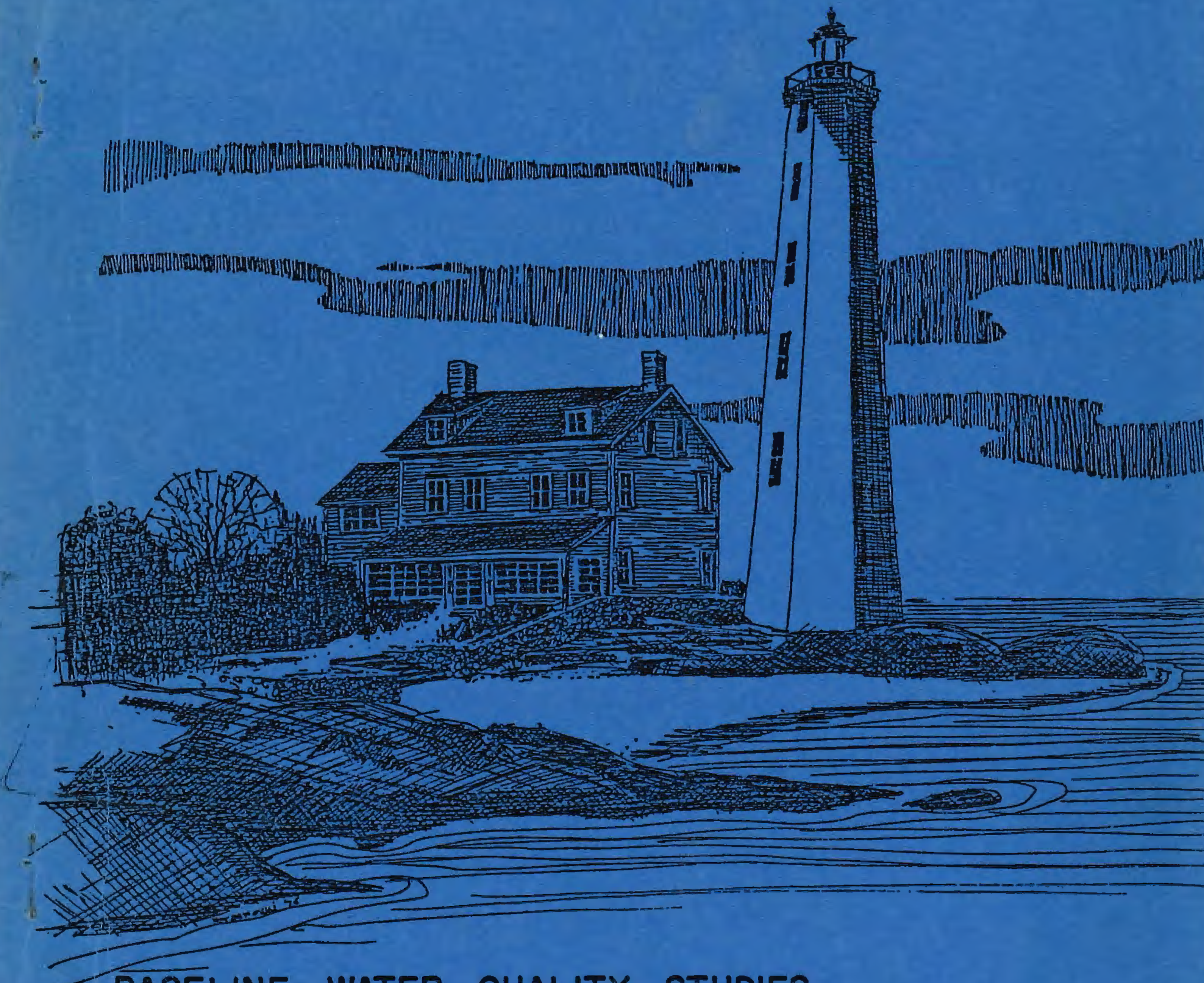
BUZZARDS BAY BASIN



BASELINE WATER QUALITY STUDIES OF SELECTED LAKES AND PONDS

massachusetts department of environmental quality engineering
DIVISION OF WATER POLLUTION CONTROL
thomas c. mcmahon, director

BASELINE WATER QUALITY STUDIES
OF
SELECTED LAKES AND PONDS
IN THE
BUZZARDS BAY BASIN

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BUZZARDS BAY BASIN BASELINE LAKE SURVEYS

Introduction

This report tabulates and graphically presents baseline water quality data collected from four (4) lakes and ponds in the Buzzards Bay Basin during the summer months of 1979 and 1980. The location of these bodies of water are illustrated in Figure 1. The lakes and ponds chosen for study are concentrated in the western portion of the watershed.

The baseline lake survey is accomplished in one day. It generally consists of bathymetric mapping (if necessary), a perimeter survey, and sampling the water column at the open water station(s), inlet(s), and outlet(s). Occasional special samples (e.g., in front of bathing beaches) are also collected from around the lake. The perimeter survey includes the qualitative and semi-quantitative mapping of aquatic vegetation.

The results from a baseline survey enables the Division of Water Pollution Control to classify and identify the water quality of Massachusetts lakes and ponds as part of its statewide Lake Classification Program.

Further objectives of the surveys included:

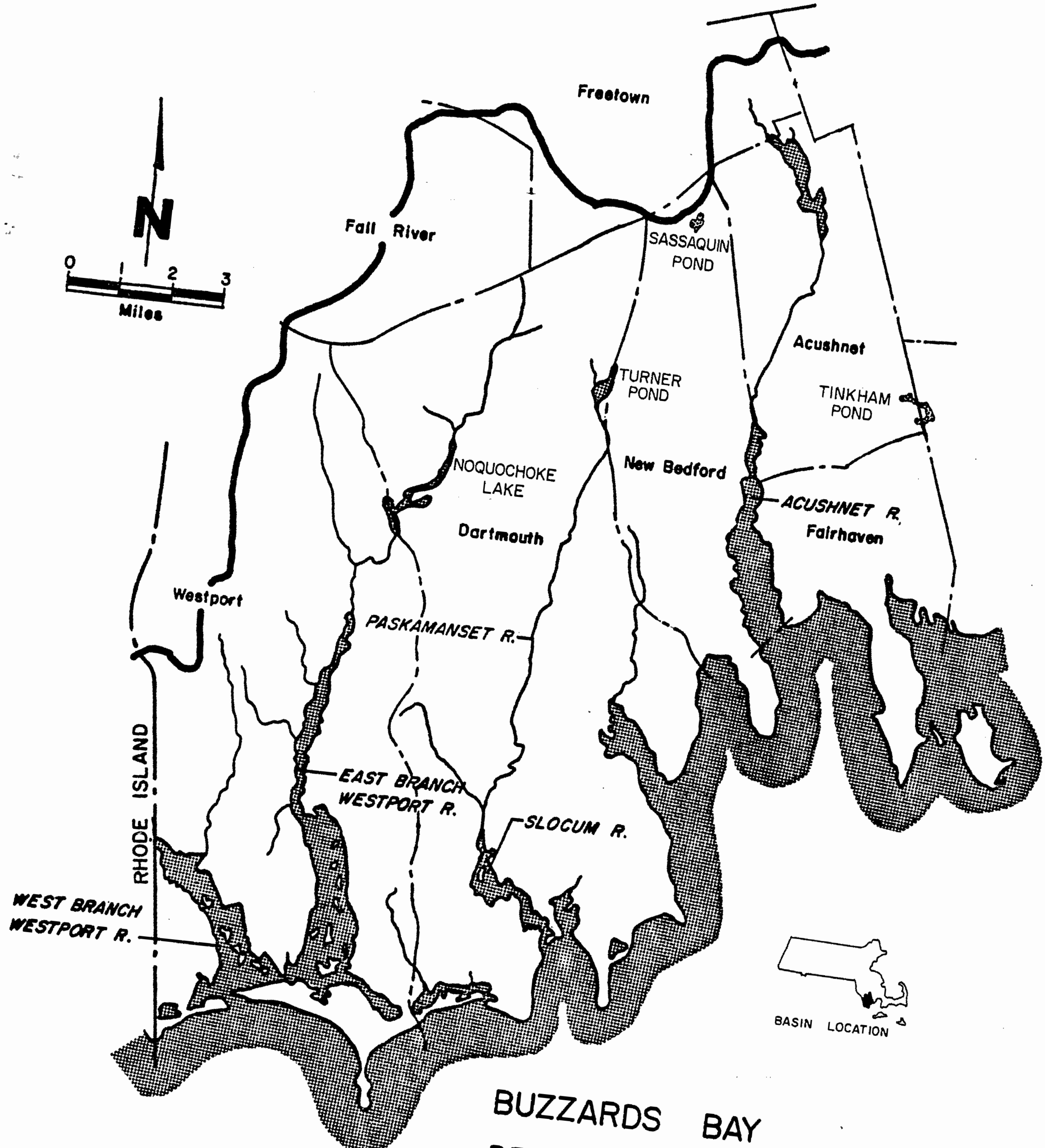
1. To gather baseline water quality and biological data and compile an inventory on selected waterbodies in the Coastal Plain region of Massachusetts;

2. To estimate and characterize the lakes' trophic levels;

3. To satisfy the requirements of Section 314 of Public Law 95-217, the Federal Water Pollution Control Act Amendments of 1977; and

4. To satisfy the increased public demand for attention to lake and pond water quality problems.

The purpose of this report is strictly a presentation of the water quality data collected. Analytical interpretation of the data has been excluded. The baseline data can describe and position the trophic level of the lake but cannot go far in establishing the complete limnology of that lake. It is hoped that the following data can be useful to a wide spectrum of people interested in the water quality of Massachusetts lakes.



BUZZARDS BAY DRAINAGE (I)

FIGURE I

The following are the trophic levels for the lakes and ponds surveyed in the Buzzards Bay Basin during 1979 and 1980 according to the Division of Water Pollution Control's lake identification and classification system (see: Massachusetts Lake Classification Program, DWPC, 1981).

Noquochoke Lake	Stratified	Eutrophic
Sassaquin Pond	Stratified	Oligotrophic
Tinkham Pond	Unstratified	Eutrophic
Turner Pond	Unstratified	Mesotrophic/Eutrophic

BASELINE SURVEY METHODOLOGY

Morphometry

Bathymetric maps of the lakes and ponds in the Buzzards Bay Basin were prepared either from an original Massachusetts Division of Fisheries and Wildlife map or from field data obtained by using a fathometer (Ray Jefferson Fish Flasher, Model 6006). Morphometric data was measured from the bathymetric maps utilizing a planimeter and rotometer according to Hutchinson (1957) and Welch (1948).

Sample Station Location

For each baseline survey, the following sampling stations were established:

1. Open water station(s) on lake (maximum depth);

2. Inlet stream(s); and

3. Outlet stream.

Occasional special samples were also collected (e.g., storm drain pipes and bathing beaches).

Data Collection

Physical and Chemical Data

Temperature profiles were made "in situ" with a tele-thermometer (Yellow Springs Instrument, Model 42 sc). Transparency measurements were made with a standard 20 cm. Secchi disc (Hutchinson, 1957). Field pH tests were taken with a Hach Model 17N Wide Range pH test kit. In addition, meteorological conditions were recorded on each survey.

Chemical analyses were performed on water samples from the inlets, the outlet, and maximum depth stations. The deep water samples were collected with a standard-type brass Kemmerer water sampler. The inlets, outlet and surface samples were collected below the surface by hand after thoroughly rinsing the sample bottle. Bacteriological samples were collected below the surface by hand in sterilized, screw-capped glass bottles. All samples for chemical and bacteriological analyses were packed in ice and transported as soon as possible to the Lawrence

Experiment Station of the Department of Environmental Quality Engineering, Division of Laboratories, and analyzed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1976). The following analyses were conducted on each sample: pH, total alkalinity, total Kjeldahl-nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, chloride, specific conductance, total hardness, suspended solids, total solids, iron, and manganese as well as bacterial analyses for total and fecal coliform bacteria.

Dissolved oxygen samples were collected in the manner prescribed by Welch (1948). Dissolved oxygen concentrations were measured by the azide modification of the Winkler technique (Standard Methods, APHA, 1976). Titrations were made within a few hours after being fixed in the field with manganese sulfate and alkali-azide-iodide reagents. The sulfuric acid was added just prior to the titrations in the laboratory.

Biological Data

Phytoplankton and Chlorophyll *a*

During stratification, phytoplankton samples were obtained by a standard procedure described by the Maine Department of Environmental Protection, Division of Lakes and Biological Studies. Each sample consisted of a composite core taken with a one-quarter inch I.D. plastic tube with a weight attached to one end. The tube was lowered at the deep station to the thermocline, pinched below the meniscus, and raised into the boat. The sample was allowed to drain into a clean and rinsed collection bottle. The procedure was repeated until a volume of 500 ml was collected. If unstratified conditions were present then a phytoplankton grab sample was taken instead of a composite sample. The samples were normally analyzed for phytoplankton on the day of collection using a Whipple micrometer and Sedgewick-Rafter cell. Algal counts were reported as cells per milliliter (Smith, 1950 and Prescott, 1954).

Chlorophyll *a* analysis (Appendix A) was based on methodology from a modified EPA fluorometric procedure developed by the Division of Water Pollution Control at Westborough (Kimball, 1979). Filtered samples were refrigerated for 24 hours after being ground and extracted in 90% acetone. Fluorometer readings were taken at 750 and 630 nannometers before and after treatment with 1N Hydrochloric acid (HCl) to correct for pheophytin interference.

Aquatic Macrophytes

The aquatic macrophyton community in each lake was located and mapped by slowly examining the entire littoral zone by boat. Where the bottom was not visible, it was dragged for aquatic vegetation using a weighted grappling hook. Identification for the most part was made "in situ", except for a few samples which were taken back to the laboratory and identified according to Fassett (1957), Weldon et al. (1973), or Hotchkiss (1972). Some plants could not be keyed to species because the plants were not in flower or fruit.

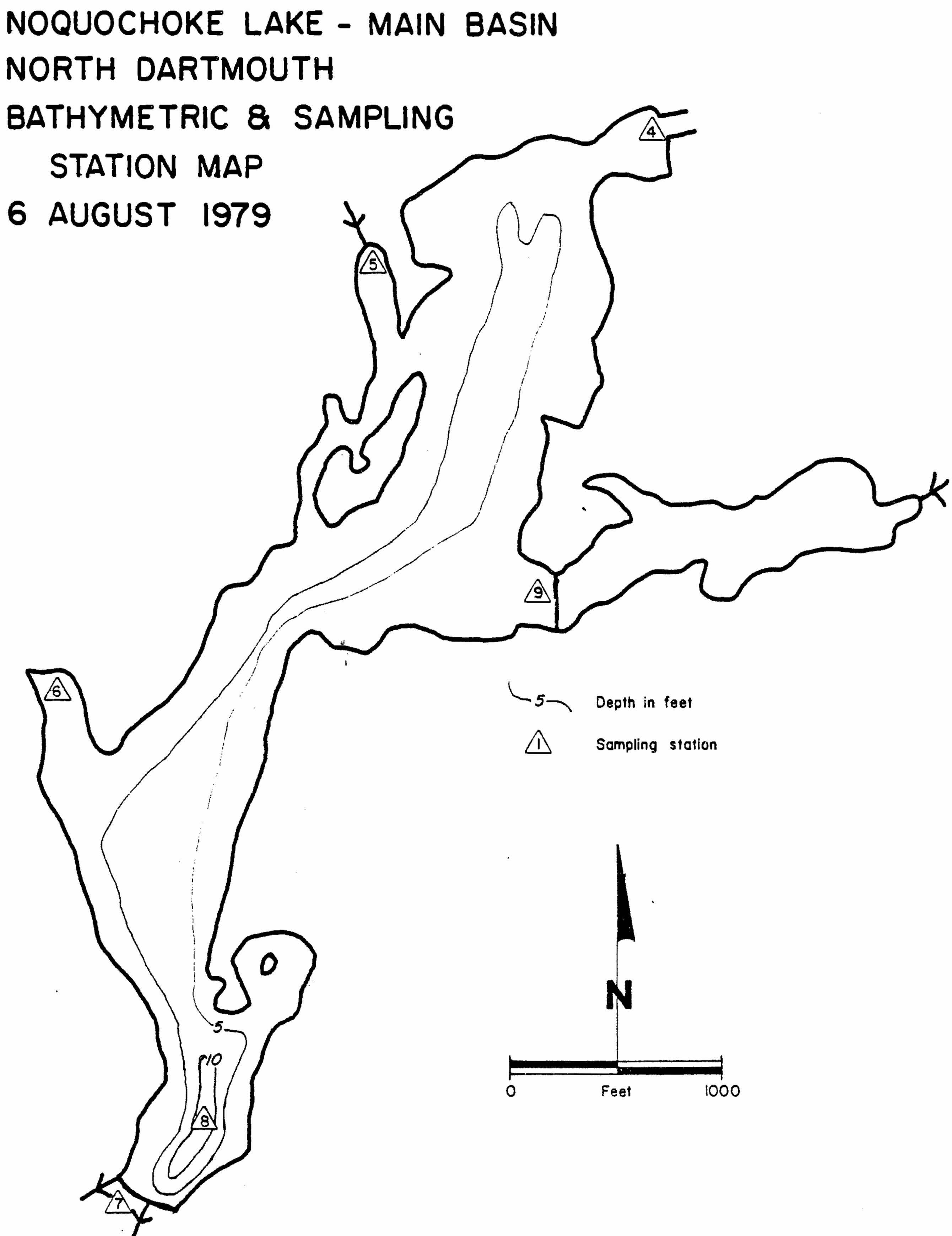

NOQUOCHOKE LAKE - MAIN BASIN
NORTH DARTMOUTH
BATHYMETRIC & SAMPLING
STATION MAP
6 AUGUST 1979
4
5
6
7
8
9
5
10
0
5
Depth in feet
1
Sampling station
N
0
Feet
1000

FIGURE 2

NOQUOCHOKE LAKE

COMMUNITY: North Dartmouth

LOCATION: Interstate 195 crosses the northern basin of the lake while Route 6 borders the southern shore of the lake.

WATERSHED: Buzzards Bay

DESCRIPTION: Medium development around the lake. Extensive wetlands around the lake.

INLETS: There are four inlets. One enters from the north, two from the northwest and one from the east.

OUTLET: A dam at the southern end of the lake.

DATE SAMPLED: 6 August 1979

THERMAL CHARACTERISTICS: Stratified

TROPHIC LEVEL: Eutrophic

PHYTOPLANKTON: High total count with diatoms dominant.

AQUATIC MACROPHYTON: Medium to dense growth with no one dominant species.

RECREATIONAL USES: Boating, canoeing and fishing.

ACCESS: Informal

NOQUOCHOKE LAKE - MIDDLE/NORTH BASIN
NORTH DARTMOUTH
SAMPLING STATION MAP
6 AUGUST 1979

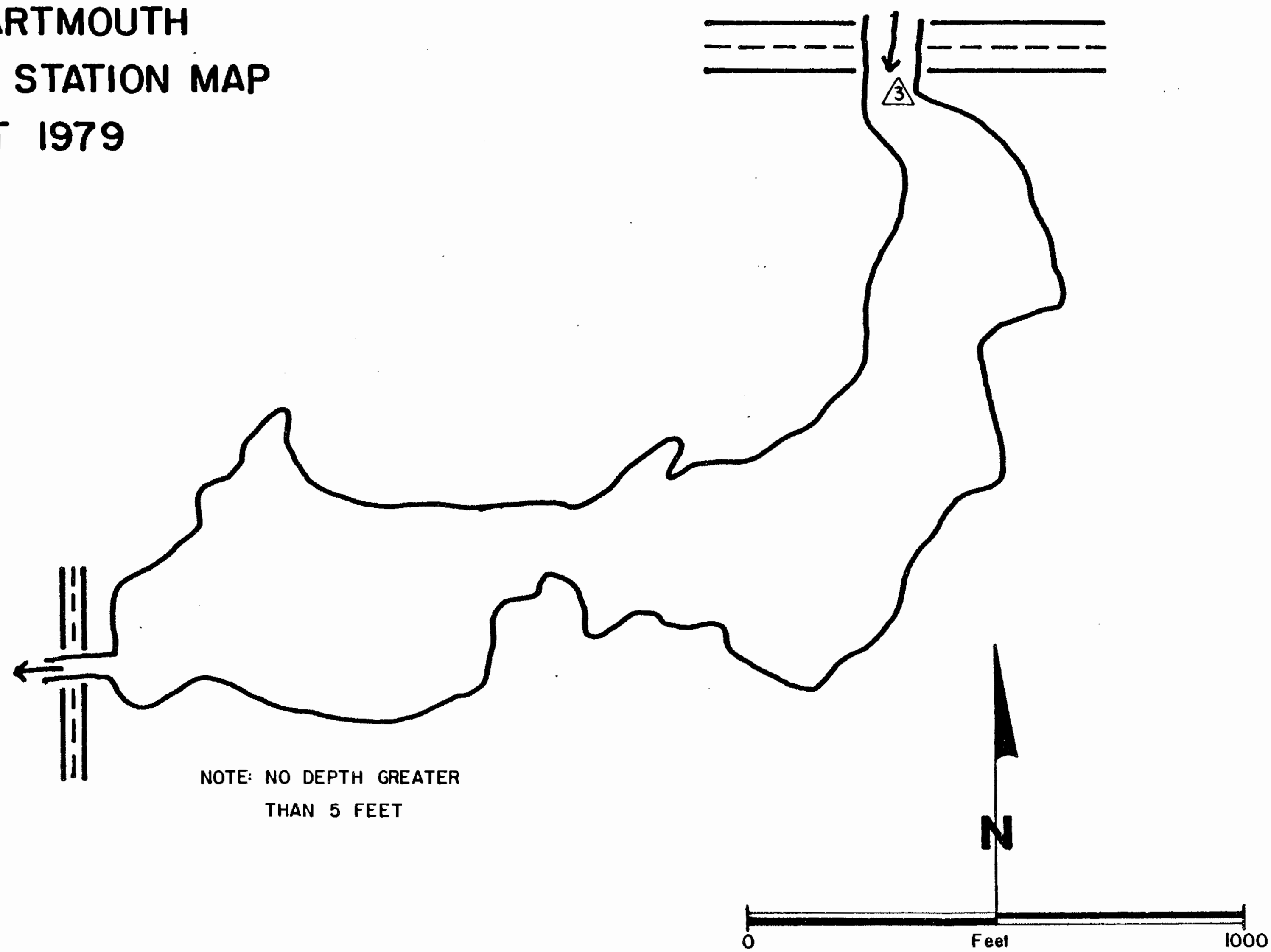


FIGURE 3

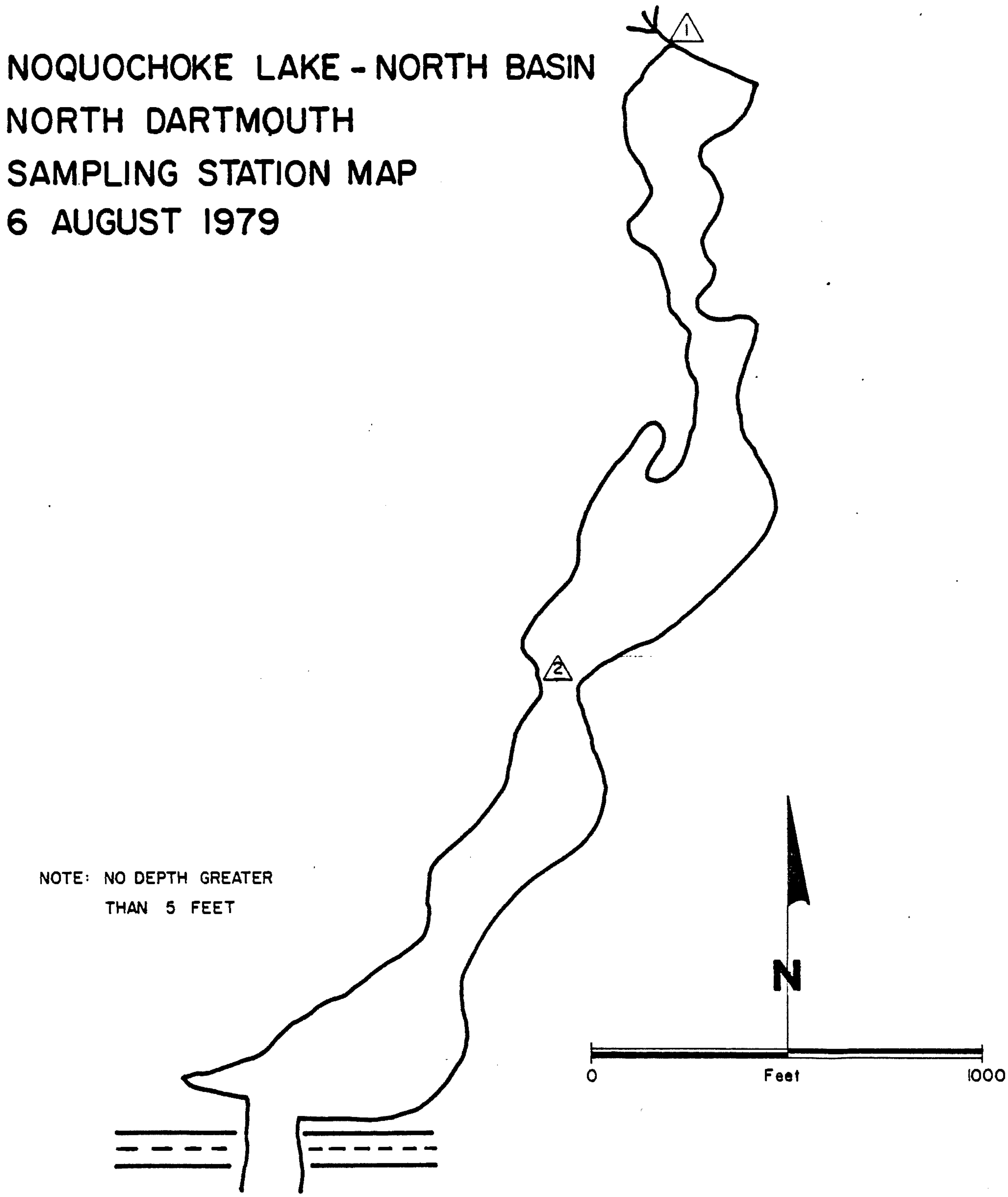
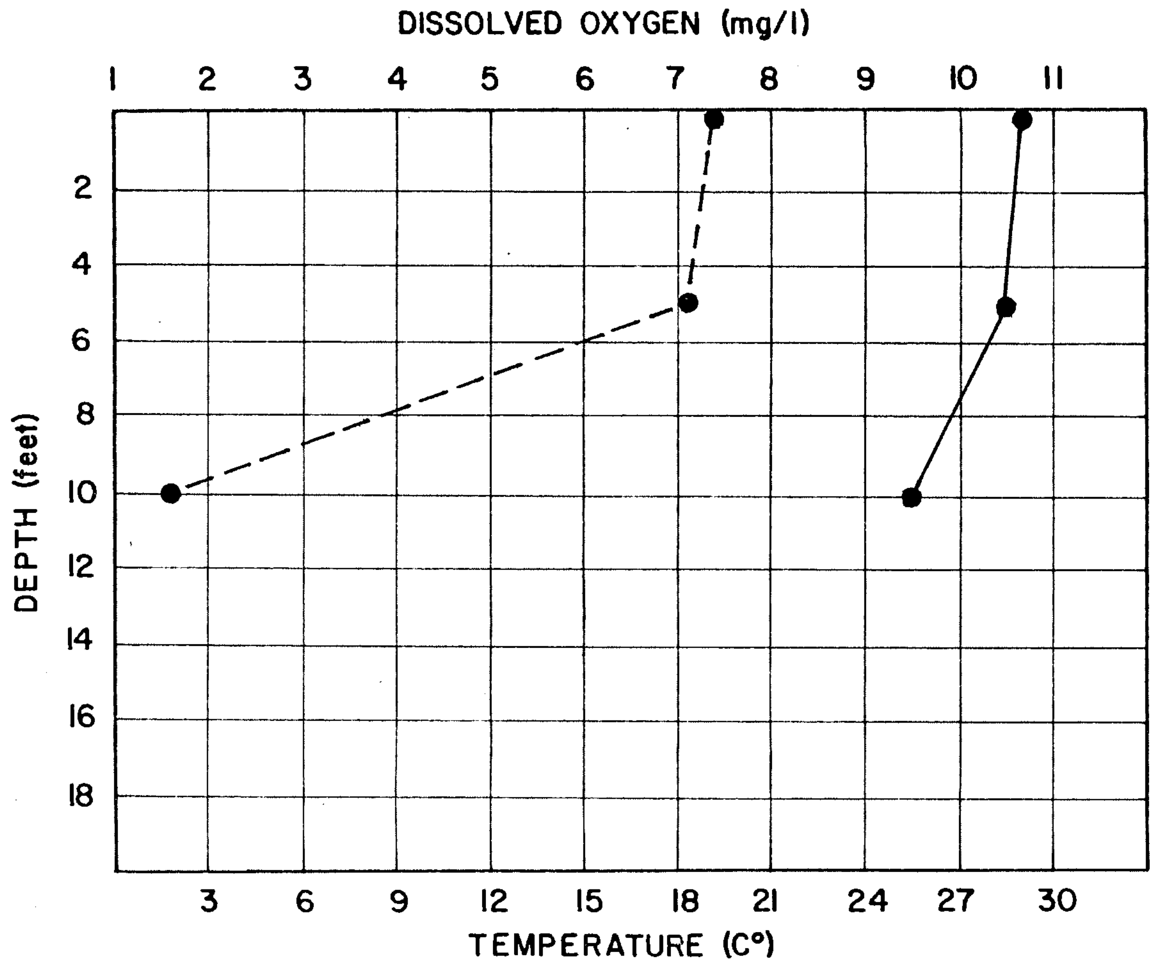

NOQUOCHOKE LAKE - NORTH BASIN
NORTH DARTMOUTH
SAMPLING STATION MAP
6 AUGUST 1979
1
2
NOTE: NO DEPTH GREATER
THAN 5 FEET
N
0
Feet
1000

FIGURE 4

DISSOLVED OXYGEN & TEMPERATURE PROFILE 6 AUGUST 1979
NOQUOCHOKE LAKE NORTH DARTMOUTH

STATION 8

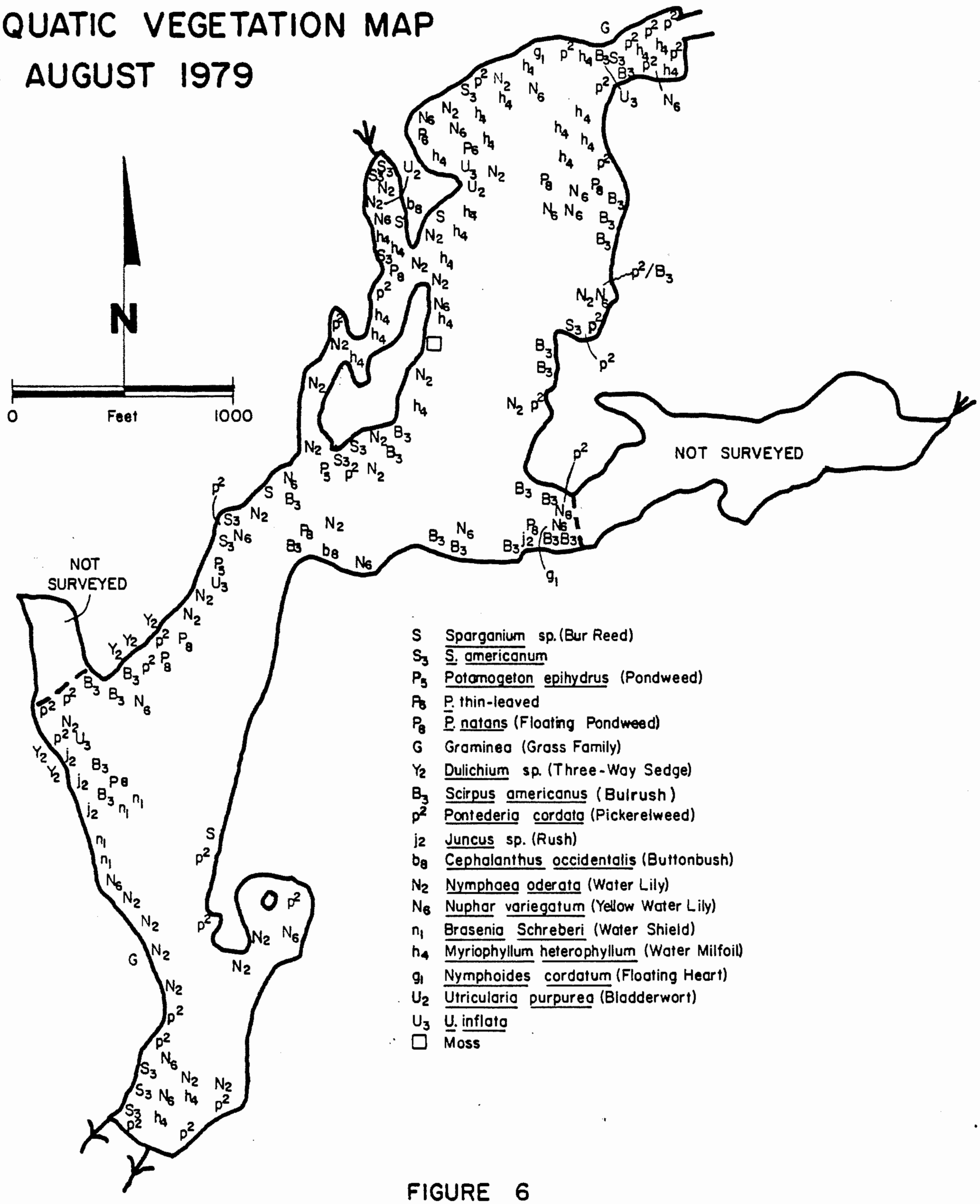
Temp. C°	D.O. mg/l	Depth feet
29.0	7.4	0
28.5	7.2	5
25.5	1.6	10



——— Temperature
– – – Dissolved Oxygen

FIGURE 5

NOQUOCHOKE LAKE - MAIN BASIN
NORTH DARTMOUTH
AQUATIC VEGETATION MAP
6 AUGUST 1979



S	Sparganium sp. (Bur Reed)
S_3	S. americanum
P_5	Potamogeton epihydrus (Pondweed)
P_6	P. thin-leaved
P_8	P. natans (Floating Pondweed)
G	Graminea (Grass Family)
Y_2	Dulichium sp. (Three-Way Sedge)
B_3	Scirpus americanus (Bulrush)
p^2	Pontederia cordata (Pickerelweed)
j_2	Juncus sp. (Rush)
b_8	Cephalanthus occidentalis (Buttonbush)
N_2	Nymphaea oderata (Water Lily)
N_6	Nuphar variegatum (Yellow Water Lily)
n_1	Brasenia Schreberi (Water Shield)
h_4	Myriophyllum heterophyllum (Water Milfoil)
g_1	Nymphoides cordatum (Floating Heart)
U_2	Utricularia purpurea (Bladderwort)
U_3	U. inflata
□	Moss

FIGURE 6

NOQUOCHOKE LAKE - MIDDLE/NORTH BASIN
NORTH DARTMOUTH
AQUATIC VEGETATION MAP
6 AUGUST 1979

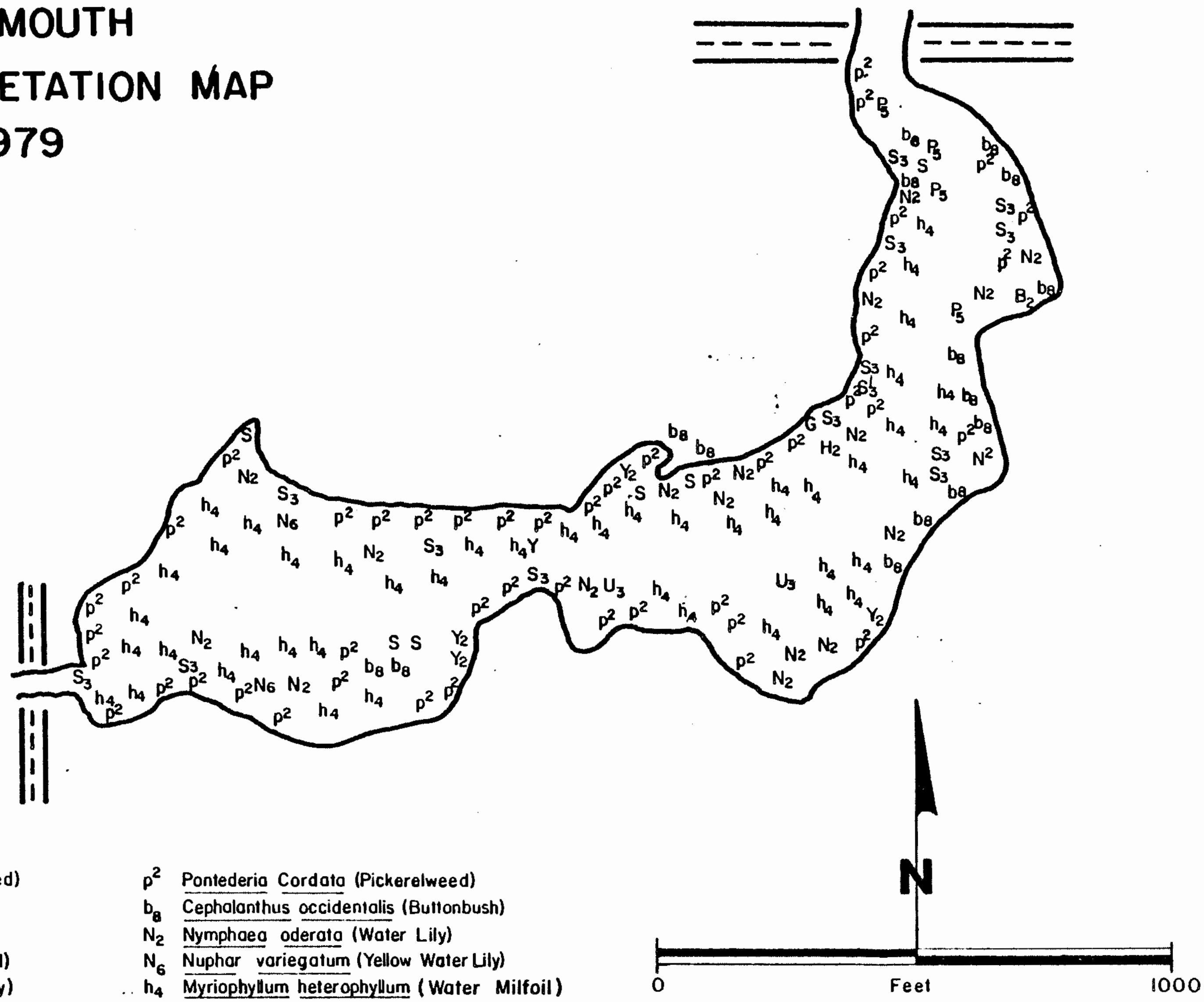


FIGURE 7

S	Sparganium sp. (Bur Reed)	p^2	Pontederia Cordata (Pickerelweed)
S_3	S. americanum	b_8	Cephalanthus occidentalis (Buttonbush)
P_5	Potamogeton epihydrus	N_2	Nymphaea oderata (Water Lily)
H_2	Elodea sp. (Waterweed)	N_6	Nuphar variegatum (Yellow Water Lily)
G	Gramineae (Grass Family)	h_4	Myriophyllum heterophyllum (Water Milfoil)
Y_2	Dulichium sp. (Three-way Sedge)	U_2	Utricularia purpurea (Bladderwort)

NOQUOCHOKE LAKE - NORTH BASIN
NORTH DARTMOUTH
AQUATIC VEGETATION MAP
6 AUGUST 1979

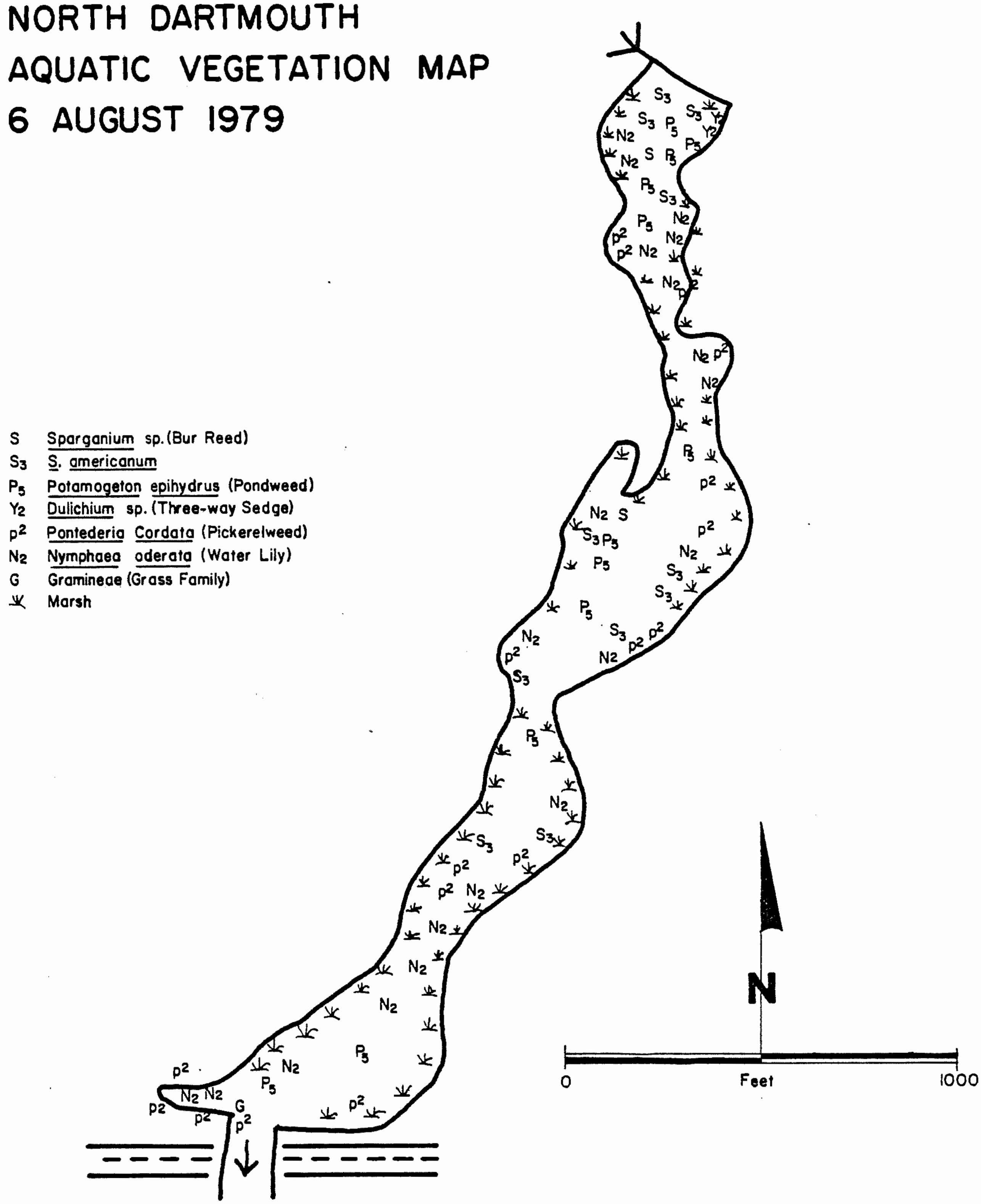


FIGURE 8

TABLE 3

NOQUOCHOKE LAKE

MICROSCOPIC EXAMINATION*

ORGANISM		STATION 8
ALGAE		
Bacillariophyceae (Diatom)		
Cyclotella sp.	816.3	
Fragillaria sp.	5,714.1	
Tabellaria sp.	16,326.0	
Diatoma sp.	816.3	
Synedra sp.	58,773.6	
Unidentified	2,448.9	
SUBTOTAL		84,895.2
Cyanophyceae (Blue-Green)		
Merismopedia sp.	1,632.6	
SUBTOTAL		1,632.6
Chlorophyceae (Green)		
Scenedesmus sp.	1,632.6	
Sphaerocystis sp.	816.3	
Ulothrix sp.	816.3	
Unidentified	1,632.6	
SUBTOTAL		4,897.8
PROTOZOA		
Green Flagellates		
Euglena sp.	816.3	
SUBTOTAL		816.3
Dinoflagellates		
Gymnodinum sp.	816.3	
Chrysococcus sp.	6,530.4	
Mallomonas sp.	816.3	
Unidentified	1,632.6	
SUBTOTAL		10,611.9
TOTAL		102,037.5
Chlorophyll *a* (mg/m^3)		15.85

*Cells/ml

SASSAQUIN POND

ACUSHNET

BATHYMETRIC AND SAMPLING STATION MAP

12 JUNE 1980

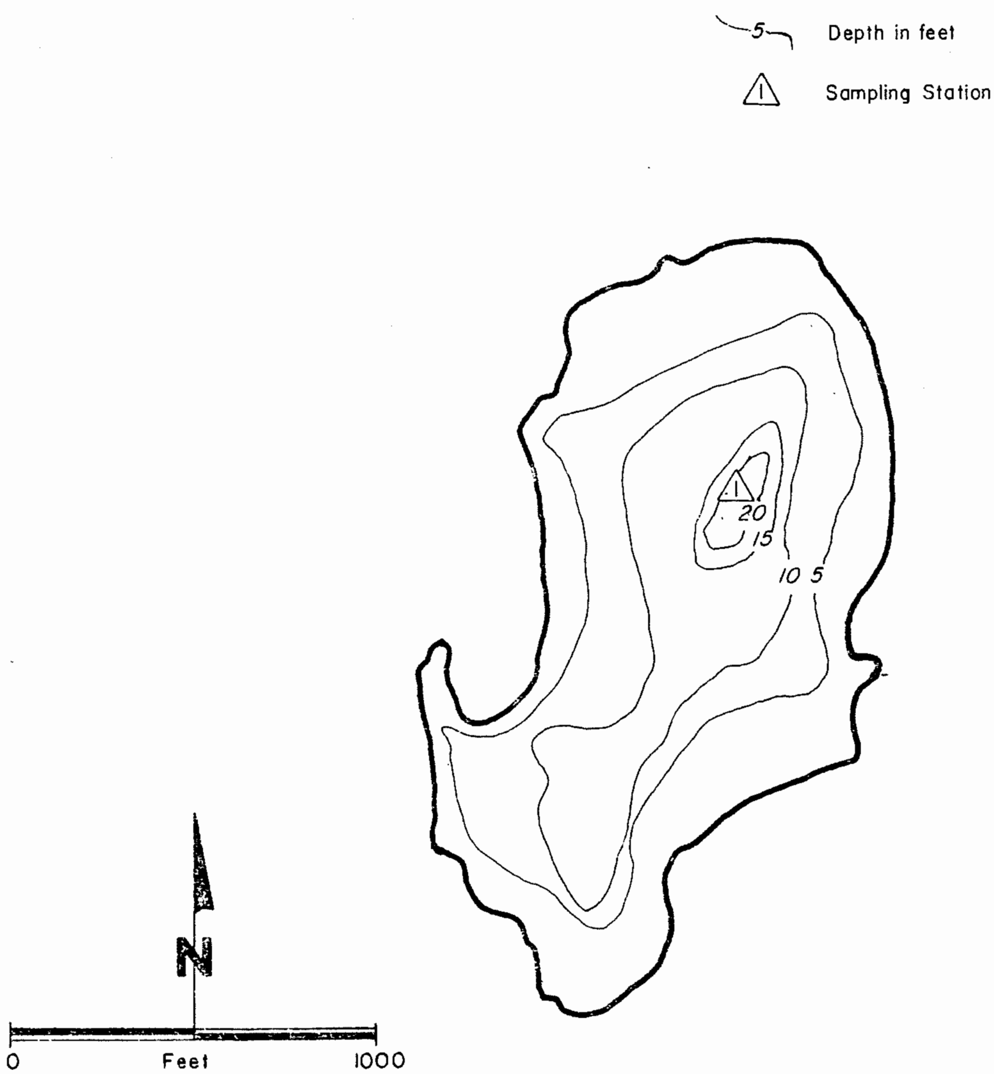


FIGURE 9

SASSAQUIN POND

COMMUNITY: Acushnet

LOCATION: Less than one-half mile east of Route 140 and one-half mile southwest of Union Hospital.

WATERSHED: Buzzards Bay

DESCRIPTION: The pond's perimeter is densely populated. However, northwest of the pond is the Bolton Cedar Swamp.

INLETS: None observed

OUTLET: None observed

DATE SAMPLED: 12 June 1980

THERMAL CHARACTERISTICS: Stratified

TROPHIC LEVEL: Oligotrophic

PHYTOPLANKTON: Low total number dominated by green coccoid algae.

AQUATIC MACROPHYTON: Sparse growth with quillwort, spike rush and yellow water lily prevalent.

RECREATIONAL USES: Swimming, fishing and boating

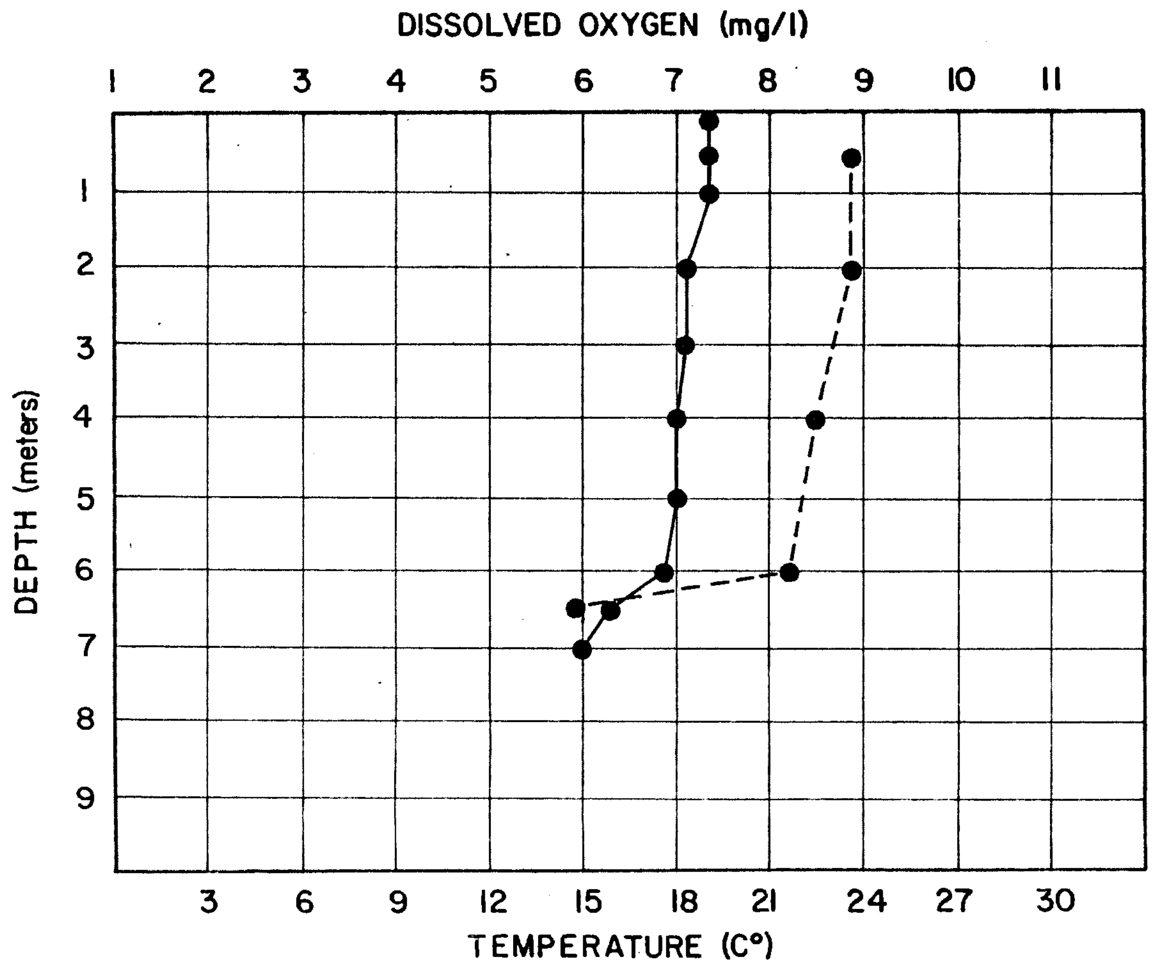
ACCESS: Informal access at the town beach located on the south-eastern shore.

DISSOLVED OXYGEN & TEMPERATURE PROFILE — 12 JUNE 1980

SASSAQUIN POND — ACUSHNET

STATION I

Temp. C°	D.O. mg/l	Depth (meters)
19.0	-	0
19.0	8.8	0.5
19.0	-	1.0
18.5	8.9	2.0
18.5	-	3.0
18.0	8.5	4.0
18.0	-	5.0
17.5	8.2	6.0
16.0	5.9	6.5
15.0	-	7.0



——— Temperature

– – – Dissolved Oxygen

FIGURE 10

TABLE 4

SASSAQUIN POND

MORPHOMETRIC DATA

Maximum Length	2,077 ft.
Maximum Effective Length	2,077 ft.
Maximum Width	1,000 ft.
Maximum Effective Width	1,000 ft.
Maximum Depth	21 ft.
Mean Depth	6.6 ft.
Mean Width	817 ft.
Area	39 acres
Volume	257 acre-ft.
Shoreline	5,400 ft.
Development of Shoreline	1.2
Development of Volume	0.9
Mean to Maximum Depth Ratio	0.3

TABLE 5

SASSAQUIN POND

WATER QUALITY DATA (mg/1)

12 June 1980

STATION:	1	
PARAMETERS	0.5 m	6.5 m
pH (Standard Units)	7.1	6.9
Total Alkalinity	10	11
Total Hardness	13	13
Suspended Solids	1.5	1.0
Total Solids	46	64
Specific Conductance (μmhos/cm)	96	96
Chloride	16	15
Total Kjeldahl-Nitrogen	0.43	0.37
Ammonia-Nitrogen	0.00	0.02
Nitrate-Nitrogen	0.0	0.0
Total Phosphorus	0.24	0.13
Iron	0.03	0.04
Manganese	0.03	0.02
Total Coliform per 100 ml	10	--
Fecal Coliform per 100 ml	<5	--

SASSAQUIN POND
ACUSHNET
AQUATIC VEGETATION MAP
12 JUNE 1980

S — *Sparganium* sp. (Bur Reed)
A_3 — *Sagittaria* sp. (Arrowhead, Duck Potato)
E — *Eleocharis* sp. (Spike Rush)
N_5 — *Nuphar* sp. (Yellow Water Lily)
C_2 — *Nitella* (Stonewort)
I — *Isoetes* sp. (Quillwort)

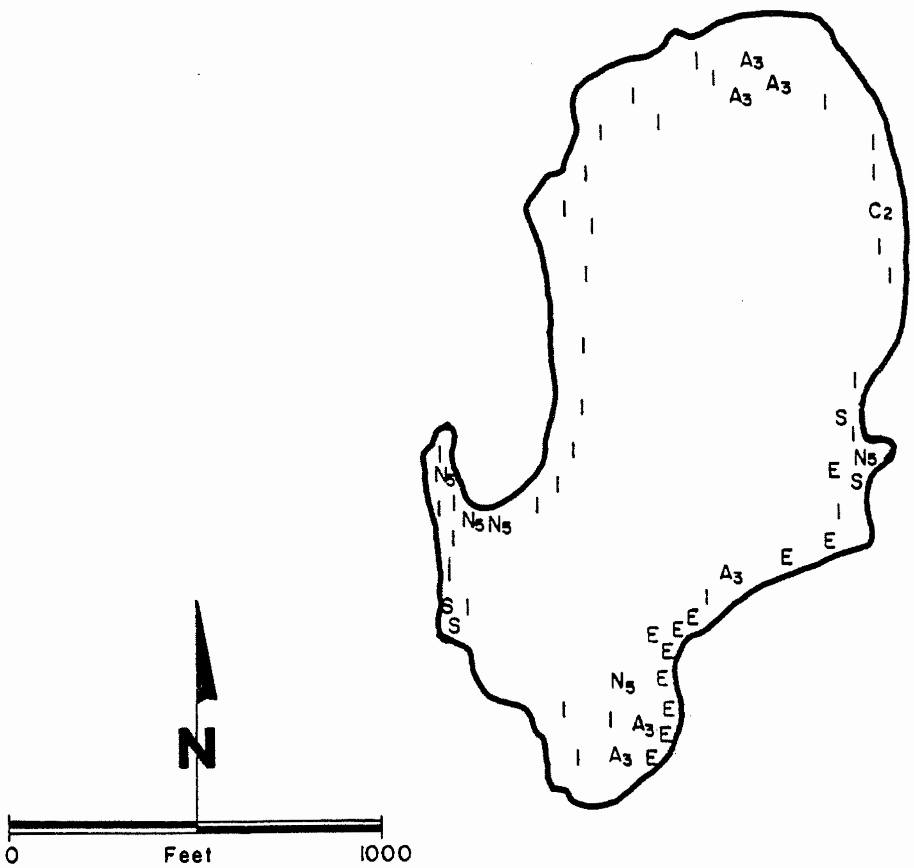


FIGURE II

TABLE 6

SASSAQUIN POND

MICROSCOPIC EXAMINATION*

ORGANISM		STATION 2
ALGAE		
Chlorophyceae (Green)		
Sphaerocystis sp.	281.0	
Golenkinia sp.	28.1	
Oocystis sp.	28.1	
SUBTOTAL		337.2
PROTOZOA		
Green Flagellates		
Cryptomonas sp.	112.4	
Lobomonas sp.	28.1	
Trachelomonas sp.	28.1	
SUBTOTAL		168.6
Dinoflagellates		
Ceratium sp.	28.1	
SUBTOTAL		28.1
TOTAL		533.9
Chlorophyll *a* (mg/m^3)		4.98

*Cells/ml

TINKHAM POND
ACUSHNET/MATTAPOISETT
SAMPLING STATION MAP
28 AUGUST 1980

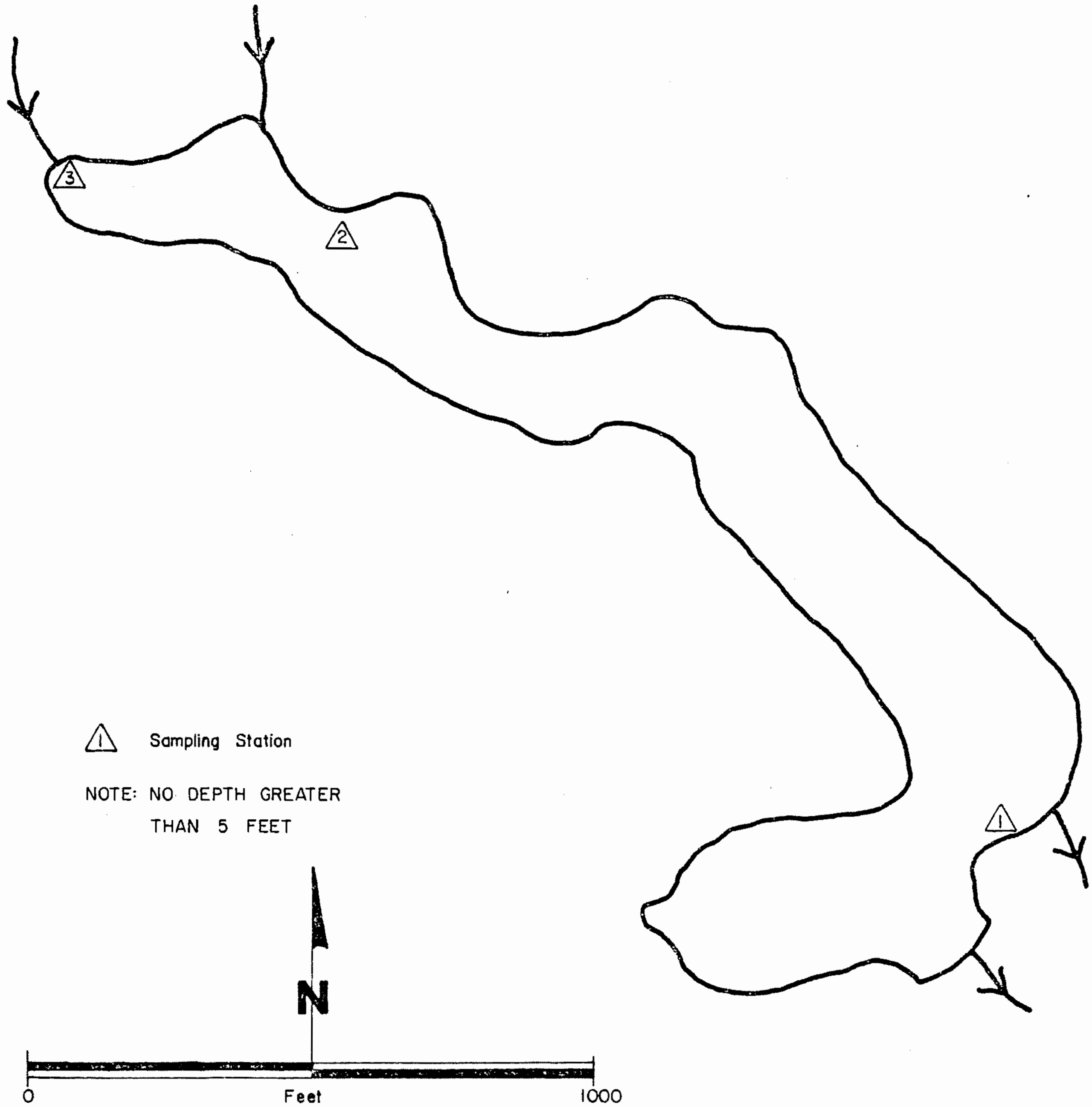


FIGURE 12

TINKHAM POND

COMMUNITY: Acushnet/Mattapoisett

LOCATION: A quarter of a mile west of Tinkhamtown.

WATERSHED: Buzzards Bay

DESCRIPTION: Sparsely settled watershed. Wetlands border the north and northeast shores of the pond.

INLETS: Two inlets enter from the north through a swampy area.

OUTLETS: Two outlets leave the pond from the southeast, one over a dam.

DATE SAMPLED: 28 August 1980

THERMAL CHARACTERISTICS: Unstratified

TROPHIC LEVEL: Eutrophic

PHYTOPLANKTON: High total count with dinoflagellates dominating.

AQUATIC MACROPHYTON: Dense growth dominated by white and yellow water lilies and watershield.

RECREATIONAL USES: Canoeing

ACCESS: Informal access from the dam.

TABLE 7

TINKHAM POND

MORPHOMETRIC DATA

Maximum Length	1,538 ft.
Maximum Effective Length	1,538 ft.
Maximum Width	692 ft.
Maximum Effective Width	692 ft.
Maximum Depth	4.0 ft.
Mean Depth	1.7 ft.
Mean Width	400 ft.
Area	14 acres
Volume	24 acre-ft.
Shoreline	6,200 ft.
Development of Shoreline	2.2
Development of Volume	1.3
Mean to Maximum Depth Ratio	0.4

TABLE 8

TINKHAM POND

WATER QUALITY DATA (mg/1)

STATION:	1	2	3
PARAMETERS			
pH (Standard Units)	5.0	4.7	4.7
Total Alkalinity	2	0	1
Total Hardness	14	12	12
Suspended Solids	22.5	2.5	5.5
Total Solids	92	66	70
Specific Conductance (μmhos/cm)	72	68	68
Chloride	12	10	10
Total Kjeldahl-Nitrogen	1.9	1.1	1.1
Ammonia-Nitrogen	0.03	0.11	0.74
Nitrate-Nitrogen	0.7	0.4	0.5
Total Phosphorus	0.12	0.05	0.04
Iron	1.1	0.70	0.70
Manganese	0.05	0.02	0.02
Total Coliform per 100 ml	600	1,200	40
Fecal Coliform per 100 ml	150	600	<5

TINKHAM POND
ACUSHNET/MATTAPOISETT
AQUATIC VEGETATION MAP
28 AUGUST 1980

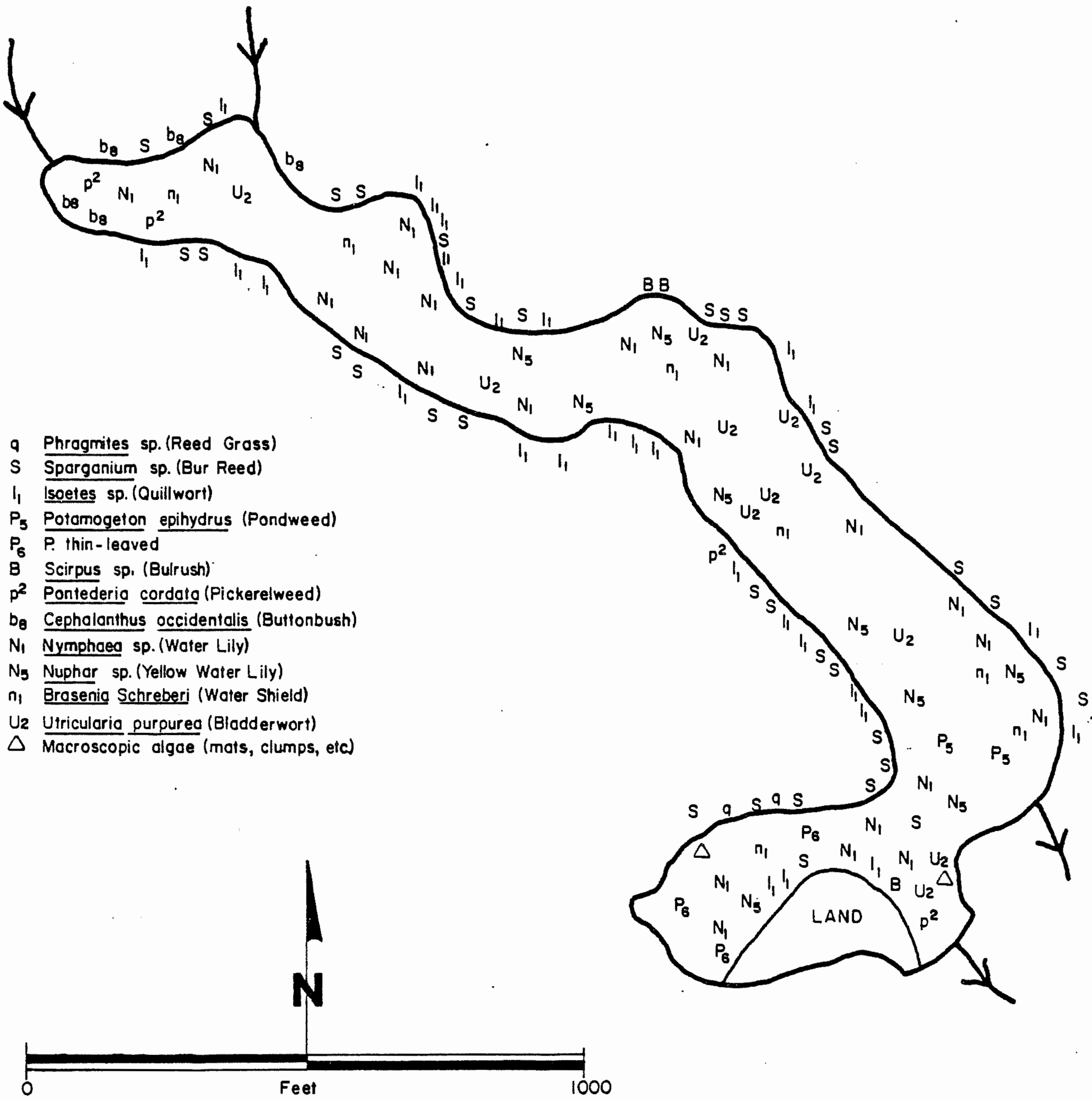


FIGURE 13

TABLE 9

TINKHAM POND

MICROSCOPIC EXAMINATION*

ORGANISM		STATION 2
ALGAE		
Bacillariophyceae (Diatoms)		
Melosira sp.	112.4	
Synedra sp.	28.1	
Asterionella sp.	140.5	
Cymbella sp.	28.1	
SUBTOTAL		309.1
PROTOZOA		
Green Flagellates		
Cryptomonas sp.	140.5	
Chroomonas sp.	56.2	
Cryptochrysis sp.	28.1	
Trachelomonas sp.	28.1	
SUBTOTAL		252.9
Dinoflagellates		
Chrysococcus sp.	843.0	
Mallomonas sp.	843.0	
Synura sp.	56.2	
SUBTOTAL		1,742.2
TOTAL		2,304.2
Chlorophyll *a* (mg/m^3)		7.92

*Cells/ml

TURNER POND
DARTMOUTH / NEW BEDFORD
SAMPLING STATION MAP
25 JUNE 1980

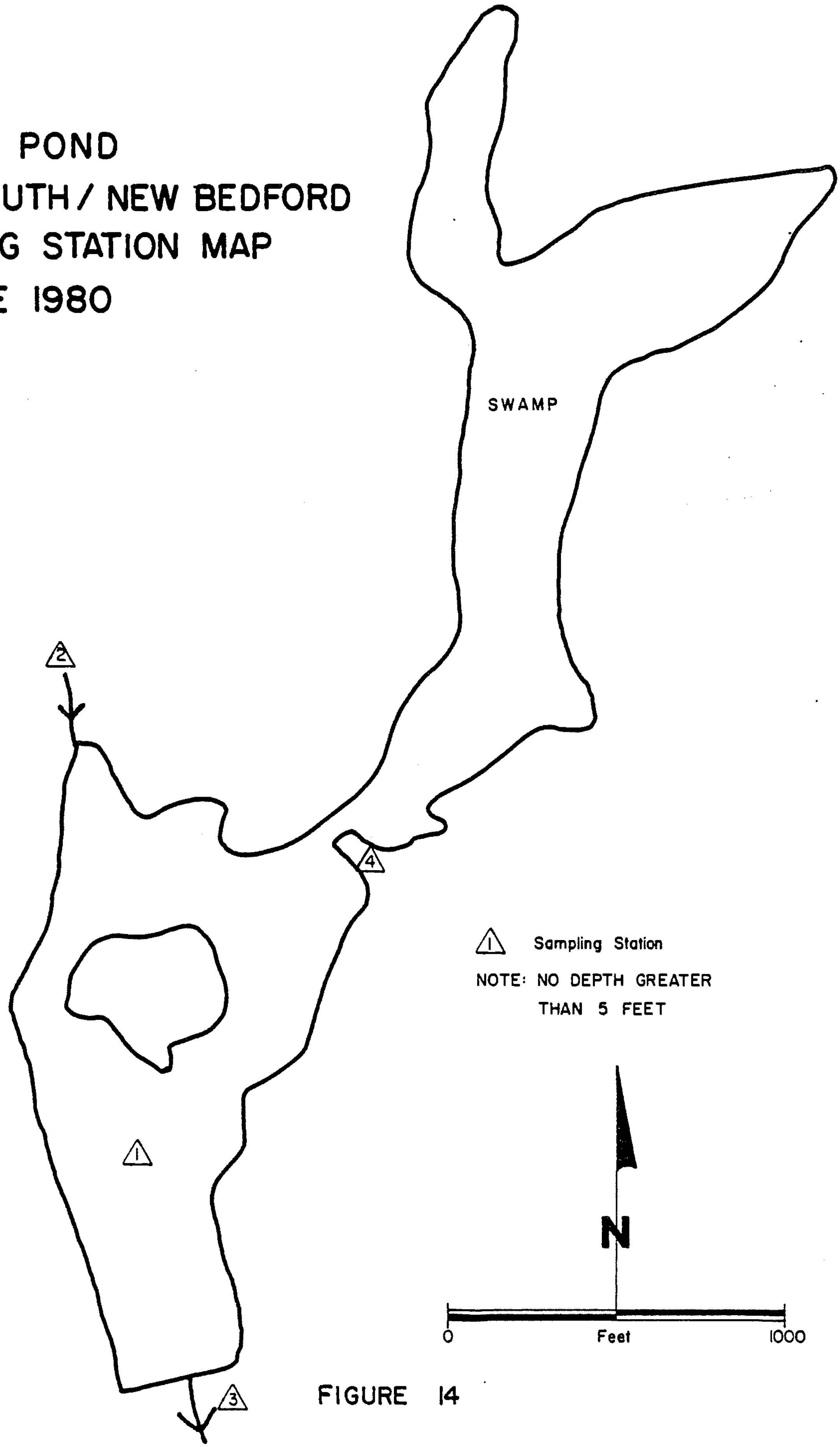


FIGURE 14

TURNER POND

COMMUNITY: Dartmouth/New Bedford

LOCATION: Bounded on the south by Old Fall River Road and bisected by High Hill Road.

WATERSHED: Buzzards Bay

DESCRIPTION: The Acushnet Cedar Swamp borders the north-northeast shores of the pond. The watershed is sparsely settled.

INLETS: One inlet is present and flows into the pond from the northwest.

OUTLETS: Water leaves via a dam.

DATE SAMPLED: 25 June 1980

THERMAL CHARACTERISTICS: Unstratified

TROPHIC LEVEL: Mesotrophic-Eutrophic

PHYTOPLANKTON: High total count with green flagellates being dominate.

AQUATIC MACROPHYTON: Dense growth dominated by white and yellow water lilies.

RECREATIONAL USES: Passive recreation

ACCESS: Informal

TABLE 10

TURNER POND

MORPHOMETRIC DATA

Maximum Length	4,154 ft.
Maximum Effective Length	4,154 ft.
Maximum Width	1,000 ft.
Maximum Effective Width	1,000 ft.
Maximum Depth	5.0 ft.
Mean Depth	1.7 ft.
Mean Width	278 ft.
Area	26 acres
Volume	44 acre-ft.
Shoreline	5,000 ft.
Development of Shoreline	1.3
Development of Volume	1.0
Mean to Maximum Depth Ratio	0.3

TABLE 11

TURNER POND

WATER QUALITY DATA (mg/l)

STATION:	1	2	3	4
PARAMETERS				
pH (Standard Units)	4.6	5.3	4.4	4.6
Total Alkalinity	1	2	--	1
Total Hardness	9	8	9	6
Suspended Solids	1.5	7.0	1.5	1.5
Total Solids	76	62	86	82
Specific Conductance (μmhos/cm)	74	50	74	74
Chloride	17	7	8	12
Total Kjeldahl-Nitrogen	0.83	0.59	0.66	0.60
Ammonia-Nitrogen	0.00	0.00	0.00	0.00
Nitrate-Nitrogen	0.0	0.1	0.0	0.0
Total Phosphorus	0.08	0.06	0.07	0.06
Iron	0.85	1.0	0.83	0.85
Manganese	0.06	0.12	0.06	0.06
Total Coliform per 100 ml	20	80	40	10
Fecal Coliform per 100 ml	10	20	10	10

TURNER POND
DARTMOUTH / NEW BEDFORD
AQUATIC VEGETATION MAP
25 JUNE 1980

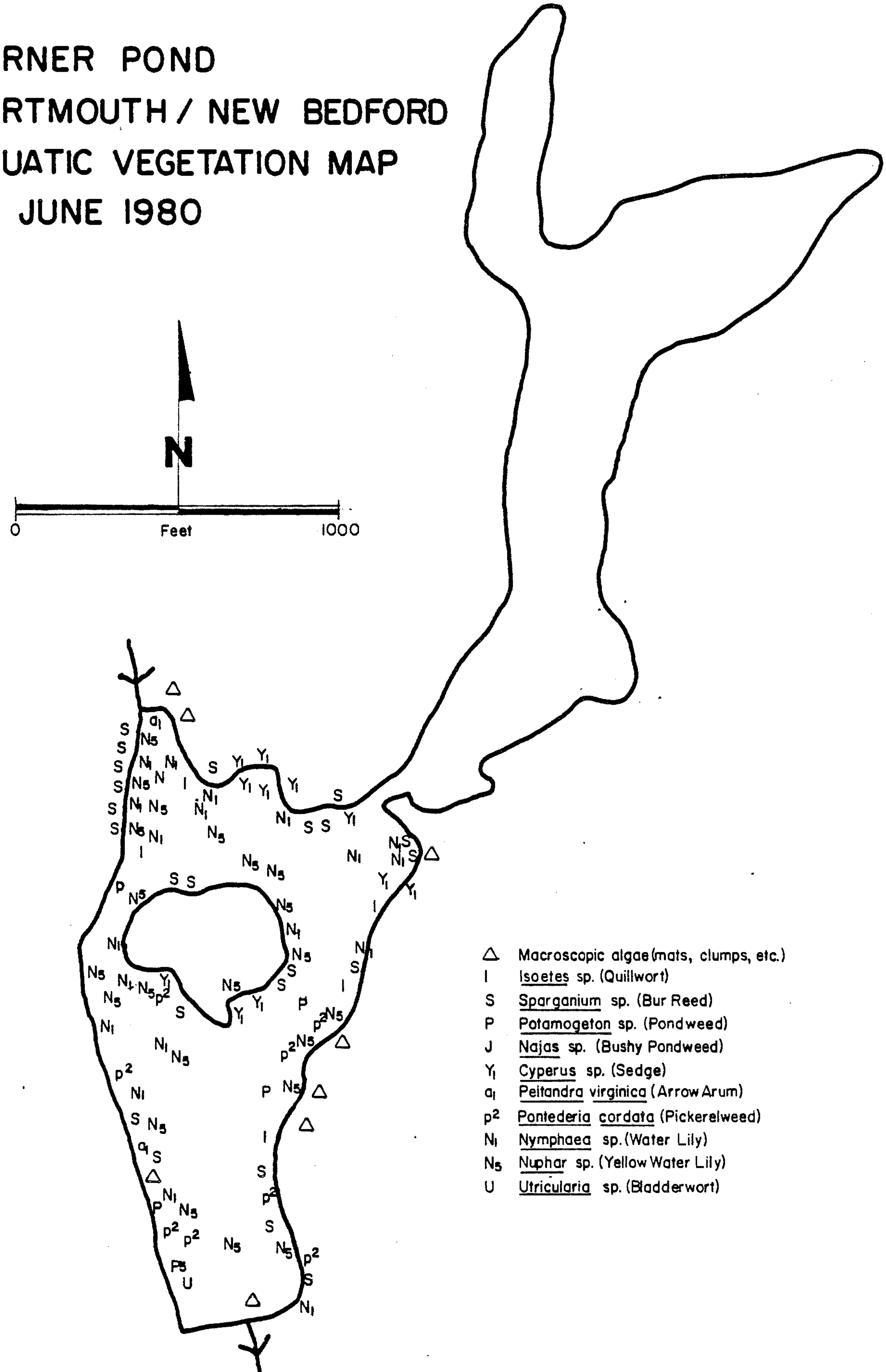


FIGURE 15

TABLE 12

TURNER POND

MICROSCOPIC EXAMINATION*

ORGANISM		STATION 1
ALGAE		
Cyanophyceae (Blue-Green)		
Chroococcus sp.	28.1	
SUBTOTAL		28.1
Chlorophyceae (Green)		
Unidentified Coccoid	140.5	
SUBTOTAL		140.5
PROTOZOA		
Green Flagellates		
Chroomonas sp.	702.5	
Chlamydomonas sp.	84.3	
Unidentified	730.6	
SUBTOTAL		1,517.4
Dinoflagellates		
Mallomonas sp.	84.3	
SUBTOTAL		84.3
TOTAL		1,770.3
Chlorophyll *a* (mg/m^3)		10.19

*Cells/ml

A NOTE ON LIMNOLOGY AND LAKE RESTORATION PROJECTS

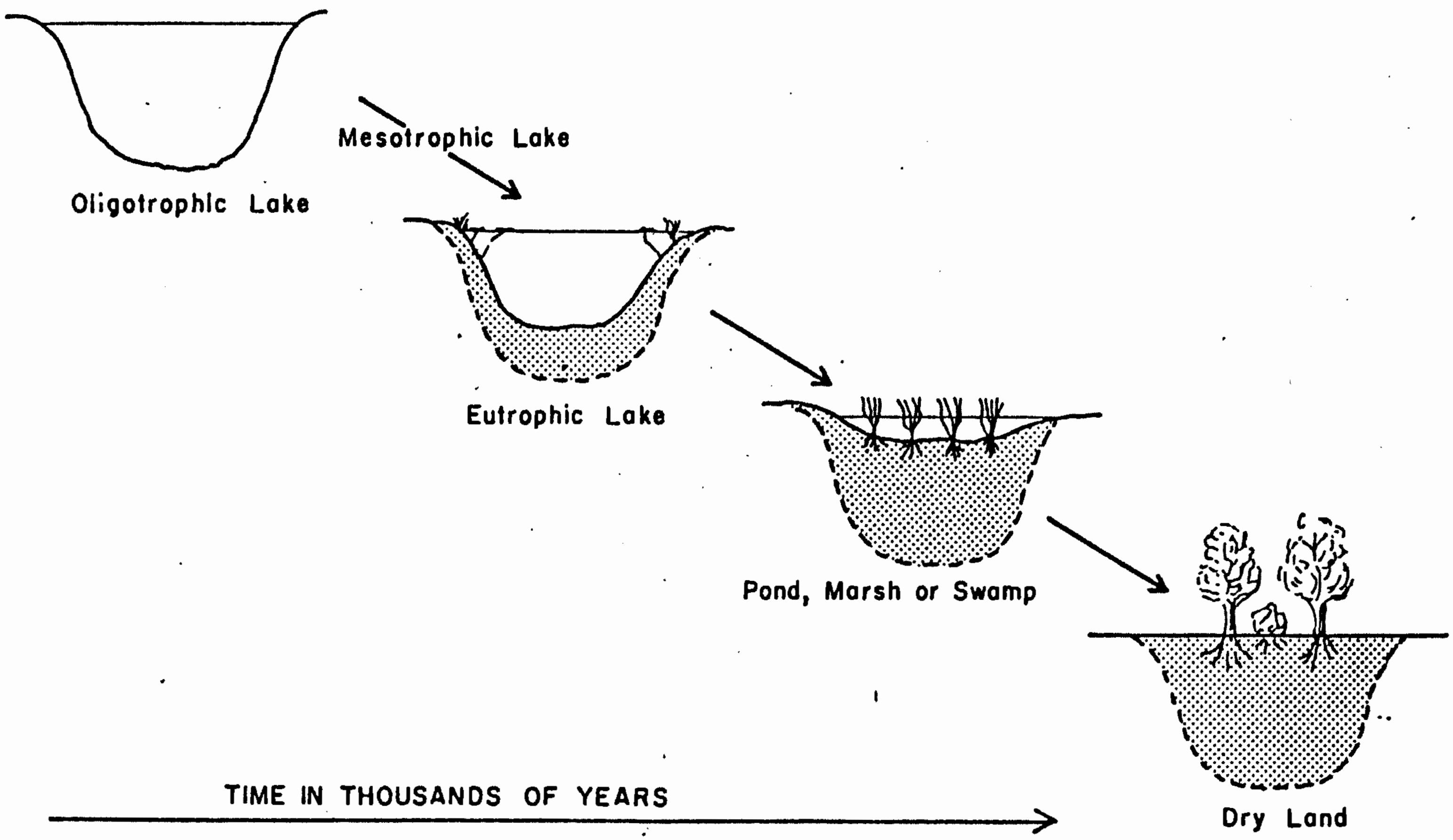
Limnology is the study of inland fresh waters, especially lakes and ponds (lentic water vs. lotic water for streams and rivers). The science encompasses the geological, physical, chemical, and biological events that operate together in a lake basin and are dependent on each other (Hutchinson, 1957). It is the study of both biotic and abiotic features that make up a lake's ecosystem. As pointed out by Dillon (1974) and others before him, in order to understand lake conditions, one must realize that the entire watershed and not just the lake, or the lake and its shoreline, is the basic ecosystem. A very important factor, and one on which the life depends, is the gravitational movement of minerals from the watershed to the lake. Admittedly, the report contained herein concentrates mainly on the lake itself. Yet the foremost problem affecting the lakes and ponds today is accelerated cultural eutrophication, which originates in the watershed and is translated into various non-point sources of pollution. A great deal of lake restoration projects will have to focus on shoreland and lake watershed management.

Hynes (1974) sums up the science well in stating:

> ...The conclusions... are therefore that any interference with the normal condition of a lake or a stream is almost certain to have some adverse biological effect, even if, from an engineering point of view, the interference results in considerable improvement. At present, it would seem that this is little realized and that often much unnecessary damage is done to river and lake communities simply because of ignorance. It is of course manifest that sometimes engineering or water-supply projects have over-riding importance and even if they have not, the question of balancing one interest against the other must often arise. But, regrettably, even the possibility of biological consequences is often ignored. It cannot be emphasized too strongly that when it is proposed to alter an aquatic environment the project should be considered from the biological as well as the engineering viewpoint. Only then can the full implications of the proposed alteration be assessed properly, and a reasonable decision be taken. Obviously this will vary with the circumstances and the relative importance of the various consequences involved, but, at present, unnecessary and sometimes costly mistakes are often made because the importance of biological study is unknown to many administrators. Often, as for instance in drainage operations, it would be possible to work out compromises which would satisfy both engineering and biological interests.[1]

[1]Hynes, H.B.N., 1974. The Biology of Polluted Waters. University of Toronto Press, Toronto, Ontario, Canada.

FIGURE A



EUTROPHICATION – the process of aging by ecological succession.

Source: Measures for the Restoration and Enhancement of Quality of Freshwater Lakes. Washington, D.C.: United States Environmental Protection Agency, 1973.

TABLE A

LAKE TROPHIC CHARACTERISTICS

1. Oligotrophic Lakes

   a. Very deep, thermocline high; volume of hypolimnion large; water of hypolimnion cold.

   b. Organic materials on bottom and in suspension very low.

   c. Electrolytes low or variable; calcium, phosphorus, and nitrogen relatively poor; humic materials very low or absent.

   d. Dissolved oxygen content high at all depths and throughout year.

   e. Larger aquatic plants scarce.

   f. Plankton quantitatively restricted; species many; algal blooms rare; Chlorophyceae dominant.

   g. Profundal fauna relatively rich in species and quantity; Tanytarsus type; Corethra usually absent.

   h. Deep-dwelling, cold-water fishes (salmon, cisco, trout) common to abundant

   i. Succession into eutrophic type.

2. Eutrophic Lakes

   a. Relatively shallow; deep, cold water minimal or absent.

   b. Organic materials on bottom and in suspension abundant.

   c. Electrolytes variable, often high; calcium, phosphorus, and nitrogen abundant; humic materials slight.

   d. Dissolved oxygen in deep stratified lakes of this type minimal or absent in hypolimnion.

   e. Larger aquatic plants abundant.

   f. Plankton quantitatively abundant; quality variable; water blooms common, Myxophyceae and diatoms predominant.

   g. Profundal fauna, in deeper stratified lakes of this type; poor in species and quantity in hypolimnion; Chironomus type; Corethra present.

TABLE A (CONTINUED)

h. Deep-dwelling, cold water-fishes usualy absent; suitable for perch, pike, bass, and other warm-water fishes.

i. Succession into pond, swamp, or marsh.

3. Dystrophic Lakes

a. Usually shallow; temperature variable; in bog surroundings or in old mountains.

b. Organic materials in bottom and in suspension abundant.

c. Electrolytes low; calcium, phosphorus, and nitrogen very scanty; humic materials abundant.

d. Dissolved oxygen almost or entirely absent in deeper water.

e. Larger aquatic plants scanty.

f. Plankton variable; commonly low in species and quantity; Myxophyceae may be very rich quantitively.

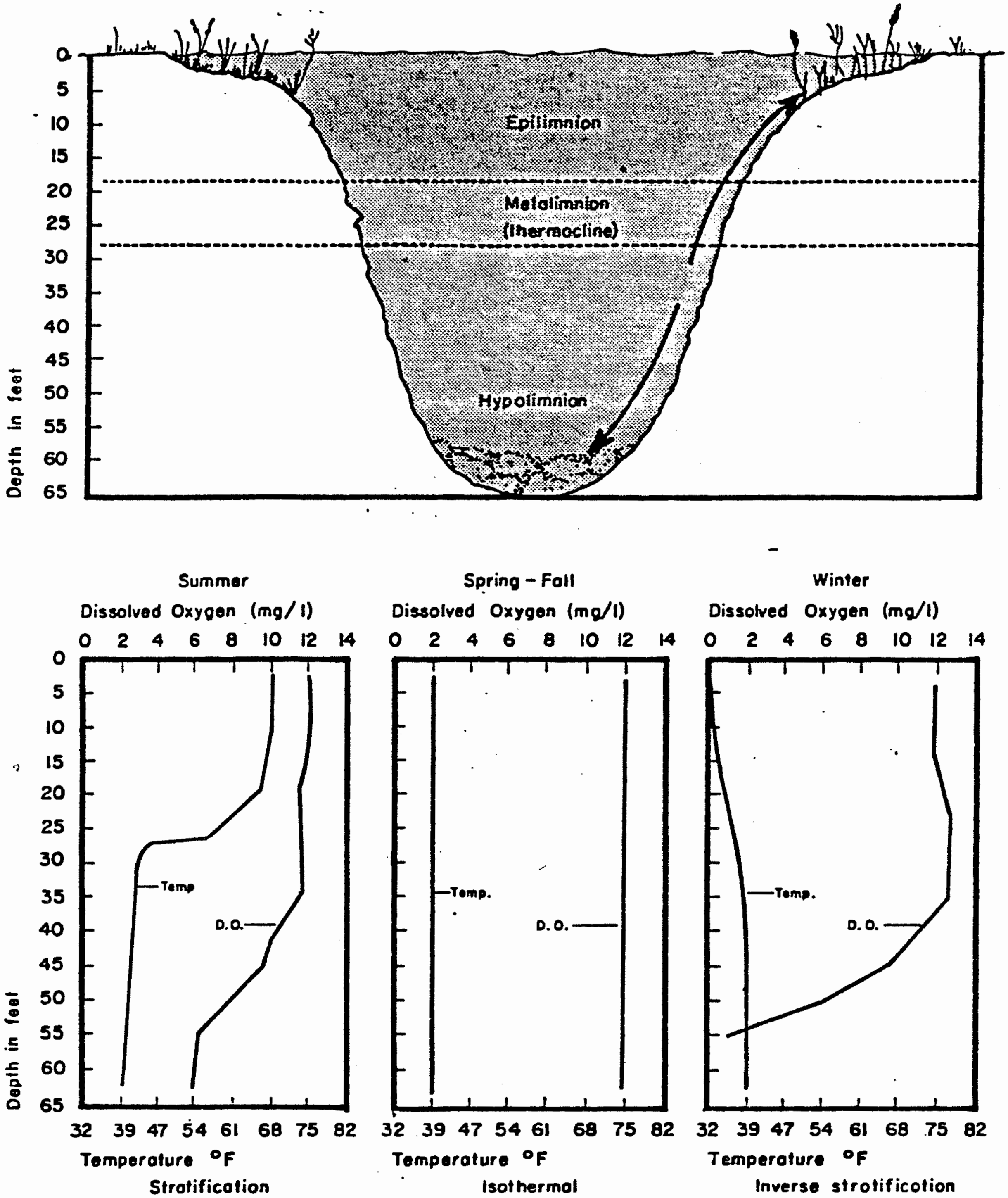
g. Profundal macrofauna poor to absent; all bottom deposits with very scant fauna; Chironomus sometimes present; Corethra present.

h. Deep-dwelling, cold-water fishes always absent in advanced dystrophic lakes; sometimes devoid of fish fauna; when present, fish production usually poor.

i. Succession into peat bog.

Source: Welch, P.S., Limnology, McGraw Hill Book Co., New York, 1952. (Reprinted with permission of the publisher.)

Diagrammatic sketch showing thermal characteristics of temperate lakes



Source: Measures for the Restoration and Enhancement of Quality of Freshwater Lakes. Washington, D.C.: United States Environmental Protection Agency, 1973.

FIGURE B

EUTROPHICATION

The term "eutrophic" means well-nourished; thus, "eutrophication" refers to natural or artificial addition of nutrients to bodies of water and to the effects of added nutrients (Eutrophication: Causes, Consequences And Correctives, 1969). The process of eutrophication is nothing new or invented by man. It is the process whereby a lake ages and eventually disappears. An undistributed lake will slowly undergo a natural succession of stages, the end product usually being a bog and, finally, dry land (see Figure A). These stages can be identified by measuring various physical, chemical, and biological aspects of the lake's ecosystem. Man can and often does affect the rate of eutrophication. From a pollutional point of view, these effects are caused by increased population, industrial growth, agricultural practices, watershed development, recreational use of land and waters, and other forms of watershed exploitation.

It might also be mentioned that some forms of water pollution are natural. Streams and ponds located in densely wooded regions may experience such heavy leaf fall as to cause asphyxiation of some organisms. Discoloration of many waters in Massachusetts is caused by purely natural processes. As pointed out by Hynes (1974), it is extremely difficult to define just what is meant by "natural waters, " which is not necessarily synonomous with "clean waters."

For restorative or preservative purposes of a lake and its watershed, it is important to identify both a lake's problem and the cause of the problem. Problems associated with eutrophication include nuisance algal blooms (especially blue-green algae), excessive aquatic plant growth, low dissolved oxygen content, degradation of sport fisheries, low transparency, mucky bottoms, changes in species type and diversity, and others. The pollutional cause is identified as either point or non-point in origin. A point source of pollution may be an inlet to the lake carrying some waste discharge from upstream. Or it may be an industrial, agricultural, or domestic (e.g., washing machine pipe) waste discharge which can be easily identified, quantified, and evaluated.

Non-point sources of pollution, which are the more common type affecting a lake, are more difficult to identify. They include agricultural runoff, urban runoff, fertilizers, septic or cesspool leakage, land clearing, and many more. They are often difficult to quantify, and thus evaluate.

An objective of a lake survey is to measure a lake's trophic state; that is, to describe the point at which the lake is in the aging process. The measure most widely used is a lake's productivity. Technically, this involves finding out the amount of carbon fixed per meter per day by the primary producers. Since it is a rather involved procedure to determine the energy flow through a lake system, the lake survey attempts to indirectly describe the lake's trophic state or level of biological productivity.

During the process of eutrophication, a lake passes through three major broad stages of succession: oligotrophy, mesotrophy, and eutrophy. Each stage has its characteristics (Table A). Data from a lake survey can be analyzed for assessment of the lake's trophic state. Although the level of productivity is not quantified, the physical, chemical, and biological parameters measured go a long way in positioning the lake as to its trophic status. The perimeter survey helps locate and identify sources of pollution. It should be noted, however, that at the present time, there is no single determination that is a universal measure of eutrophication.

Figure B shows the various zones of a typical stratified lake. In addition to the lake's life history mentioned above, a lake also has characteristic annual cycles. Depending on the season, a lake has a particular temperature and dissolved oxygen profile (Figure B). During the summer season, the epilimnion, or warm surface water, occupies the top zone. Below this is the metalimnion, which is characterized by a thermocline. In a stratified lake, this is the zone of rapid temperature change with depth. The bottom waters, or hypolimnion, contain colder water. The epilimnion is well mixed by wind action, whereas the hypolimmion does not normally circulate. During the spring and fall seasons, these regions break down due to temperature change and the whole lake circulates as one body. In shallow lakes (i.e., 10 to 15 feet maximum depth) affected by wind action, these zones do not exist except for short periods during calm weather.

The summer season (July and August) is the best time to survey a lake in order to measure its trophic status. This is the time when productivity and biomass are at their highest and when their direct or indirect effects can best be measured and observed. The oxygen concentration in the hypolimnion is an important characteristic for a lake. A high level of productivity in the surface waters usually results in low oxygen concentrations in the lake's bottom. Low oxygen in the hypolimnion can adversely affect the life in the lake, especially the cold-water fish which require a certain oxygen concentration. Organic material brought in via an inlet can also cause an oxygen deficit in the hypolimnion. Hutchinson (1957) has amply stressed the importance of dissolved oxygen in a lake.

> A skilled limnologist can probably learn more about the nature of a lake from a series of oxygen determinations than from any other kind of chemical data. If the oxygen determinations are accompanied by observations on secchi disc transparency, lake color, and some morphometric data, a very great deal is known about the lake.

Nitrogen and phosphorus have assumed prominance in nearly every lake investigation in relating nutrients to productivity (eutrophication). Some investigators (Odum, 1959) use the maximum nitrogen and phosphorus concentrations found during the winter as the basis of nutrient productivity correlation due to the biological minimum caused by environmental conditions. Others use data following the spring overturn as a more reliable basis for nutrient productivity correlation. In any event, considerable caution must be used in transporting nutrient concentration limits found in other lakes to the present situation.

TABLE B

SELECTED DATA FOR TWO HYPOTHETICAL LAKES[1]

CONCENTRATIONS IN mg/l

TROPHIC STATUS[2]	DISSOLVED OXYGEN AT BOTTOM	TRANSPARENCY (SECCHI LEVEL)	NH_3-N	NO_3-N	TOTAL P	PHYTOPLANKTON ASSEMBLAGES	AQUATIC VEGETATION	CHARACTERISTIC FISHERIES
Lake A (Oligotrophic)	High >5.0	High	Low <.03	Low <0.3	Low <0.01	High diversity, low numbers, nearly complete absence of blue-greens.	Sparse	Cold water types
Lake B (Eutrophic)	Low <5.0	Low	High >0.3	High >0.3	High >0.01	Low diversity, high numbers, abundance of blue-greens.	Abundant	Warm-water types

[1]Not established as State standards.

[2]Oligotrophic - nutrient - poor
Eutrophic - high concentrations of nutrients

Table B depicts concentrations of various substances and other data for two hypothetical lakes, one eutrophic, the other oligotrophic. It is intended as a guide for comparison to the data presented in this report. Each lake, of course, is different from all others. There is no hard and fast rule as to the critical concentrations for each lake. The morphology of a lake (e.g., mean depth) plays an important part in its general well-being. A small, deep lake will react differently to nutrient loading than a large, shallow lake. In the final analysis, each lake is found unique and must be evaluated on an individual basis.

DESCRIPTION OF TERMS

The terms related to limnology and other limnological entities, as used in this report, are defined below to assist the reader in interpreting some of the data presented:

AREA of a lake refers to the size of the surface, exclusive of islands, measured in square units by planimetry.

AQUATIC PLANTS or aquatic macrophyton can be defined as those vascular plants which germinate and grow with at least their base in the water and are large enough to be seen with the naked eye. The following three broad categories are recognized:

1. Emergent types are those plants rooted at the bottom and projecting out of the water for part of their length. Examples: arrowhead (*Sagittaria* spp.), pickerelweed (*Pontederia* spp.)

2. Floating types are those which wholly or in part float on the surface of the water and usually do not project above it. Examples: water shield (*Brasenia* spp.), yellow water lily (*Nuphar* spp.)

3. Submerged types are those which are continuously submerged (except for possible floating or emergent inflorescences). Examples: bladderwort (*Utricularia* spp.), pondweed (*Potamogeton* spp.)

CLINOGRADE is a stratification curve of temperature or of a chemical substance in a lake that exhibits a uniform slope from the surface into deep water.

CULTURAL EUTROPHICATION refers to the enrichment or rapid increase in productivity of a body of water caused by man. It is an accelerated process as opposed to natural, slow aging of a body of water. Visual effects include nuisance algal blooms, low transparency, extensive aquatic plant growth, and loss of cold-water fisheries due to oxygen depletion. It is caused by the rapid increase in nutrient additions to a lake.

DEVELOPMENT OF SHORELINE is the degree of regularity or irregularity of a shoreline expressed as an index figure. It is the ratio of the length of the shoreline to the length of the circumference of a circle of an area equal to that of the lake. It cannot be less than unity. The quantity can be regarded as a measure of the potential effect of littoral processes on the lake.

DEVELOPMENT OF VOLUME is defined as the ratio of the volume of the lake to that of a cone of basal area equal to the lake's area and height equal to the maximum depth.

DIMICTIC LAKE is one with spring and fall turnovers (temperate lakes).

DISSOLVED OXYGEN (D.O.) refers to the uncombined oxygen in water which is available to aquatic life; D.O. is therefore the critical parameter for fish propagation. Numerous factors influence D.O., including organic wastes, bottom deposits, hydrologic characteristics, nutrients, and aquatic organisms. Saturation D.O., or the theoretical maximum value, is primarily a function of temperature. D.O. values in excess of saturation are usually the result of algal blooms and therefore indicate an upset in the ecological balance. Optimum D.O. values range from 6.0 mg/l (minimum allowable for cold water fisheries) to saturation values. The latter range from 14.6 mg/l at $0^{\circ}C$ ($32^{\circ}F$) to 6.6 mg/l at $40^{\circ}C$ ($104^{\circ}F$).

EPILIMNION refers to the circulating, superficial layer of a lake or pond lying above the metalimnion which does not usually exhibit thermal stratification.

HETEROGRADE is a stratification curve for temperature or a chemical substrate in a lake which exhibits a non-uniform slope from top to bottom. It can be positive (metalimnetic maximum) or negative (metalimnetic minimun).

HYPOLIMNION refers to the deep layer of a lake lying below the metalimnion and removed from surface influences (i.e., not circulating).

LENTIC refers to still or calm water, such as lakes or ponds.

LOTIC refers to moving water, such as rivers or streams.

MAXIMUM DEPTH is the maximum depth known for a lake.

MAXIMUM EFFECTIVE LENGTH is the length of a straight line connecting the most remote extremities of a lake along which wing and wave action occur without any kind of land interruption. It is often identical with maximum length.

MAXIMUM EFFECTIVE WIDTH is similar to maximum effective length but at right angles to it.

MAXIMUM LENGTH is the length of a line connecting the two most remote extremities of a lake. It represents the true open-water length and does not cross any land other than islands.

MAXIMUM WIDTH is the length of a straight line connecting the most remote transverse extremities over the water at right angles to the maximum length axis.

MEAN DEPTH is the volume of a lake divided by its surface area.

MEAN DEPTH-MAXIMUM DEPTH RATIO is the mean depth divided by the maximum depth. It serves an an index figure which indicates in general the character of the approach of basin shape to conical form.

MEAN WIDTH is the area of a lake divided by its maximum length.

METALIMNION is the layer of water in a lake between the epilimnion and the hypolimnion in which the temperature exhibits the greatest difference in a vertical direction.

MILLIGRAMS PER LITER (mg/l) is used to express concentrations in water chemistry because it allows simpler calculations than the English System. The basis of the metric system is the unit weight and volume of water at standard conditions ($20^{o}C$). At these conditions, one milliliter of water equals one cubic centimeter and weighs one gram. One milligram per liter is therefore essentially equal to one part per million by weight or volume.

NON-POINT SOURCE POLLUTION can be defined as any pollutant which reaches a water body by means other than through a pipe. Examples of non-point sources include leachate from dumps and agricultural runoff from dairy farms.

NUTRIENTS are basically organic compounds made up of carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. Small amounts are vital to the ecological balance of a water body. Larger amounts can lead to an upset of the balance by allowing one type of organism, such as algae, to proliferate. The most significant nutrients in water bodies are those of carbon, nitrogen, and phosphorus. Nutrients of carbon are measured indirectly in the BOD test; separate tests are run to measure nutrients of nitrogen and phosphorus.

ORTHOGRADE is a stratification curve for temperature or a chemical substance in a lake which has a straight, uniform course.

pH is the measure of the hydrogen ion concentration of a solution on an inverse logarithmic scale ranging from 0 to 14. Values from 0 to 6.9 indicate acidic solutions, while values from 7.1 to 14 indicate alkaline solutions. A pH of 7.0 indicates a neutral solution. Natural streams usually show pH values between 6.5 and 7.5, although higher and lower values may be caused by natural conditions. Low pH values may result from the presence of heavy metals from acid mine drainage or metal-finishing waste. High pH values may result from detergents or photosynthetic activities of phytoplankton.

POINT SOURCE OF POLLUTION refers to continuous discharge of pollutants through a pipe or similar conduit. Primarily included are sewage and industrial waste, whether treated or untreated.

SESTON refers to all the particulate matter suspended in the water.

SHORELINE is the length of a lake's perimeter, measured from a map with a rotometer(map measurer).

SILICA ($SiSO_2$) is necessary for diatom growth. The concentration of silica is often closely linked with the diatom population's growth. The limiting concentration is usually considered to be 0.5 mg/l.

THERMOCLINE is coincident with the metalimnion and relates to the lakes zone with the greatest temperature change in a vertical direction.

VOLUME is determined by computing the volume of each horizontal stratum as limited by the several submerged contours on the bathymetric (hydrographic) map and taking the sum of the volumes of all such strata.

REFERENCES

1. American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater. 14th Edition, New York.

2. Commonwealth of Massachusetts, Division of Water Pollution Control. 1975. Compilation of Lakes, Ponds, and Reservoirs Relative to the Massachusetts Lake Classification Program. Westborough, Massachusetts.

3. Commonwealth of Massachusetts, Division of Water Pollution Control. 1981. Massachusetts Lake Classification Program. Westborough, Massachusetts.

4. Dillon, P.J. 1974. Manual for Calculating the Capacity of a Lake for Development. Ontario Ministry of the Environment, Water Resources Branch, Ontario, Canada.

5. Fassett, N.C. 1972. A Manual of Aquatic Plants. University of Wisconsin Press, Madison, Wisconsin.

6. Hotchkiss, N. 1972. Common Marsh, Underwater, and Floating - Leaved Plants of the United States and Canada. Dover Publications, Inc., New York.

7. Hutchinson, G.E. 1957. Geography, Physics, and Chemistry. Volume I of A Treatise on Limnology. John Wiley and Sons, Inc., New York.

8. Hutchinson, G.E. 1967. Introduction to Lake Biology and the Limnoplankton. Volume II of A Treatise on Limnology. John Wiley and Sons, Inc., New York.

9. Kimball, W.A. 1979. Chlorophyll a Procedure. Massachusetts Division of Water Pollution Control, Westborough, Massachusetts (unpublished).

10. Maine Department of Environmental Protection, Division of Lakes and Biological Studies. 1974. Standard Procedures for Biological Evaluation. Augusta, Maine.

11. National Academy of Sciences. 1967. Eutrophication: Causes, Consequences, and Correctives. Washington, D.C.

12. Needham, J.G. and P.R. Needham. 1962. A Guide to the Study of Fresh-Water Biology. Holden-Day, Inc., San Francisco, California.

13. Odum, E.P. 1959. Fundamentals of Ecology. W.B. Saunders Co., Philadelphia, Pennsylvania.

14. Palmer, M.C. 1962. Algae in Water Supplies. United States Department of Health, Education, and Welfare, Public Health Service, Washington, D.C.

15. Prescott, G.E. 1969. The Aquatic Plants. William C. Brown Co., Dubuque, Iowa.

16. Prescott, G.E. 1954. The Fresh-Water Algae. William C. Brown, Co., Dubuque, Iowa.

17. Reid, G.K. 1961. Ecology of Inland Waters and Estuaries. Reinhold Publishing Co., New York.

18. Ruttner, F. 1953. Fundamentals of Limnology. University of Toronto Press, Toronto, Canada.

19. Smith G.M. 1950. Fresh-Water Algae of the United States. McGraw-Hill Book Co., New York.

20. Ward, H.B. and G.C. Whipple. 1959. Fresh-Water Biology, Edited by W.T. Edmondson. John Wiley and Sons, Inc., New York.

21 Weber, C.I. (Editor). 1973 Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. United States Environmental Protection Agency, Cincinnati, Ohio.

22. Welch, P.C. 1948. Limnological Methods. McGraw-Hill Book Co., New York.

23. Welch, P.C. 1952. Limnology. McGraw-Hill Book Co., New York.

24. Weldon, L.W., R.D. Blackburn, and D.A. Harrington, 1973. Common Aquatic Weeds. Dover Publications, Inc., New York.

25. Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia, Pennsylvania.

APPENDIX A

CHLOROPHYLL a

PROCEDURES

I. Reagents and apparatus

A. Flourometer

1. "Blue lamp" Turner No. 110-853

2. Excitation Filter: Corning CS-5-60, #5543, 2 in^2, 4.9 mm polished

3. Emission Filter: Corning CS-2-64, #2408 2 in^2, 3.0 mm polished

4. R-136 photo multiplier tube

B. Tissue grinder and tube

C. Vacuum flask and pump

D. Millipore filter holder

E. Glass fiber filters: Reeve Angel, grade 934AH, 2.1 cm.

F. Centrifuge (Fisher Scientific Safety Centrifuge)

G. 15 ml graduated conical end centrifuge tubes with rubber stoppers

H. 90% acetone

I. 1 N HCl (11.1 dilution of distilled water to conc. HCl)

J. Saturated Magnesium Carbonate solution in distilled H_2O

II. Procedure

A. Filter 50 ml (or less if necessary) of sample through glass fiber filter under vacuum

B. Push the filter to the bottom of tissue grinding tube

C. Add about 3 ml of 90% acetone and 0.2 ml of the $HgCO_3$ solution

D. Grind contents for 3 minutes

E. The contents of the grinding tube are carefully washed into a 15 ml graduated centrifuge tube

F. Q.S. to 10 ml with 90% acetone

G. Tubes are then centrifuged for 20 minutes and the supernatent decanted immediately into stoppered test tubes.

H. Test tubes are wrapped with aluminum foil and stored in the refrigerator for 24 hours.

I. The tubes are allowed to come to room temperature, the temperature recorded, the samples poured into cuvettes, and then the samples are read on the fluorometer. (The fluorometer must be warmed up for at least ½ hr. before taking a reading.)

J. 0.2 ml of the 1 N HCl solution is added to the sample in the cuvette, the cuvette stoppered and inverted and righted 4 times to mix thoroughly, and the sample is read again

K. Both values are recorded, along with the window orifice size and whether the high-sensitivity or the regular door was used