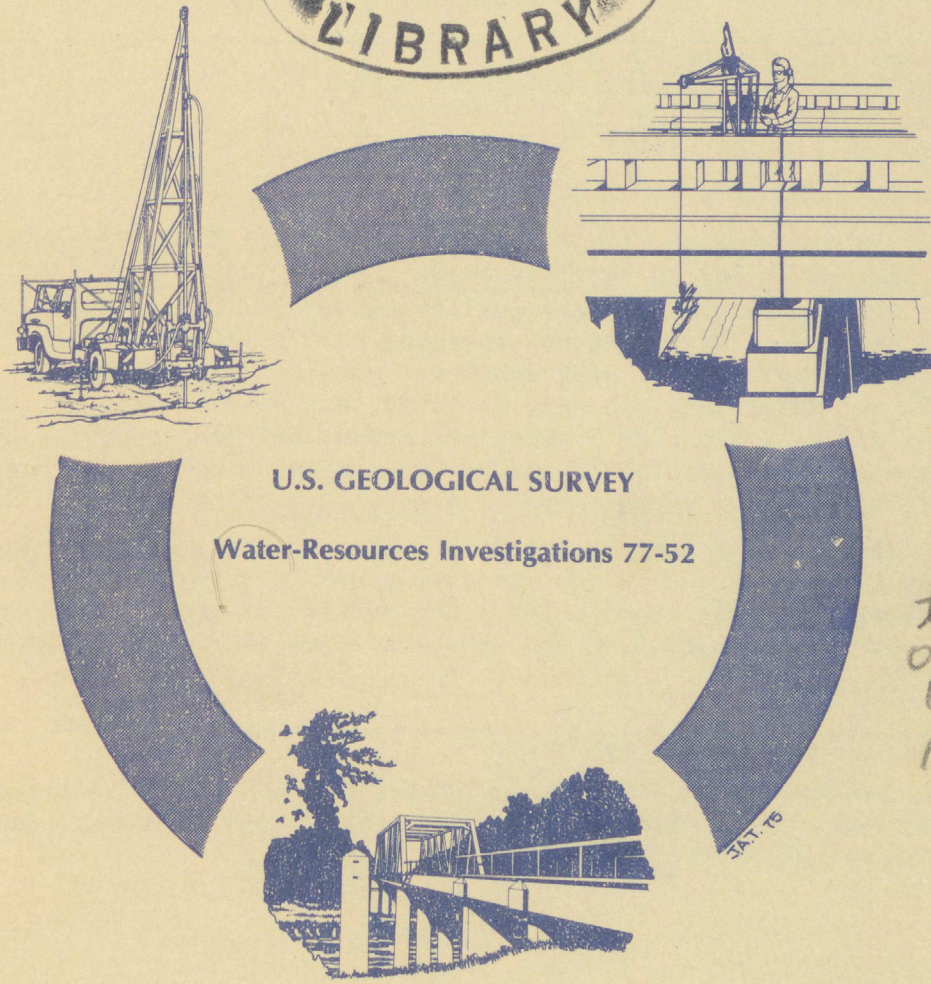
EVALUATION OF CHEMICAL, BIOLOGICAL, AND PHYSICAL CONDITIONS IN THE WINTER HAVEN CHAIN OF LAKES, FLORIDA, MARCH–JUNE 1976



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-52

Prepared in cooperation with the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
WINTER HAVEN LAKE REGION BOAT COURSE DISTRICT
and the PEACE RIVER BASIN BOARD

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle EVALUATION OF CHEMICAL, BIOLOGICAL, AND PHYSICAL CONDITIONS IN THE WINTER HAVEN CHAIN OF LAKES, FLORIDA, MARCH-JUNE 1976			5. Report Date July 1977 6.
7. Author(s) R. C. Reichenbaugh and G. H. Hughes			8. Performing Organization Rept. No. USGS WRI/NTIS 77-52
9. Performing Organization Name and Address U.S.Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S.Geological Survey, Water Resources Division 325 John Knox Road, F-240 Tallahassee, Florida 32303			13. Type of Report & Period Covered 14.

15. Supplementary Notes
Prepared in cooperation with the Southwest Florida Water Management District, Winter Haven Lake Region Boat Course District & Peace River Basin Board

16. Abstracts
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17. Key Words and Document Analysis. 17a. Descriptors

*Lakes; *Water level fluctuations; *Lakes basins; *Eutrophication; *Water quality; hydrogeology; hydrograph; well; groundwater; antecedent precipitation; sewage disposal; water pollution effects.

17b. Identifiers/Open-Ended Terms

Winter Haven Chain of Lakes; Winter Haven; Polk County; Florida.

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	33
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

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July 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

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CONVERSION FACTORS

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for terms used in this report are listed below:

Multiply English units	By	To obtain metric units
inches (in)	25.4	millimeters (mm)
square miles (mi^2)	2.590	square kilometers (km^2)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)

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EVALUATION OF CHEMICAL, BIOLOGICAL, AND PHYSICAL CONDITIONS IN THE WINTER HAVEN CHAIN OF LAKES, FLORIDA, MARCH - JUNE 1976

By

R. C. Reichenbaugh and G. H. Hughes

ABSTRACT

Reconnaissance of water-quality conditions of 14 interconnected navigable lakes, in and around Winter Haven, revealed that in March and May 1976 most were eutrophic, on the basis of high nutrient (nitrogen and phosphorus) concentrations. Lakes Lulu and Shipp were the most enriched; a result of surface runoff from residential, agricultural, and highly urbanized areas and many years of municipal and industrial waste effluent input. Phytoplankton counts were greater than a million cells per milliliter in some lakes sampled; algal blooms have occurred, and water clarity was low.

The level of Lake Howard fell to the lowest recorded stage in 31 years during May 1976. The record low was likely due to rainfall deficiency in the study area. Leakage of water through the lake beds to the ground-water system is also possible, but determination of the escaping water volume would require additional study.

INTRODUCTION

The Winter Haven Chain of Lakes consists of 14 interconnected lakes with a total area of 6.5 mi^2 within and around the City of Winter Haven in Polk County, Florida (fig. 1). The lakes fall under the authority of the Winter Haven Lake Region Boat Course District. The Chain of Lakes, a valuable recreational and economic resource, extends from Lakes Jessie and Hartridge on the north to Lake Winterset on the south (fig. 1). There is no surface outflow from the Chain except during extremely wet periods. Lake Eloise is the site of Cypress Gardens, a well-known tourist attraction. Tourism, citrus production, and phosphate mining are the principal industries in the area.

The residents of the Winter Haven area have expressed great concern about the extended periods of low lake levels and the apparent water-quality deterioration in the Chain of Lakes. The lake levels reached a record low on May 18, 1976. The U. S. Geological Survey, in cooperation with the Southwest Florida Water Management District, the Peace River Basin Board, and the Winter Haven Lake Region Boat Course District, began a reconnaissance on March 1, 1976 to collect hydrologic data and evaluate chemical, biological, and physical conditions in the Winter Haven Chain of Lakes. The investigation was divided into two phases. This report describes the results of the first phase of the investigation which extended from March 1 to June 30, 1976.

Lakes Jessie, Hartridge, Idylwild, Cannon, Mirror, Spring, Howard, Shipp, Lulu, Eloise, and Winterset, the major interconnected lakes in the chain, were studies in the first phase. Lakes Arietta and Otis were used as a reference to conditions outside the chain.

The assistance of Mr. George Galloway, Mr. James Harrington, and Mr. Joseph Lawlor of the Boat Course District in project planning and activities is gratefully acknowledged.

DATA COLLECTION

Records of historic conditions of stage on the lakes, precipitation on the area, and fluctuations of the potentiometric surface of the Floridan aquifer were examined. The Geological Survey has maintained stage recording stations on Lakes Hartridge and Howard since 1946 and Lake Otis since 1954. Precipitation from National Weather Service stations in Bartow, Lake Alfred, Lakeland and Winter Haven (U. S. Dept. Comm.), less than 15 mi distant, were used in the study.

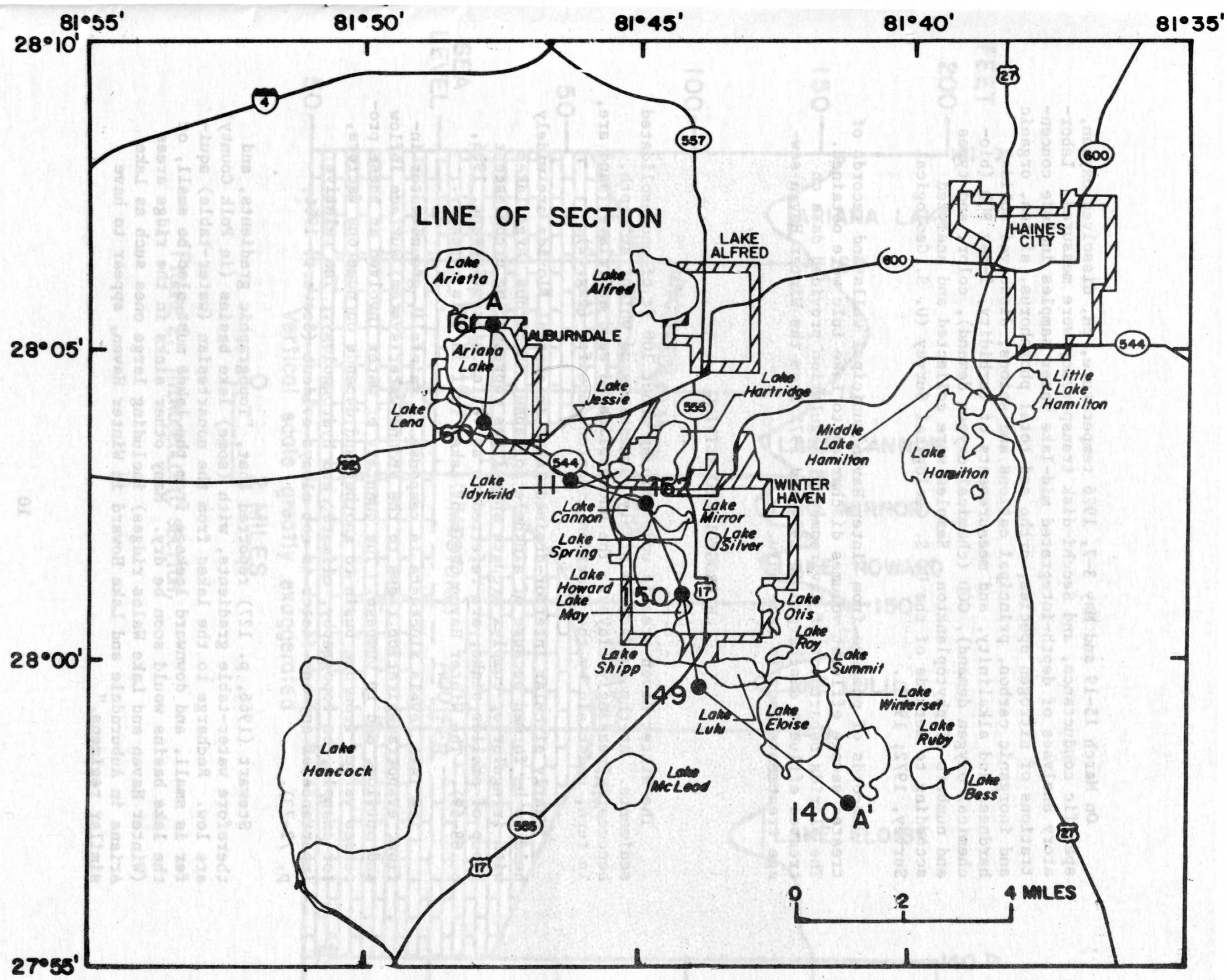

FIGURE 1. WINTER HAVEN CHAIN OF LAKES AND VICINITY.

On March 15-19 and May 3-7, 1976 temperature, pH, dissolved oxygen, specific conductance, and Secchi-disk transparency were measured. Laboratory analyses of depth-integrated mid-lake water samples include concentrations of nitrogen species, ortho and total phosphorus, silica, organic and inorganic carbon, principal cations and anions, dissolved solids, hardness and alkalinity, and measurements of turbidity, 5-day BOD (biochemical oxygen demand), COD (chemical oxygen demand), color, and types and numbers of phytoplankton. Samples were collected and analyzed according to methods of the U. S. Geological Survey (U. S. Geological Survey, 1972; 1973).

Records of pumpage from Winter Haven municipal wells and records of treated sewage effluent volumes discharged to Lake Lulu were obtained. The Florida Department of Environmental Regulation provided data on treated effluent discharged in 1974 and 1975 from the Winter Haven sewage treatment plant to Lake Lulu.

HYDROGEOLOGIC SETTING

The Winter Haven area is underlain by about 100 ft of unconsolidated sediments. At the surface is highly permeable sand which, at depth, becomes increasingly clayey. The unconsolidated sand and clayey sand are, in turn, underlain by the Floridan limestone aquifer (fig. 2).

Nearly circular interior-drained lakes in central Florida are widely held to be formed because of sinkhole collapse. Numerous large lakes with irregular or complex arcuate shorelines representing a coalescent group of smaller sinks, are referred to as valley sinks (Stewart, 1966, p. 68-69). The Winter Haven Chain of Lakes fall in this category.

The lake levels fluctuate in response to rainfall, ground-water inflow, evapotranspiration, loss to the ground-water system, surface inflow and outflow, and to pumpage. The quantity of water involved in these processes varies from one basin to another and depends on numerous factors, for example, on topography, climate, and hydrogeology. The relative importance of any one factor is not always evident (Stewart, 1966, p. 72-73).

Stewart (1966, p. 127) reported that, "Topographic gradients, and therefore water-table gradients, with (some) lake basins (in Polk County) are low. Recharge to the lakes from the nonartesian (water-table) aquifer is small, and downward leakage from the lakes must also be small, or the lake basins would soon be dry. Many other sinks in the ridge areas (Winter Haven and Lake Wales ridges) including large ones such as Lake Ariana in Auburndale and Lake Howard in Winter Haven, appear to have similar regimens."

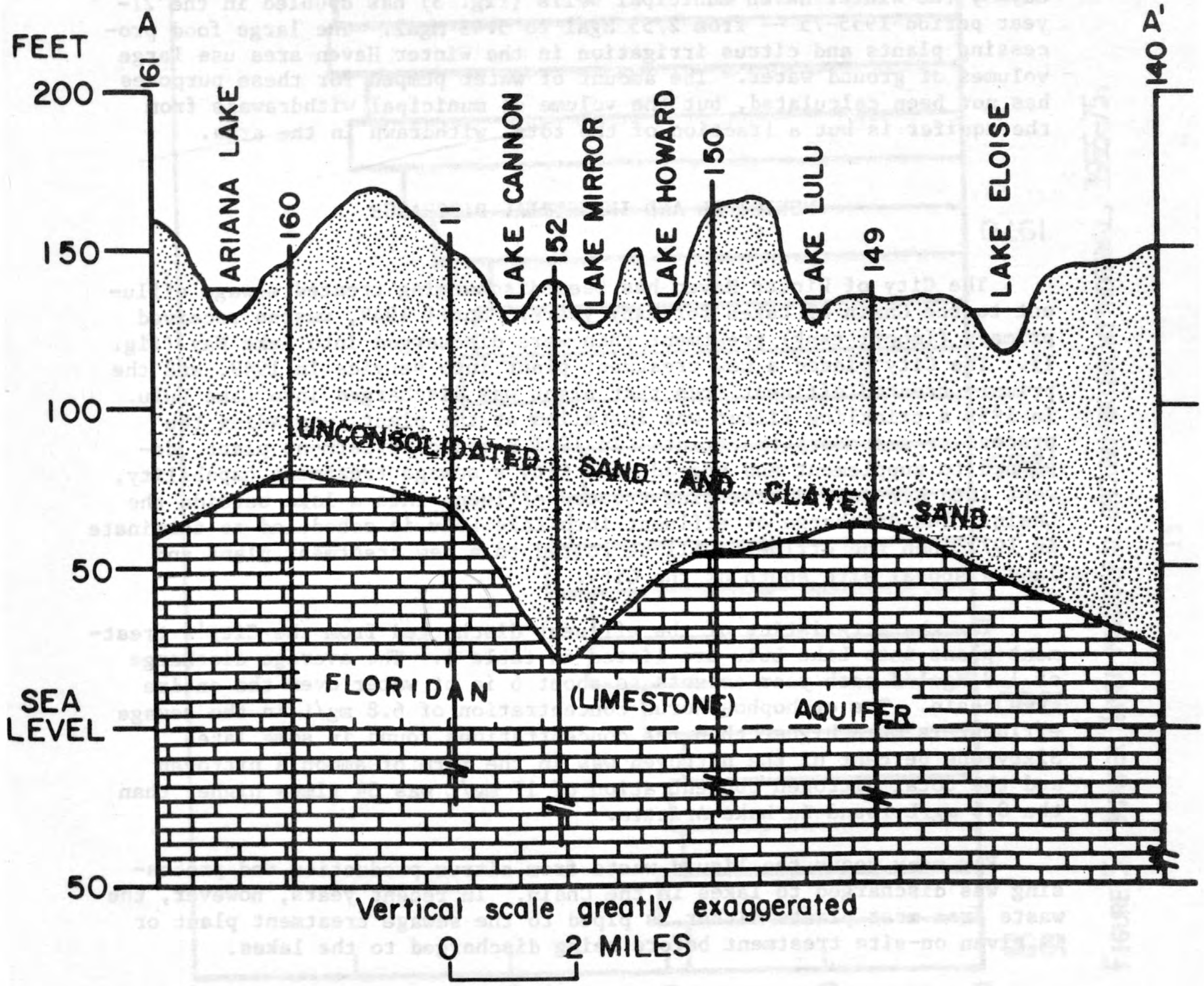

FIGURE 2. HYDROGEOLOGIC SECTION.

GROUND-WATER WITHDRAWAL

The quantity of ground water pumped from the Floridan aquifer each day by the Winter Haven municipal wells (fig. 3) has doubled in the 21-year period 1955-75 -- from 2.55 Mgal to 5.43 Mgal. The large food processing plants and citrus irrigation in the Winter Haven area use large volumes of ground water. The amount of water pumped for these purposes has not been calculated, but the volume of municipal withdrawals from the aquifer is but a fraction of the total withdrawn in the area.

MUNICIPAL AND INDUSTRIAL DISCHARGE

The City of Winter Haven has been discharging treated sewage effluent to the Chain of Lakes for many years. Until 1949, wastes received primary (Imhoff tank) treatment then were discharged into Lake May (fig. 1). The City placed a new treatment plant into service in 1949, and the primary treated effluent from that plant was discharged into Lake Lulu. In 1959 a trickling filter was installed at the plant, upgrading the process to secondary treatment. In 1971 a second treatment plant, designed to supplement and upgrade the City's sewage treatment capability, went into service, discharging treated effluent into a lake outside the Chain. The discharge of effluent into Lake Lulu is scheduled to terminate in 1977 when the effluent will be routed to a new treatment plant and land disposal site south of the City.

The characteristics of the effluent discharged from the City's treatment plant into Lake Lulu are listed in table 1. The average discharge of 1.8 Mgal/d each year amounts to about 6 in of water over the entire lake chain. The orthophosphorus concentration of 6.8 mg/L in the sewage effluent is much higher than the concentrations found in some lakes. Sixty-one percent of the nitrogen was in the form of ammonia nitrogen and the total nitrogen concentration of 17 mg/L was 34 times higher than the 0.5 mg/L found in Lake Arietta.

For many years the liquid waste from citrus production and processing was discharged to lakes in the Chain. In recent years, however, the waste from most plants either is piped to the sewage treatment plant or is given on-site treatment before being discharged to the lakes.

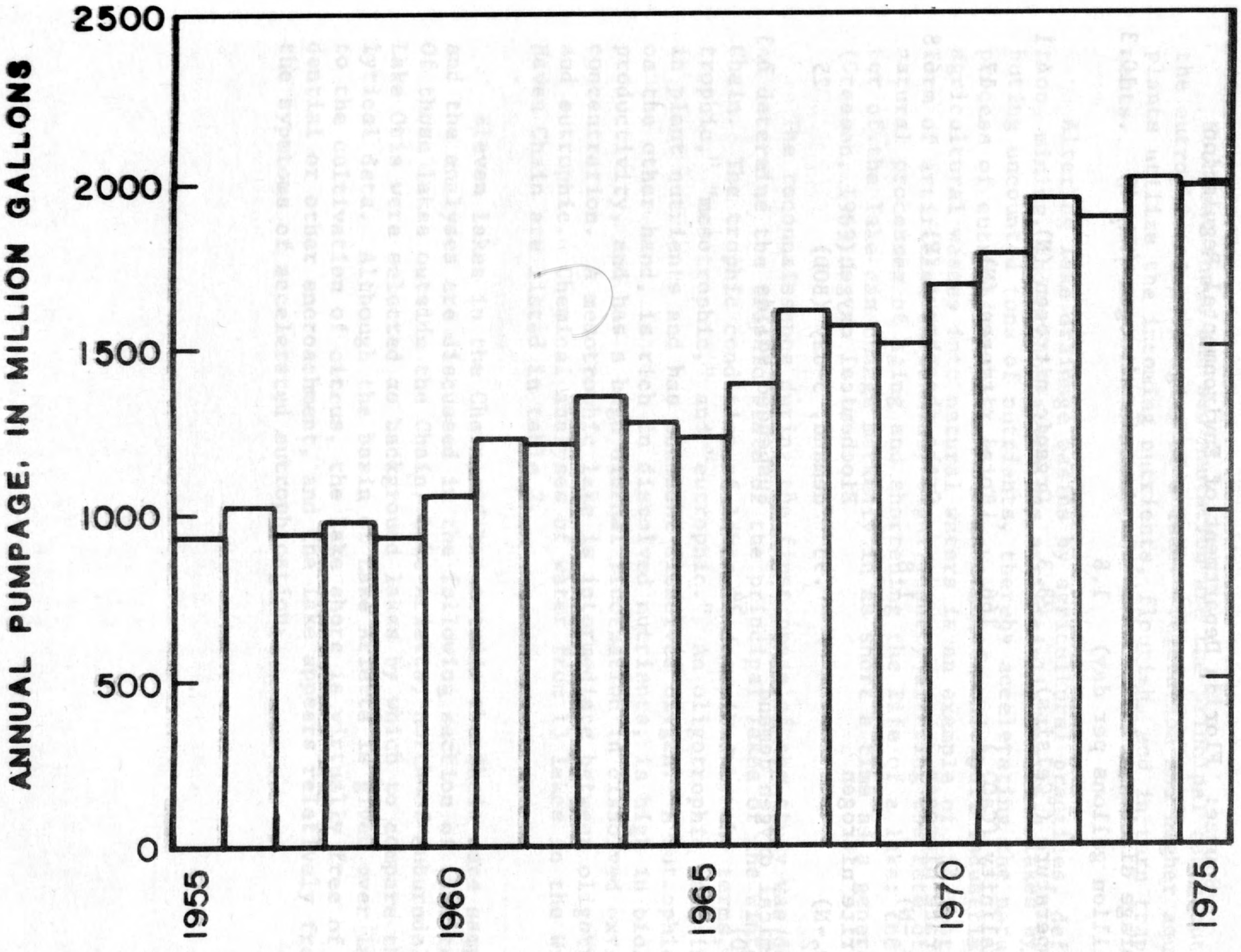

FIGURE 3. WINTER HAVEN MUNICIPAL GROUND-WATER WITHDRAWAL, 1955-75.

Table 1. -- Average of analyses of Winter Haven sewage effluent, 1974-76.

(Results in milligrams per liter except temperature and discharge.)

Source: Florida Department of Environmental Regulation

Average discharge 1972-75 (million gallons per day)	1.8	Ammonia nitrogen (NH_4-N)	10.3
Temperature (°Celsius)	28.3	Organic nitrogen (N)	4.1
Alkalinity ($CaCO_3$)	166	Total nitrogen (N)	17
Nitrate nitrogen (NO_3-N)	1.8	Ortho phosphorus (P)	6.8
Nitrite nitrogen (NO_2-N)	.93	Biochemical oxygen demand, 5-day (BOD)	25
Chemical oxygen demand (COD)	54	Suspended solids	7.3

CHEMICAL AND BIOLOGICAL CONDITIONS

Nutrient input and sedimentation are the principal contributors to the eutrophication or aging of a lake. Vegetation and higher aquatic plants utilize the incoming nutrients, flourish, and in turn trap sediments.

Altering lake drainage basins by agricultural practices, deforestation, mining, and urbanization has artificially enriched lakes by contributing uncounted tons of nutrients, thereby accelerating the natural process of eutrophication. The discharge of municipal, industrial, and agricultural wastes into natural waters is an example of the most severe form of artificial enrichment, significantly altering the rate of the natural processes of aging and shortening the life of a lake; the character of the lake can change markedly in as short a time as a generation (Greeson, 1969).

The reconnaissance during the first phase of the study was designed to determine the trophic state of the principal lakes of the Winter Haven Chain. The trophic condition of lakes is described by the terms, "oligotrophic," "mesotrophic," and "eutrophic." An oligotrophic lake is low in plant nutrients and has abundant dissolved oxygen. A eutrophic lake, on the other hand, is rich in dissolved nutrients, is high in biological productivity, and has a high diurnal fluctuation in dissolved oxygen concentration. A mesotrophic lake is intermediate between oligotrophic and eutrophic. Chemical analyses of water from 13 lakes in the Winter Haven Chain are listed in table 2.

Eleven lakes in the Chain and two outside the Chain were sampled and the analyses are discussed in the following section of this report. Of those lakes outside the Chain, Lake Arietta, north of Auburndale, and Lake Otis were selected as background lakes by which to compare the analytical data. Although the basin of Lake Arietta is given over largely to the cultivation of citrus, the lake shore is virtually free of residential or other encroachment, and the lake appears relatively free of the sypmtoms of accelerated eutrophication.

Table 2. -- Chemical analyses of water from 13 lakes in the Winter Haven area.

(Results are in milligrams per liter except as noted.)

Lake name	Date of collection	Time of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Alkalinity as $CACO_3$, total	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate, total as N	Nitrite, total as N	Nitrogen ammonia, total as N	Nitrogen, total organic as N	Nitrogen, total as N	Phosphorus, total ortho as P	Phsophorus, total as P
Winterset	3-16-76	1130	0.2	22	8.8	36	11	88	0	72	41	42	0.4	0	0	0.08	1.5	1.6	0.01	0.06
	5-04-76	1215														.10	1.1	1.2	.02	.05
Eloise	3-16-76	1300	.2	26	7.8	33	0.10	101	0	83	39	36	.4	0	0	.06	1.8	1.9	.18	.38
	5-04-76	1330														.19	2.6	2.8	.12	.31
Lulu	3-16-76	1500	5.5	24	6.7	33	9.4	100	0	82	36	32	.3	0	0	.11	5.0	5.1	1.4	1.4
	5-04-76	1530	6.8	23	5.8	34	9.8	97	0	80	42	--	.4			.46	4.7	5.2	.40	1.3
Shipp	3-15-76	1730												0	0	.27	2.7	3.0	.05	.19
	5-04-76	1700														.33	2.9	3.2	.02	.18
Howard	3-15-76	1515	.3	20	5.3	16	5.3	68	0	56	24	23	.3	0	0	.29	2.1	2.4	.05	.10
	5-05-76	1700	.6	20	5.6	16	6.0	72	0	59	26	20	.5			.39	3.4	3.8	.07	.09
Mirror	3-17-76	1500												0	0	0	1.4	1.4	.04	.04
	5-05-76	1600														.22	1.7	1.9	.04	.06
Spring	3-17-76	1530														--	---	---	---	---
	5-05-76	----												0	0	.41	0.98	1.4	.02	.06
Cannon	3-15-76	1615												0	0	.17	1.4	1.6	.03	.08
	5-05-76	1640														.30	1.9	2.2	.05	.09
Idylwild	3-17-76	1415												0	0	.02	.61	0.63	.03	.06
	5-05-76	1430														.17	.72	.89	.02	.08
Hartridge	3-17-76	1300	2.2	4.8	5.8	16	5.5	17	0	14	32	22	.2	0	0	.03	.59	.62	.03	.04
	5-05-76	1130	1.9	5.7	6.0	17	6.8	21	0	17	30	24	.3			.06	3.1	3.2	.01	.04
Jessie	3-17-76	1130												0	0	.06	0.96	1.0	.08	.12
	5-05-76	1300														.17	1.3	1.5	.03	.10
Arietta	3-18-76	1615	0.1	6.5	10	19	4.7	14	0	11	50	28	.3	0	0	.05	0.37	.42	0	.08
	5-06-76	1245														.03	0.46	.49	.01	.02
Otis	5-06-76	1530																		

Table 2 (Continued). -- Chemical analyses of water from 13 lakes in the Winter Haven area.

(Results are in milligrams per liter except as noted.)

Lake name	Date of collection	Time of collection	Dissolved solids (residue at 180°C)	Hardness as $CaCo_3$ (Ca, mg)	Specific conductance (micromhos/cm at 25°C)	pH (units)	Color (units)	Turbidity (JTU)	Transparency Secchi Disk (feet)	Dissolved oxygen (DO)	Biochemical oxygen demand (BOD) 5-day 20°C	Chemical oxygen demand (COD)	Phytoplankton (cells/ml)	Total organic carbon (C)	Total inorganic carbon (C)	Total carbon (C)
Winterset	3-16-76	1130	231	91	395	8.1	20	3	4.1	8.5	2.1	37	$0.3x10^6$	13	16	29
	5-04-76	1215	---		405	8.1	15	2	4.0	7.1	2.5	47	----	12	17	29
Eloise	3-16-76	1300	240	97	390	9.2	45	6	2.4	7.9	5.0	69	$1.8x10^6$	26	15	41
	5-04-76	1330	---		397	9.6	33	7	---	10.9	7.4	56	----	18	15	33
Lulu	3-16-76	1500	218	88	372	9.4	80	35	0.8	8.6	9.1	150	$0.91x10^6$	42	14	56
	5-04-76	1530	266	82	365	9.9	60	40	---	11.8	12	160	----	49	12	61
Shipp	3-16-76	1730	---		275	9.3	--	15	1.2	10.7	12.1	80	----	13	15	28
	5-04-76	1700	---		280	9.4	60	9	1.0	11.2	16	87	----	24	13	37
Howard	3-15-76	1515	149	72	242	8.3	45	8	1.5	9.7	9.6	69	$1.6x10^6$	9	12	21
	5-05-76	1700	145	73	255	9.2	150	15	1.5	8.5	8.4	83	----	23	11	34
Mirror	3-17-76	1500	---		259	7.8	--	7	1.8	7.8	3.7	43	----	18	11	29
	5-05-76	1600	---		292	8.3	29	6	1.8	6.9	4.0	55	----	15	13	28
Spring	3-17-76	1530	---		257	---	--	--	2.3	8.6	---	--	----	--	--	--
	5-05-76	-----	---		305	7.2	24	3	3.0	---	3.6	27	----	11	14	25
Cannon	3-15-76	1615	---		208	8.4	--	6	1.8	10.4	4.9	39	----	5	10	15
	5-05-76	1640	---		232	9.2	70	15	1.8	8.4	4.6	55	----	18	8	26
Idylwild	3-17-76	1415	---		174	6.9	--	5	3.4	7.7	2.8	28	----	10	6	16
	5-05-76	1430	---		207	8.7	32	6	2.4	8.3	3.1	43	----	13	5	18
Hartridge	3-17-76	1300	103	36	173	6.6	20	5	4.0	8.0	2.6	34	86,000	9	2	11
	5-05-76	1130	99	39	186	6.1	18	3	4.2	6.9	1.8	23	----	7	5	12
Jessie	3-17-76	1130	---		162	6.6	--	6	2.4	7.7	3.4	34	----	8	5	11
	5-05-76	1300	---		187	8.3	36	6	2.2	7.9	3.6	41	----	7	6	13
Arietta	3-18-76	1615	131	57	236	6.0	10	2	6[a]	8.6	1.3	9.3	45,000	5	1	6
	5-06-76	1245	---		255	7.9	6	1	4[a]	7.0	1.3	11	----	4	3	7
Otis	5-06-76	1530	---		279	8.2	10	1	---	---	1.1	16	----	3	7	10

[a]estimated value

Specific Conductance

Specific conductance is a physical property of water which, among other things, is an index to the concentration of dissolved solids in the water. Specific conductance of water from lakes in the upper part of the Chain, Lakes Jessie and Hartridge, was 180 umho/cm at 25°C and increased generally through the Chain to about 400 umho/cm in Lakes Eloise and Winterset. Lake Arietta contained water whose specific conductance averaged about 250 umho/cm, (fig. 4).

Turbidity

Turbidity data for natural waters are applied to several uses, including: (1) determination of the depth to which photosynthesis can occur, (2) aesthetic evaluation of water used for recreation, and (3) estimation of concentration of suspended sediment. Turbidity generally is measured as an optical phenomenon and should be reported in optical units (Pickering, 1976). The instrument originally designed for turbidity measurement is the Jackson Candle Turbidimeter, a laboratory device that actually measures a combination of optical parameters such as light scattering, absorption, and reflectance, using the human eye as the detector (Pickering, 1976). The turbidity data listed in this report are reported as JTU (Jackson Turbidity Units).

Turbidity in samples from lakes in the Chain was generally less than 15 JTU, except in Lake Lulu, where turbidity was 35-40 JTU. Water from Lake Winterset in the Chain had the lowest turbidity, about 2 JTU. The turbidity of water in Lake Arietta was 1 to 2 JTU (fig. 5).

Biochemical Oxygen Demand

The 5-day BOD, a measure of the oxygen consumed by biochemical processes in 5 days, is an indication of the degree of organic pollution from such sources as domestic wastes. BOD was less than 5 mg/L in Lakes Jessie, Hartridge, Cannon, and Winterset, and more than 5 mg/L in Lakes Howard, Shipp, Lulu, and Eloise (fig. 6). BOD in Lake Arietta was 1.3 mg/L.

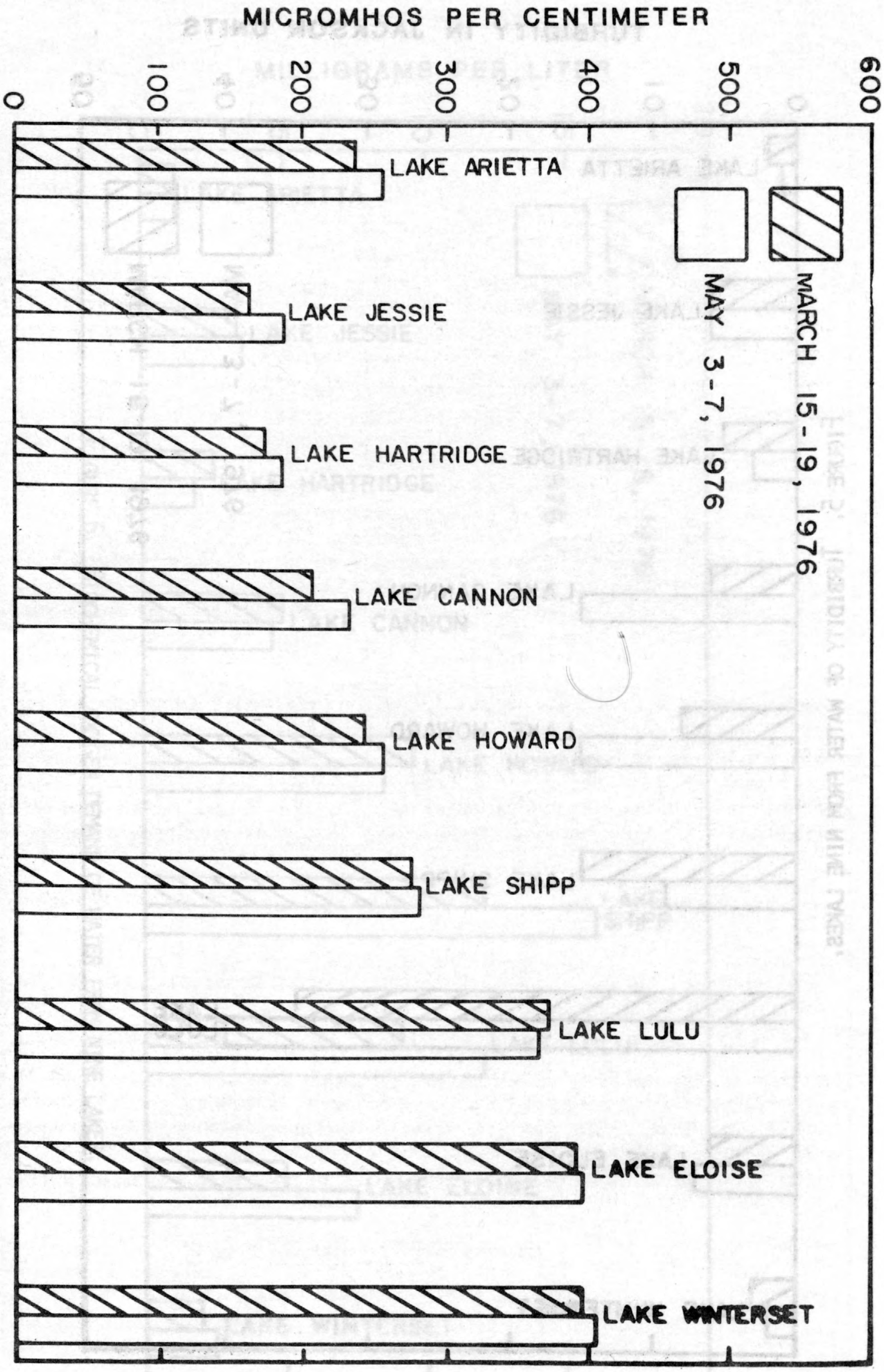

FIGURE 4. SPECIFIC CONDUCTANCE OF WATER FROM NINE LAKES.

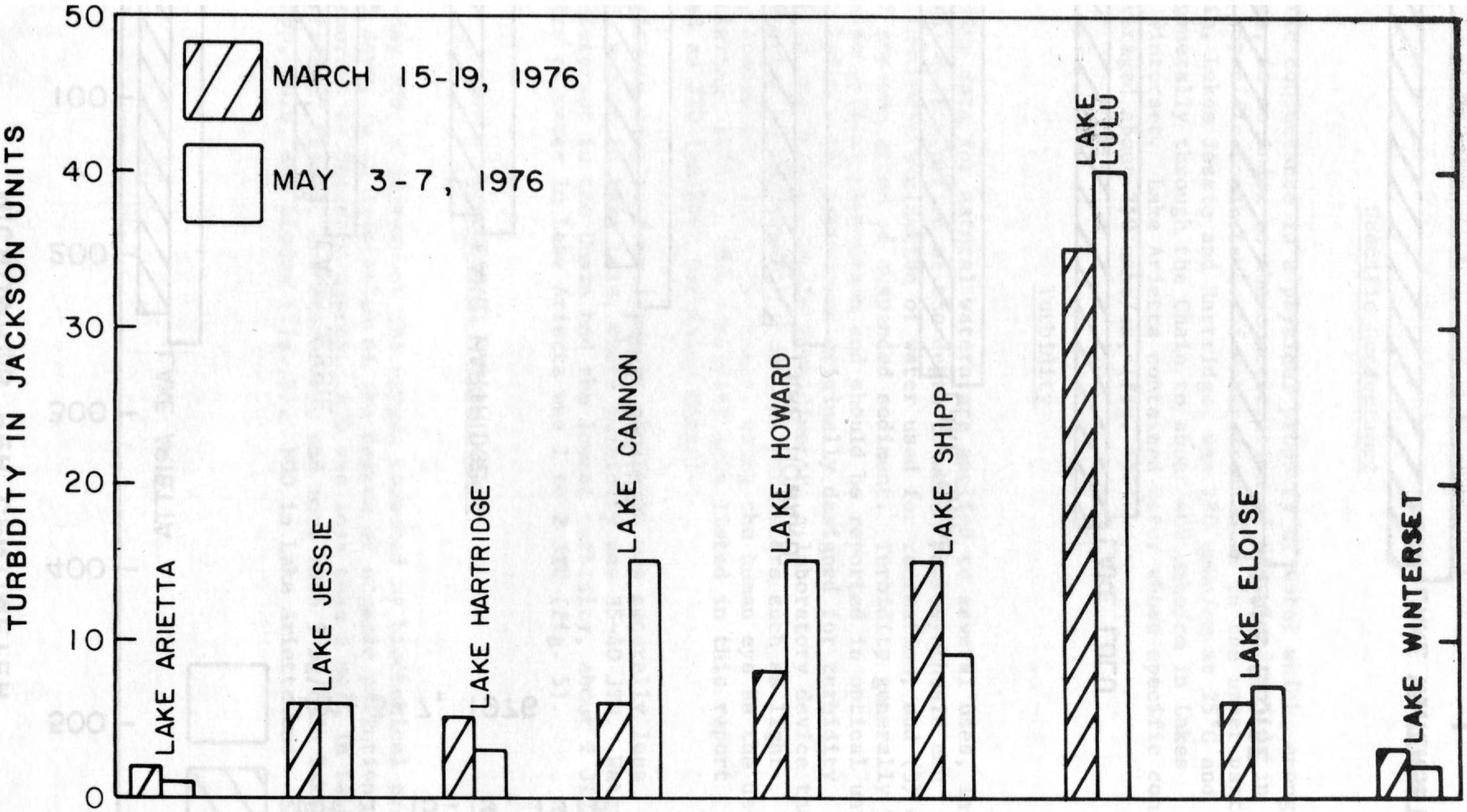

FIGURE 5. TURBIDITY OF WATER FROM NINE LAKES.

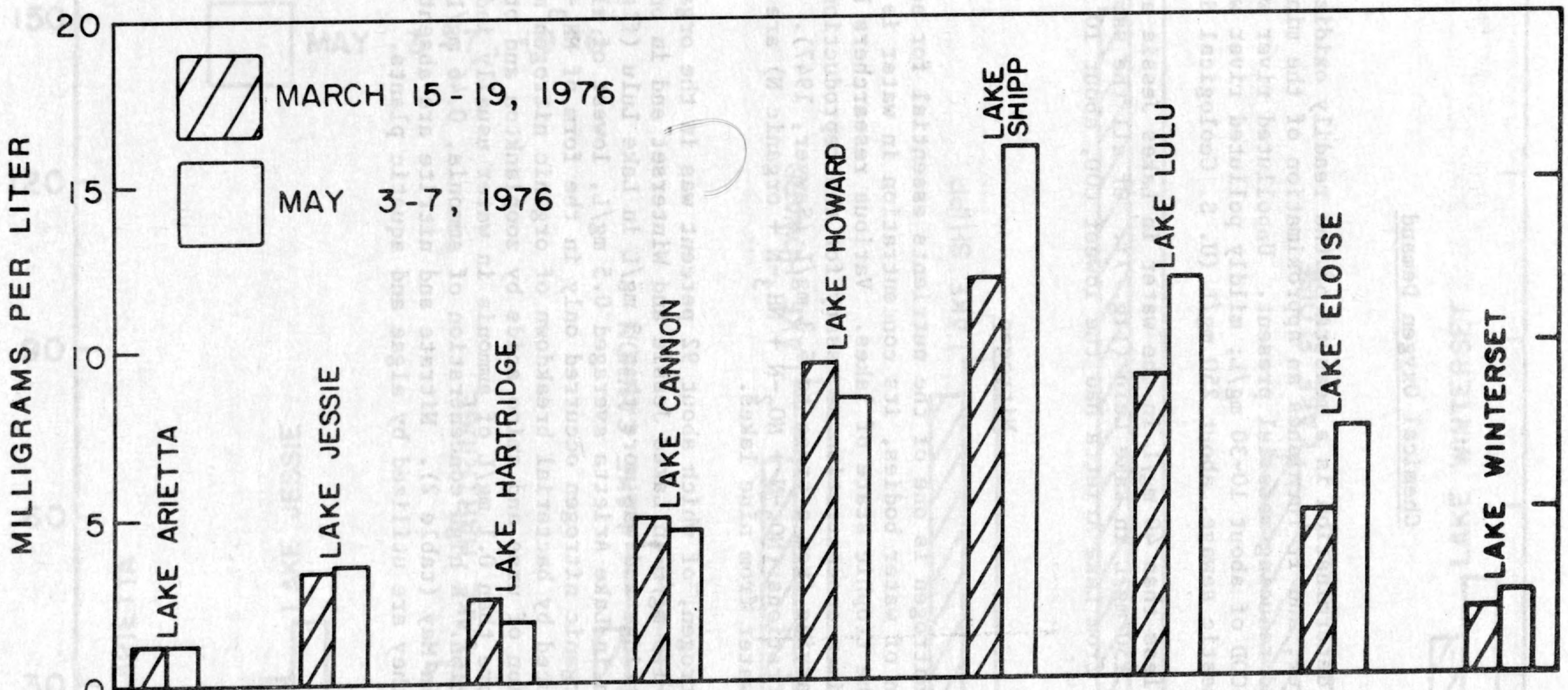

FIGURE 6. BIOCHEMICAL OXYGEN DEMAND OF WATER FROM NINE LAKES.

Chemical Oxygen Demand

The COD determination is a measure of the readily oxidizable material in the water, and it furnishes an approximation of the minimum amount of organic and reducing material present. Unpolluted river water generally has a COD of about 10-30 mg/L; mildly polluted river water, 25-50 mg/L, and domestic sewage, about 250 mg/L (U. S. Geological Survey, 1972).

COD was less than 40 mg/L in the water in Lakes Jessie and Hartridge and more than 150 mg/L in Lake Lulu (fig. 7). Of all the samples collected, those from Lake Arietta had the lowest COD, about 10 mg/L.

Nitrogen

Because nitrogen is one of the nutrients essential for accelerated eutrophication of water bodies, its concentration in water is one of the measures of the trophic state of lakes. Various researchers have estimated the minimum concentration necessary for the reproduction and growth of algae as varying from a trace to 5.3 mg/L (Sawyer, 1947). Total nitrogen concentrations (NO_3-N + NO_2-N + NH_3-N + organic N) are shown in figure 8 for water from nine lakes.

Total nitrogen, of which about 92 percent was in the organic form, was less than 1.6 mg/L in Lakes Jessie and Winterset and in one sample from Lake Hartridge and was more than 5 mg/L in Lake Lulu (fig. 8). Total nitrogen in Lake Arietta averaged 0.5 mg/L, lowest of all lakes sampled. Inorganic nitrogen occurred only in the form of NH_3-N. Ammonia is produced by bacterial breakdown of organic nitrogen material and by excretion of urea and amino acids by zooplankton and other aquatic organisms. More than 0.1 mg/L of ammonia in water usually indicates organic pollution. A high concentration of ammonia, 0.46 mg/L, occurred in Lake Lulu in May (table 2). Nitrate and nitrite are absent from solution because they are utilized by algae and aquatic plants.

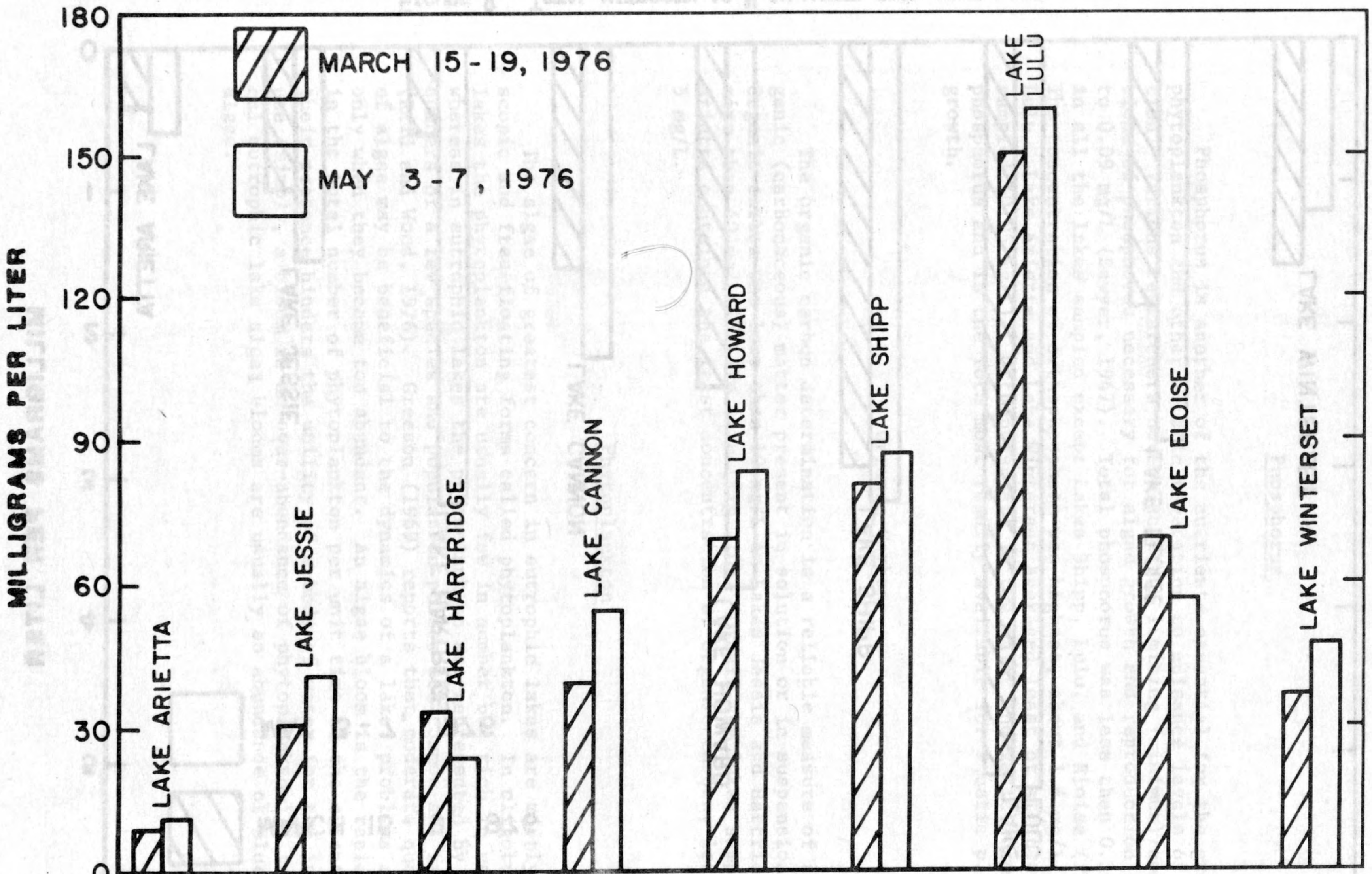

FIGURE 7. CHEMICAL OXYGEN DEMAND OF WATER FROM NINE LAKES.

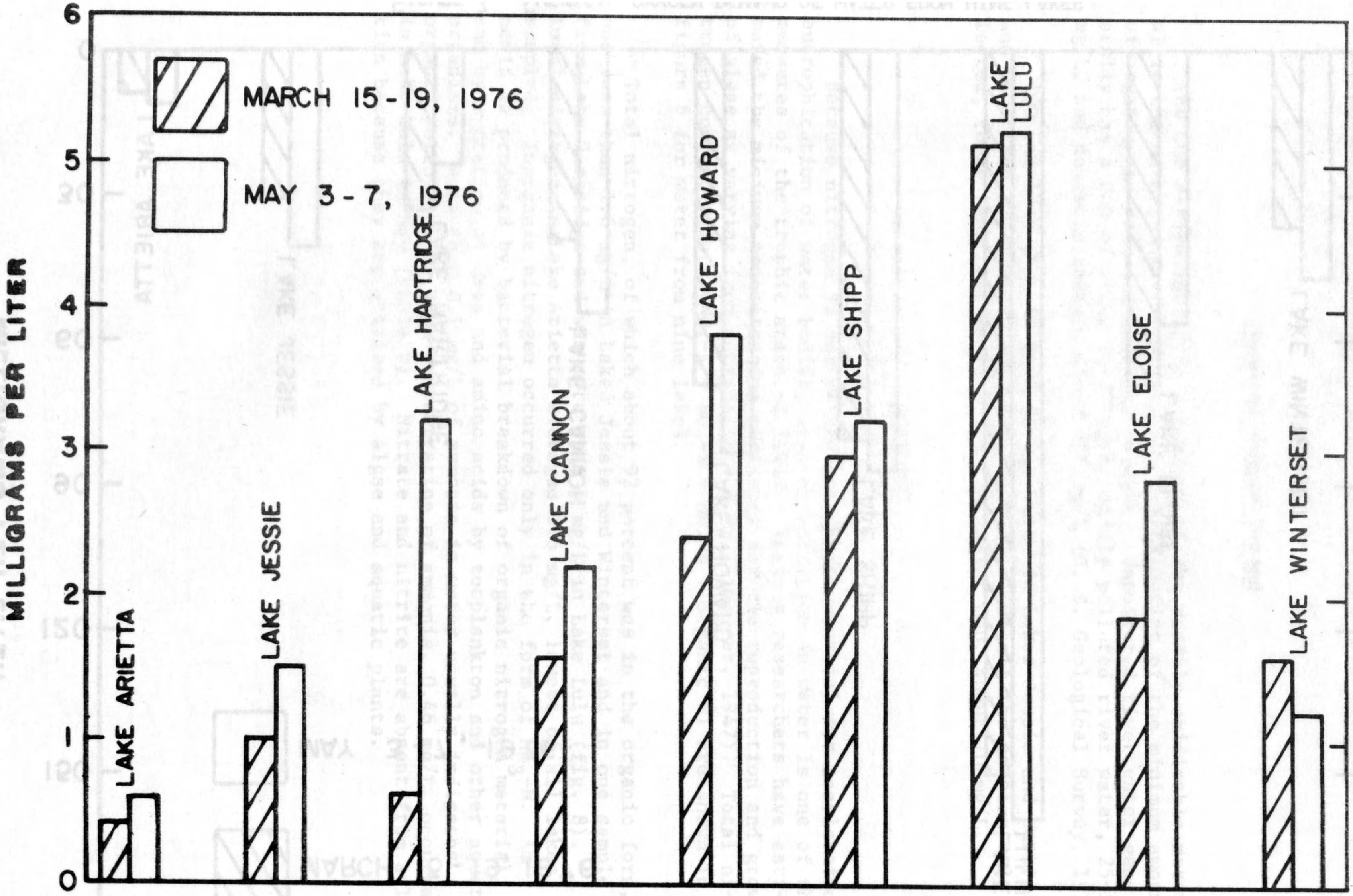

FIGURE 8. TOTAL NITROGEN AS N IN WATER FROM NINE LAKES.

Phosphorus

Phosphorus is another of the nutrients essential for the growth of phytoplankton and other aquatic vegetation to nuisance levels of production. Various researchers have placed the limiting (minimum) concentrations of phosphorus necessary for algae growth and reproduction as 0.002 to 0.09 mg/L (Sawyer, 1947). Total phosphorus was less than 0.10 mg/L in all the lakes sampled except Lakes Shipp, Lulu, and Eloise (fig. 9). The concentration of orthophosphate was highest, about 1.4 mg/L, in Lake Lulu. Lake Arietta and Lake Winterset averaged least of all the lakes sampled (0.05 mg/L). Orthophosphate is the major inorganic form of phosphorus and is the form most readily available for aquatic plant growth.

Organic Carbon

The organic carbon determination is a reliable measure of the organic (carbonaceous) matter present in solution or in suspension in water. Organic carbon was less than 10 mg/L in Lakes Jessie and Hartridge and more than 40 mg/L in Lake Lulu (fig. 10). Of all the lakes sampled, Lake Arietta contained the least concentration of organic carbon, less than 5 mg/L.

Phytoplankton

The algae of greatest concern in eutrophic lakes are mostly microscopic and free-floating forms called phytoplankton. In oligotrophic lakes the phytoplankton are usually few in number but rich in variety, whereas in eutrophic lakes the phytoplankton are represented by large numbers of a few species and population pulses are common and frequent (Reid and Wood, 1976). Greeson (1969) reports that moderate quantities of algae may be beneficial to the dynamics of a lake; problems arise only when they become too abundant. An algae bloom is the rapid increase in the total number of phytoplankton per unit time to the extent that their presence hinders the utility of a body of water for the intended use (simply, a bloom is an over-abundance of phytoplankton). In a typical eutrophic lake algal blooms are usually an abundance of blue-green algae.

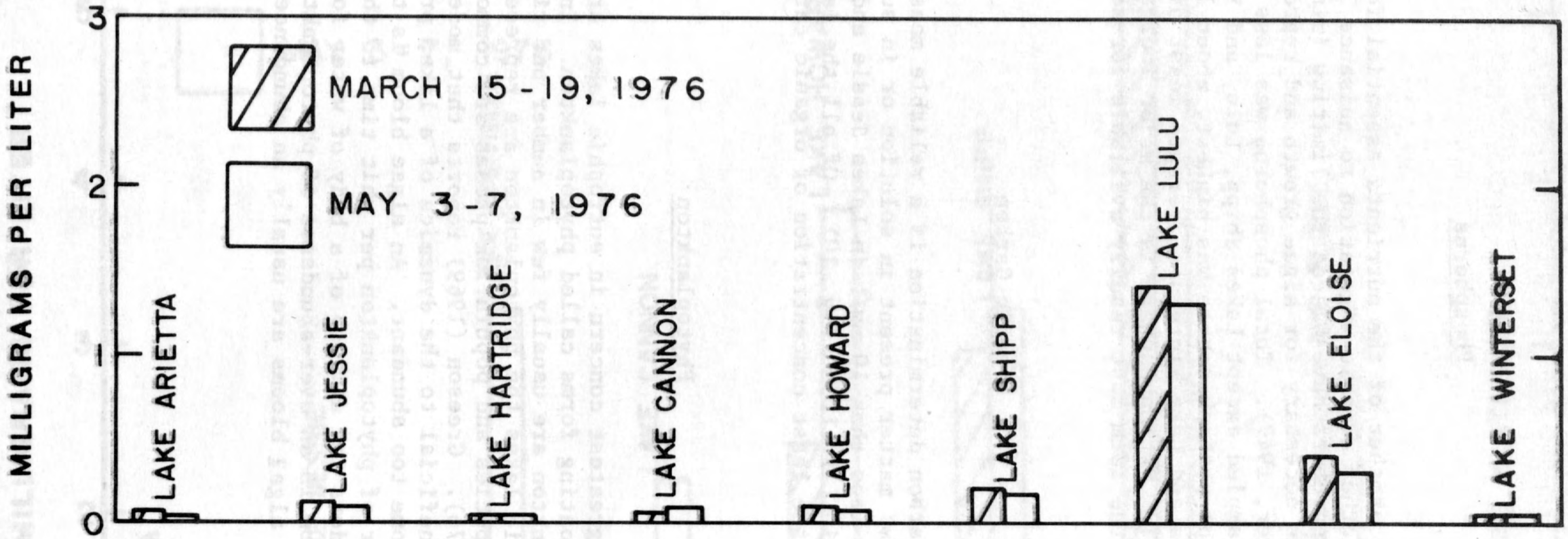

FIGURE 9. TOTAL PHOSPHORUS AS P IN WATER FROM NINE LAKES.

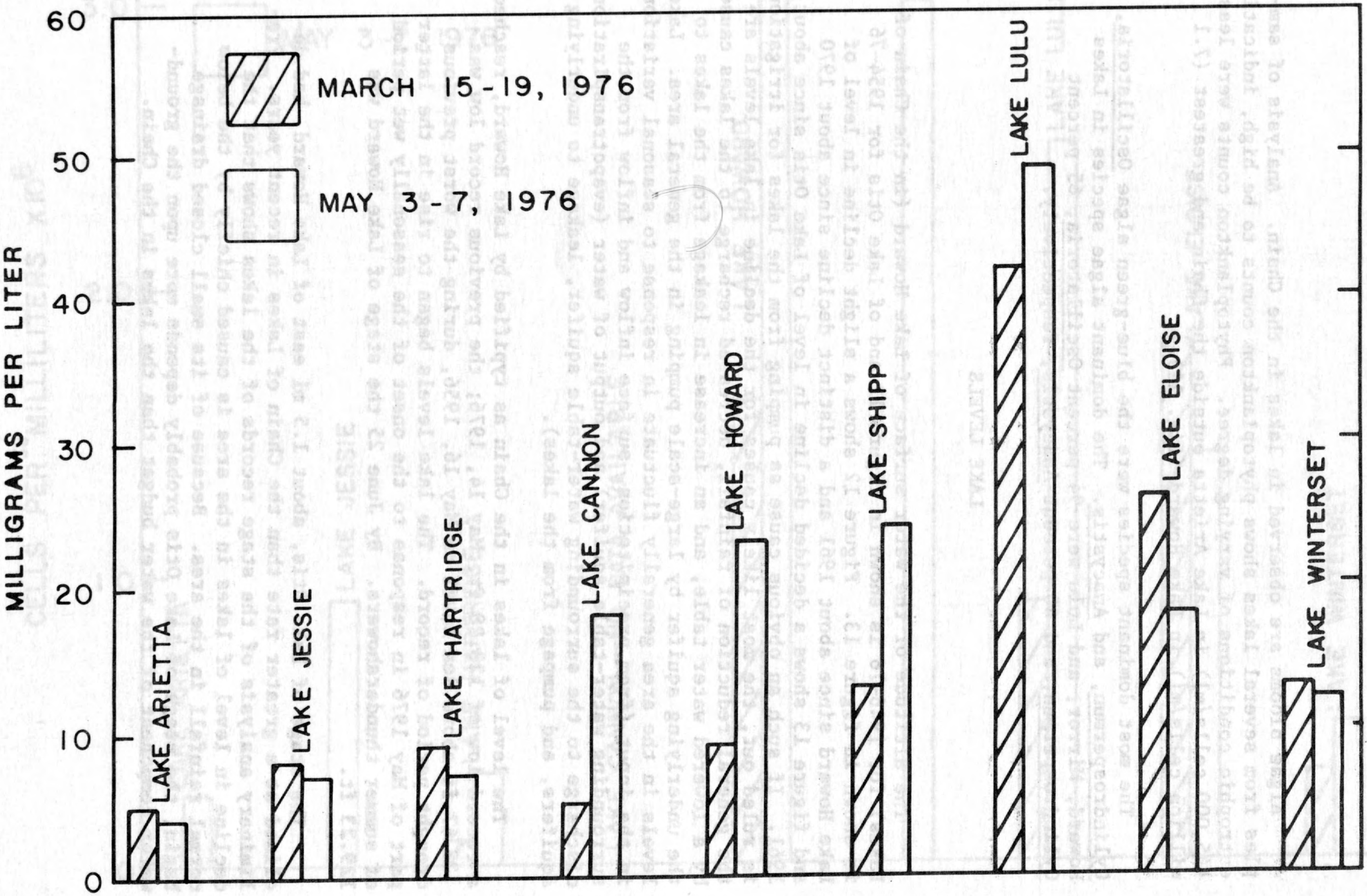

FIGURE 10. ORGANIC CARBON IN WATER FROM NINE LAKES.

Algae blooms are observed in lakes in the Chain. Analysis of samples from several lakes shows phytoplankton counts to be high, indicating eutrophic conditions of varying degree. Phytoplankton counts were least (45,000 cells/ml) in Lake Arietta outside the Chain and greatest (7.1 million cells/ml) in Lake Howard (fig. 11).

The most dominant species were the blue-green algae *Oscillatoria*, *Cylindrospermun*, and *Anacystis*. The dominant algae species in Lakes Howard, Mirror, and Lulu were 94 percent *Oscillatoria*, 65 percent *Cylindrospermun*, and 60 percent *Anacystis*, respectively.

LAKE LEVELS

The altitude of the water surface of Lake Howard (in the Chain of Lakes) for 1946-76 is shown in figure 12 and of Lake Otis for 1954-76 is shown in figure 13. Figure 12 shows a slight decline in level of Lake Howard since about 1961 and a distinct decline since about 1970 and figure 13 shows a decided decline in level of Lake Otis since about 1961. If such an obvious cause as pumping from the lakes for irrigation is ruled out, the most likely causes for the decline in lake levels are the general reduction of rainfall, decreased recharge to the lakes caused by a lowered water table, and an increase in leakage from the lakes to the underlying aquifer by large-scale pumping in the general area. Lake levels in the area generally fluctuate in response to seasonal variations in the input (from precipitation, surface inflow and inflow from the surrounding water-table aquifer) and output of water (evapotranspiration, discharge to the surrounding water-table aquifer, leakage to underlying aquifers, and pumpage from the lakes).

The level of lakes in the Chain as typified by Lake Howard, reached a record low of 128.28 ft, May 14, 1976; the previous record low was 128.67 ft above sea level on May 16, 1956, during the worst previous drought period of record. The lake levels began to rise in the latter part of May 1976 in response to the onset of the seasonally wet period of summer thundershowers. By June 25 the stage of Lake Howard was 129.23 ft.

The stage of Lake Otis, about 1.5 mi east of Lake Howard, had declined at a greater rate than the Chain of Lakes in recent years. Preliminary analysis of the stage records of the lakes shows that the decline in level of lakes in the area is caused chiefly by the below normal rainfall in the area. Because of its small closed drainage basin, the stage of Lake Otis probably depends more upon the groundwater component of the water budget than the lakes in the Chain.

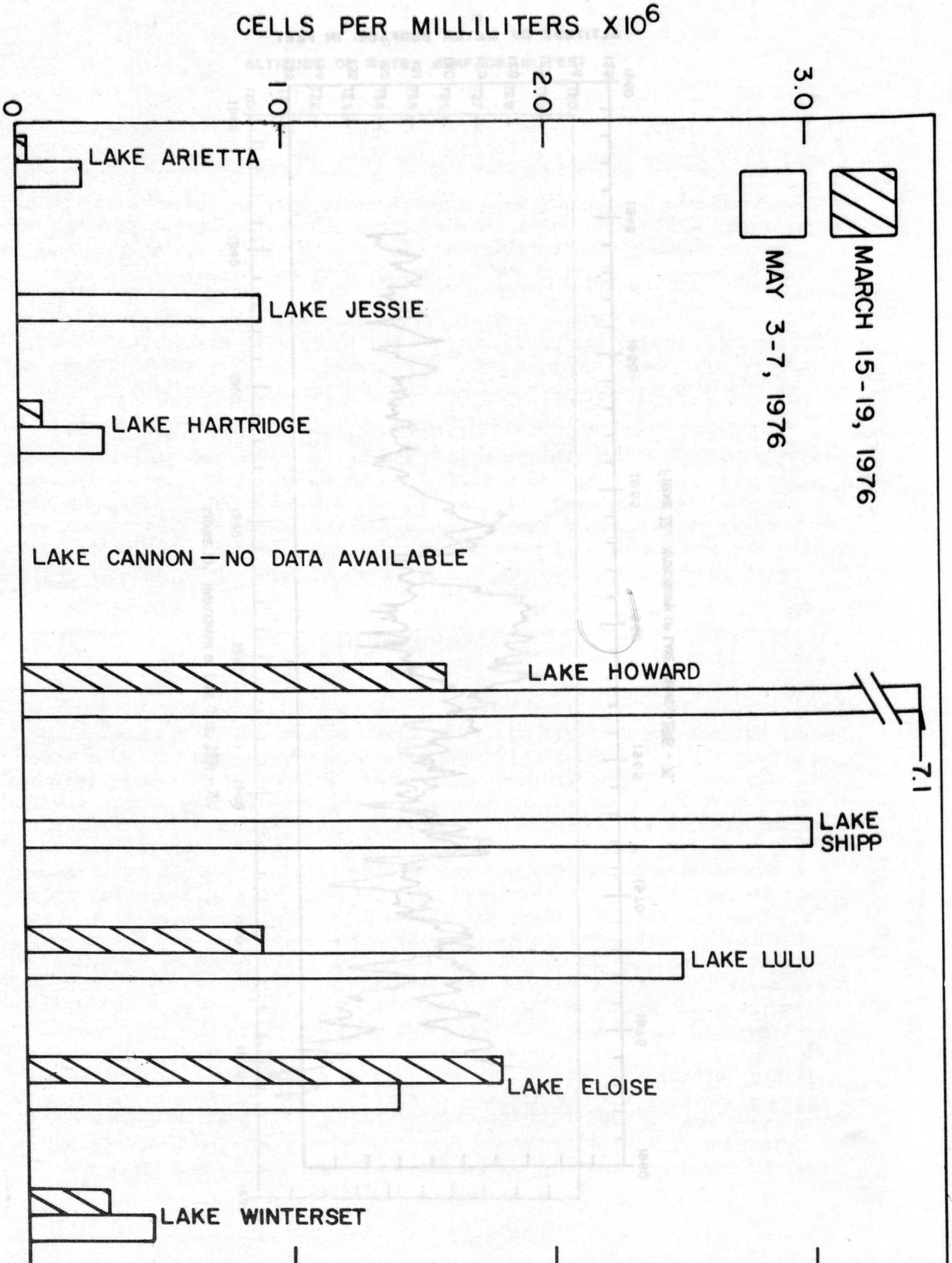

FIGURE 11. PHYTOPLANKTON IN WATER FROM NINE LAKES.

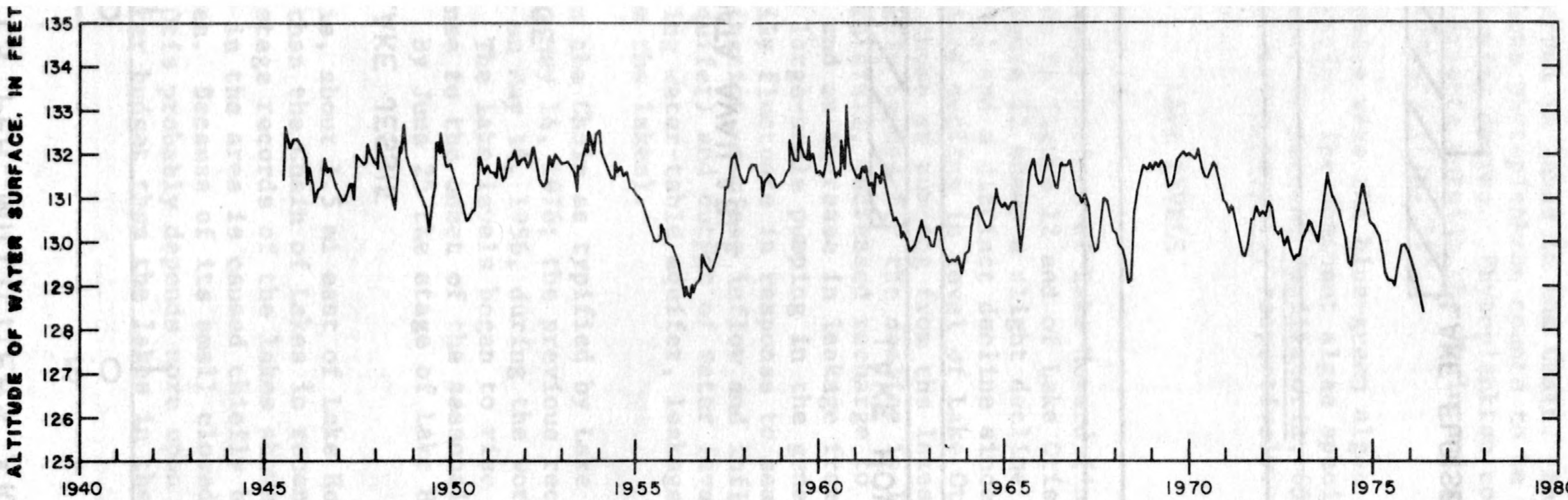

FIGURE 12. HYDROGRAPH OF LAKE HOWARD, 1945 - 76.

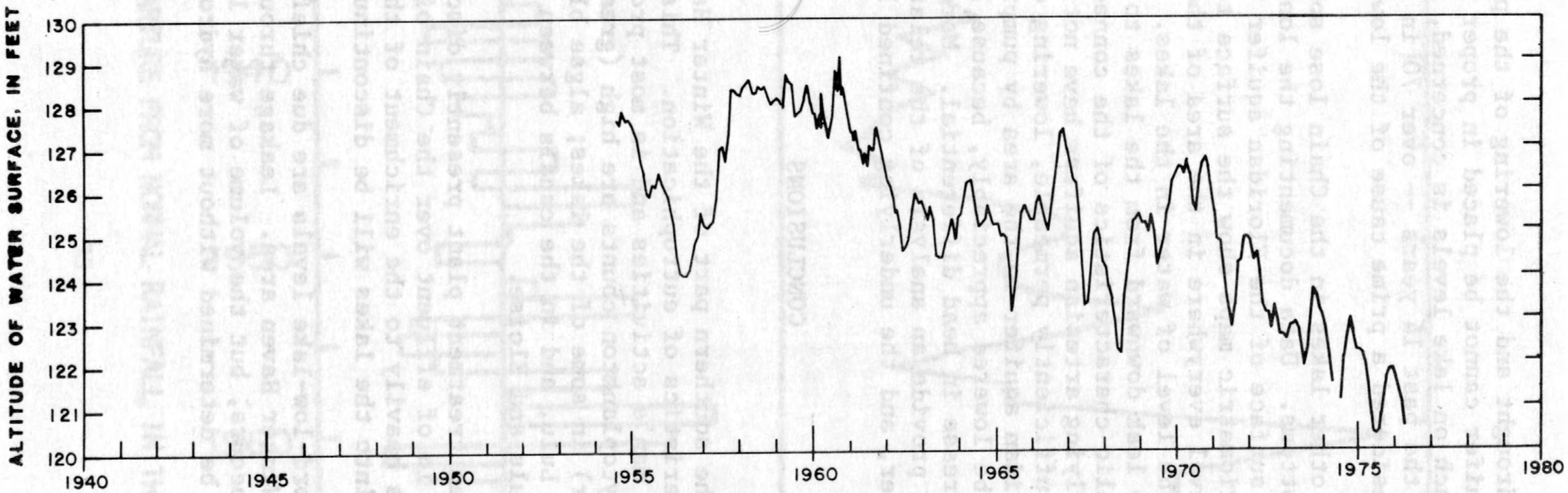

FIGURE 13. HYDROGRAPH OF LAKE OTIS, 1954 - 76.

Although the drought and the lowering of the potentiometric surface of the Floridan aquifer cannot be placed in proper perspective insofar as the effect of each on lake levels is concerned, the extreme deficiency of rainfall during the past 14 years -- over 70 in from 1960 until April 1976 -- must be considered a prime cause of the low lake levels (fig. 14).

Lake Otis and other lakes in the Chain lose some water by leakage through the lake bottoms. Data documenting the long-term fluctuations in the potentiometric surface of the Floridan aquifer in the area are sparse, but regional potentiometric maps show the surface to be between 110 and 120 ft above sea level everywhere in the area of the Chain, or roughly 10 to 20 ft below the level of water in the lakes. Hence, the potential exists for water to leak downward from the lakes to the Floridan aquifer. However, the hydraulic characteristics of the connection between the lakes and the underlying artesian aquifers have not been defined. If the connection is sufficiently permeable, lowering of the potentiometric surface of the Floridan aquifer in the area by pumping would also cause the lake levels to be lowered appreciably, because leakage would increase with the increase in head differential. More detailed information is required to provide an analysis of the relation between the lakes, the surficial aquifer, and the underlying confined limestone aquifer.

CONCLUSIONS

The lakes in the southern part of the Winter Haven Chain of Lakes exhibit the characteristics of eutrophication. This eutrophication has been accelerated by man's activities and is most pronounced in Lakes Lulu and Shipp. Phytoplankton counts are high (greater than a million cells per milliliter) in some of the lakes; algae blooms were observed in Lakes Howard and Lulu, and in the canals between Lakes Shipp and Lulu, and between Lakes Lulu and Eloise.

The Winter Haven treatment plant presently discharges annually on the average about 6 in of effluent over the Chain of Lakes. The sewage effluent contributes heavily to the enrichment of the lakes. The discharge of effluent into the lakes will be discontinued in 1977.

The recent record-low-lake levels are due chiefly to the deficiency of rainfall in the Winter Haven area. Leakage through the bottoms of the lakes probably occurs, but the volume of water lost to the underlying aquifers cannot be determined without more hydrologic information.

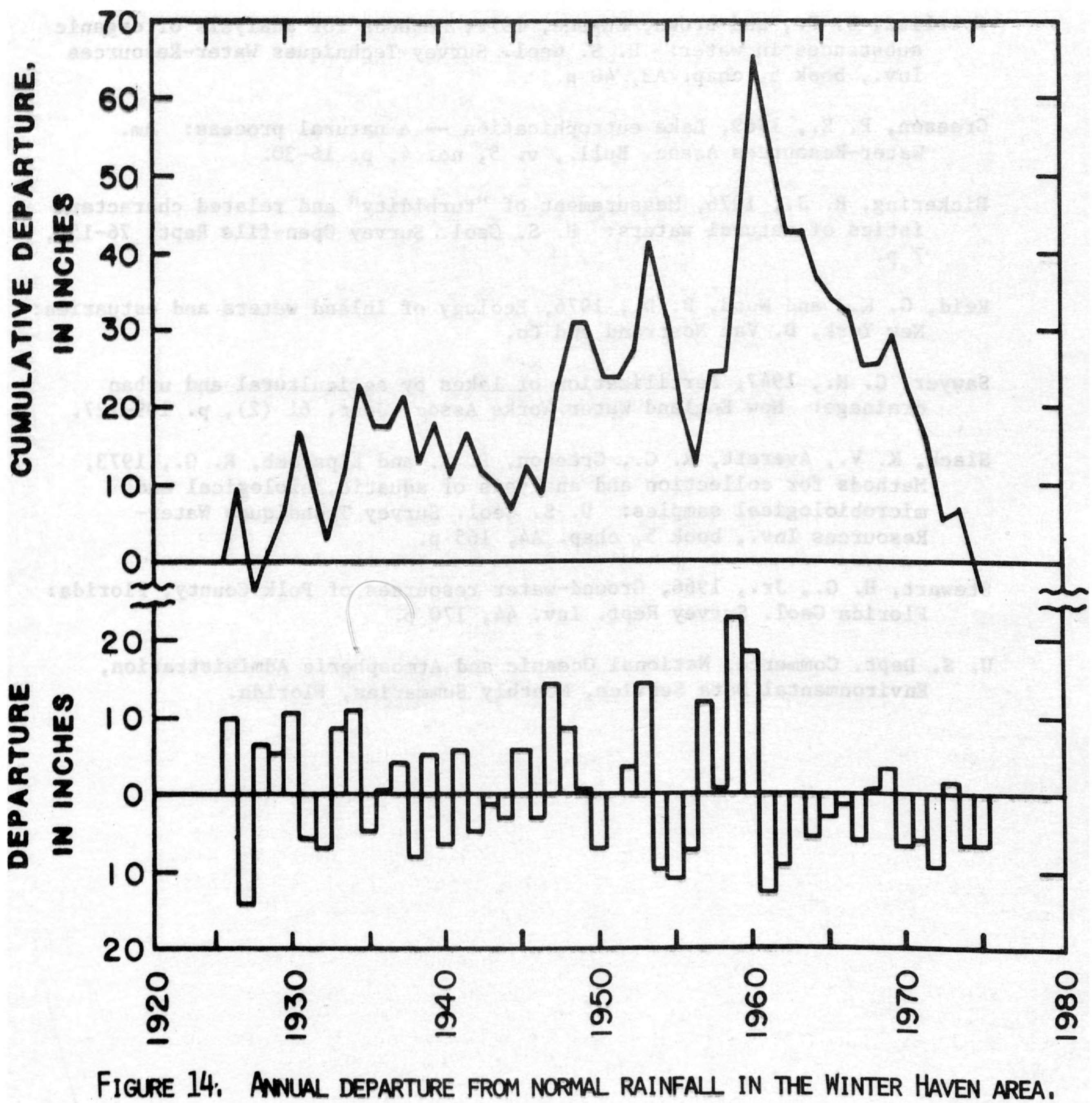

FIGURE 14. ANNUAL DEPARTURE FROM NORMAL RAINFALL IN THE WINTER HAVEN AREA.

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