting an oxygen demand which may on occasion deplete all the oxygen available in the water.

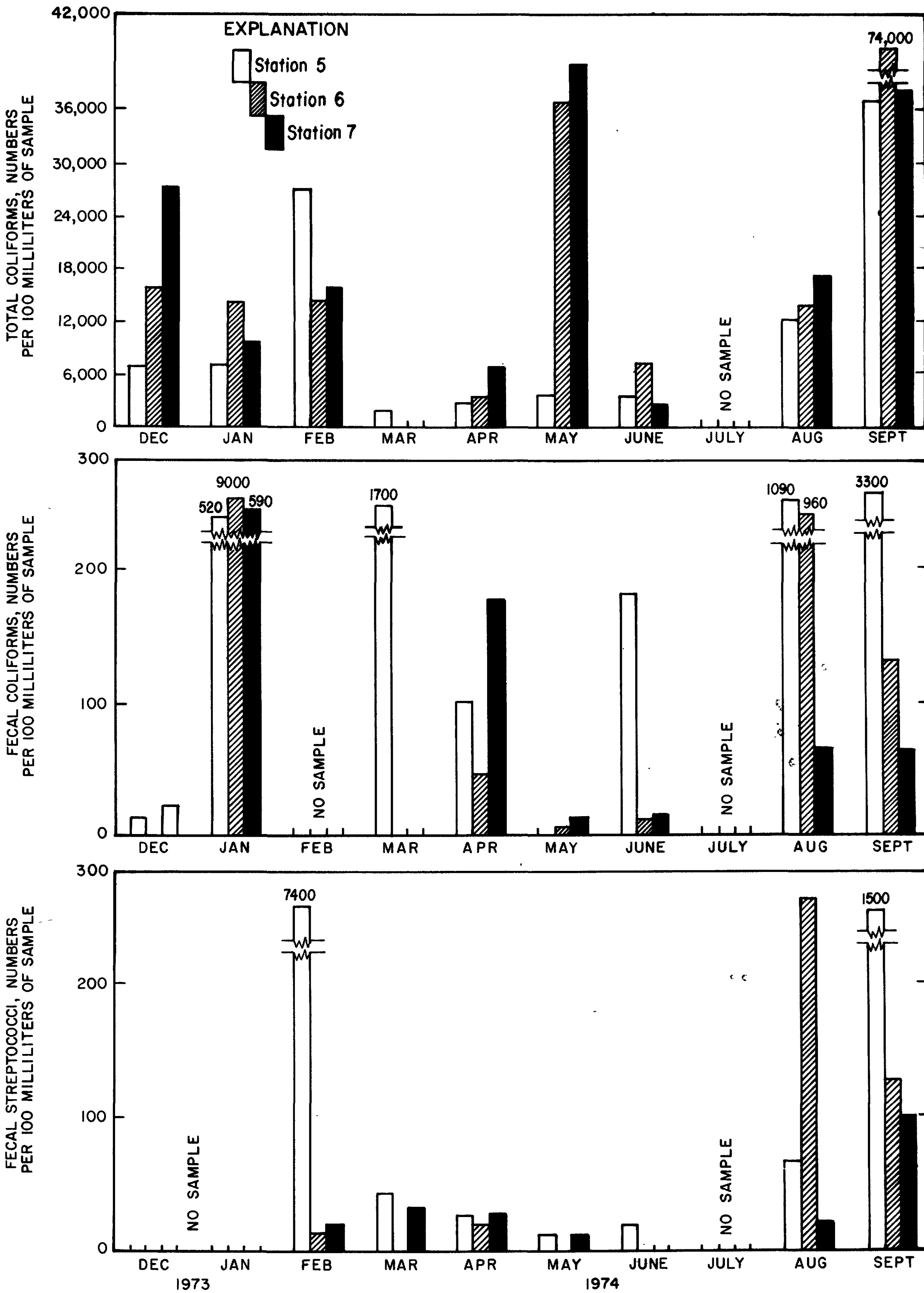

Figure 21.--Seasonal fluctuation in the total number of coliforms, fecal coliforms and fecal streptococci bacteria at stations 5, 6 and 7 in Lago Loíza.

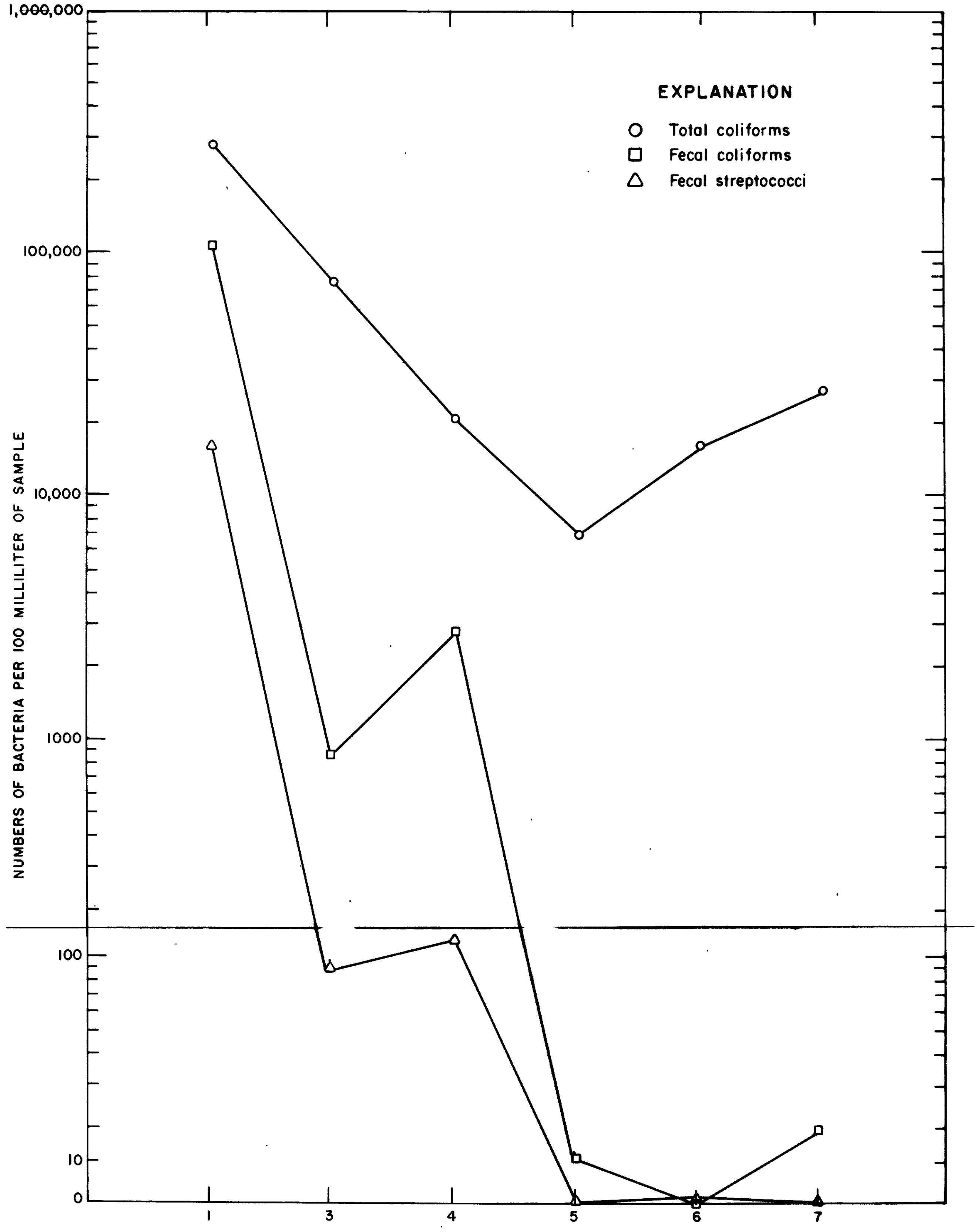

Figure 22.--Typical downstream decay of bacteria in Lago Loíza, December 1973.

The DO concentration in Lago Loíza was determined monthly through the entire water column at stations 5, 6, and 7 during daylight hours. The daylight hour measurements are not representative of the overall DO conditions in the lake, but of conditions below about 2.0 meters because of diurnal fluctuations. Above this depth, the measurements represent maximum or near maximum DO concentrations. Because the measurements were made early in the afternoon hours, near the peak of the productivity in the lake, they represent conditions of high DO concentration in the upper layers.

The monthly vertical profiles at station 7 are shown in figure 23. The data show that DO profiles in Lago Loíza are similar to those classified by Hutchinson (1967) as clinograde curves. Clinograde oxygen curves are characterized by a sharp decrease in the DO concentration a few meters from the surface. Concentration reaches zero or near zero values near the bottom. In the upper layers of the lake, or epilimnion, photosynthetic activity and air-water exchange maintain a relatively high oxygen concentration. In the bottom layers of the lake, or hypolimnion, oxygen is lost or consumed as a result of animal and plant respiration, and chemical oxidation of organic matter in solution. No photosynthetic activity occurs in this layer.

The group of curves on the upper left of figure 23 shows that two of the factors indicated above were acting to produce variable DO conditions in Lago Loíza. Late in September 1973, DO concentrations at or greater than saturation were recorded near the surface and at about 1.0-m depth. This was probably the result of wind action and the exchange of oxygen with the air in combination with photosynthetic activity. The oxygen concentration dropped rapidly below depths of 1.0 m, being nearly zero at 5.0 m. This is due to the biological and chemical demands in the lower layers as well as the absence of oxygen exchange between the air-water phases and the lack of photosynthesis. Conditions in the epilimnion changed from September to mid-October 1973. Dissolved-oxygen concentrations during October were about one-half those in September. A lower standing crop of phytoplankton and a change in the rate of oxygen exchange between the air-water phases may have caused the decline.

The lake was nearly flushed by the rains of early December 1973. The large volume of "new" water probably had a higher DO concentration than the receiving waters. Accordingly, conditions at station 7 changed significantly The measurements of December 13, 1973 (fig. 23), indicated that about 2.0 mg/L of DO was available at about 8.0 m, contrasting with the previous zero DO concentration in November. These DO conditions were maintained throughout most of the first half of 1974, except for small fluctuations in the epilimnion. The measurements of June 1974 indicate an increase in the DO in most of the hypolimnion. There were no significant events which may explain this condition. Flows were very low and phytoplankton numbers did not increase sharply during the period.

The situation deteriorated to its worst condition at the peak of the drought in August 1974. The DO concentrations were nearly zero at 5.0 m. At 2.0 m, only about 2.0 mg/L DO was available. A fishkill resulted, possibly due to a combination of low DO concentrations and an increase in the concentration of fish with decreasing water volume.

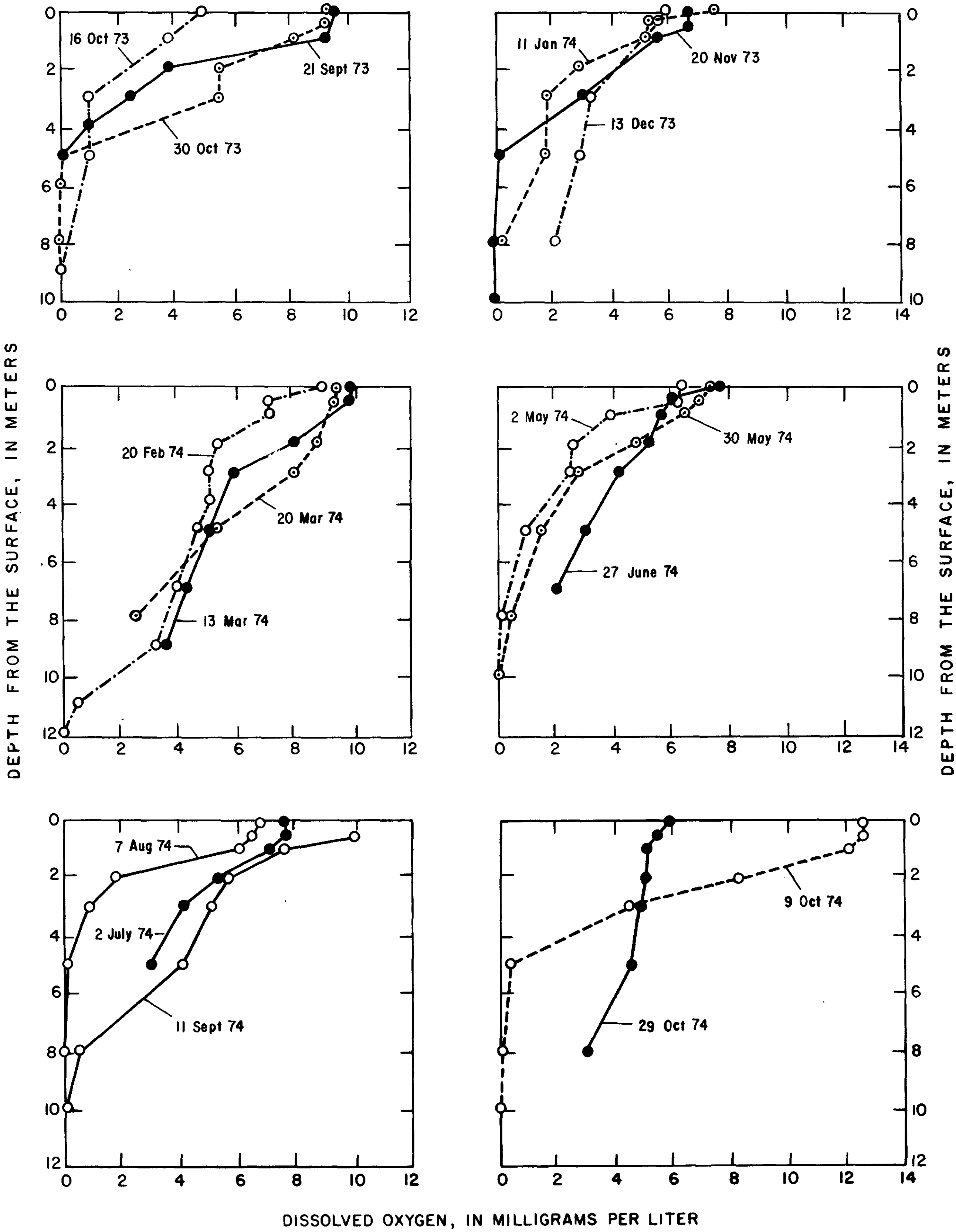

Figure 23.--Seasonal fluctuation in the concentration of dissolved oxygen at station 7 in Lago Loíza.

The storms of late August 1974 improved the DO concentrations in the lake. The measurements of September 11, 1974, show that at the 2.0-m depth concentrations increased to 5.7 mg/L, and to about 0.5 mg/L at the 8.0-m depth. In late October, when the entire lake was flushed, the DO concentration in the whole water column averaged about 5.0 mg/L and exceeded 3.0 mg/L at the 8.0-m depth. A thorough mixing of the lake waters and a breakdown of stratification was evident.

The average daylight-hour DO conditions throughout the lake (as represented from the average of the DO profiles at stations 5, 6,and 7 in figure 24) are very similar to those at station 7. The importance of the DO concentrations and the factors that induce these changes in Lago Loíza will be discussed in the section covering the interactions in the lake.

Temperature

The thermal properties of a lake are an important factor in the stability of the aquatic communities. Fish, zooplankton, and phytoplankton, among other groups, are affected by changes in temperature. Hutchinson (1967) suggests that optimal temperatures exist for each population in a lake system.

In temperate zones, lakes have a large seasonal variation in temperature. Temperature gradients develop between the epilimnion (warm upper layers) and the hypolimnion (cold lower layers). An area of rapid change in temperature known as the thermocline may develop between these two zones. Lakes in Puerto Rico may be classified as tropical lakes (Hutchinson, 1967) on the basis of the small annual temperature variation.

There is not a significant degree of thermal stratification in Lago Loíza. Profiles measured throughout the lake show that temperature differentials between the surface and bottom do not exceed 4°C (fig. 25). Late in September 1973, the temperature near the surface was about 30.5°C, gradually declining to about 25.5°C at a depth of around 8.0 m. Temperatures declined gradually during the cooler months through January 1974. Nearly vertical uniform temperatures were observed during December and January 1974. In December the temperature was uniform at 25°C from the surface to 7.0 m. The warmer days of the tropical summer slowly increased the temperature in 1974. There was minimal stratification even at the peak of the drought when the lake receded more than 5 m.

A composite of the seasonal changes in temperature throughout Lago Loíza is shown in figure 26. Through the early months of the study a temperature gradient of about 4°C between the surface and bottom waters was recorded. The rains of December 1973 mixed the waters in the lake inducing nearly uniform temperatures in the water column. The lake then started to warm, with temperatures ranging from 28 to 30°C. The heavy rains of August and September 1974 flushed the lake several times. The flushing and mixing resulted in near uniform temperatures throughout Lago Loíza.

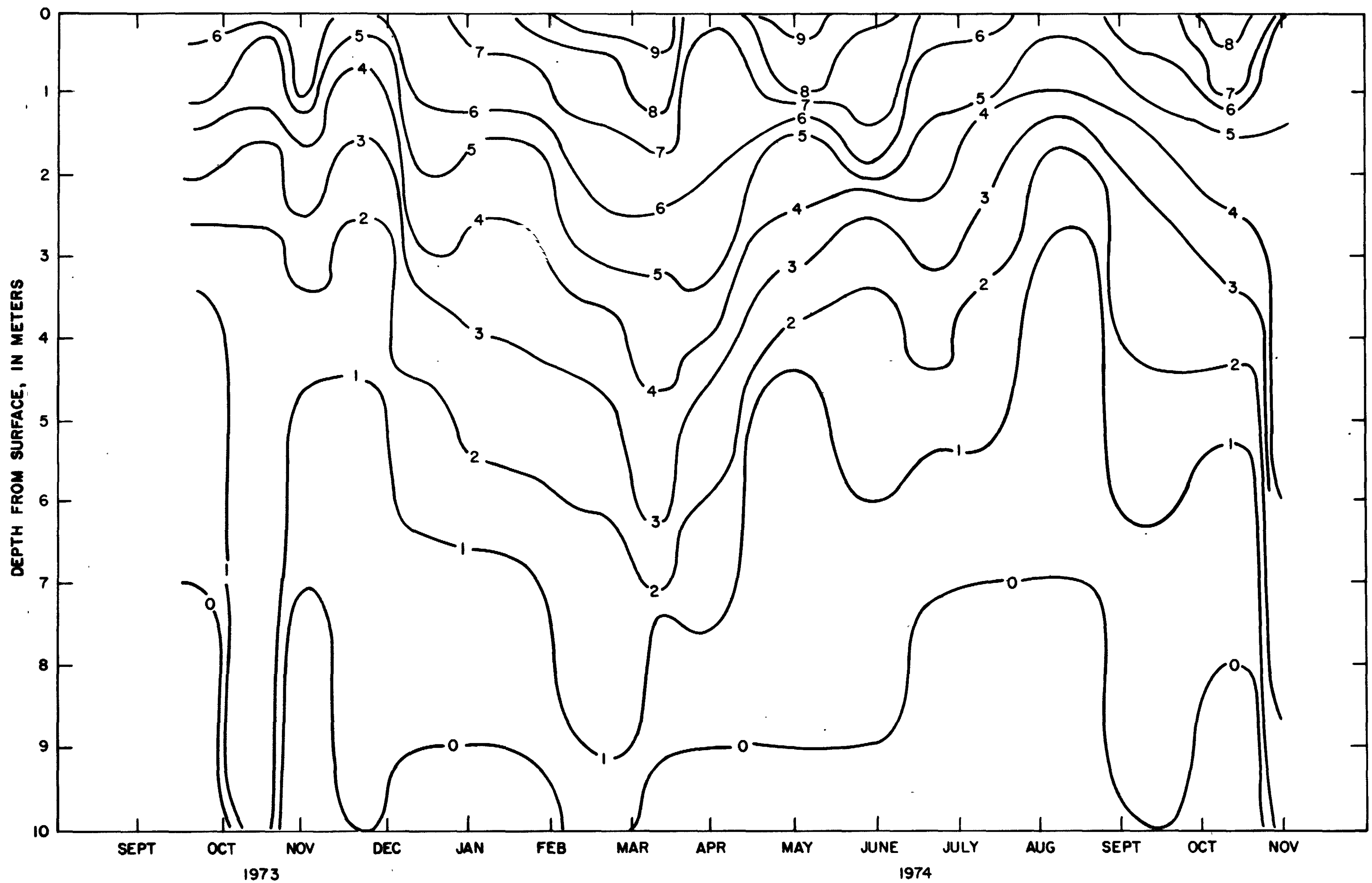

Figure 24.--Generalized seasonal fluctuation in the concentration of dissolved oxygen in milligrams per liter in Lago Loíza (average from stations 5, 6 and 7).

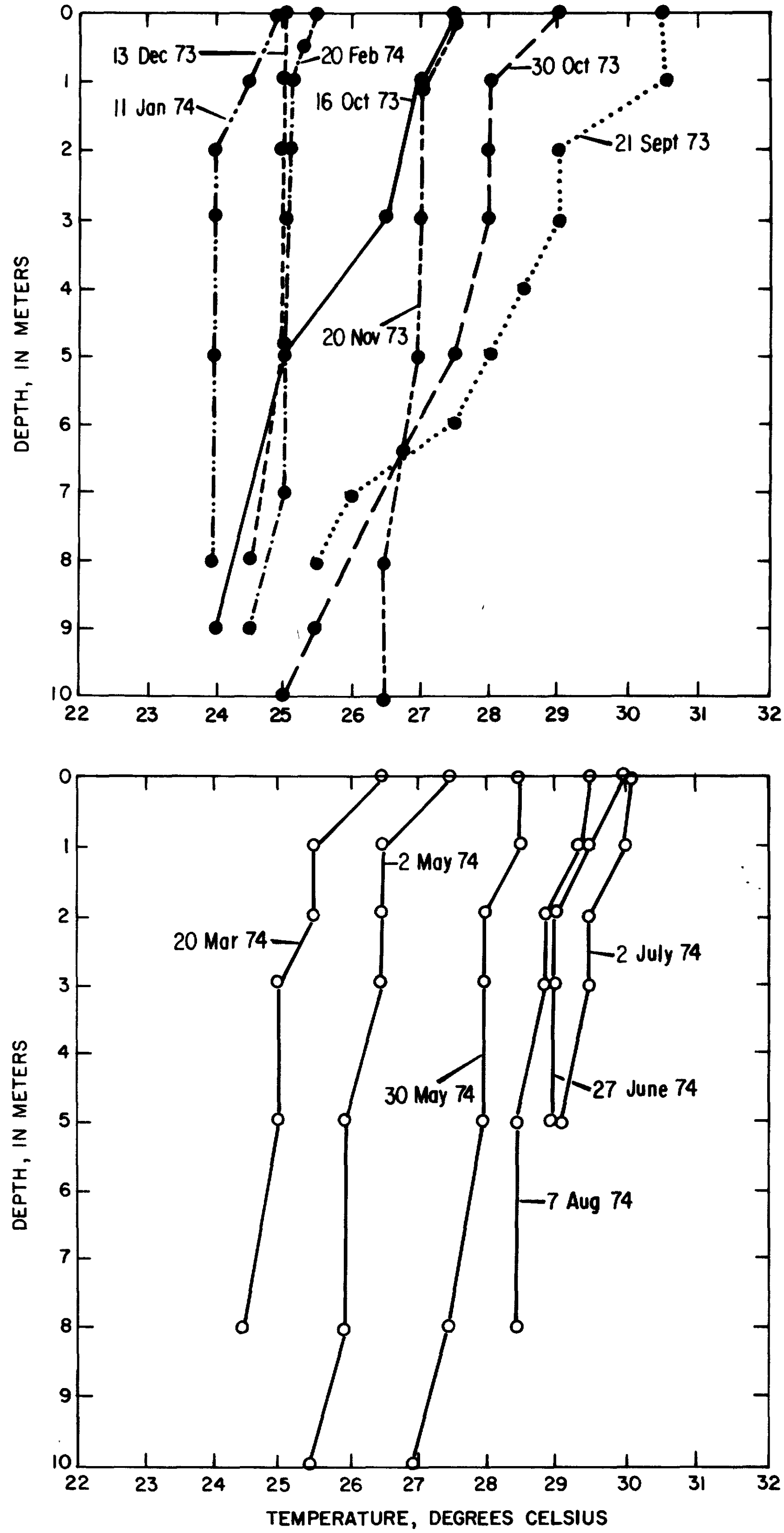

Figure 25.--Seasonal fluctuation in the temperature profiles at station 7 in Lago Loíza.

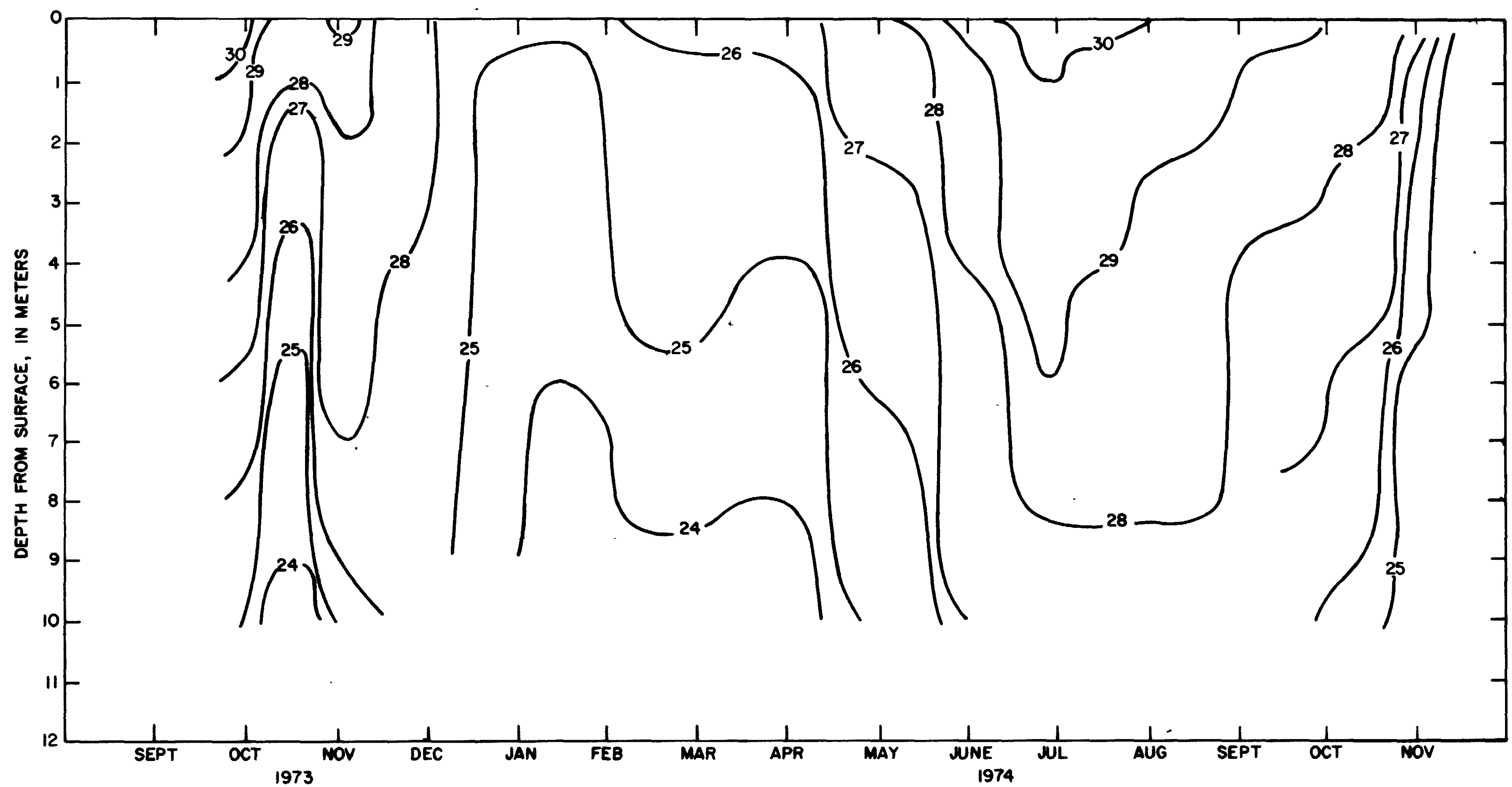

Figure 26.--Generalized seasonal fluctuation of temperature in degrees Celsius (°C) in Lago Loíza.

Nitrogen and Phosphorus in Lago Loíza

Distribution

The role of nutrients in a lake is much more significant than in flowing waters. In terms of nutrients, a flowing stream is essentially an unsteady system. Continuous changes in the flow and nutrient concentration prevents reaching a complete equilibrium. The organisms that utilize these nutrients are exposed to almost constantly shifting conditions and are required to adapt to such changes. A lake is basically a steady system because travel times are much slower. Even in reservoirs with high flushing rates such as Lago Loíza, much more stable conditions are maintained than in a stream.

In a lake, the effects of eutrophication are much more evident than in a stream. When nutrient concentrations exceed critical levels, accelerated plant growth and other nuisance effects usually are more visible than in a stream. Although many elements are considered essential to plant life (Greeson, 1971), critical levels are usually expressed in terms of nitrogen and phosphorus.

Criteria have been established for maximum acceptable concentrations of nitrogen and phosphorus. Concentrations exceeding the defined limits may cause an acceleration in the natural eutrophication process. Sawyer (1974) suggested that at a concentration greater than 0.015 mg/L of inorganic phosphorus and 0.3 mg/L of inorganic nitrogen, nuisance effects such as algal blooms can be expected. Vollenweider (1968) developed criteria based on areal loading and mean depth, estimating that lakes with an average depth of 5 m and receiving as much as 1.0 g/m^2 of total nitrogen and 0.07 g/m^2 of total phosphorus would not show algal blooms or other nuisance effects of eutrophication. Lakes receiving more than 2.0 g/m^2 per year of nitrogen and 0.13 g/m^2 per year of phosphorus would be considered critically loaded. Brozonik and Shannon (1971) revised Sawyer and Vollenweider's estimates. On a volumetric basis, they reported that as much as 0.12 g/m^3 total phosphorus and 0.86 g/m^3 total nitrogen would be permissible before nuisance effects due to eutrophication became visible. On an areal basis, permissible levels would be 0.28 and 2.0 g/m^2 per year total phosphorus and total nitrogen, respectively. Brezonik and Shannon's study suggests that Florida lakes can assimilate more nutrients than those in Vollenweider's analyses in Europe and throughout the United States. Lakes with high turnover rates, such as Lago Loíza, tolerate higher loading rates before showing the effects of eutrophication (Dillon, 1975).

The transport of nitrogen and phosphorus into a lake system may be in one of several chemical forms (Brezonik, 1972). Usually a combination of both organic and inorganic forms is present. The distribution of the individual forms is generally associated with the source from which nitrogen and phosphorus flow into a body of water. In systems receiving untreated sewage discharges or similar wastes, usually a high concentration of ammonia and organic nitrogen as well as organic phosphorus is present. Oxidation of these forms during treatment processes most often results in a shift toward nitrite and nitrate-nitrogen, as well as orthophosphate-phosphorus. Within the lake proper, transformations of these chemical forms occurs as a result of chemical and biological activity. These transformations are discussed in detail by Greeson (1971), Hutchinson (1973), and others. The study of these transformations may be useful in understanding conditions and changes that occur in Lago Loíza and will be discussed in a later section of this report.

As shown in the previous section, inflow of nitrogen and phosphorus to Lago Loíza consists primarily of inorganic nitrogen and phosphorus from Río Grande de Loíza and Río Gurabo. Flows from Río Caguitas and Río Bairoa contribute mostly organic nitrogen and phosphorus compounds. Within the lake proper, the concentration of the different compounds did not change significantly during the study period. Seasonal changes in the different nitrogen and phosphorus forms analyzed in Lago Loíza are shown in figure 27.

At station 5, both the total nitrogen and total phosphorus concentrations increased seasonally as the 1974 drought progressed. At stations 6 and 7, the increase was only in the total nitrogen concentration, while the total phosphorus remained nearly unchanged. Increased nutrient concentrations are probably due to the same factors that caused increases in the concentrations of other ions; mainly reduced flows and more influence from high nutrient concentrations in the Ríos Caguitas and Bairoa. Average total phosphorus concentrations at stations 5, 6, and 7, respectively, are 0.41, 0.30, and 0.28 mg/L, while average total nitrogen concentrations are 2.1, 1.6 and 1.5 mg/L. There is a decline in the concentration of phosphorus and nitrogen as the water moves downstream toward the damsite. Some of the nutrients may be in particulate matter which falls from suspension as the water moves downstream.

Nitrate was the principal nitrogen form throughout the lake, with an average concentration of 1.0 mg/L. Organic nitrogen followed in order of importance, fluctuating from 0.10 to 1.20 mg/L, averaging 0.65 mg/L. The concentration of organic nitrogen increased as the volume of water in the lake decreased. At the peak of the drought in August 1974, organic nitrogen concentrations in the lake ranged from 0.50 to 1.20 mg/L.

Ammonium concentrations were much higher at station 5 than at the other stations. Oxidation of the ammonium to nitrates and utilization by algae probably occurs downstream from station 5. At stations 6 and 7, ammonium concentrations averaged 0.10 mg/L.

Nitrite is present in low concentrations throughout the lake. None was detected on many occasions and a peak concentration of 0.20 mg/L at station 5 is probably a local condition.

Of the nitrogen forms in Lago Loíza, nitrate and ammonium comprise about 70 percent of the total nitrogen in the water. Ammonium and nitrate have been shown to be the most important nitrogen sources for algae (Brezonik, 1972). Inorganic orthophosphate, which has also been identified as the phosphorus

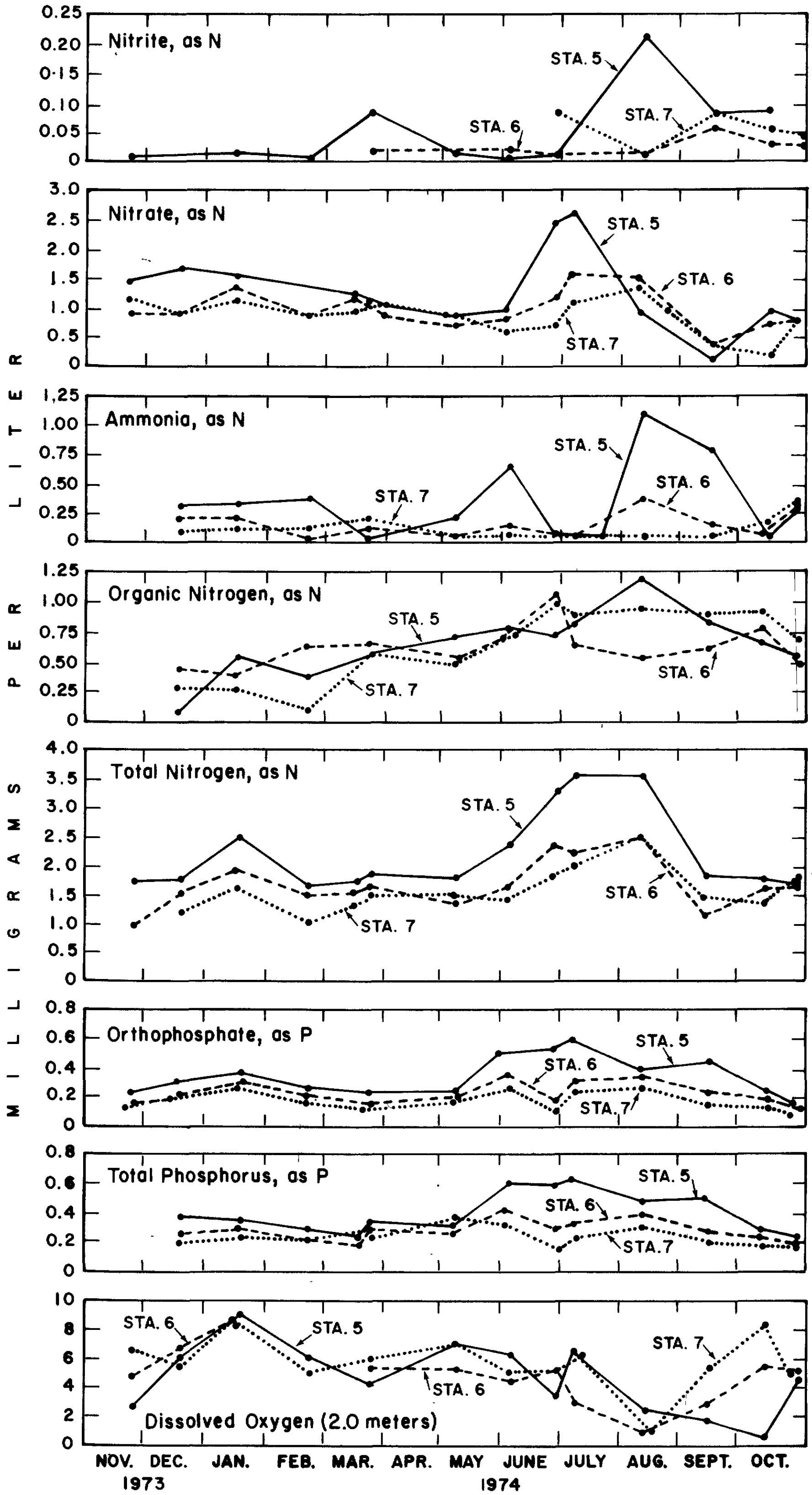

Figure 27.--Seasonal fluctuation in the concentration of nitrogen, phosphorus and dissolved oxygen at stations 5, 6 and 7 in Lago Loíza.

form most often assimilated by algae, represents about 65 percent of the total phosphorus throughout the lake. The necessary nutritional conditions in terms of nitrogen and phosphorus are present in Lago Loíza to promote accelerated algae growth.

Budgets

The studies by Vollenweider (1968) and Dillon (1975) show that loading factors in terms of an areal basis are a more significant index in lake eutrophication studies than criteria using only concentration. This approach was followed in this study in order to compare the Lago Loíza conditions with other lakes and as a reference for future studies.

Loading factors can be determined from nitrogen and phosphorus budgets. The budgets for Lago Loíza are approximate and are based on several assumptions. These are explained following each component of the budget calculations. The principal components considered in the calculations include nutrient inputs from the gaged tributaries, estimates from the ungaged area, contributions from precipitation, changes in storage and exports in discharge outflows.

The contributions from the main tributaries were computed on the basis of average monthly concentrations and mean discharges. The total nitrogen and total phosphorus concentrations from individual samples at the main tributaries and at the damsite outflow are summarized in table 22. The concentration-volume weighted estimates are shown in table 23.

The sites listed in table 23 comprise about 93.4 percent of the drainage area at the damsite. About 79 km^2 of drainage area was not gaged. The nitrogen and phosphorus contributions from this ungaged area were estimated from the gaged areas. It was assumed that a yield similar to the adjacent known area would be a good approximation. Because the ungaged area is only 6.6 percent of the total, any error in the assumption would be minor in the overall budget.

Urban encroachment into the slopes of and areas adjacent to the lake has been dramatic during the last 20 years. The number of dwellings in the area has increased by a factor of 20. Aerial photographs taken in March 1973 showed that there were nearly 2,750 houses and structures in the area adjacent to the lake. There are no sewer systems in the area; most of the houses and small businesses have septic tanks. It is not known whether these septic tanks have been properly designed and built. Only an estimate can be made as to the amount of nutrients contributed from this source. Uttormark and others (1974) report that a conservative estimate of nutrient loadings to lakes from septic tanks may be computed estimating a per capita per year yield of 1.5 kg phosphorus and 6.5 kg nitrogen. Porcella and others (1974) and Vollenweider (1968) estimated mean per capita per year nitrogen and phosphorus contributions from human wastes as follows:

Total phosphorus 1.6 kg   Total nitrogen 4.0 kg

Table 22.--Total nitrogen (upper number) and total phosphorus (lower number) concentrations at the main tributaries and the outflow to Lago Loíza, November 1973 to October 1974 (milligrams per liter).

Site	1973 Nov	1973 Dec	1974 Jan	1974 Feb	1974 Mar	1974 Apr	1974 May	1974 June	1974 July	1974 Aug	1974 Sept	1974 Oct
Río Grande de Loíza (0550)	1.1 0.20	1.2 0.15	1.5 0.35	1.4 0.30	1.9 0.18	1.2 0.30	1.2 0.31	1.3 0.40	1.2 0.32	1.3 0.35	1.3[e] 0.35	1.4 0.36
Río Gurabo (0574)	3.4 0.23	2.0 0.22	2.0 0.35	3.1 0.38	2.0 0.35	2.5 0.42	1.9 0.50	1.9 0.35	2.0 0.30	3.0 1.0	4.9 0.80	3.1 0.70
Río Caguitas (055250)	3.0 1.9	6.2 1.4	2.0 0.8	4.0 1.5	6.8 0.4	3.2 2.4	6.0 0.8	2.6 3.0	10.2 0.9	5.0 3.4	5.5[e] 2.8	6.5 2.6
Río Bairoa (0534)	2.0 1.0	2.0 1.2	10.0 2.7	28.0 7.0	2.0 1.7	15.0 5.0	14.5 6.0	1.8 1.0	1.9 1.2	2.4 1.0	7.0[e] 2.5	10.0 3.8
Río Cañas (0584)	0.8 0.05	1.1 0.05	1.6 0.9	0.8 0.05	1.0 0.15	0.4 0.05	0.4 0.12	0.4 0.08	0.6 0.05	0.9 0.15	1.2[e] 0.10	1.6 0.08
Lago Loíza dam-site (0590)	0.8 0.10	1.2 0.15	1.2 0.20	2.0 0.20	1.5 0.45	1.4 0.25	1.3 0.28	1.4 0.25	1.9 0.42	1.8 0.30	1.4[e] 0.25	1.1 0.20

[e] Estimate

Table 23.--Summary of water volume and nitrogen and phosphorus loads from the main tributaries to Lago Loíza, November 1973 to October 1974.

Tributary	Total discharge, 10^6 m^3	Total nitrogen load, metric tons	Total phosphorus load, metric tons
Río Grande de Loíza	139.14	179	40.9
Río Gurabo	96.68	201	31.9
Río Caguitas	13.12	65.7	22.0
Río Bairoa	3.60	34.0	10.0
Río Cañas	4.67	3.8	0.6

Table 24.--Concentrations of nitrogen and phosphorus in precipitation at the Lago Loíza damsite station (milligrams per liter).

Date	$NO_2 + NO_3$ (N)	Kjeldahl nitrogen (N)	Total nitrogen (N)	PO_4 (P)	Total phosphorus (P)
1-15-74	0	0.03	0.03	--	--
3-07-74	.17	.54	.71	0.27	--
3-29-74	.13	.07	.20	.01	0.01
4-29-74	.17	--	--	--	.02
5-20-74	.89	--	--	--	.22
5-21-74	.22	.34	.52	0	.01
6-06-74	.64	--	--	.58	--
8-19-74	.09	.25	.34	.53	.55
8-27-74	.08	.65	.73	.50	.51
8-30-74	.04	.33	.37	.69	.72

Both Uttormark and Porcella indicate that these values may be reduced, as appropriate, to account for retention in soils, seasonal occupancy, population density and drainage activities. None of the conditions reported by any of these investigators are similar to those in Lago Loíza and extrapolation of their data is not justified. Since the area involved is only a small percentage of the basin, a value less than those reported was arbitrarily chosen. In the computations the following reduced values per capita per year were used:

total phosphorus 1.0 kg   total nitrogen 3.0 kg

It was also assumed that the average number of persons per dwelling was 5, for a total population in the area of 13,750.

The total nitrogen contribution from this source to Lago Loíza was estimated as 41.2 metric tons. Phosphorus loads were estimated as 13.8 metric tons. To improve these estimates for future studies more detailed survey of the sanitary facilities in the area is needed. Extensive sewaging would be required to curtail this nonpoint source of nutrients to Lago Loíza.

Nitrogen and phosphorus contributions from precipitation over the lake area are minor. These loads were estimated from analyses of rainfall samples collected at the damsite (table 24). No corrections for dry fallout were made to the samples. An average total nitrogen concentration of 0.41 mg/L and an average total phosphorus concentration of 0.25 mg/L were computed from the data in table 11. Precipitation over the lake area for the study period was estimated as 2.88×10^6 m^3. The total nitrogen and total phosphorus loads contributed from rainfall into Lago Loíza are 0.2 and 0.8 percent, respectively, of the total input to the lake.

Within Lago Loíza the average nitrogen concentration increased slightly during the study, while the average phosphorus decreased. The volume of water in the lake was about the same at the beginning and at the end of the study. The amount of nitrogen and phosphorus stored in solution in the lake waters changed by +7.5 and -4.0 metric tons, respectively. This computation, although estimated on the basis of average concentrations, is essential to compute the retention of nutrients by Lago Loíza.

The individual monthly concentrations from the samples collected at the damsite outflow (table 22) were used to compute the nutrient loads exported from Lago Loíza. The samples were assumed to be representative of either pumpage from the reservoir, spills or seepage. This assumption is justified on the basis of the relatively constant concentrations of nitrogen and phosphorus in the lake throughout the period of study. A total of 389 metric tons of nitrogen and 70.5 metric tons of phosphorus were exported from the lake. About 149 metric tons of nitrogen and 27 metric tons of phosphorus were pumped to the Sergio Cuevas water treatment plant in the San Juan metropolitan area. The remaining tonnage was discharged downstream from the damsite during spills and as seepage.

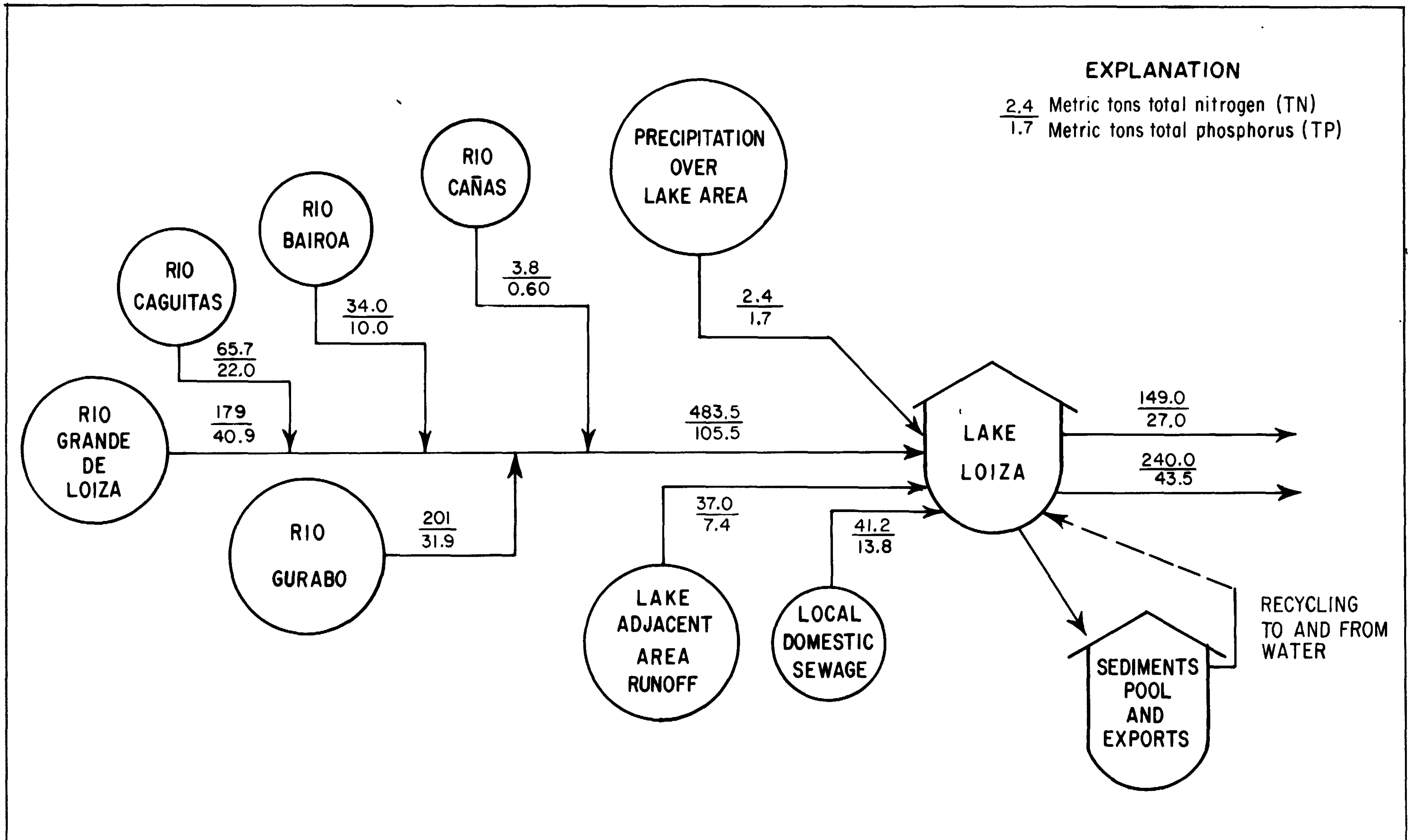

Figure 28.--Total nitrogen and total phosphorus budgets of Lago Loíza, November 1973 to October 1974.

The nitrogen and phosphorus budgets in Lago Loîza are summarized in figure 28. A total of 564.1 metric tons of nitrogen and 1.28.3 metric tons of phosphorus were transported into the lake during the study period. Exports amounted to 389.0 metric tons of nitrogen and 70.5 metric tons of phosphorus. If the assumption is made that the lake retained the whole difference between inputs and outputs, about 31 percent of the nitrogen and 45 percent of the phosphorus was retained in the lake. In a later section it will be shown that lake retention is probably much smaller, as water hyacinths are discharged from the lake during storms and these contain nutrients removed from the water (Peterson and others, 1974).

Río Caguitas and Río Gurabo, although contributing only a small percentage of the water volume to Lago Loîza, contribute a relatively large percentage of the nitrogen and phosphorus loads. The nitrogen and phosphorus loads and volume contributions from each tributary are summarized in table 25. Although the combined discharges from Ríos Caguitas and Bairoa are only 6.0 percent of the total, the nitrogen and phosphorus loads are 17.7 and 24.9 percent, respectively. The primary sources of nitrogen and phosphorus in these streams are point sources.

The data in table 25 also show that Río Gurabo, which contributes less water to Lago Loîza than Río Grande de Loîza (about 15 percent less), contributed more nitrogen (about 4 percent more). This is probably due to more intense agricultural activities in the Gurabo basin, resulting in higher nitrogen loads.

BIOLOGICAL CHARACTERISTICS OF LAGO LOIZA

Phytoplankton

The phytoplankton is the assemblage of plants which perform the greatest part of the photosynthetic activity in most lakes. Their numbers, diversity, species, and other characteristics may be used as indicators of the stability of the system and relative quality of the water (Hutchinson, 1967, and Odum, 1971).

The study of the phytoplankton in Lago Loîza was started in March 1974. Samples were collected about monthly at stations 5, 6, and 7; however, no samples were collected during April and June. Analyses included cell counts and identification of the principal genera. Samples were also collected during the 24-hour productivity studies. The seasonal fluctuation in the number of cells and the dominant genera are shown in figures 29 and 30.

The number of phytoplankton cells throughout Lago Loîza ranged from a low of 200 cells/mL at station 5 in November 1974 to 18,000 cells/mL at station 6 in March 1974. The lowest concentrations were consistently observed at station 5. Concentrations at stations 6 and 7 were similar, averaging about 10,000 cells/mL. Contrary to expectations, the number of cells did not increase with increasing nitrogen and phosphorus concentrations. In fact, there was a general decrease in the number of cells at all the stations as the

Table 25.--Summary of volume and nitrogen and phosphorus loads into Lago Loíza, November 1973 to October 1974.

Source	Volume, 10^6 m^3	Volume, percent of total	Total nitrogen load, metric tons	Total nitrogen, percent	Total phosphorus load, metric tons	Total phosphorus, percent
Río Grande de Loíza	139.1	49.7	179	31.7	40.9	31.9
Río Gurabo	96.7	34.6	201	35.6	31.9	24.9
Río Caguitas	13.1	4.7	65.7	11.7	22.0	17.1
Río Bairoa	3.6	1.3	34.0	6.0	10.0	7.8
Río Cañas	4.7	1.7	3.8	.7	.6	.5
Direct precipitation	2.9	1.0	2.4	.4	1.7	1.3
Ungaged area	19.6	7.0	37.0	6.6	7.4	5.8
Local domestic sewage			41.2	7.3	13.8	10.8
Totals	279.7	100.0	564.1	100	128.3	100.1

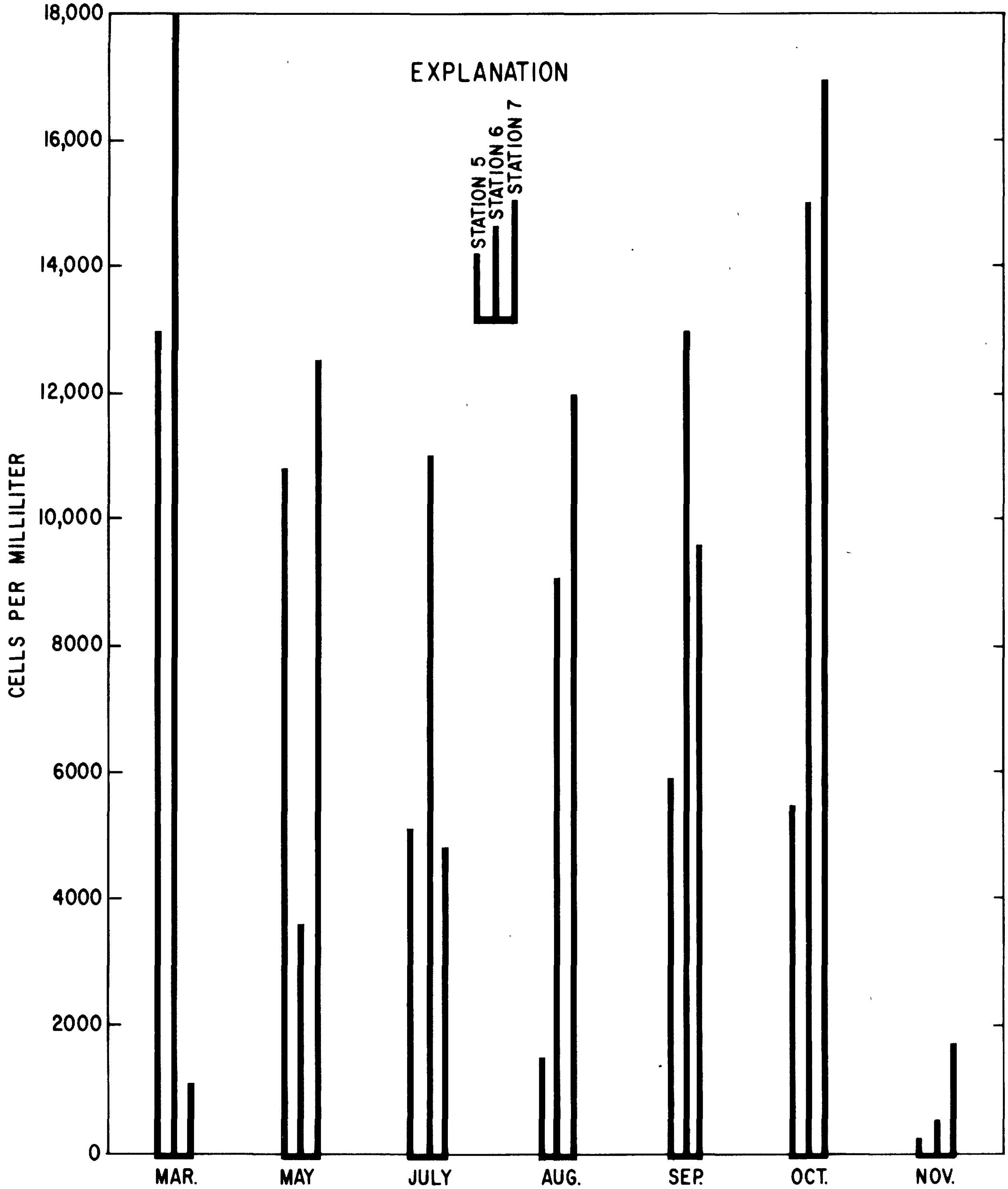

Figure 29.--Phytoplankton concentrations at stations 5, 6 and 7 in Lago Loíza, March to November 1974.

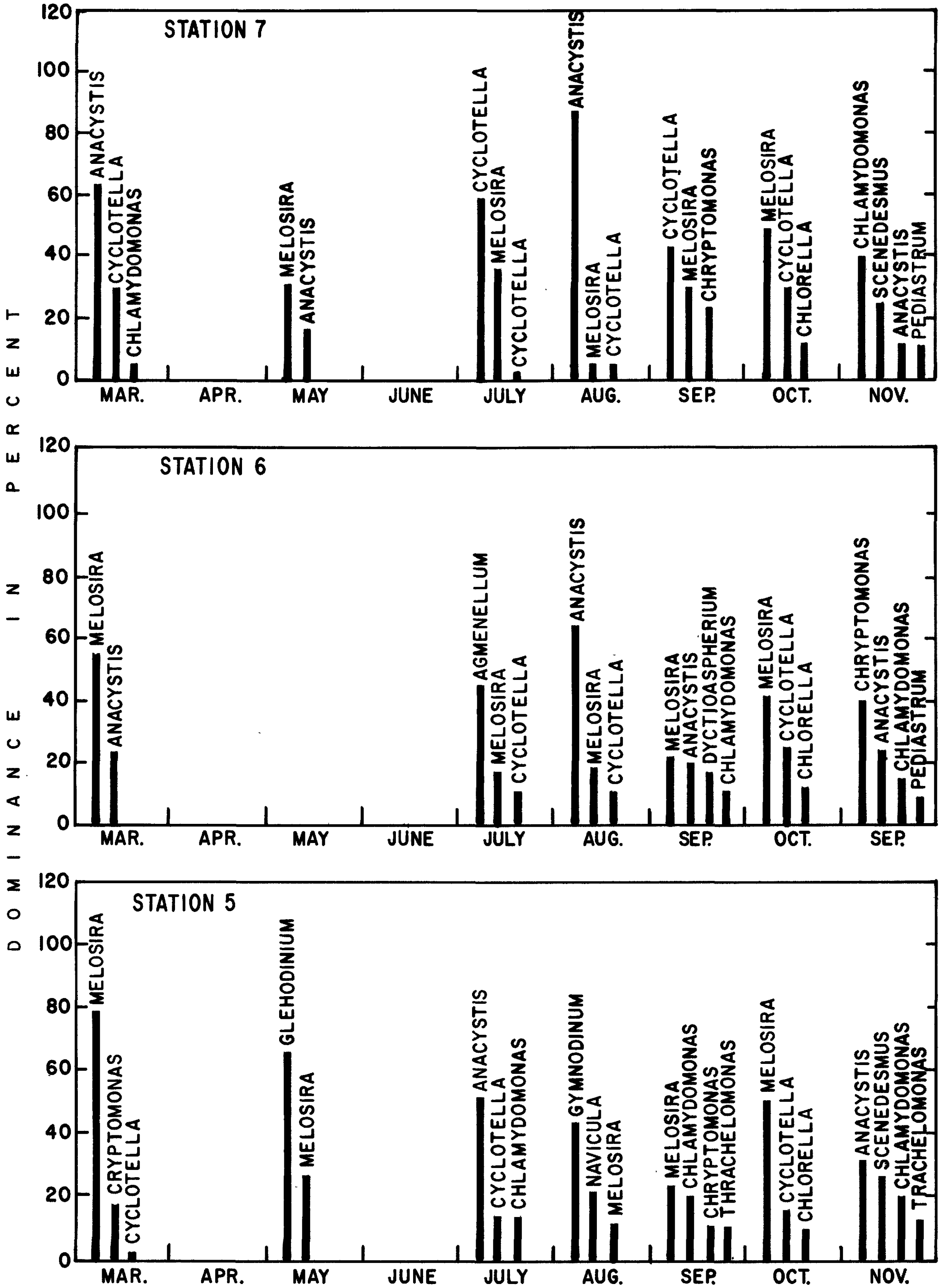

Figure 30.--Seasonal fluctuation and percent dominance of phytoplankton genera in Lago Loíza.

drought progressed and the nitrogen and phosphorus concentrations increased. After the rains started in late August the number of cells increased again.

The phytoplankton growth is regulated by many factors, any of which may be limiting (Greeson, 1971). As previously shown, both nitrogen and phosphorus abound in the lake. The average number of cells throughout the lake exceeded concentrations described as "blooms" (Brown and others, 1970). However, even these "blooms" were low compared with other lakes where nitrogen and phosphorus concentrations were lower (Greeson, 1971). This suggests that some other factors are limiting the phytoplankton growth in Lago Loíza.

The feeding habits of tilapia may be one of the limiting factors. The large number of tilapia and zooplankton in the lake continuously grazing on the phytoplankton population may constitute a check to their growth. An additional factor is the poor light penetration into the water column, thus limiting the euphotic zone in the lake. Secchi disk measurements at stations throughout the lake are shown in figure 31. At stations 5, 6, and 7, the average secchi disk reading was about 0.8 m, causing the euphotic zone to be about 1.6 m.

The transparency of the water column is affected by the amount of suspended sediment. During periods of high flows and transport of large loads of suspended sediment (October 1973 and September 1974), secchi disk readings throughout the lake were less than 0.3 m. The poor light penetration limits the depth of the zone of production, possibly hindering the phytoplankton growth.

The phytoplankton in Lago Loíza is dominated by blue-green algae and diatoms. Throughout the lake, Anacystis spp., Cyclotella spp., and Melosira wpp. were the dominant alagae. These are commonly found in eutrophic systems, but usually at much higher concentrations (Hutchinson, 1967).

Different species of phytoplankton may dominate from month to month (fig. 30). These changes in species composition were not investigated in detail

Zooplankton

Zooplankton include the animal part of the whole plankton. Zooplankton feed on bacteria, smaller organisms, detritus, and algae. They constitute a vital link in the aquatic food chain, grazing on other organisms and being consumed by fish or other invertebrates.

The studies of zooplankton in Lago Loíza included partial identification (to genus), density of organisms, and seasonal and diurnal fluctuations. The information collected provides a baseline for future studies.

The seasonal fluctuations (from February to November 1974) in the number of zooplankton per cubic meter at stations 5, 6, and 7 in Lago Loíza are shown

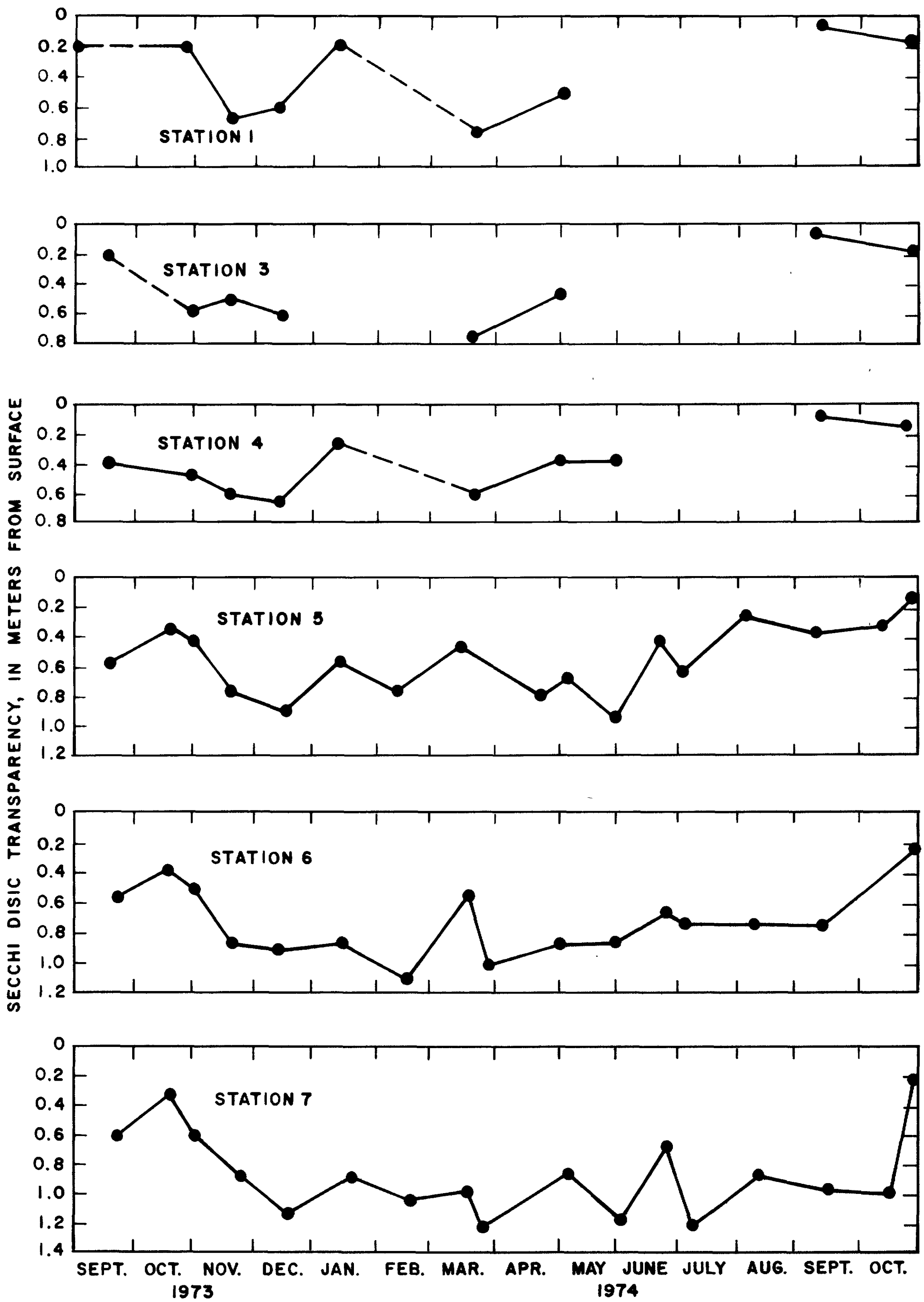

Figure 31.--Seasonal fluctuation in the Secchi disk transparency in Lago Loíza, September 1973 to October 1974.

in figure 32. The number of zooplankton per volume unit was very high as compared with studies in South America and Florida (Brinson, 1973; Brezonik, 1972). Zooplankton ranged from a maximum of 3.7×10^6 individuals/m^3 (at station 6 in February 1974) to a low of 2×10^5 individuals/m^3 (at station 5 in November 1974 after heavy rains). In general, the number of zooplankton decreased through the first quarter of 1974, then increased slowly until the end of the drought in August 1974.

The number of zooplankton fluctuates seasonally in proportion to the phytoplankton concentration (fig. 33). Although a complete analysis was not made, the data show an increase in the number of zooplankton as the phytoplankton concentration decreases. This could be due to grazing of the phytoplankton by the zooplankton, but other factors are probably involved.

The zooplankton in Lago Loíza are dominated by Cyclopoidic copepods of the family Cyclopidae. The seasonal fluctuations in the dominant genera and nauplii at station 7 are shown in figure 34. Similar distributions occur at stations 5 and 6.

Macrocyclops spp. was the dominant zooplankter during June, August and October (fig. 35). During June and August the nauplii constituted about 25 percent of the total number of organisms. In September, while the number of Macrocyclops spp. declined to about 7 percent of the total, the number of nauplii were about 59 percent of the total. Early in October the nauplii had probably grown into adults, mostly Macrocyclops spp. whose numbers increased to about 71 percent of the total. A similar shift in the populations was observed between early and late October. Both pulses and shifts in the populations coincided with the heavy rains that flushed the lake in August and October. Vertical seasonal migrations may account for some of the shifts in populations. Selective predation by fish may also account for the shifts in dominance (Brooks, 1969). The larger size Macrocyclops spp. may be selectively preyed on by carnivorous fish. The smaller Paracyclops spp. and Halicyclops spp. remained at about the same percent during the sampling period.

The diurnal fluctuations in the total number of zooplankton per cubic meter at station 7 from 0.5-, 2.0-, and 5.0-meter depth are shown in figure 36. At the start of the study, around 0930 July 2, most of the zooplankters had migrated to the deeper parts of the lake. There was a sharp migration toward the surface around 1630, after which movement toward the bottom probably occurred again. The number of organisms near the surface increased substantially during the night hours, remaining so until the early morning of July 3. These vertical migrations are probably affected by changes in the oxygen concentration at different depths. Most of the water column at 5.0 m is virtually devoid of oxygen. This condition may act as a driving force which curtails the movement of zooplankters during daylight hours toward the deeper parts of the lake.

The diurnal fluctuation in the dominant genera at different depths in Lago Loíza was also investigated. Data for station 7 are shown in figure 37.

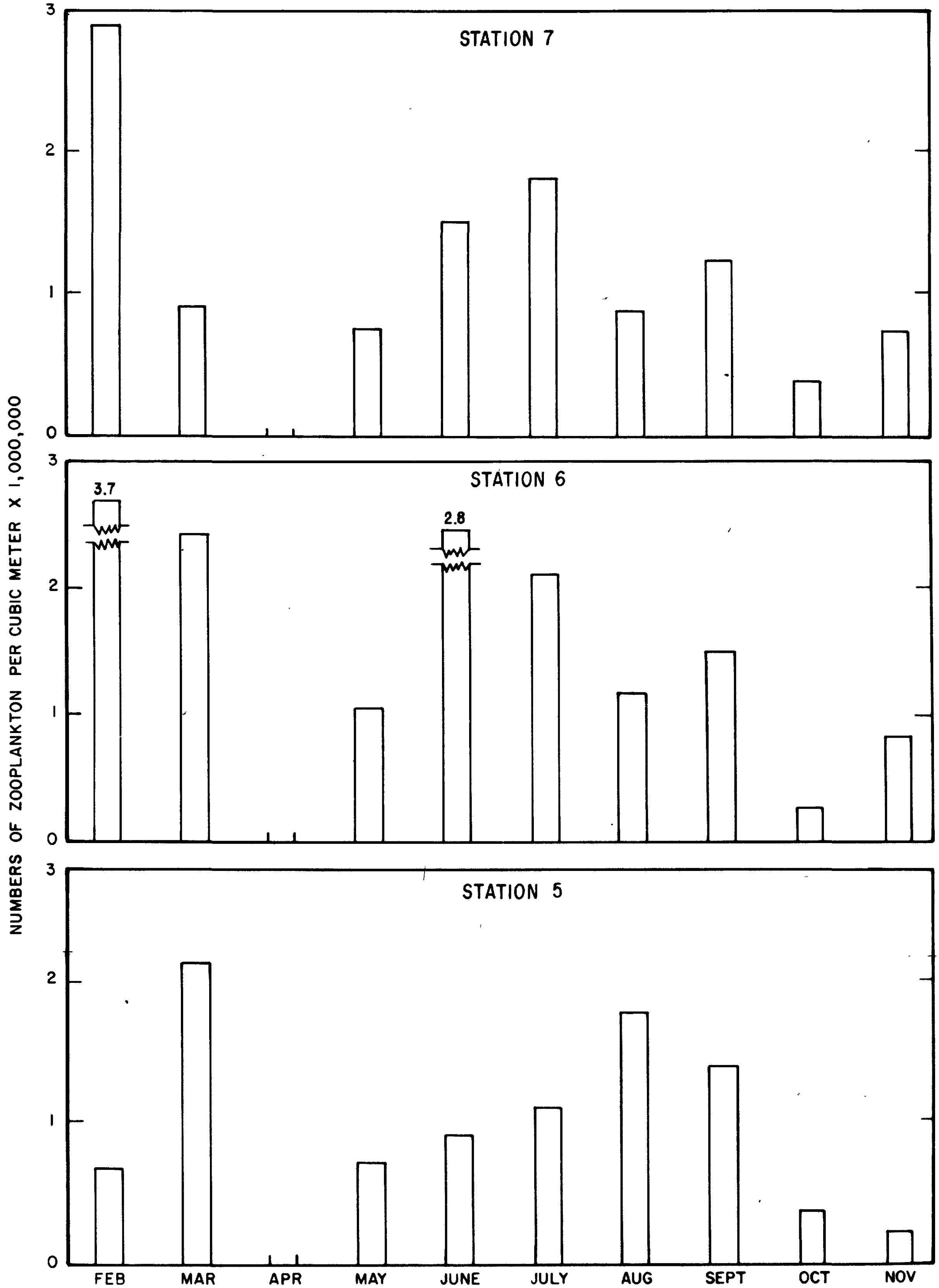

Figure 32.--Seasonal variation in the number of zooplankton in Lago Loíza, February to November 1974.

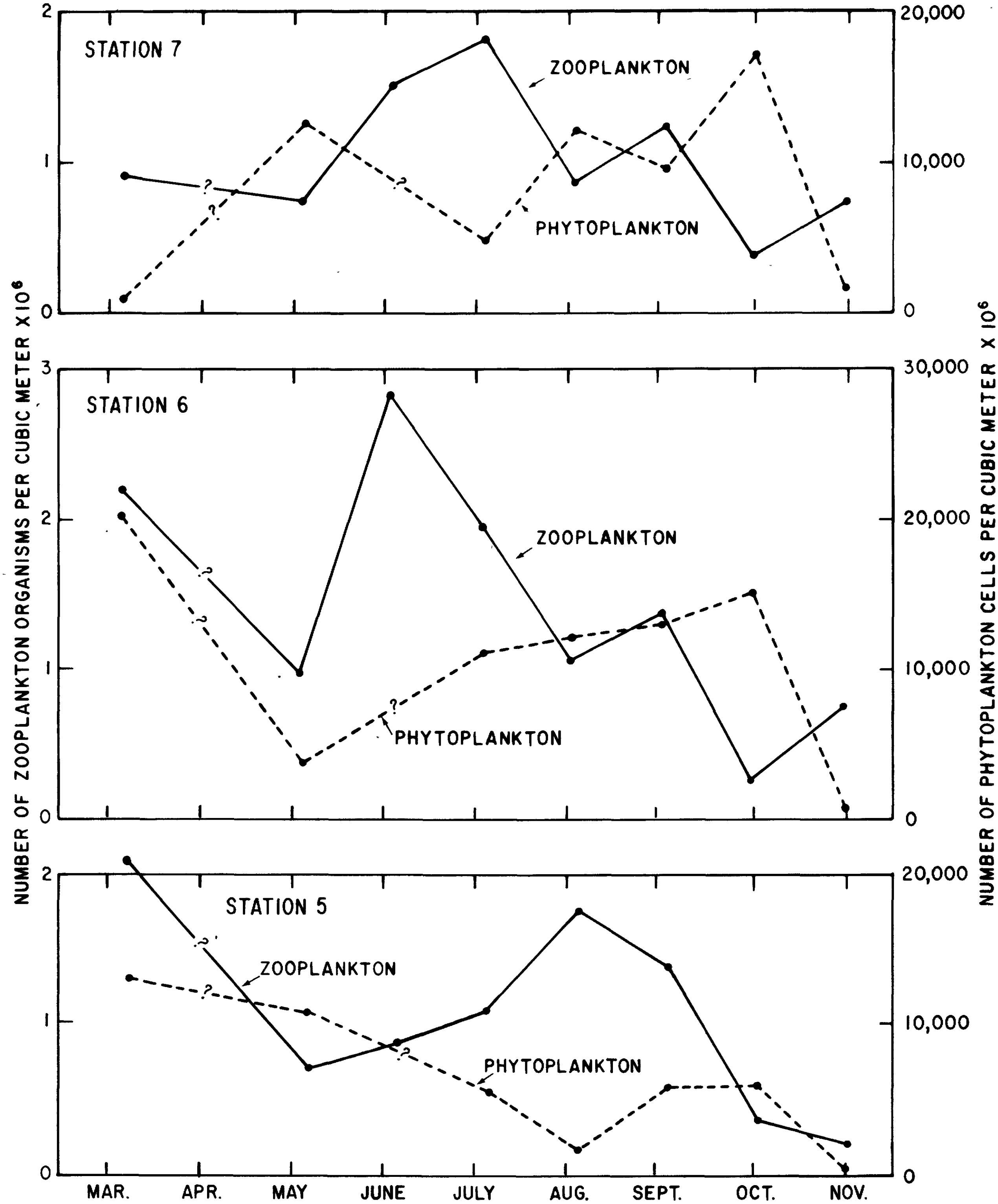

Figure 33.--Relation between the number of zooplankton organisms and Phytoplankton cells in Lago Loíza, March-November 1974.

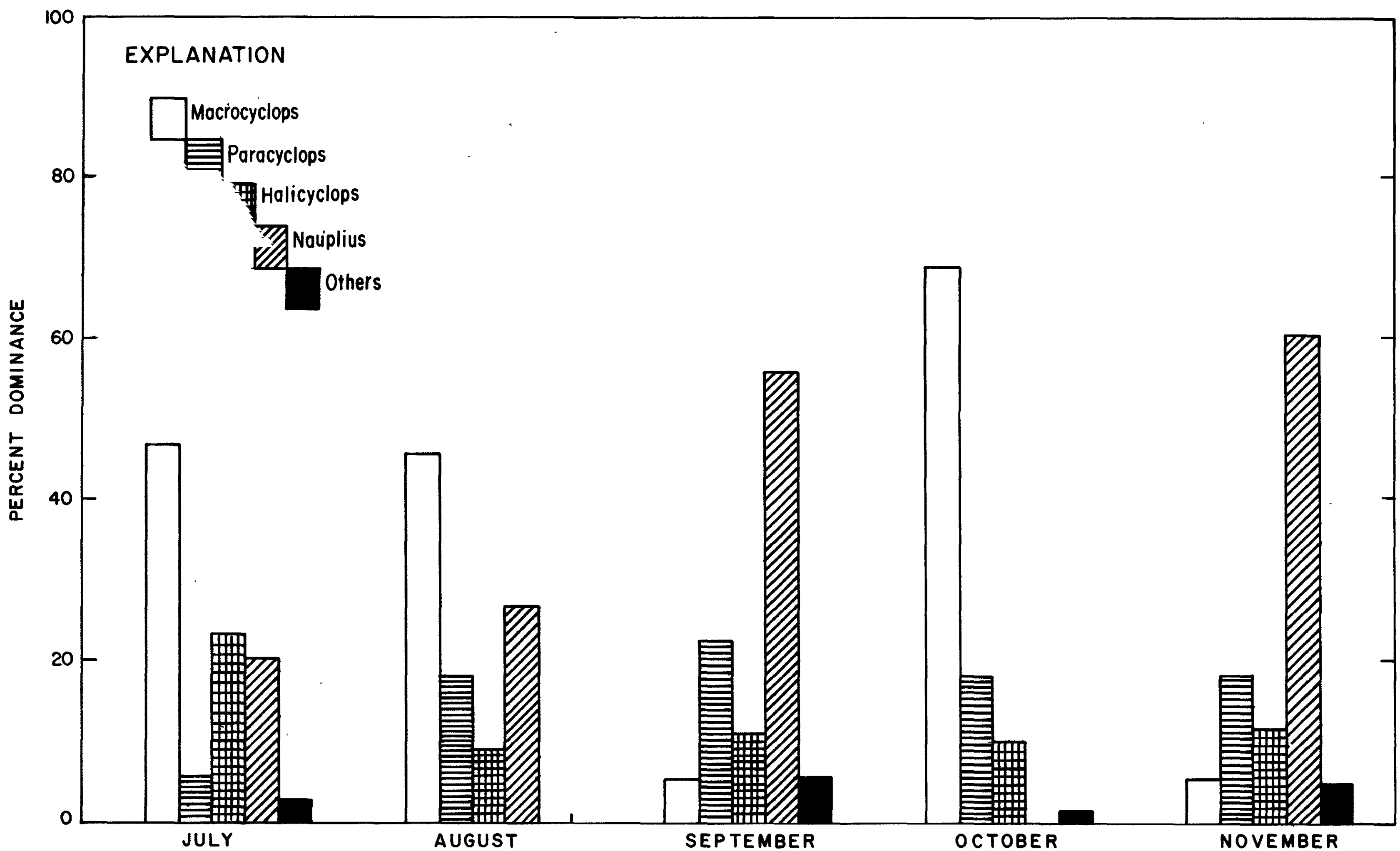

Figure 34.--Seasonal fluctuation in the dominance of the nauplius and principal genera of zooplankton at station 7 in Lago Loíza during 1974.

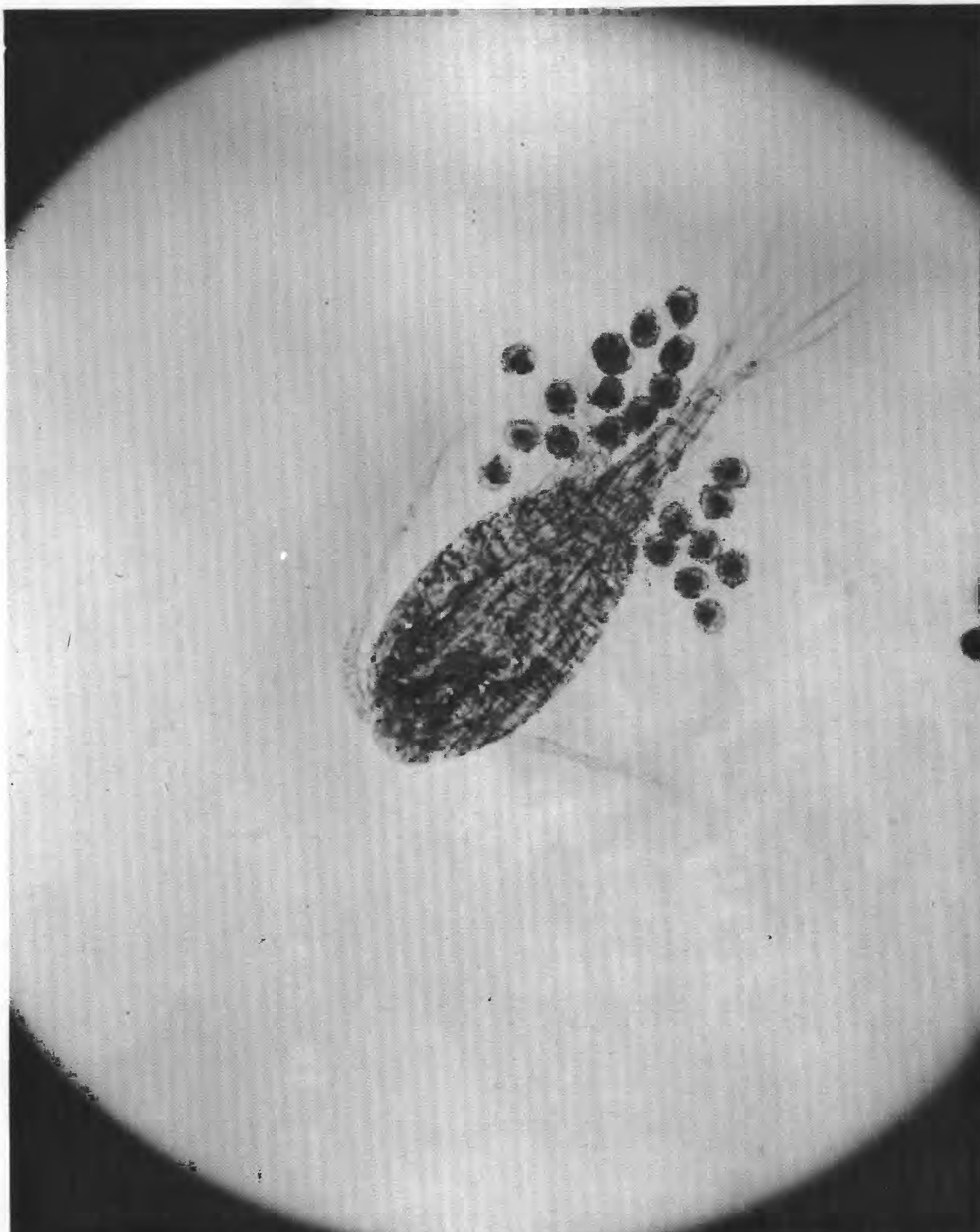

Figure 35.--Macrocyclops spp. , the dominant zooplankter in Lago Loíza.

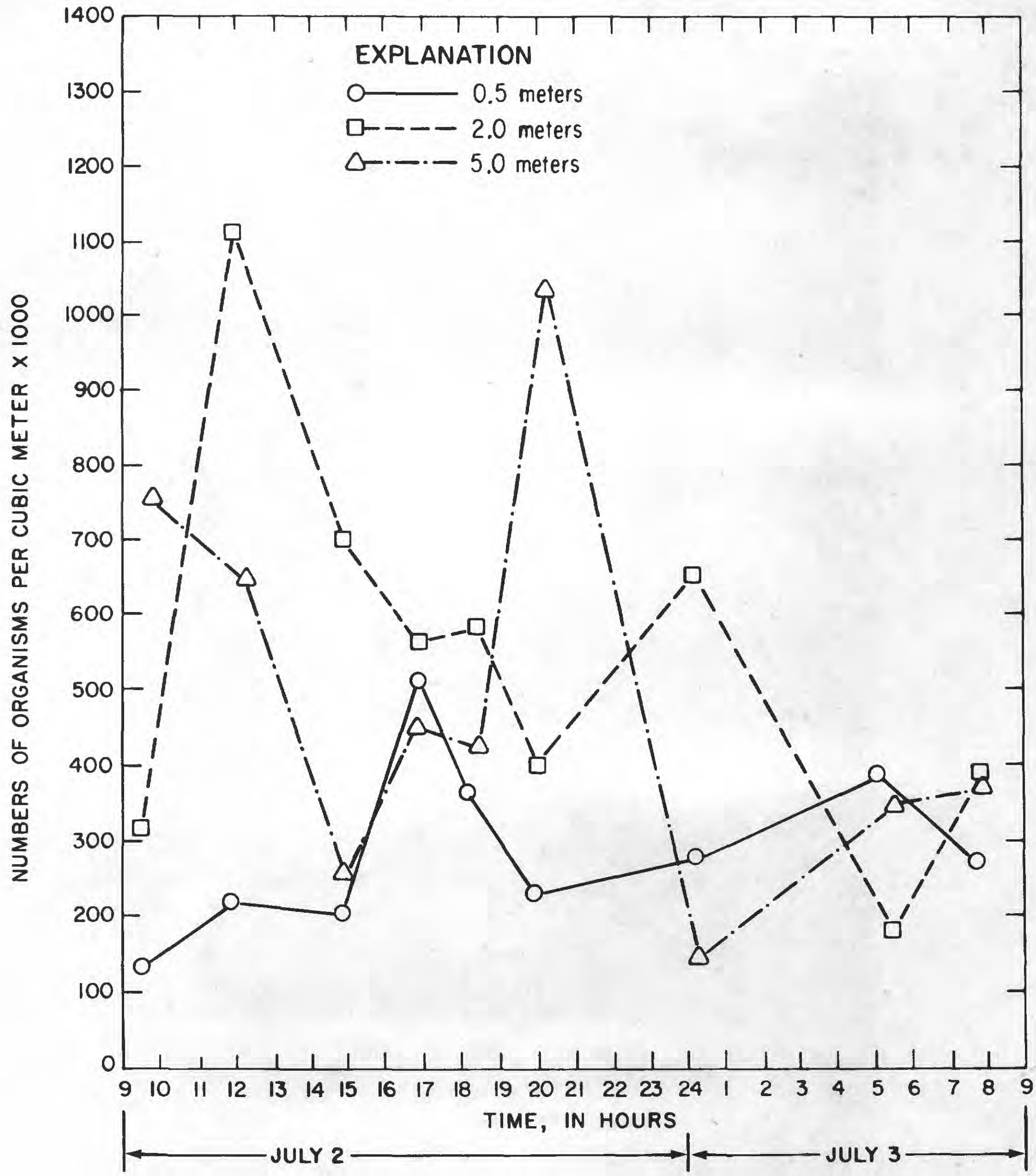

Figure 36.--Diel fluctuation in the number of zooplankton at different depths at station 7, July 2-3, 1974.

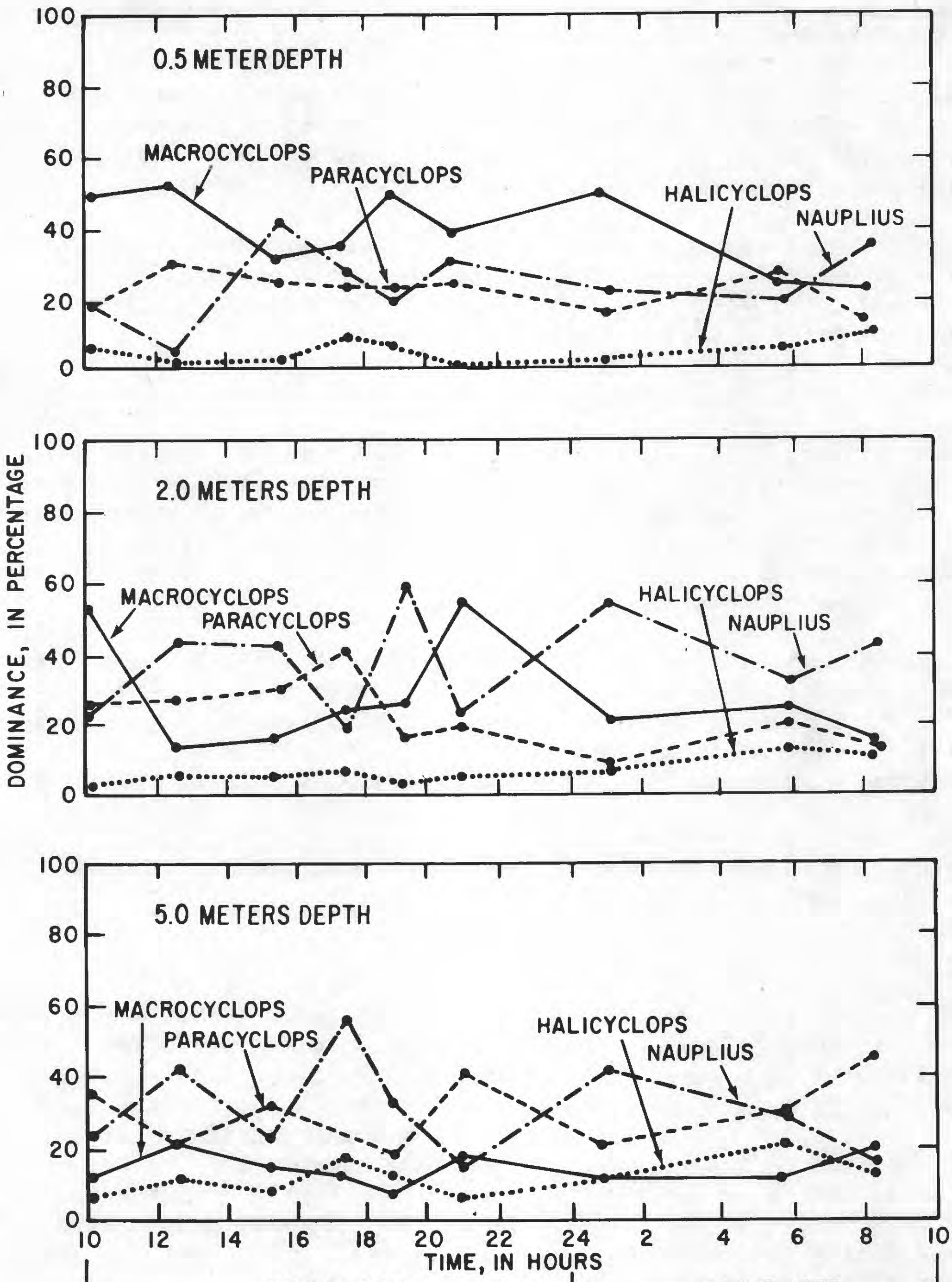

Figure 37.--Diel fluctuation in the percent dominance of the nauplius and principal genera of zooplankton at different depths at station 7, July 2-3, 1974.

There were no significant trends in the diurnal vertical migration among the organisms identified. At different depths there is a shift in the dominant organisms. Near the surface, at 0.5-m depth, Macrocyclops spp. are the dominant zooplankters. Toward the bottom, at 2.0 and 5.0 m, the nauplii constitute most of the organisms. At 5.0 m, Macrocyclops spp. are about 12 percent of the total as compared with about 30 percent at 0.5 meters. The other genera identified, Paracyclops spp. and Halicyclops spp., did not change significantly in numbers at different depths.

Several additional genera of zooplankton were also identified throughout the lake. These included species of Moina (Cladoceran), several Rotifera (Testudinella, Gastopus, Brachionus, Polyanthra). However, their numbers were very small compared with the dominant Cyclopoida.

Aquatic Plants

The water hyacinth (Eichornia crassipes) is the dominant aquatic plant in Lago Loíza. The hyacinths are found in almost every place in the lake and its tributaries. At places like San Lorenzo and Las Piedras, miles upstream from the lake, hyacinths are common in the tributaries to the main streams. Figure 38 shows the hyacinths piled up against the dam, while figure 39 shows the dam structure under normal conditions.

The growth of the water hyacinths in Lago Loíza is directly related to the high nitrogen and phosphorus concentrations (Pirie, 1960). Uptake of nutrients by the hyacinths promotes rapid growth and infestation throughout the lake. In late June 1975, an area of about 0.5 km^2 near the damsite was completely covered with hyacinths. Upstream from the dam, large masses of hyacinths float toward station 5 as "islands." At times, the movement of boats throughout the lake is completely restricted by the hyacinths. A small number of water lettuce plants (Pistia stratiotes) were also identified. These do not constitute a problem in the lake.

Fish

The fish in Lago Loíza have been the subject of an extensive study by the Puerto Rico Department of Natural Resources (T. M. Schulte, oral commun., 1975). The fish population is dominated by two species of exotic tilapia (Tilapia mossambica and T. vendalli). During the 1973-74 fiscal year, a census indicated that of about 1,300 kg of fish caught using hooks and lines, about 62.5 percent belonged to the tilapia species. The census also indicated that about 8,500 kg of fish were caught using cast nets. Nearly 98 percent of these were tilapia. The report from the Puerto Rico Department of Natural Resources indicates that during the last 3 years the creel census has shown a continuous reduction in the bass population in the lake.

The overpopulation of tilapia in Lago Loíza and the reduction of the more desirable bass is the direct result of several factors interacting in the lake ecosystem. The tilapia species are omnivorous and are at a distinct advantage

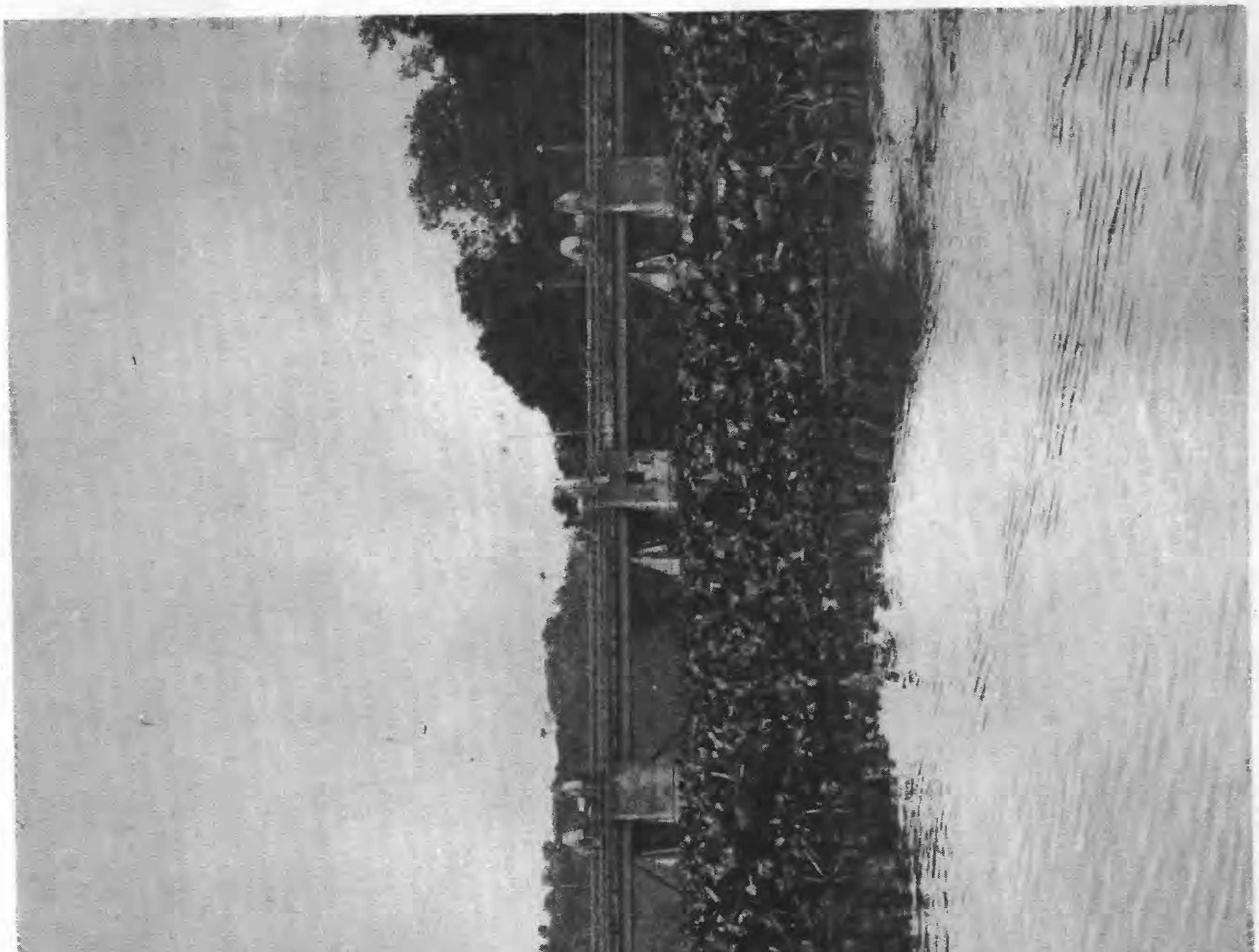

Figure 38.--Water hyacinths near the dam structure at Lago Loíza in July 1974.

Figure 39.--Lago Loíza dam clear of water hyacinths after the October 1974 floods.

in the lake. They are much better adapted to stress and are more tolerant organisms, being capable of reproducing in almost any environment. The bass, on the other hand, are affected by the poor water quality in the lake. Their reproduction is affected by the lack of suitable spawning areas. For their subsistence, light is an important factor because they are predators. Massive water hyacinth growth and increased turbidity due to sediments decrease the visibility in the water and their prey capabilities. They cannot compete favorably with the tilapia under these conditions.

Schulte (1975) described several species of fish in Lago Loíza including largemouth bass (Micropterus salmoides), channel catfish (Ictalurus punctatus), "guavinas" (Gobiomorus dormitor) and several others. Of these, the channel catfish and the "guavinas" comprise about 20 percent of the catch. The percentages of total catch in numbers during 1972-73 of the principal species in Lago Loíza are shown in figure 40.

Community Primary Productivity

The metabolism of the plant and animal organisms in an aquatic system produces changes in the concentration of dissolved oxygen, carbon, and other organic and inorganic compounds. The amount of oxygen produced or inorganic matter fixed into organic matter may be used as an indicator of the degree of eutrophication of a body of water (Hooper, 1969; and Odum, 1971).

The plankton primary productivity may be used as an approximation of the metabolic activity within a system and its trophic state. Light- and dark-bottle primary productivity measurements in Lago Loíza were unsuccessful due to the interference of large masses of water hyacinths shading the bottles. Light and dark bottles placed in an open area were shaded unexpectedly by the moving water hyacinth masses.

Two diurnal studies of oxygen production in Lago Loíza were conducted to estimate the community primary production. The studies were conducted during March 13-14, 1974, and July 2-3, 1974. The data for both studies are summarized in table 26. The dissolved-oxygen diurnal curves from 0.5 and 2.0-m depth at station 7 are shown in figure 41. Similar curves were obtained for stations 5 and 6.

During the March 13-14 study, the peak dissolved-oxygen concentration was 10.0 mg/L, while during the July 2-3 study it was 11.6 mg/L at 0.5-m depth. Peak oxygen concentrations occurred at 1700 hours and 1800 hours, respectively. The oxygen diurnal curves show two unusual characteristics. During the March study, effective oxygen production did not start until after 1000 hours. This may have been caused by a local condition in the vicinity of station 7. Strong winds had moved hyacinths over the area, shading the water column. During the July study, oxygen production increased from 0730 to about 1200 hours. A sharp decline in the dissolved-oxygen concentration, from 10.4 to 7.9 mg/L occurred from 1200 to 1500 hours. This was probably due to a storm in the area which reduced the amount of incident light on the surface of the lake. Photosynthetic activity probably declined during this period.

Table 26.--Summary of community productivity studies in Lago Loíza (grams of oxygen per cubic meter per day).

	MARCH 13-14, 1974						JULY 2-3, 1974					
	Station 5		Station 6		Station 7		Station 5		Station 6		Station 7	
	0.5 m	2.0 m	0.5 m	2.0 m	0.5 m	2.0 m	0.5 m	2.0 m	0.5 m	2.0 m	0.5 m	2.0 m
Gross productivity	12.2	2.0	14.0	10.2	9.6	8.0	9.4	10.5	14.7	--	14.7	16.5
Community respiration	14.4	7.2	13.5	14.4	12.0	10.8	12.0	12.0	16.8	--	15.6	19.2
Night respiration	7.2	3.6	5.6	7.2	6.0	6.3	6.0	6.0	8.4	--	8.6	8.8
Net day productivity	5.0	2.3	6.1	3.0	3.6	3.5	3.4	4.5	6.3	--	6.3	6.1

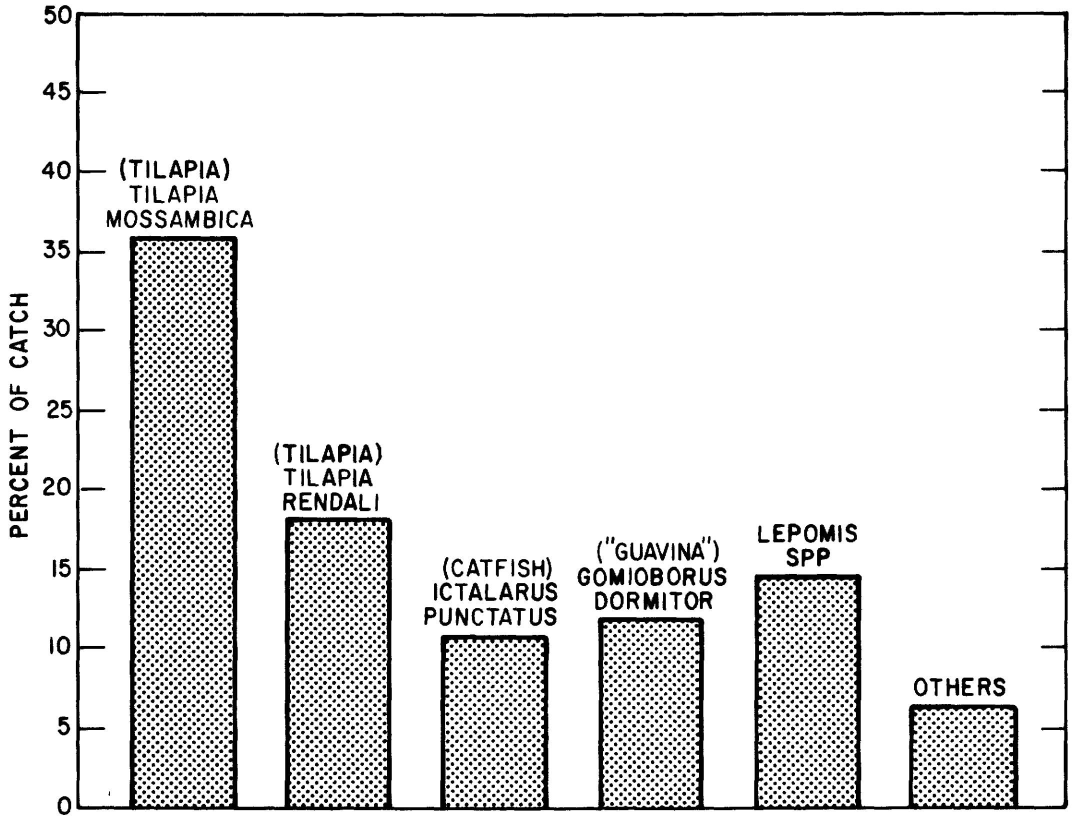

Figure 40.--Percent distribution of the total catch by numbers of the principal fish species in Lago Loíza during 1972-73 (modified from Schulte, 1975).

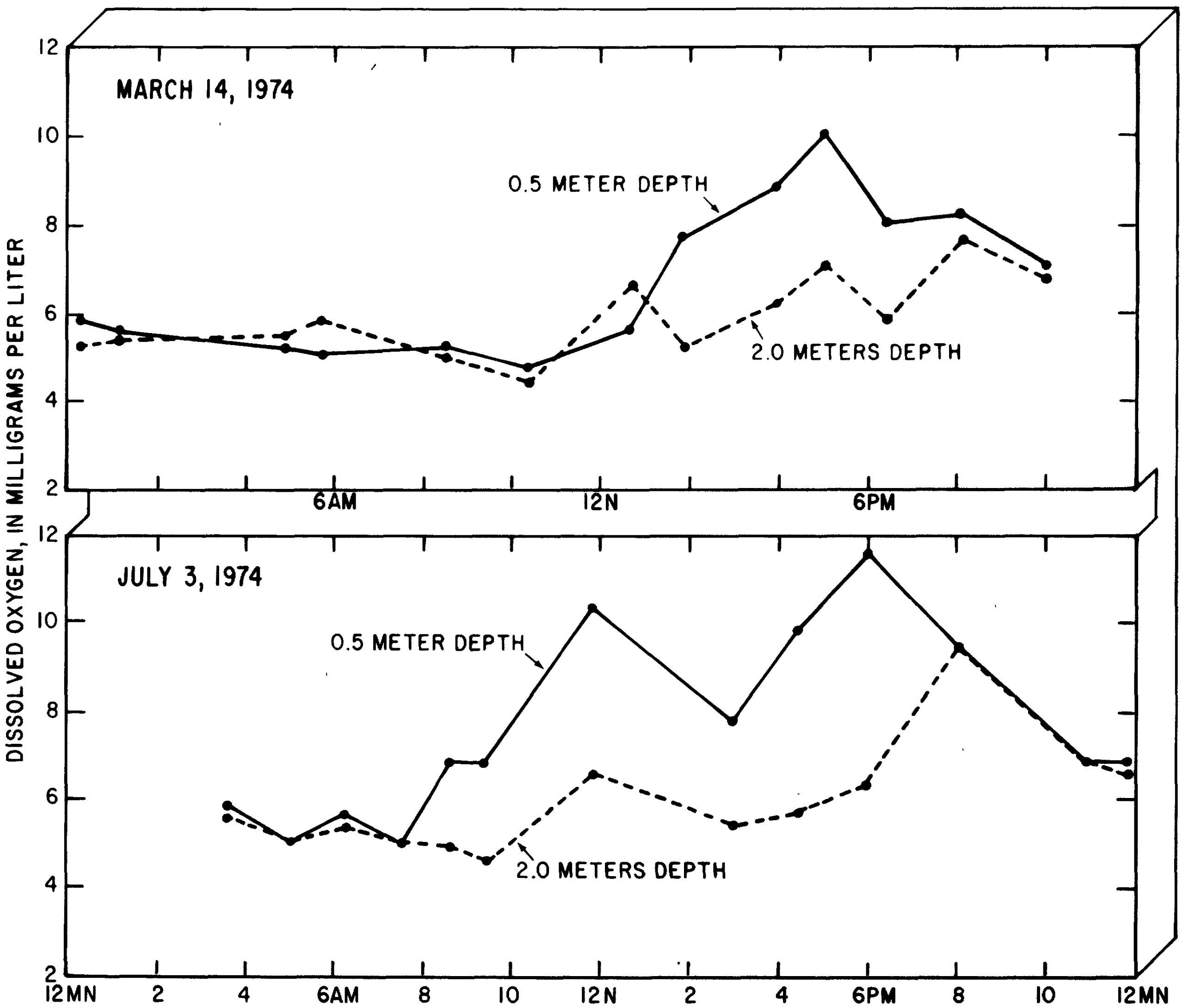

Figure 41.--Diurnal fluctuation in the concentration of dissolved oxygen at station 7.

The data in table 26 indicate that except at the surface of station 5, the net community oxygen production was higher during July than during March. At station 5 the phytoplankton concentration was much higher during March than during July (fig. 32) which may account for the higher productivity. At station 7 there was a higher density of phytoplankton during July. The higher solar intensity during the summer months, which induces a higher efficiency among the algae, together with the increased algal population, probably resulted in more oxygen production.

The average gross community primary productivity throughout the lake for the March and July studies were 10.0 and 13.2 gO_2/m^3 (grams of oxygen per cubic meter) per day, respectively. If the number of daylight hours is assumed to be 12, the average hourly productivity for both studies was 0.83 and 1.1 gO_2/m^3 per hour. This is equivalent to about 0.31 and 0.41 gC/m^3 (grams of carbon per cubic meter) per hour, respectively. In similar studies in North Central Florida, Brezonik and Shannon (1971) reported that lakes which were classified as hypereutrophic exhibited a mean primary production of $0.205 \pm .094$ gC/m^3 per hour. The constant phytoplankton blooms in Lago Loíza and the abundance of nutrients in the lake water promote high productivities, causing the lake to be hypereutrophic.

CHEMICAL, PHYSICAL AND BIOLOGICAL INTERACTIONS IN LAGO LOIZA

There are many factors interacting in the Lago Loíza system. Chemically, Lago Loíza is nearly homogeneous, both vertically and horizontally. In the lake proper (downstream of station 4) there is little difference in the chemical nature of the waters. Except for the amount of dissolved oxygen, the waters are well mixed and are representative of the calcium-bicarbonate waters flowing from the Río Gurabo and the Río Grande de Loíza.

The input of nutrients from the upper basin tributaries is the principal factor in the eutrophication problem in Lago Loíza. The large loads of nutrients enhance high productivity rates and extensive blooms of water hyacinths and phytoplankton.

The water hyacinths constitute a major problem with several ramifications, all of which affect the entire lake system. The plants themselves are a major nuisance that contributes to a reduction of oxygen in the water column. The shading effect of the hyacinth mass reduces the rate of production and the rate of transfer of oxygen from the air into the water (Lugo and others, 1975). At the same time the hyacinths contribute large loads of organic matter which are either oxidized in situ or sink to the bottom. The organic matter that accumulates on the bottom exerts a high oxygen demand, resulting in the anaerobic conditions that exist below 5 meters. The muddy anaerobic bottom creates unfavorable conditions for desirable species of fish, such as bass.

The interrelationships between the water hyacinths, dissolved oxygen and nutrients in Lago Loíza are summarized in the simplified model shown in figure 42. The model shows that the growth of hyacinths is controlled by the solar energy and nutrient inputs. The oxygen pool is depleted in proportion to the amount of organic matter in the system.

Low dissolved-oxygen concentrations in a lake will contribute to the recycling of phosphorus and the production of hydrogen sulfide gas (H_2S). In the presence of iron, under aerobic conditions, phosphorus precipitates as ferric phosphate ($FePO_4$). The redox potential defines the ferrous to ferric iron ratio (Fe^{++}/Fe^{+++}). As the redox potential decreases under anaerobic conditions, the ferric phosphates are reduced to the ferrous state, releasing the phosphates from the sediments into the water. The sediments, which under normal aerobic conditions act as a nutrient sink, contribute to the recycling of a portion of these, primarily orthophosphate and ammonium.

The problem of the anaerobic bottoms in Lago Loíza is directly related to the water hyacinths and the current practices for their control. Until recently, herbicides were used to destroy the water hyacinths. Upon death, the plants would sink to the bottom of the lake, contributing to the organic load, reducing the available oxygen, and the eventual recycling of nutrients.

High nutrient concentrations, solar energy, and residues from the water hyacinths contribute to the high productivity rates in several trophic levels in Lago Loíza. Community primary productivity is relatively high. Phytoplankton populations are probably limited by the shallowness of the zone of production and by grazing by zooplankters and fish. The zooplankton numbers are extremely high. The carnivorous species of zooplankton are probably enhanced by the abundant communities of bacteria and other smaller organisms that proliferate in the root systems of the water hyacinths (Reid, 1967). Filter feeders among the zooplankters are favored by detritus and other particles from the decomposition of the hyacinths. At the top of the trophic levels in Lago Loíza, the rapid growth of tilapia and other planktivorous fish reflects the ultimate effect of the eutrophication process in the lake's biological system.

The interactions between primary producers, consumers, nutrients, and dissolved oxygen in Lago Loíza are summarized in the simplified model shown in figure 43. The model shows the importance of the nutrients as the driving force in the primary production, although the path flow of solar energy may be as limiting as the nutrient flow (short circuiting or reduced flows in any of the pathways stops or reduces the action). At all trophic levels, demands are placed on the dissolved oxygen pool. As the system becomes more eutrophic, productivity increases, increasing zooplankton and fish populations as well as increasing the amount of organic matter in the system. The oxygen demands increase proportionally, creating the conditions illustrated in figure 43.

The effects on the tilapia and bass populations of the eutrophication problem in Lago Loíza are summarized in the simplified model shown in figure 44. The ecological advantages of the omnivorous tilapia are illustrated in the model. Energy inputs flow to the tilapia from both the producers (hyacinths and

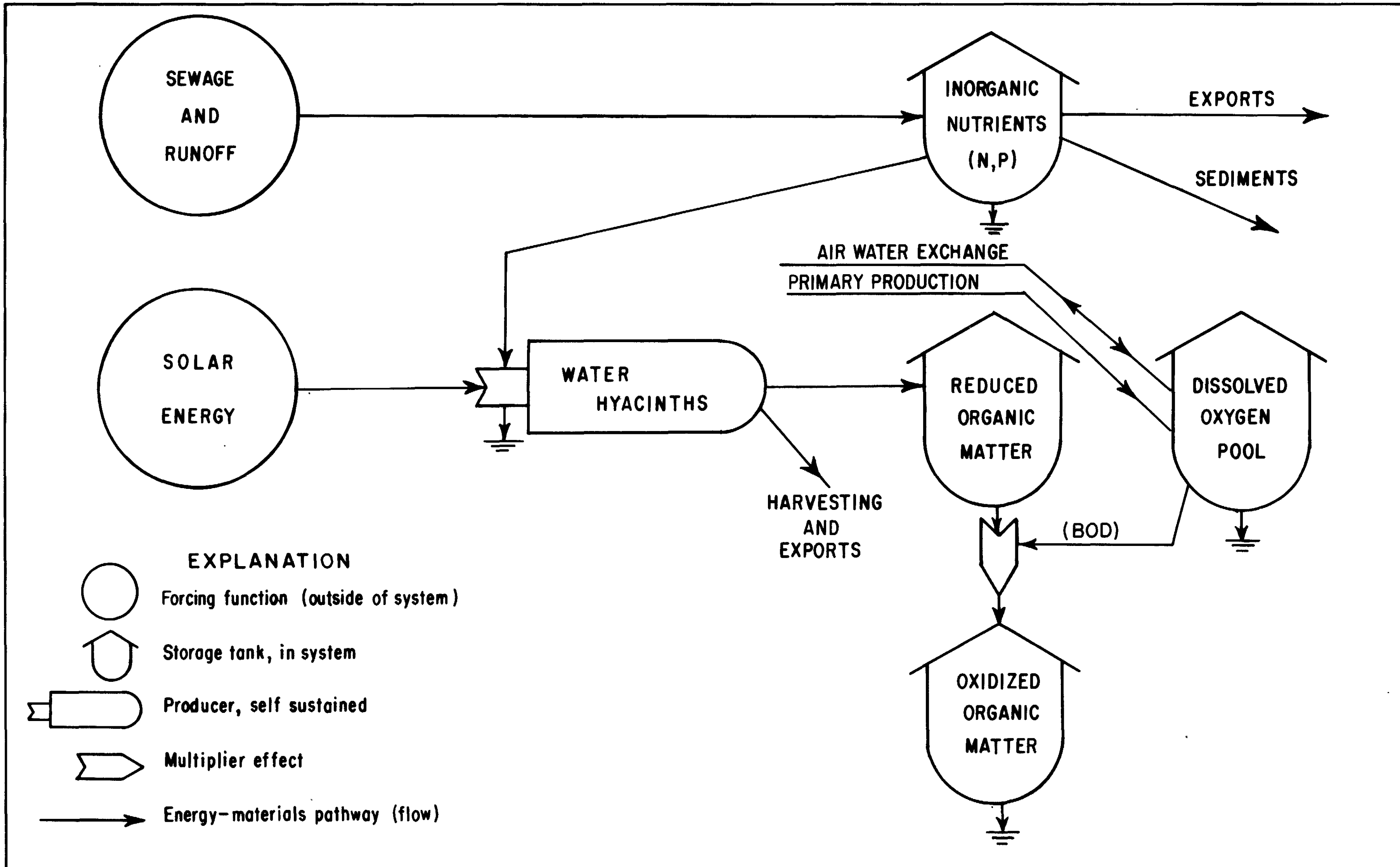

Figure 42.--Simplified model of the interactions between the water hyacinths, nutrients, and dissolved oxygen in Lago Loíza.

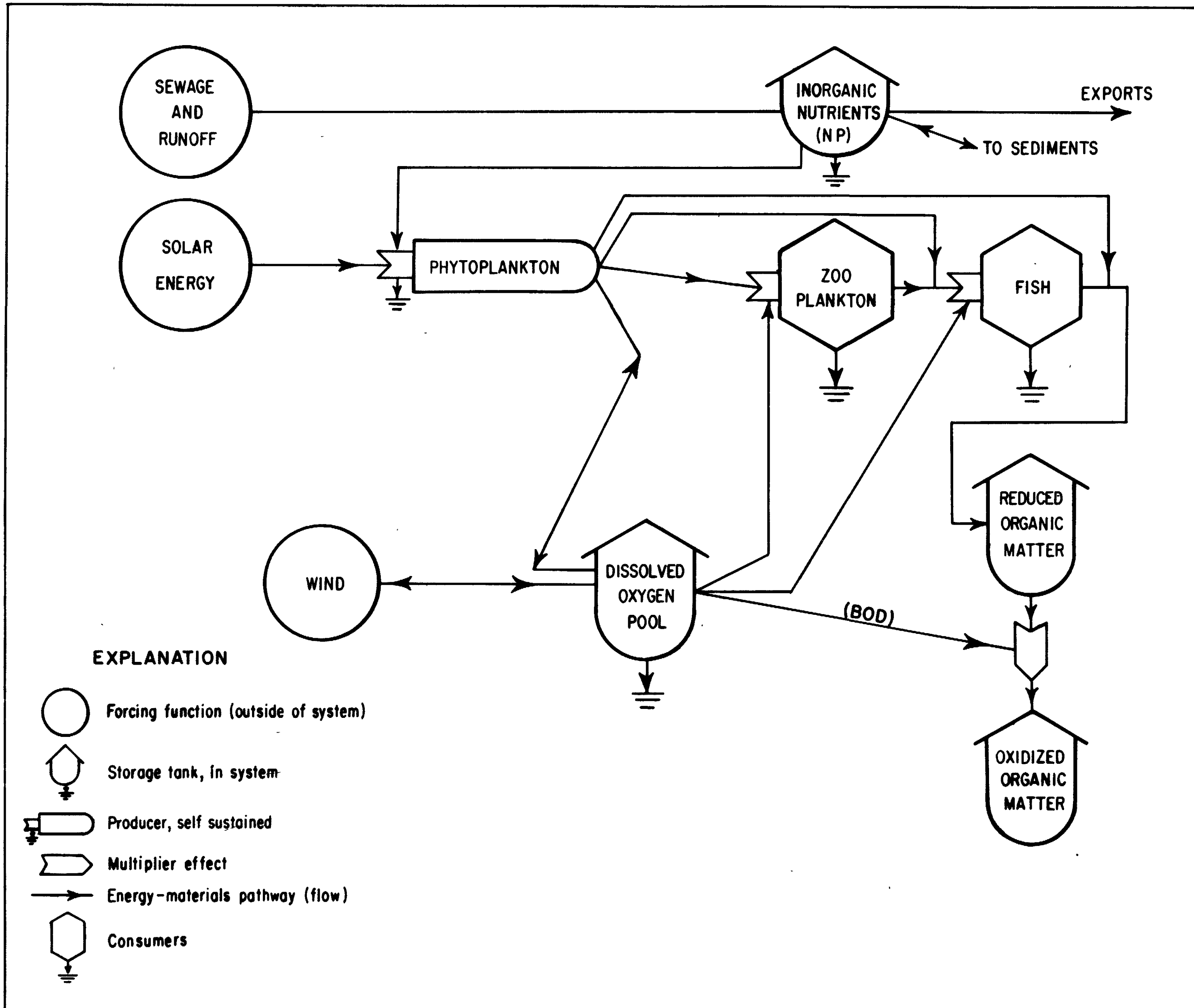

Figure 43.--Simplified model of the interactions between primary producers, consumers, nutrients, dissolved oxygen, and organic matter in Lago Loíza.

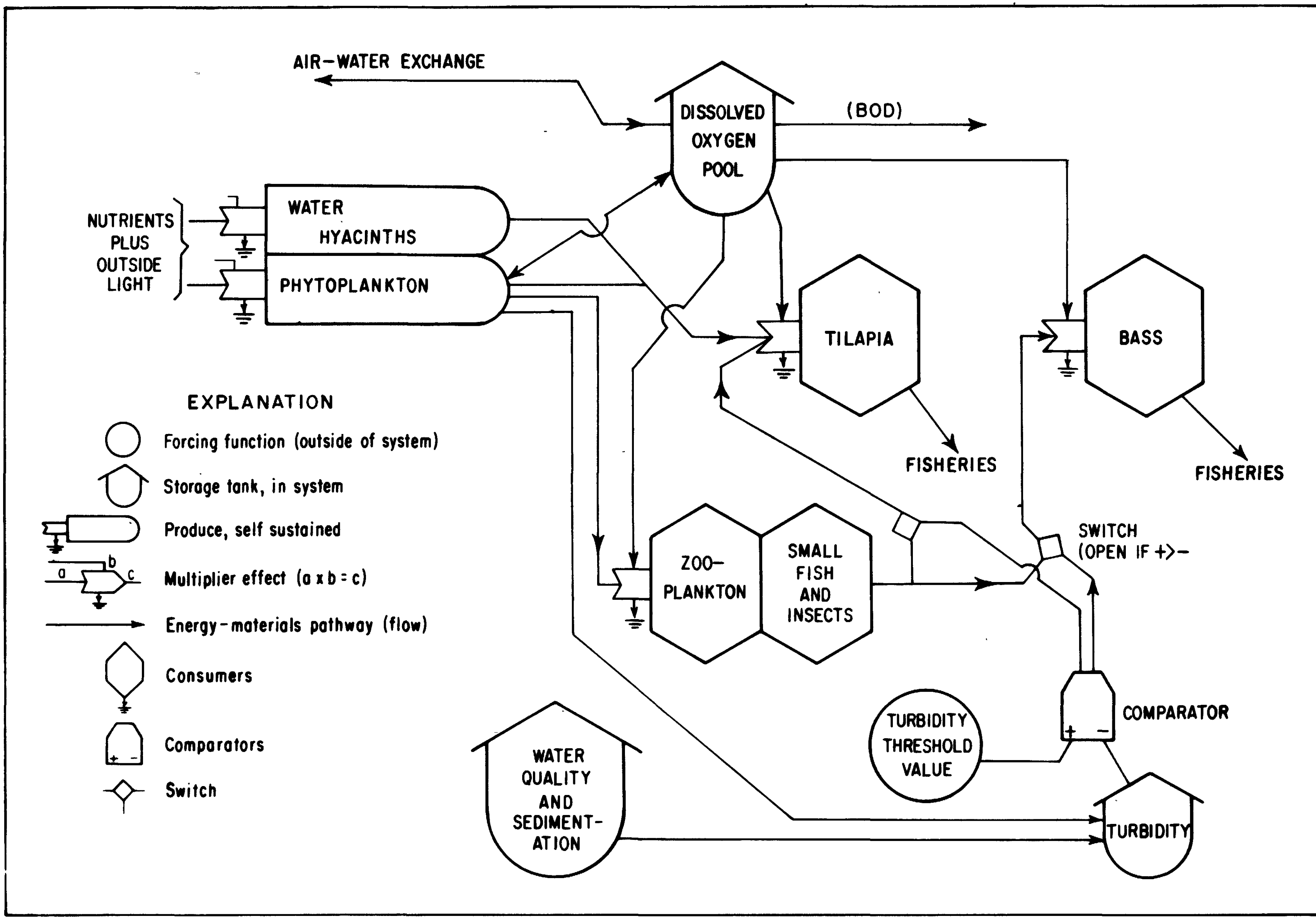

Figure 44.--Simplified model of the interactions involving tilapia and bass in Lago Loíza.

phytoplankton) and the consumers (zooplankton and fish). The bass, however, feeds only on the small fish, insects and zooplankton and other small animals. The preying capabilities of the bass are affected by the turbidity in the system, which is a measure of the quality of the water. If one of the two circuits supplying energy to the tilapia is shorted, the flow will continue through the other circuit. For the bass, turbidities higher than the threshold value slow down or short the energy input from their prey capability.

The lake's system is affected by two additional important factors, nutrient loads and flushing rates. On an area basis, the average nitrogen and phosphorus loadings to Lago Loíza during the study period were 232 g/m^2 per year of nitrogen and 53 g/m^2 per year of phosphorus. These loads exceed by a factor of 100 the dangerous loading levels (in terms of nuisance effects of eutrophication) for lakes of similar mean depth as reported by Vollenweider (1968). However, Dillon (1975) has shown the importance of flushing rates in the phosphorus budgets of lakes. High flushing rates, or the ratio of annual discharge to the lake volume, counterbalance high nutrient loading rates. In Lago Loíza, flushing rates from 1960 to 1974 averaged about 19.5 per year, although one storm may flush the lake the equivalent of several times. Flushing of the lake so many times during the year not only introduces a constant supply of waters with lower nutrient concentrations, but also large loads of suspended sediment. The lower nutrient concentrations of the flushing waters check the buildup of these in the lake. The suspended sediment decreases the light transmission in the water column, reducing productivity levels of algae. Both of these factors act as controls of denser algal blooms in Lago Loíza.

An additional problem in Lago Loíza and its tributaries is the potential infestation of the parasite bilharzia (Schistosoma mansoni). Although this problem was not investigated during the study, host snails of the parasite were observed in all the streams and on the lake shore. Eggs from the parasites are transmitted in sewage, which has been shown to be discharged into most of the tributaries to the lake.

SUMMARY AND CONCLUSIONS

Lago Loíza is the principal source of water to the San Juan metropolitan area, supplying about 300,000 m^3/d of water for domestic and industrial uses. The lake has a mean depth of about 6.1 m and a maximum depth of about 17.2 m.

The total flow into Lago Loíza during the study period was 279.7×10^6 m^3. The Río Grande de Loíza contributed about 50 percent of the total flow, while the Río Gurabo contributed about 35 percent. Storm runoff during October 1974 accounted for about 37 percent of the total inflow.

During the study period the lake was flushed an equivalent of about 19.5 times. The flood of October 1974 discharged an equivalent amount of water to flush the lake about 7 times. Abnormally low flows from January through August reduced inflows below withdrawal rates, causing a drop in the water level of about 5.1 m.

A sedimentation survey from a bathymetric study shows that the actual capacity of Lago Loíza is about 14.9×10^6 m^3. About 39 percent of the original capacity as reported by Arnow and Crooks (1960) has been lost due to sedimentation. The annual rate of loss in capacity is about 1.9 percent, while the expected usable life of the reservoir is about 40 years.

Clays constitute from 60 to 90 percent of the bottom sediments in Lago Loíza. Silts range from 30 to 60 percent, while sands are less than 15 percent of the total upper foot of sediments. About 10 to 12 percent of the sediments are organic matter, while from 0.3 to 1.4 percent of the organic matter is organic carbon. The sediments also contain an average 0.18 percent of nitrogen and 0.09 percent of phosphorus. Minor concentrations of chlordane, DDD, dieldrin, and mercury were detected in the bottom sediments.

The Río Grande de Loíza and Río Gurabo are the main tributaries to Lago Loíza. The waters in both streams are very similar with moderate concentrations of calcium, bicarbonate, chloride, and sulfate. Agricultural runoff and partially treated sewage contribute significant amounts of nitrogen, phosphorus and bacteria to both streams. In Río Grande de Loíza these average 1.3 mg/L of total nitrogen, 0.28 mg/L of total phosphorus, and a fecal coliform range from 100 to 60,000 colonies/100-mL sample. In Río Gurabo, total nitrogen and total phosphorus average 2.5 mg/L and 0.35 mg/L, respectively, while fecal coloform bacteria range from 200 to 17,000 colonies per 100-mL sample.

Río Caguitas and Río Bairoa are the next most important tributaries to the lake. Both streams receive raw or partially treated sewage. Adverse effects of the sewage inputs are similar in both streams. Typical fecal coliform concentrations in Río Caguitas range from 2,000 to 4,300,000 colonies per 100-mL sample, with a median of about 1,100,000 colonies/100 mL. Dissolved-oxygen concentrations average 4.2 mg/L, while 5-day biochemical-oxygen demands average 19 mg/L. In Río Bairoa, fecal coliforms range from 2,700 to 6,700,000 colonies/100-mL sample, with a median of 1,400,000 colonies/mL sample. Dissolved-oxygen values averaged 4.6 mg/L and 5-day biochemical-oxygen demands averaged 23 mg/L. Sewage also contributes high nitrogen and phosphorus concentrations to both streams. In Río Caguitas the nitrogen concentration averaged 5.0 mg/L and the phosphorus 1.7 mg/L; in Río Bairoa the nitrogen concentration averaged 9.4 mg/L and the phosphorus 2.8 mg/L. The quality of the waters in Río Caguitas and Río Bairoa is among the worst in Puerto Rico.

Río Cañas is the least important of the tributaries to Lago Loíza. It is also the least polluted except for intermittent industrial alkaline waste discharges. Typical pH values in Río Cañas range from 7.0 to 9.4 with a median of 7.6 units.

The chemical characteristics of the water in Lago Loíza are nearly uniform throughout the lake. The mean specific conductance is 294 umho/cm. Sodium and bicarbonate are the most abundant ions, averaging 25.2 and 100 mg/L, respectively. Chloride concentrations average 24.3 mg/L, while sulfates average 17.7 mg/L.

The concentration of most of the ions fluctuates seasonally, increasing during drought and decreasing during high-flow periods. However, fluctuations are small. The pH in the lake ranged from 7.0 to 7.9 units.

Analyses of water and sediment samples from the lake do not show significant concentrations of heavy metals or pesticides.

Fecal coliform bacteria in the lake waters exceed 200 colonies/100 mL only during periods of high flow when their numbers may be as great as 9,000 colonies/100 mL. Fecal streptococci seldom exceed 40 colonies/100 mL. There is rapid decay in the number of bacteria toward the damsite.

The dissolved oxygen concentration in the lake fluctuated seasonally and vertically. Near the surface the concentration was never below 5.0 mg/L. However, during the peak of the drought, dissolved oxygen in the water column throughout the lake ranged from 3.0 mg/L at 1.5 m to 1.0 mg/L at 3.0-m depth. Most of the time, the concentration does not exceed 1.0 mg/L below 5.0-m depth. Major storms in the basin may flush the lake and thoroughly mix the water column, breaking any stratification. After the October 1974 floods, the dissolved oxygen concentration throughout the lake at 5.0-m depth averaged 5.0 mg/L.

There is not a significant degree of thermal stratification in Lago Loíza. At the surface, temperatures ranged seasonally from 24°to 31°C. Vertically, a 5-degree difference between the surface and 8-m depth was the maximum recorded during September 1973.

About 564 metric tons of nitrogen and 128 metric tons of phosphorus were transported into the lake during the study period. The Río Grande de Loíza contributed about 32 percent of the total nitrogen and about 32 percent of the total phosphorus, while the Río Gurabo contributed about 36 percent of the nitrogen and about 25 percent of the phosphorus. While Río Caguitas and Río Bairoa combined flows were only 6 percent of the total, their nitrogen and phosphorus contributions were 17.7 and 24.9 percent, respectively. About 21.0 percent of the nitrogen and 45.1 percent of the phosphorus were retained in the lake.

Nearly constant blooms of phytoplankton occur in Lago Loíza. *Anacystis* spp., *Cyclotella* spp., and *Melosira* spp. are the dominant phytoplankton. Zooplankton numbers range from 200,000 to 3,700,000 per cubic meter, evidence of the high productivity of the lake. *Macrocyclops* spp. is the dominant zooplankter. Average gross community primary productivity ranged from 0.31 to 0.41 gC/m^3 per hour.

The principal aquatic plant in Lago Loíza is the water hyacinth (*Eichornia crassippes*). Constant blooms are enhanced by the nutrient-rich waters. The decaying hyaciths exert high oxygen demands in the water and promote anaerobic conditions.

The fish population in Lago Loíza is dominated by two tilapia species (Tilapia mossambica and T. rendalli). These constitute more than 62 percent of the total species in the lake. Overpopulation by the tilapia and poor water-quality conditions have induced the near disappearance of bass and other desirable species.

The overall water-quality conditions in Lago Loíza are a result of the interaction of several key factors. Agricultural runoff and sewage discharges contribute nutrients in concentrations that promote rapid growth of the water hyacinths. Organic loads in sewage combined with residues of dead water hyacinths help to reduce dissolved-oxygen concentrations below levels necessary for fish and other organisms. The water quality is also affected by high suspended-sediment concentrations. The sediments contribute to reducing the usable storage in the lake and also to damaging or destroying habitats of fish and other organisms. In order to improve the quality of the waters in Lago Loíza, an extensive program involving control of agricultural and domestic effluents will be required.

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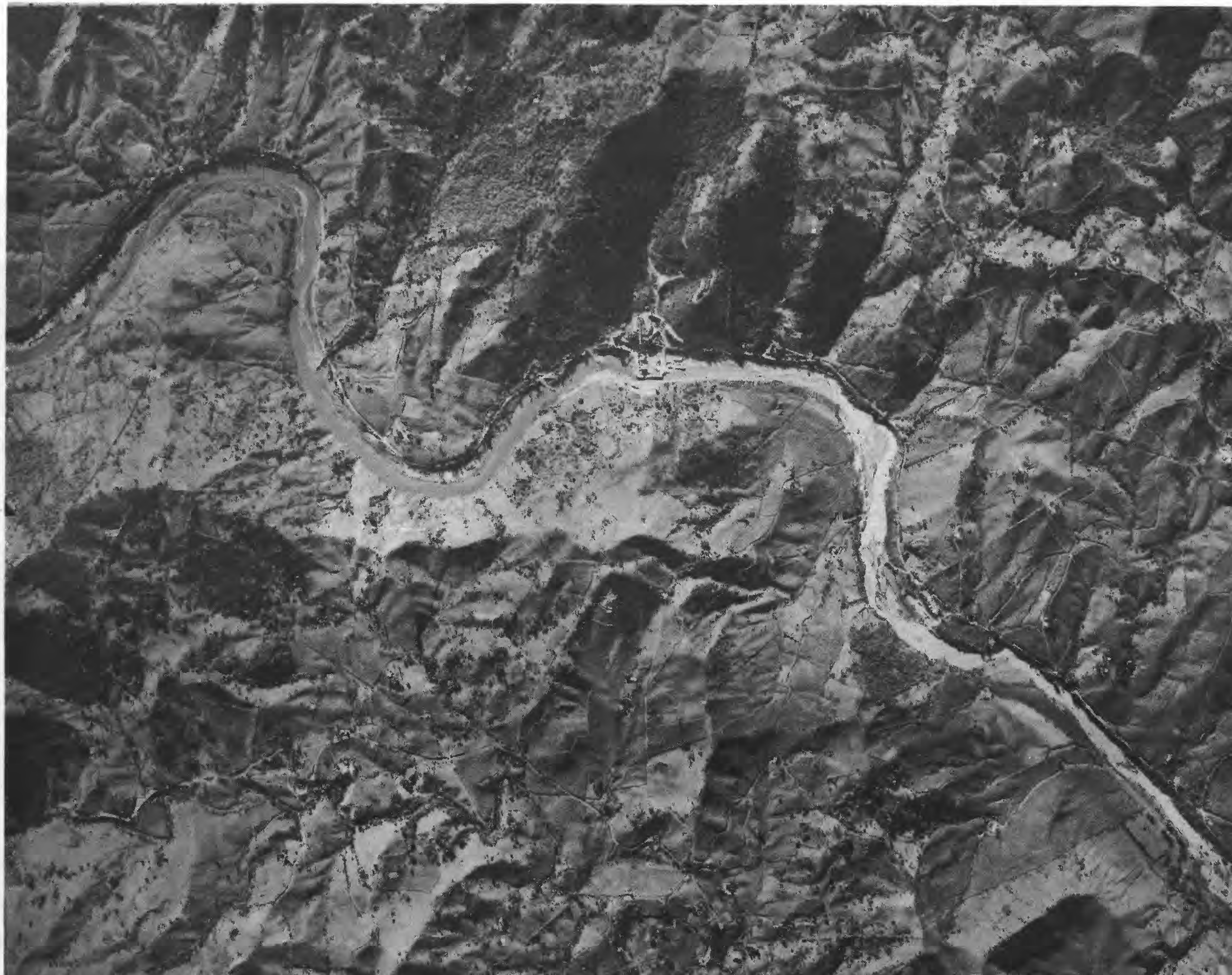

Early 1950 air photo showing Río Grande de Loíza dam under construction, near Trujillo Alto.