IMNOLOGICAL STUDY OF 43 SELECTED MAINE LAKES

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-69

Prepared in cooperation with the

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION

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UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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FACTORS FOR CONVERTING INTERNATIONAL SYSTEM OF UNITS TO INCH-POUND UNITS

The following factors may be used to convert the International System of Units (SI) published herein to Inch-Pound Units.

Multiply SI Units	by	to obtain inch-pound units
Length		
millimeter (m)	0.0394	inches (in)
centimeter (cm)	0.3937	inches (in)
meter (m)	3.281	feet (ft)
kilometer (km)	.6214	mile (mi)
millimeter^2 (mm^2)	.0155	inches^2 (in^2)
meter^2 (m^2)	10.764	feet^2 (ft^2)
Area		
hectometer^2 (hm^2)	2.471	acre
kilometer^2 (km^2)	.3861	mile^2 (mi^2)
Volume		
liter (l)	0.2642	gallon (gal)
meter^3 (m^3)	35.31	feet^3 (ft^3)
meter^3 per second (m^3/s)	35.31	feet^3 per second (ft^3/s)
meter^3 per second (m^3/s)	15,850.	gallon per minute (gal/min)
hectometer^3 (hm^3)	813.0	acre-feet
Mass		
gram (g)	.03527	ounce avoirdupois (oz avdp)
kilogram (kg)	2.205	pound avoirdupois (lb avdp)
Temperature		
degrees Celsius (°C)	1.8°C +32	degrees Farenheit (°F)

A LIMNOLOGICAL STUDY OF 43 SELECTED MAINE LAKES

By Derrill J. Cowing[1] and Matthew Scott[2]

ABSTRACT

Federal and State legislation require the trophic classification of lakes and ponds in the State of Maine as part of a lake management program. In 1974, the State of Maine Department of Environmental Protection (DEP) adopted a preliminary set of procedures for establishing an index of lake trophic status. Also in 1974, this three-year study of selected Maine lakes was initiated to evaluate and improve this trophic classification system.

Analyses of project results led to the following recommendations for modifications in Maine's lake-management program. Lake trophic state should be established using a mean annual value of twice monthly observations of chlorophyll a in epilimnetic waters during the open-water season. Actual Trophic State Index (TSI) values for lakes are calculated using the formula: TSI = 77.7 - 27.3 ($\log_{10}$ annual mean chlorophyll a, in mg/L). In lakes with colors less than or equal to 30 platinum-cobalt units, mean annual Secchi disk transparencies may be used for calculation of lake TSI using the formula: TSI = 40.0 + 33.0 ($\log_{10}$ annual mean Secchi disk, in meters).

Supplemental information recommended for inclusion in the lake management program should include: morphological, hydrologic, and geologic data; baseline profile water-quality surveys; and benthic invertebrate, vegetation, and cultural surveys. Another recommendation is to change DEP's method of calculating the mean annual runoff for a lake drainage basin to an empirical formula based on drainage area characteristics. This resulted in more accurate estimations of mean annual hydraulic retention times for lakes. Many of these parameters recommended for inclusion in the lake management program will allow comparisons with future surveys to determine the impacts of cultural development on Maine lakes.

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INTRODUCTION

Recreational use of Maine's lakes provides great esthetic and economic benefits to both visitors and residents. Proper management of lakes to sustain these benefits requires that physical, chemical, and biological characteristics of lakes be available to many agencies.

This study by the USGS (U.S. Geological Survey) in cooperation with the DEP (Maine Department of Environmental Protection) was designed to provide data for several lakes extending from soutern to northern Maine representing a wide variety of hydrological, physical, chemical, and biological characteristics and to evaluate methods for the collection and interpretation of the data for lake management.

Lake management responsibilities, as set forth in Section 314.(a)(1) of Public Law 92-500 (Federal Water Pollution Control Act Amendments of 1972) requires each state to identify and classify its publicly owned lakes and ponds by trophic condition. Title 38, Revised Statutes (1973) establishes the DEP as the state agency responsible for Maine's Great Ponds (Research) Program.

Specific objectives of the study include:

1. Collection and publication of hydrologic, physical, chemical, and biological data on a wide variety of lake types in Maine.
2. Evaluation of water quality sampling methods, frequencies, and parameters for greatest usefulness in classifying and monitoring water quality of Maine lakes.
3. Evaluation of a lake trophic classification system proposed by DEP.
4. Evaluation of the impact of cultural development around the shoreline on the trophic conditions of Maine lakes.
5. Development of guidelines to aid in the management of Maine's lake resources.

Maine lakes have been studied previously by Cooper (1938-46), Maine IF&W (Maine Department of Inland Fisheries and Wildlife) (1974), and Davis and others (1977). Davis and others provides a comprehensive review of earlier studies and information concerning limnological characteristics of Maine lakes. Most of the early studies were related to fisheries management and were based on less limnological data than are currently available. However, data collected during these studies were used to assist in the selection of lakes for this study, and Cooper's studies (1938-1946) were particularly valuable for this purpose. The sampling methods and frequencies, and the parameters selected for analysis during this study are based largely on examination of results reported by Davis.

Physical, chemical, and biological data from lake surveys published by the IF&W (1974) were used for each of the study lakes.

Status of DEP's Current Lake Management Program

DEP's lake management program is in the first stages of data collection. Its primary objective is to gather information on the current trophic condition and assimilative capacity of the state's lakes and ponds. DEP's management strategy is to use the data collected in forming protection policies for the 2900 lakes currently without water quality problems. Second in priority is use of the data to help develop restoration programs for approximately 20 problem lakes in Maine (DEP, 1975).

The current trophic condition of selected lakes is being determined with the help of volunteer citizen observers referred to as lay monitors. These lay monitors measure Secchi disk transparencies weekly or every other week during the open-water period under the supervision of professional staff members of the DEP, Lakes and Biological Studies Division. These data are then used by the DEP to calculate a Trophic State Index (TSI) value for each lake. A description of these TSI calculations and data requirements can be found in "The Voluntary Water Quality Monitoring Project Report, 1979" on page 130 (Welch, 1979). DEP plans to eventually obtain TSI information on most lakes, gradually expanding the use of lay monitors.

Mean depth and hydraulic retention times are being used to estimate the assimilative capacities of lakes. Mean depths are being computed for about 1500 lakes and ponds which have been bathymetrically surveyed by IF&W. Hydraulic retention times are being computed according to Regulation 581.3 of the DEP, Bureau of Water Quality Control, as follows: hydraulic retention time equals lake volume divided by the product of lake drainage area and precipitation-runoff coefficient (DEP, 1977). Drainage areas for lakes and ponds are currently being determined by a cooperative study between the DEP and USGS, assisted by the Department of Conservation, Land Use Regulation Commission, and the Maine State Planning Office.

Miscellaneous information concerning lakes and ponds is also available from sources such as IF&W, colleges and universities, and regional planning commissions, and may be used to assign provisional TSI values for these bodies of water until updated by a more comprehensive study.

Lake data which have been processed for computer storage and retrieval are available from the DEP upon request.

Acknowledgments

Personnel of the DEP who deserve special acknowledgments for their contributions to the study are John Bailey, David Courtemanch, Jeffrey Dennis, Jeffrey McNelly, Barry Mower, and Barbara Welch.

Assistance was provided by staff biologists of the IF&W in the selection of study lakes and in sampling on a number of lakes. A special thanks to Mr. Fred Kircheis of IF&W for his work on Floods Pond.

Mr. Jerome "Frenchy" Guevremont of the town of Rangeley was invaluable in his assistance at Haley Pond and Saddleback Lake during the project.

METHODS

Selection of Study Lakes

Forty-three lakes, widely scattered throughout Maine, were selected for this study. The lakes fall into two groups. The first group, consisting of eight lakes, is referred to as special study lakes in this report. The lakes were of joint interest to the DEP and IF&W and were studied to provide supplementary baseline biologic and hydrologic data. These lakes are listed by name in table 1 along with the town and county in which the lake outlet is located.

The second group, consisting of 35 lakes, is referred to as regular study lakes. This group was selected to address the five objectives of the study listed on page 3. These lakes are listed by name in table 1, along with the town and county in which the lake outlet is located. The locations of the lakes in each of the two groups are shown in figure 1.

The lakes in these two groups represent a wide variety of hydrologic and trophic environments. Ranges of some common lake parameters follow:

	Minimum	Maximum
Surface area	9.3 hm^2(23 acres)	225.9 hm^2(5,581 acres)
Drainage area	1.8 km^2(0.7 mi^2)	1,968 km^2(760 mi^2)
Maximum depth	5.5 m(18 ft)	51.8 m(170 ft)
Mean depth	2.4 m(8 ft)	13.7 m(45 ft)
Hydraulic residence time	0.07 yr	7.6 yr
Secchi disk (mean)	1.9 m(6.2 ft)	9.0 m(30 ft)
Total phosphorus (mean)	5. ug/L	14. ug/L
Chlorophyll _a_ (mean)	1.4 ug/L	10.6 ug/L

Table 1.--List of study lakes with town and county in which the outlet is located.

Lake	Township	County
Special Study Lakes		
Eastern Grand Lake	Forest City	Washington
Floods Pond	Otis	Hancock
Great East Lake	Acton	York
Haley Pond	Rangeley	Franklin
Saddleback Lake	Dallas	Franklin
Tomah Lake	Forest	Washington
Wilson Pond (Lower)	Greenville	Piscataquis
Wilson Pond (Upper)	Greenville	Piscataquis
Regular Study Lakes		
Beddington Lake	Beddington	Washington
Beech Hill Pond	Otis	Hancock
Branch Lake	Ellsworth	Hancock
Brettuns Pond	Livermore	Androscoggin
Brewer Lake	Orrington	Penobscot
Clearwater Pond	Industry	Franklin
Coffee Pond	Casco	Cumberland
Crescent Lake	Raymond	Cumberland
Crystal Lake	Gray	Cumberland
Eagle Lake	Wallagrass	Aroostook
Forest Lake	Gray	Cumberland
Green Lake	Ellsworth	Hancock
Highland Lake	Westbrook	Cumberland
Hopkins Pond	Mariaville	Hancock
Lead Mtn Pond (Upper)	T28MD	Hancock
Long Pond	Livermore	Androscoggin
Madawaska Lake	Westmanland	Aroostook
Minnehonk Lake	Mount Vernon	Kennebec
Molasses Pond	Eastbrook	Hancock
Mopang Lake	T29MD	Washington
Nubble Pond	Raymond	Cumberland
Panther Pond	Raymond	Cumberland
Phillips Lake	Dedham	Hancock
Pleasant Pond	T4R3	Aroostook
Pleasant River Lake	Beddington	Washington
Portage Lake	Portage Lake	Aroostook
Porter Lake	New Vineyard	Franklin
Pushaw Lake	Hudson	Penobscot
Raymond Pond	Raymond	Cumberland
Shin Pond (Lower)	T5R7	Penobscot
Shin Pond (Upper)	Mount Chase	Penobscot
Spectacle Pond	Osborn	Hancock
Webb Lake	Weld	Franklin
Wilson Pond	Wilton	Franklin
Woodbury Pond	Litchfield	Kennebec

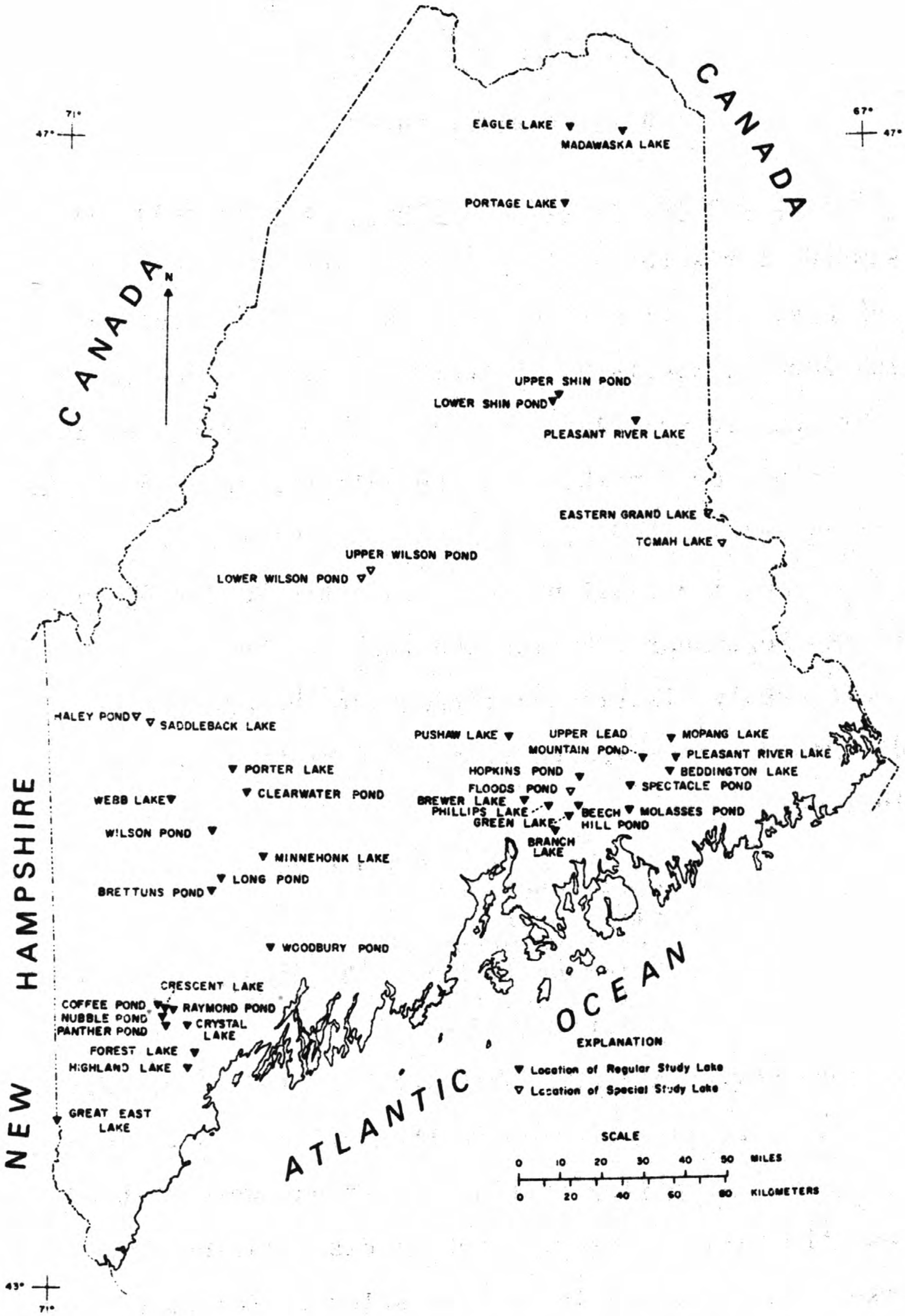


Figure 1.--Names and locations of regular and special study lakes.

Data Collection Program

Water Quality Surveys

Sampling Scheme for Regular Study Lakes.--These lakes were sampled for water quality information using two sampling formats. The first, referred to as the "intensive" sampling format, consisted of twelve visits to each of the lakes between ice-out (April or May) in the spring and ice-cover (November or December) in the fall during each of the three study years. During the first year of the project, trips for intensive sampling were concentrated during July, August, and September. During the last two years, these trips were evenly distributed throughout the open-water period. Parameters measured over the deep basin in each lake included:

- Secchi disk transparency
- total phosphorus
- air temperature
- water temperature
- chlorophyll *a* (depth integrated sample from the top 10 m (33 ft) of the water column)

In addition, phytoplankton samples were collected as part of the intensive sampling program in the 1974 and 1975 field seasons. In 1974, phytoplankton populations were sampled once near the minimum observed Secchi disk reading for each lake. In 1975, six lakes were selected for collection of phytoplankton data six times each (approximately once a month) during the open-water period. Observations of weather and lake conditions were recorded during all visits.

The second sampling format, designated as "baseline", includes two profile samples from each of the lakes. One set of profile data was collected during late summer stratification and the other during late winter stratification under ice cover. Sites for profile sampling were located in the major basins of each lake. Field determinations included: air temperature, Secchi disk transparency, profile measurements of dissolved oxygen and water temperature, with color, pH, specific conductance, and alkalinity measurements of point samples from the water column. Laboratory analyses of samples from the water column included the following 16 parameters:

Total orthophosphorus (low level)*	Dissolved silica
Total phosphorus (low level)*	Total iron
Ammonia nitrogen	Total manganese
Total nitrite nitrogen	Total calcium (summer only)
Total nitrate nitrogen	Total magnesium (summer only)
Total Kjeldahl nitrogen	Total sodium (summer only)
Dissolved chloride	Total potassium (summer only)
Dissolved sulfate	
Chlorophyll a (depth integrated sample from top 10 m (33 ft) of the water column.)	

* 0.00X mg/L detection level

Point locations for collection of samples from the water column were selected by examining the profile measurements of dissolved oxygen and temperature. Lakes which exhibited no significant stratification were sampled 0.6 m (2 ft) below the surface, mid-depth, and approximately 1 m (3 ft) above the bottom. In lakes less than 6 m (20 ft) deep, the mid-depth sample was eliminated. Lakes which exhibited thermal stratification were sampled at the top and bottom of the epilimnion and top and bottom of the hypolimnion. If the hypolimnion was very small, very large, or showed dissolved oxygen depressions, sample sites were either dropped or added at the discretion of the field personnel.

In addition to lake samples, flowing tributaries were sampled for water temperature, specific conductance, total phosphorus, and fecal coliform and fecal streptococcal bacteria during each of the two baseline sample trips.

During the late summer baseline sample visit to each of the study lakes, cottage counts and aquatic vegetation surveys were made. Benthic invertebrate samples were collected during the winter baseline sample trip to each of the lakes.

Sampling Scheme for Special Study Lakes.--Using the "baseline" format, the eight special study lakes were sampled five times each during 3-year project. Three sets of samples were taken in the late summer and two in late winter. Zooplankton samples were collected during the 3-year period on four of the lakes which are of special interest to IF&W for fishery studies.

Field Methods.--Descriptions of field methods are included for the following three tasks: location of sample sites, collection of samples, and determination of field parameters. The sample sites were located using IF&W lake survey bathymetric maps and an electronic depth sounding device. Horizontal location was estimated from the IF&W map, and final location of the deep basin sampling site was made from readings of the sounding device. Tributary sample sites were selected sufficiently upstream to avoid back-water effects from the lake.

Point samples from tributary streams were collected by taking samples 0.3 m (1 ft) below the surface. Tributary samples for bacterial analyses were collected with clean, sterile glass bottles and chilled immediately for preservation.

Lake water samples were collected by two methods: 1) collecting point samples from different depths over the deep basin with a plexiglass Van Dorn sampler, and 2) collecting depth-integrated samples by the "core technique". The latter samples were obtained by slowly lowering a flexible section of transparent plastic tubing into the water column. The tube was 10 m (33 ft) long, had an inside diameter of 1.27 cm (0.5 in.), and its bottom end was weighted to minimize horizontal drift during lowering. The tube was submerged full length, (or to a depth approximately 0.6 m (2.0 ft) from the bottom in shallow lakes), the top pinched closed, and the tube retrieved. Its contents were then emptied into a clean mixing container and the procedure repeated as necessary to get the required sample volume. The mixing container was agitated to homogenize the contents, and sample water was decanted into the appropriate sample bottles. The core technique was used to collect water for determination of chlorophyll a and phytoplankton populations throughout the study and total phosphorus values for "intensive" samples during the 1976 field season only. All other analyses reported were for point samples.

Methods for collecting samples for zooplankton and benthic invertebrate communities are described in the introductory material in each of three data reports by Cowing and Scott (1975, 1976, 1977).

Methods for determination of field parameters are as follows:

Alkalinity - 100 ml of sample were titrated to the methyl orange end point with 0.02N H_2SO_4. Alkalinities were determined for point samples from the water column during baseline sampling.

Color - as described by Brown, Skougstad, and Fishman (1970).

pH - as described by Brown, Skougstad, and Fishman (1970).

Specific conductance - as described by Brown, Skougstad, and Fishman (1970).

Water temperature - two methods were used to measure water temperature. During intensive sampling, surface water temperature of the lake was measured with a mercury-filled thermometer. During baseline sampling, profile water temperatures were measured with a YSI Model 54 or 57 dissolved oxygen/temperature meter. 1/

1/ The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Air temperature - measured with a mercury-filled thermometer.

Dissolved oxygen - measured with a YSI Model 54 or 57 dissolved oxygen/temperature meter.

Secchi disk transparency - measured with a standard disk 20 cm (7.9 in.) in diameter divided into four quadrants alternating black and white. The disk was lowered into the water column with a calibrated brass line. The descent of the disk was observed through a water scope (used to minimize difficulties in observation due to wave action, surface reflectance, and shadows) and the depth at which the disk was no longer visible was noted. The disk was then raised until it was just visible, and the average of the two depths observed was recorded as the Secchi disk transparency.

Percentage cloud cover and wind speed and direction - estimated by field personnel at time of sample collection for each lake.

Cottage counts - numbers of cottages within approximately 75 m (246 ft) of the lake shore were tabulated and the approximate locations were plotted on an IF&W lake survey field map.

Aquatic vegetation surveys - aquatic macrophyte surveys were made on each lake during the late summer baseline sample trip. The littoral area of the entire lake, including islands, was traversed by boat, and the distribution and estimated areal density of each plant type was sketched on an IF&W lake survey field map. Groups of plants which covered an area less than 100 m^2 and had a density of less than 10 percent were not mapped. The following classifications were used to record field observations:

Plant Type

- Emergent Vegetation
- Submerged
- Floating

Density

- A = $\geq 10 < 25\%$
- B = $\geq 25 < 50\%$
- C = $\geq 50 < 75\%$
- D = $\geq 75\%$

For example, one area might be: Emergent - *Scirpus*, C; Submerged - *Isoetes*, B; and Floating - *Nuphar*, A.

Laboratory Methods.--Laboratory methods used in analyzing samples (See section: Sampling Scheme for Regular Study Lakes.) are described by Brown, Skougstad, and Fishman (1970). Modifications were made to automated phosphomolybdate procedures used for orthophosphorus and total phosphorus determinations to enable detection of concentrations in the 0.001 to 0.100 mg/L range.

Bacterial determinations of tributary samples for fecal coliform and fecal streptococci bacteria were made using the membrane-filter method as discussed by Slack and others (1973). All phytoplankton samples were analyzed with a Nikon inverted microscope and a calibrated settling chamber, which allowed analysis of a known amount of sample. The smaller and generally more abundant cells were counted in an initial scan of 0.1 to 0.5 ml of sample at 1200x. The larger and less abundant cells, which did not appear in the initial scan in sufficient numbers, were then counted in a scan of 5 ml of sample at 300x. "Cells per ml", "colonies per ml", and "volume counted" were recorded for each taxon. The abbreviation "sol" is used in the colonies per ml column to indicate that a taxon is solitary rather than colonial. Species identifications were made whenever possible. The references and keys used in these identifications are listed under "selected references".

Volume and cross-sectional area of an average-sized cell were computed for each taxon. These were then multiplied times the cells per ml for each taxon to obtain volume per ml and cross-sectional area per ml. Values of these three variables were then totaled to obtain total cell number per ml (TCN), total cell volume per m^3 (TCV), and total cell cross-sectional area per L (TCA) for each taxon.

Further information concerning procedures used in analyzing biological samples can be found in the introductory material in each of three data reports by Cowing and Scott (1975, 1976, 1977). The TCV and TCA values were not included in the data reports. These data, including several 1974 quantitative counts which were not in the data report, are available from the authors.

LAKE CHARACTERIZATION

Morphology

Primary sources of data used to measure or compute the morphometric characteristics of all of the study lakes were IF&W lake survey maps and U.S. Geological Survey topographic quadrangle maps. The basic characteristics reported for each lake include:

drainage area	length of shoreline
surface area	maximum depth
surface altitude	mean depth
volume	

Details and references concerning methods used in developing these characteristics are described in data reports by Cowing and Scott (1975, 1976, 1977).

Values of the seven morphological characteristics for all the study lakes are contained in reports by Cowing and Scott (1975, 1976, 1977) and table 2 of this report. The maximum and minimum values for each of the parameters are flagged.

Table 2.--Morphometric characteristics of study lakes

Regular Study Lakes	Surface area (hm^2)	Drainage area (km^2)	Volume (hm^3)	Mean depth (m)	Maximum depth (m)	Shoreline (km)	Altitude (m)
	A	DA	V	X	X_M	L	E
Beddington Lake	163	208.8	8.87	5.5	18.3	11.3	78.0
Beech Hill Pond	547	24.6	64.1	11.6	31.7	18.3	60.7
Branch Lake	1,094	80.0	108.	9.8	37.8	33.5	72.5
Brettuns Pond	62	10.6	3.33	5.5	12.8	4.57	122.
Brewer Lake	357	31.1	24.7	7.0	14.6	11.3	35.1*
Clearwater Pond	304	15.8	40.7	13.4**	36.6	11.0	171.
Coffee Pond	55	2.6	5.55	10.1	21.3	3.66	142.
Crescent Lake	290	36.3	16.0	5.5	16.4	11.9	84.4
Crystal Lake	76	4.9	6.78	8.8	18.0	4.57	93.3
Eagle Lake	2,259	1968. **	308.	13.7	42.7	54.9	175.
Forest Lake	80	8.5	3.21	4.0	11.6	5.79	84.1
Green Lake	1,210	148.9	136.	11.0	51.8**	33.5	48.5
Highland Lake	259	22.5	17.3	6.7	20.4	13.1	57.9
Hopkins Pond	179	8.3	12.2	6.7	19.8	10.1	110.
Lead Mtn Pond (Upper)	413	17.9	30.8	7.3	17.4	11.3	108.
Long Pond	82	9.3	2.47	3.0	5.5	5.49	144.
Madawaska Lake	618	82.9	29.6	4.9	11.6	16.5	176.
Minnehonk Lake	40	43.5	3.70	9.1	22.3	3.35	100.
Molasses Pond	507	23.3	25.9	5.2	14.3	13.7	64.
Mopang Lake	602	28.7	40.7	6.7	24.7	16.8	104.
Nubble Pond	9*	1.8*	.49*	5.2	11.3	1.52*	102.
Panther Pond	582	78.0	41.9	7.3	20.7	18.9	84.4
Phillips Lake	335	30.6	32.1	9.4	32.0	18.9	69.5
Pleasant Pond	741	18.6	71.5	9.8	20.4	16.5	163.
Pleasant River Lake	384	38.8	16.0	4.3	17.1	14.3	96.6
Portage Lake	1,001	536.	23.4	2.4	7.6	27.7	186.
Porter Lake	213	14.2	16.0	7.6	26.2	6.71	192.
Pushaw Lake	2,046	293.	65.3	3.0	8.5	36.6	35.1*
Raymond Pond	140	13.5	6.90	4.9	12.8	6.71	93.0

* Minimum value
** Maximum value

Table 2.--Morphometric characteristics of study lakes--Continued

Regular Study Lakes	Surface area (hm^2)	Drainage area (km^2)	Volume (hm^3)	Mean depth (m)	Maximum depth (m)	Shoreline (km)	Altitude (m)
	A	DA	V	X	X_M	L	E
Shin Pond (Lower)	227	61.1	8.01	3.7	7.6	11.9	237.
Shin Pond (Upper)	220	45.1	12.3	5.5	19.5	10.7	241.
Spectacde Pond	710	124.3	17.3	2.4	9.1	29.3	77.7
Webb Lake	868	196.1	67.8	7.9	12.8	20.1	207.
Wilson Pond	194	69.9	16.0	8.2	26.8	10.1	174.
Woodbury Pond	176	39.9	9.00	5.2	18.9	12.5	53.6
Special Study Lakes							
Eastern Grand Lake	6,504**	357.	616. **	9.4	39.0	119. **	132.
Floods Pond	265	21.2	32.1	12.2	44.8	18.9	90.8
Great East Lake	716	42.2	74.0	10.4	31.1	17.1	175.
Haley Pond	69	25.6	1.60	2.4	7.0	3.96	465.
Saddleback Lake	145	28.5	3.21	2.1*	4.3*	5.49	532. **
Tomae Lake	23	1.8*	1.48	6.7	14.0	2.13	165.
Wilson Pond (Lower)	558	85.0	49.3	8.8	32.6	18.6	372.
Wilson Pond (Upper)	380	52.8	16.0	4.3	19.5	14.5	342.

* Minimum value
** Maximum value

Geology

Although not included as a specific objective of this study, the geology of the 43 lake basins was reviewed based on available information. This data allowed only a cursory analysis of limnologic effects of drainage basin geology on the lakes.

Steps used in summarizing the geology included:

1. A literature survey regarding the probable origin of the lakes and the surficial and bedrock geology of the lake drainage basins.

2. A literature survey regarding the influence of bedrock geology on the water quality of Maine lakes.

3. A review of the water quality data collected for each lake and its relationship to the geohydrology of the basin.

Information about lake origins and detailed lithologies of the lake drainage basins was collected from bedrock and surficial geologic quadrangle maps, regional reconnaissance surveys, open-file reports, and standard U.S.G.S. topographic maps. Detailed information was available for some lakes, but for others, only regional studies were available. When the literature gave no specific information about a lake's origin, it was inferred from surficial geology and the topographic expression of the basins.

Most lakes in Maine are characterized by low alkalinities and conductivities. However, hard-water areas exist in the State where alkalinity is greater than 40 mg/L as $CaCO_3$. These are concentrated in areas of limestone bedrock. This observation has caused interest in possible geologic controls over alkalinity, which is one of the geochemical variables related to lake productivity. Mairs (1966) summarizes much of the information available concerning the effect of geology on the alkalinities of Maine lakes.

Inorganic geochemical data were examined for the 35 regular study lakes, and an attempt was made to relate three geochemical variables (alkalinity, conductivity, pH) and eight ionic species (Cl, SO_4, Fe, Mn, Ca, Mg, K, Na) and SiO_2 to the lithologies of bedrock and surficial deposits occurring within the lake drainage basins. Near-surface summer measurements were used as most representative of lake water composition.

Bedrock lithologies were divided into three groups: granitic, calcareous, and other. Linear correlation coefficients (r) were determined within each bedrock type to determine if significant correlations between geological variables and certain species of ions occurred in some bedrock types and not in others. The results of this analysis are discussed in the "Lake Water Quality Surveys" section of this report.

Lake Origins

The lakes have been grouped by their mode of origin according to the classification system of Hutchinson (1957). Because many of the lakes show the effects of more than one process of origin, the class of an individual lake is based upon the dominant process.

A few lakes are the result of glacial scour. These lakes are listed in table 2A as Type 26. The advancing glacier excavated jointed or weathered bedrock (commonly granite) and produced depressions. The topographic expression of many lakes on granitic terrain show evidence of erosion of jointed bedrock by glaciers. Glaciers preferentially follow valleys which are oriented in the general direction of glacier movement. These valleys become widened and deepened by glacial erosion. Upon retreat of the glacier, a lake may form in the valley as a result of the damming of one end with till, in the form of a moraine (Type 30a), or by the damming of both ends (Type 30b). Lakes of these two types are listed in table 2A. Damming may also be done by outwash deposits. Lakes of this origin are listed in table 2A as Type 31.

Table 2A.--Lakes grouped according to origin, using the classification system of Hutchinson (1957).

Lake Origins				
Lakes in depressions left by glacial scour (Type 26)*	Valley lakes with one end dammed by till deposits (Type 30a)*	Valley lakes with both ends dammed by till deposits (Type 30b)*	Valley lakes dammed by outwash deposits (Type 31)*	Lakes in depressions left by melting of ice blocks in outwash deposits (Type 35)
Floods Pond	Beech Hill Pond	Eagle Lake	Clearwater Pond	Beddington Lake
Lead Mtn Pond (Upper)	Branch Lake	Minnehonk Lake	Crescent Lake	Brettuns Pond
Nubble Pond	Brewer Lake	Molasses Pond	Green Lake	Crystal Lake
Pleasant Pond	Coffee Pond	Spectacle Pond	Mopang Lake	Forest Lake
Saddleback Lake	Eastern Grand Lake	Wilson Pond	Panther Pond	
	Great East Lake		Pleasant River Lake	
	Haley Pond		Porter Lake	
	Highland Lake		Pushaw Lake	
	Hopkins Pond		Shin Pond (Upper)	
	Long Pond		Webb Lake	
	Madawaska Lake		Woodbury Pond	
	Phillips Lake			
	Portage Lake			
	Raymond Pond			
	Shin Pond (Lower)			
	Tomah Lake			
	Wilson Pond (Lower)			
	Wilson Pond (Upper)			

* Hutchinson's code number for lake origins.

During glacial retreat, large volumes of outwash may form which contain large isolated blocks of ice. When these blocks melt, depressions form in the outwash which may fill with water. Lakes having this origin are listed in table 2A as Type 35.

Lake Drainage Basin Lithologies

Although the bedrock geology of some of the lake drainage basins is complex, 28 can be characterized by relatively few dominant lithologies, as shown in table 2B. Sixteen basins are underlain exclusively by granitic bedrock; seven basins are dominated by granitic and metasedimentary rocks; and five basins have metasedimentary bedrock as the only dominant lithology.

Table 2B.--Lakes grouped according to the dominant type of bedrock in the drainage basin.

Dominant Lithology		
Granite	Granite and Metasediment	Metasediment
Branch Lake	Beech Hill Pond	Beddington Lake
Coffee Pond	Brewer Lake	Haley Pond
Crescent Lake	Clearwater Pond	Porter Lake
Crystal Lake	Great East Lake	Tomah Lake
Floods Pond	Green Lake	Wilson Pond
Forest Lake	Mopang Lake	
Highland Lake	Pleasant Pond	
Hopkins Pond		
Lead Mtn Pond (Upper)		
Molasses Pond		
Nubble Pond		
Panther Pond		
Phillips Lake		
Raymond Pond		
Saddleback Lake		
Spectacle Pond		

The bedrock of Webb Lake consists of metasedimentary rocks together with gneiss and sulfidic schist. Calcareous rocks were not found to be dominant within any lake basins in this study, but may constitute a limnologically important lithology associated with metasedimentary rocks. Examples of calcareous lithologies are found as slightly metamorphosed limestone and calcareous metasediments in Eagle, Portage, Madawaska, and Pushaw Lakes. Also, acidic and basic volcanic rocks occur within these relatively extensive drainage basins.

Calcareous rocks also may occur as lenses of marble in metamorphosed terrain such as in Brettuns and Long Ponds, Minnehonk Lake, and Woodbury Pond; these basins also contain gneiss and schist. Upper and Lower Wilson Ponds are underlain by gabbros and diorite with some metasediments. Eastern Grand Lake, Pleasant River, and Upper and Lower Shin Ponds have relatively complex geology within their basins. The dominant lithology is granite, which occurs with metasediments (some of which are iron and manganese rich), quartz diorite, diabase, basic volcanics, and a few calcareous rocks.

Hydrology

The primary objective of the hydrologic phase of the study was to develop a suitable method for calculating mean annual values for hydraulic flushing rate (p) or hydraulic retention time (T_w) for Maine lakes ($p = 1/T_w$). Additional hydrologic characterization of the study lakes included: 1) estimation of annual flushing rates for each of the 3 years of the project, and 2) estimation of the seasonal distribution of the annual flushing cycles. Sources of information used in the computations were; U.S. Geological Survey Water-Supply Papers, annual reports of water resources data for Maine, hydrologic atlas data, and open-file reports.

Estimation of Mean Annual Hydraulic Retention Time

Three different methods were compared in calculating mean annual runoff and resultant T_w for each lake. The first method, called "Associated Gage" (AG) method, involved calculation of the retention times with the runoff term being the average annual runoff from seven nearby streamgages (see figure 2). The value of runoff for each gage was the mean-annual runoff observed during the period of record at the gage. The mean-annual runoff and period of record for each of the seven gages used are listed in table 3. The T_w calculated for each study lake is reported in table 4. The formula used to compute T_w is:

$$T_w = \frac{1000V}{DA \; x R}$$

where: DA = drainage area of the lake at the outlet (km^2)

R = annual runoff (mm/yr)

V = volume of the lake (hm^3)

1000 = coefficient to convert units of the above variables to a common base

T_w = hydraulic retention time (yr)

note: DA and V were determined as described by Cowing and Scott (1975, 1976, 1977)

The second method used in determining runoff rates for study lake drainage basins was called the "HA-7" (HA) method. Runoff figures were determined for the individual lakes from U.S. Geological Survey Hydrologic Investigation Atlas-7 (Knox and Nordenson, 1955). The resultant T_w for each lake is reported in table 4.

The third method to determine annual runoff, called the "Empirical Formula" (EF) method, was an equation presented by Parker (1978). Parker's equation was developed to allow prediction of mean annual flows at ungaged sites using drainage basin characteristics. The formula is:

$$Q_a = 1.329 \times 10^2 A^{0.985} P^{1.347}$$

where: Q_a = mean annual flow (ft^3/s)
A = drainage area (mi^2)
P = mean annual precipitation in the basin as shown in HA-7 (in/yr)

The T_w values obtained using these runoff figures are also reported in table 4.

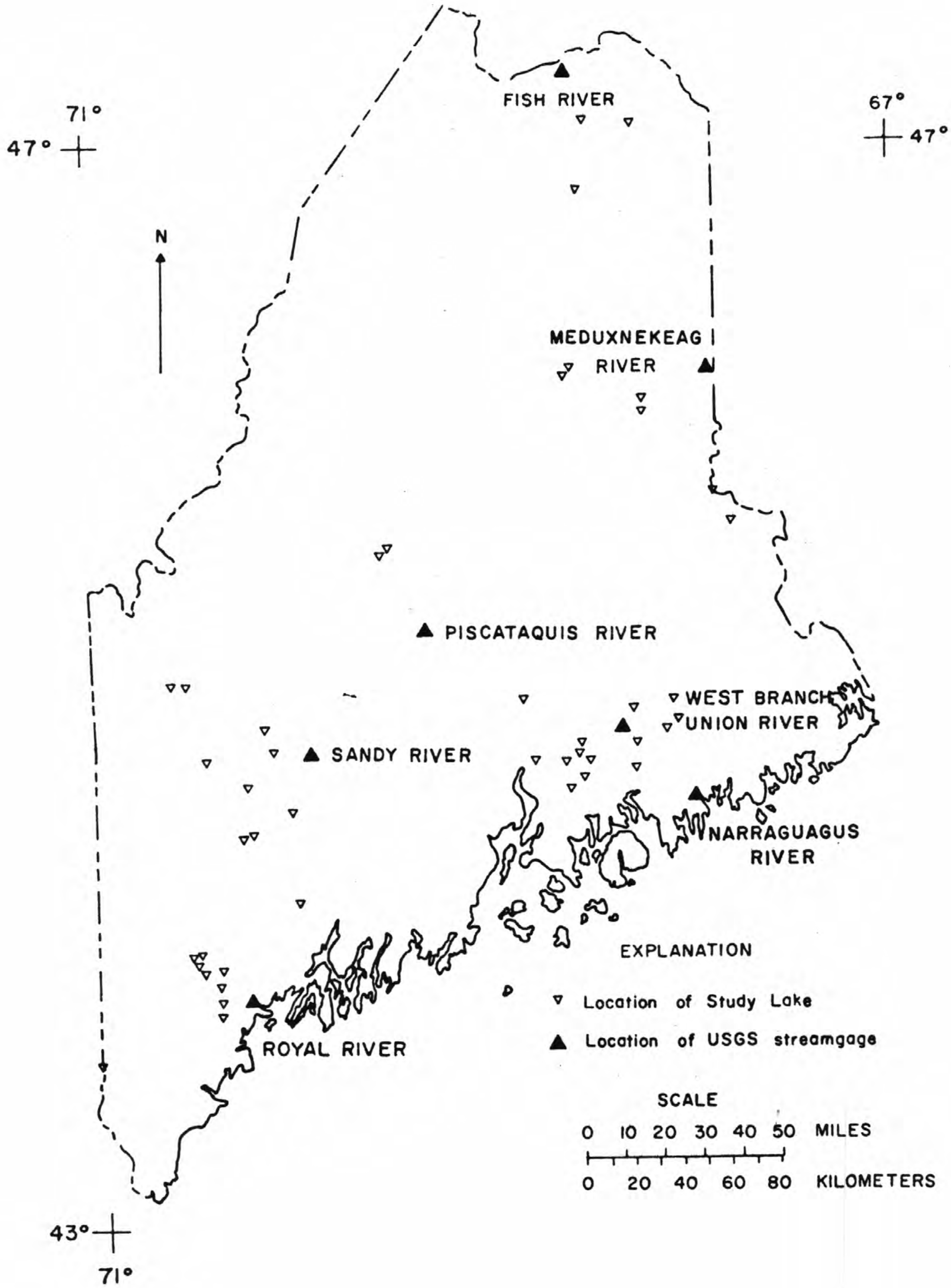


Figure 2.--Names and locations of the streamgages used in the "Associated Gage Method".

Table 3.--Runoff at streamgages used in the "Associated Gage" method of calculating lake flushing rates.

Streamgage	Length of Record (yrs)	Mean Annual Runoff (mm/yr)	1974 Runoff Observed (mm/yr)	Difference from mean (%)	1975 Runoff Observed (mm/yr)	Difference from mean (%)	1976 Runoff Observed (mm/yr)	Difference from mean (%)
Fish River nr Ft. Kent, ME	51	559	660	+18	483	-14	889	+59
Meduxnekeag River nr Houlton, ME	35	584	559	- 4	457	-22	991	+70
Narraguagus River at Cherryfield, ME	27	737	737	0	660	-10	914	+24
West Branch Union River at Amherst, ME	56	610	711	+17	584	- 4	914	+50
Piscataquis River nr Dover-Foxcroft, ME	73	711	838	+18	610	-14	991	+39
Sandy River nr Mercer, ME	48	635	838	+32	610	- 4	864	+36
Royal River at Yarmouth, ME	26	660	711	+ 8	635	- 4	660	0

Table 4.--Hydraulic retention times of study lakes computed using three methods for the calculation of mean annual runoff.

Regular Study Lakes	Associated Gage Method	HA-7 Method	Empirical Formula Method
Beddington Lake	.06 yr	.07 yr	.06 yr
Beech Hill Pond	4.3	4.5	3.8
Branch Lake	2.2	2.3	2.0
Brettuns Pond	.49	.56	.46
Brewer Lake	1.3	1.5	1.2
Clearwater Pond	4.1	4.6	3.8
Coffee Pond	3.2	4.2	3.0
Crescent Lake	.67	.87	.64
Crystal Lake	2.1	2.7	2.0
Eagle Lake	.28	.31	.27
Forest Lake	.57	.70	.55
Green Lake	1.5	1.6	1.4
Highland Lake	1.2	1.4	1.1
Hopkins Pond	2.4	2.6	2.1
Lead Mtn Pond (Upper)	2.8	2.8	2.5
Long Pond	.42	.50	.39
Madawaska Lake	.64	.74	.61
Minnehonk Lake	.13	.17	.13
Molasses Pond	1.8	1.8	1.6
Mopang Lake	1.9	2.3	2.1
Nubble Pond	.41	.54	.38
Panther Pond	.81	1.1	.81
Phillips Lake	1.7	1.8	1.5
Pleasant Pond	6.6	7.6	6.3
Pleasant River Lake	.56	.65	.60
Portage Lake	.08	.09	.07
Porter Lake	1.8	2.0	1.6
Pushaw Lake	.37	.44	.38
Raymond Pond	.78	1.0	.75
Shin Pond (Lower)	.22	.20	.19
Shin Pond (Upper)	.47	.43	.40
Spectacle Pond	.23	.23	.21
Webb Lake	.54	.65	.50
Wilson Pond	.36	.39	.32
Woodbury Pond	.36	.44	.33
Special Study Lakes			
Eastern Grand Lake	3.0	3.1	2.8
Floods Pond	2.5	2.7	2.2
Great East Lake	2.7	3.1	2.5
Haley Pond	.10	.12	.10
Saddleback Lake	.18	.22	.15
Tomah Lake	1.4	1.4	1.2
Wilson Pond (Lower)	.82	.95	.82
Wilson Pond (Upper)	.43	.50	.41

Comparison of the three methods showed the EF method to yield consistently higher runoff figures than either the HA method or the AG method. Figure 3 shows the graphical relationships between the estimated runoff calculated from the three methods. Runoff figures for the EF method averaged 18 percent higher than the HA method and 6 percent higher than the AG method.

There are two potential causes of the differences in these runoff figures. One reason for the low HA method values seems to be deficient runoff during the 20-year period (1930-1949) selected as a data base for HA-7. Eleven gages with long term records encompassing this 20-year period of record were used to compare runoff figures. The runoff for the 20-year period used to generate HA-7 data was consistently lower than the long-term average runoff. The average difference was about -7 percent, while individual stations ranged from -4 to -9 percent.

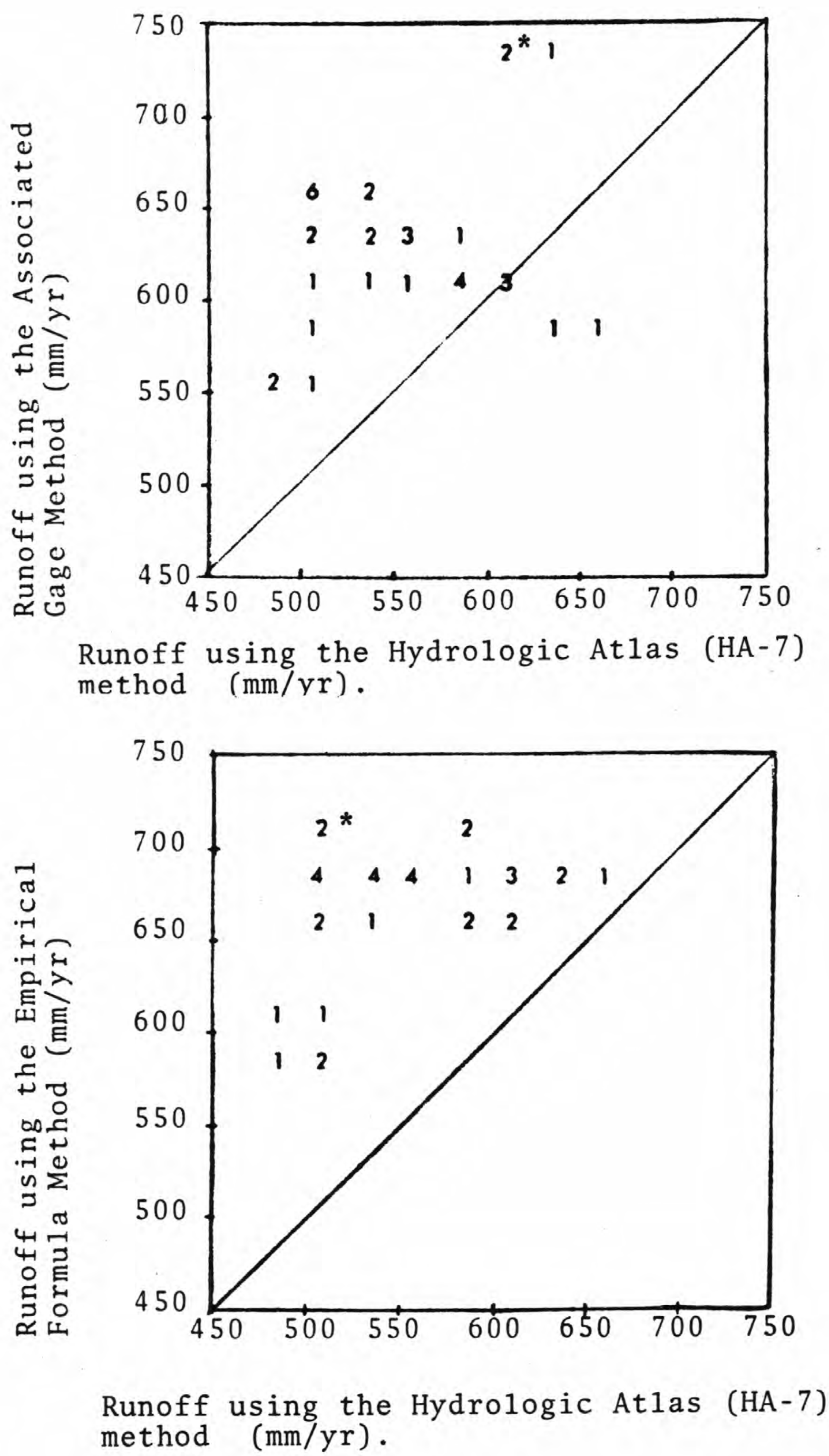
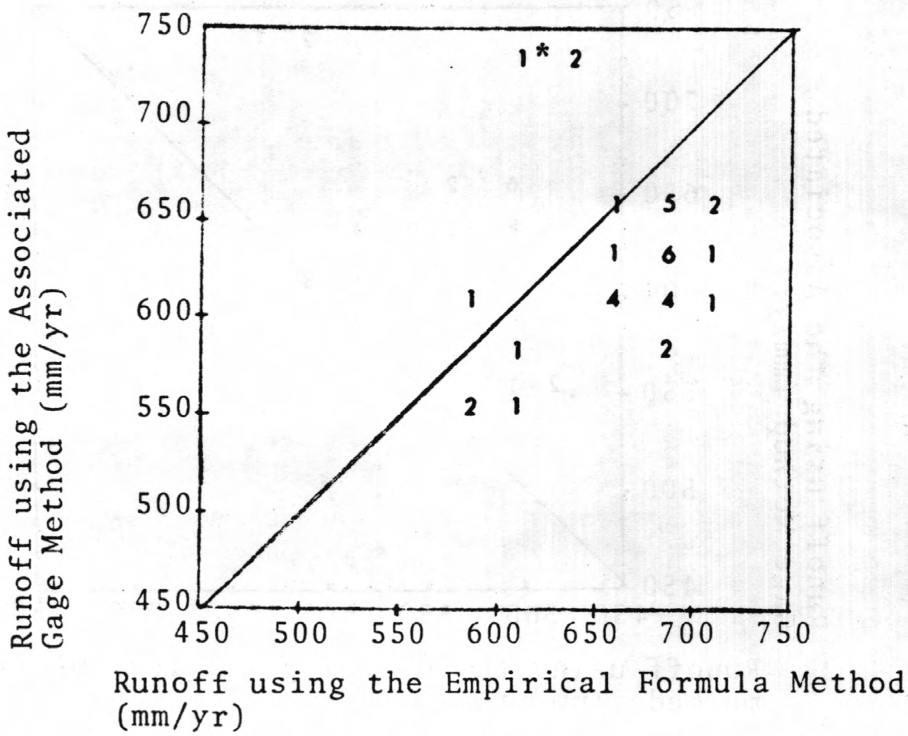


Figure 3.--Comparison of three methods of computing long-term annual runoff rates.



* numbers indicate number of lakes which plotted at the same coordinates

Figure 3.--Comparison of three methods of computing long-term annual runoff rates--Continued.

A second probable cause of the differences observed between the three methods of computing runoff is the size and location of the drainage areas of the gaging stations used in the computation of runoff figures. Both the HA method and the AG method rely heavily on data from gaging stations with both large drainage areas and long-term records. The EF method uses data from gages representing both large and small (as low as 0.93 mi^2) drainage areas. Runoff figures from large streams tend to underestimate the runoff in smaller headwater areas where many of the study lakes are located.

Based on the comparison of the three methods, it is recommended that the Empirical Formula Method be used to compute the runoff figures for determining hydraulic retention times for Maine lakes. Reliability estimates show the formula to have the equivalent accuracy of collecting 13.3 years of streamflow records at a site and a standard error of the estimate of 6.9 percent (Parker, 1978).

Estimation of Hydraulic Retention Time for a Specific Year

A secondary objective in the hydrologic analysis of flushing rates was to develop a method for estimating T_w values for the lakes during each of the three years of the study. The method selected involved the use of the streamflow records collected at the seven gaging stations used in the AG method for determining long-term flushing rates. Annual runoff figures for calendar years 1974, 1975, and 1976 were obtained for each gage from annual water-resources data report for Maine (U.S. Geological Survey, 1974, 1975, 1976, 1977). These mean annual flows in ft^3/s were converted to mm/yr and used at the associated lake to compute the T_w values. The annual runoff figures at each of the gaging stations during the study are shown in table 3. Comparisons of runoff to the long-term mean annual runoff (table 3) show variations from -22 percent of the mean at the Meduxnekeag River in 1975 to +70 percent of the mean at the same station the following year. In general, flows were above normal in 1974, below normal in 1975, and well above normal in 1976.

One of the advantages of using associated gaging station records is that the annual runoff can be compared with the long-term actual and statistical summaries of flow characteristics at the station. For gaging stations with more than 10 years of record, high-flow and low-flow frequency analyses can be made with a USGS computer program. Frequency analyses describe the high or low flow for various numbers of consecutive days that can be expected to be exceeded, on the average once in a specified number of years. Commonly these data are plotted as frequency curves.

For example, to estimate how frequently, on the average, the 1976 annual flow at the Meduxnekeag gage is exceeded (exceedance probability), the following information from a log-Pearson Type III frequency analysis can be used:

Exceedance Probability	Recurrence Interval	365 Day High Flow (cfs) Computed Runoff (mm/yr)
0.200	5	356 cfs or 711 mm/yr
0.100	10	400 cfs or 787 mm/yr
0.040	25	454 cfs or 889 mm/yr
0.020	50	491 cfs or 965 mm/yr
0.010	100	527 cfs or 1041 mm/yr

A comparison of the runoff observed in 1976 (991 mm/yr) to the annual flow computed from the 365-day high-flow frequency analysis shows that the 1976 annual runoff (and related T_w values for nearby lakes) has a probability of occurrence of slightly less than 0.020 or a recurrence interval of slightly more than 50 years.

Seasonal Variations of Hydraulic Retention Time.--Additional information available to those interested in lake hydrology are the seasonal runoff characteristics from gaging stations closely associated with particular lake basins. Long-term monthly means are available for nearly all of the full-time streamgaging stations operated by the Survey. These records contain the long-term seasonal averages for runoff at the particular gaging station. Figure 4 shows the monthly distribution of runoff observed at the seven gaging stations previously used in the AG method of runoff computation. Mean monthly flows were converted to percent mean annual flow to show seasonal patterns. In the northern section of the State, an average of about 60 percent of the annual runoff occurs in 3 months (April, May, and June). In the southern section of the State, spring runoff usually starts a month earlier and runs off less rapidly. About 50 percent of the annual runoff occurs during March, April and May. Although T_w's are calculated on an average annual basis, these seasonal patterns of runoff show that hydraulic retention times may vary by an order of magnitude within the year.

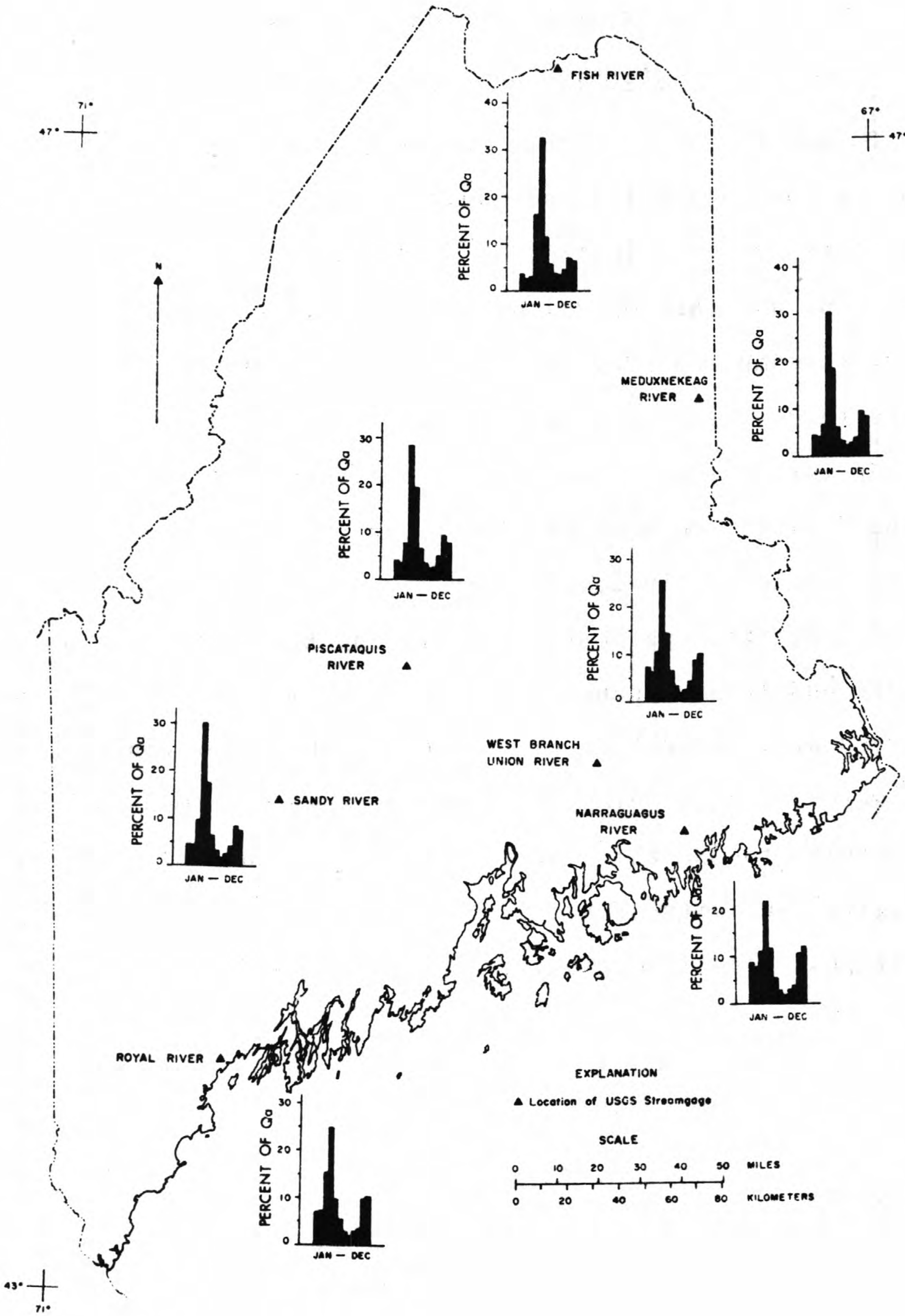


Figure 4.--Monthly runoff characteristics at selected streamgaging stations.

RESULTS OF WATER QUALITY SURVEYS

Intensive Sampling Program

During the 3-year study, water quality data were collected on an intensive sampling schedule for the 35 regular study lakes. Parameters measured included: Secchi disk transparency, total phosphorus and chlorophyll a. The primary objective of the intensive sampling program was to evaluate the usefulness of each of the three parameters for trophically classifying Maine lakes. Methods for collection and analysis of these parameters as well as the data for each of the lakes can be found in data reports by Cowing and Scott (1975, 1976, 1977).

Of the three parameters, Secchi disk transparency was the easiest and least expensive parameter to measure. The values observed were indicative of the seston and color content of the lake waters. When color and inorganic seston components exist at low levels, the Secchi disk transparency should reflect primary biological activity of the lake waters and be useful as a parameter for trophic classification.

Phosphorus has been demonstrated to be a controlling factor in limiting primary productivity in most lakes of low to moderate productivity (U.S. EPA, 1974; Weiss, 1976; Miller and others, 1974). Most of Maine's 2900 lakes and ponds are considered to be in this productivity range (Davis and others, 1977). Only 20 lakes were listed as "problem lakes" in the Maine Lake Water Quality Strategy report by DEP in 1975. With phosphorus concentrations being one of the primary controls on productivity, it is expected that phosphorus levels should be useful in the trophic classification of most Maine lakes and would correlate well with other trophic state indicators.

However, there are difficulties in using phosphorus as a classification parameter. In lakes with colored waters, phosphorus may occur in forms unavailable for biological uptake, reducing its utility for estimating lake trophic state. In addition, phosphorus levels in most Maine lakes are near or below the lower detection limit of conventional analytical techniques (0.01 mg/L); these low levels create problems in sampling, sample handling and analysis. Additional problems in measuring phosphorus are described in the section on "Problems of the Intensive Sampling Program".

Chlorophyll a determinations, like phosphorus, are subject to problems in sampling and analysis (see section on "Problems of the Intensive Sampling Program"). Samples are expensive to analyze, subject to degradation between sampling and analysis, extractions are not 100 per cent efficient, and chlorophyll to biomass ratios are affected by species composition, water temperature, nutrient levels, and available light. Despite these drawbacks, chlorophyll data have been successfully used to measure the primary productivity of water bodies making it another parameter useful in the trophic classification of lakes and ponds.

Data Analysis

In evaluating the usefulness of Secchi disk, phosphorus, and chlorophyll information for trophically classifying lakes, the data were divided into sets of annual data (1974, 1975, and 1976) and composite sets of data (1974-1975, and 1974-1975-1976). Variables which were generated from these data sets to be evaluated as potential trophic state indicators included:

1. Secchi disk
    a. mean
    b. minimum
    c. mean of the annual minimums (for composite years of data)
2. Total phosphorus
    a. mean
    b. median
    c. spring circulation mean
    d. fall circulation mean
3. Chlorophyll a
    a. mean
    b. maximum
    c. minimum

In addition, mean color values of epilimnetic waters were determined for each of the lakes using data collected during open-water conditions. These color values were used to determine the extent of color interference with the parameters selected above.

Parameters were evaluated in two steps. The first step used Spearman's rank order correlation coefficients (Ref,yr) obtained by comparing the rankings of the 35 study lakes based on the individual parameters versus the trophic ranking given the lakes by the professional project staff. Rank correlations obtained using the 1974-75-76 data set are representative of the findings. Mean chlorophyll a had the highest coefficient (r = 0.93) followed by mean total phosphorus (r = 0.77) and minimum Secchi disk (r = 0.73). The poor relationships for total phosphorus and Secchi disk, as compared to chlorophyll a, were in part due to the presence of highly colored lakes in the data set. When nine lakes with mean color values greater than 30 units were removed from the data set, mean chlorophyll a still had the highest coefficient (r = 0.92) followed by mean Secchi disk (r = 0.89) and mean total phosphorus (r = 0.86). Secchi disk and total phosphorus both improved substantially in their ability to rank lakes with color less than or equal to 30 units while chlorophyll a was unaffected.

Based on the results of the analysis above, mean chlorophyll a was selected from the variable list as the best single indicator of lake trophic state. However, due to problems in using chlorophyll a on a large scale to trophically classify lakes, regression analyses were used as a second step to determine if Secchi disk or total phosphorus values are valid alternatives for measuring trophic state.

Results of these regressions for the 1974-76 data set are shown in figures 5 and 6. Log mean Secchi disk was the best estimator of log mean chlorophyll a for the Secchi disk group of variables. Figure 5 shows the effect of lakes with highly colored waters on the relationship. Lakes with colors greater than 30 units consistently plotted to the lower left of the general regression line. By removing the nine highly colored lakes from the data set, the r^2 value (measure of the variation of chlorophyll a associated with the variation of Secchi disk) increased from 0.37 to 0.61.

Using Secchi disk measurements to determine TSI in most highly colored lakes would result in significant overestimation of primary productivity. The one highly colored lake which plotted near the upper regression line of figure 5 was Nubble Pond, the most productive of all the study lakes.

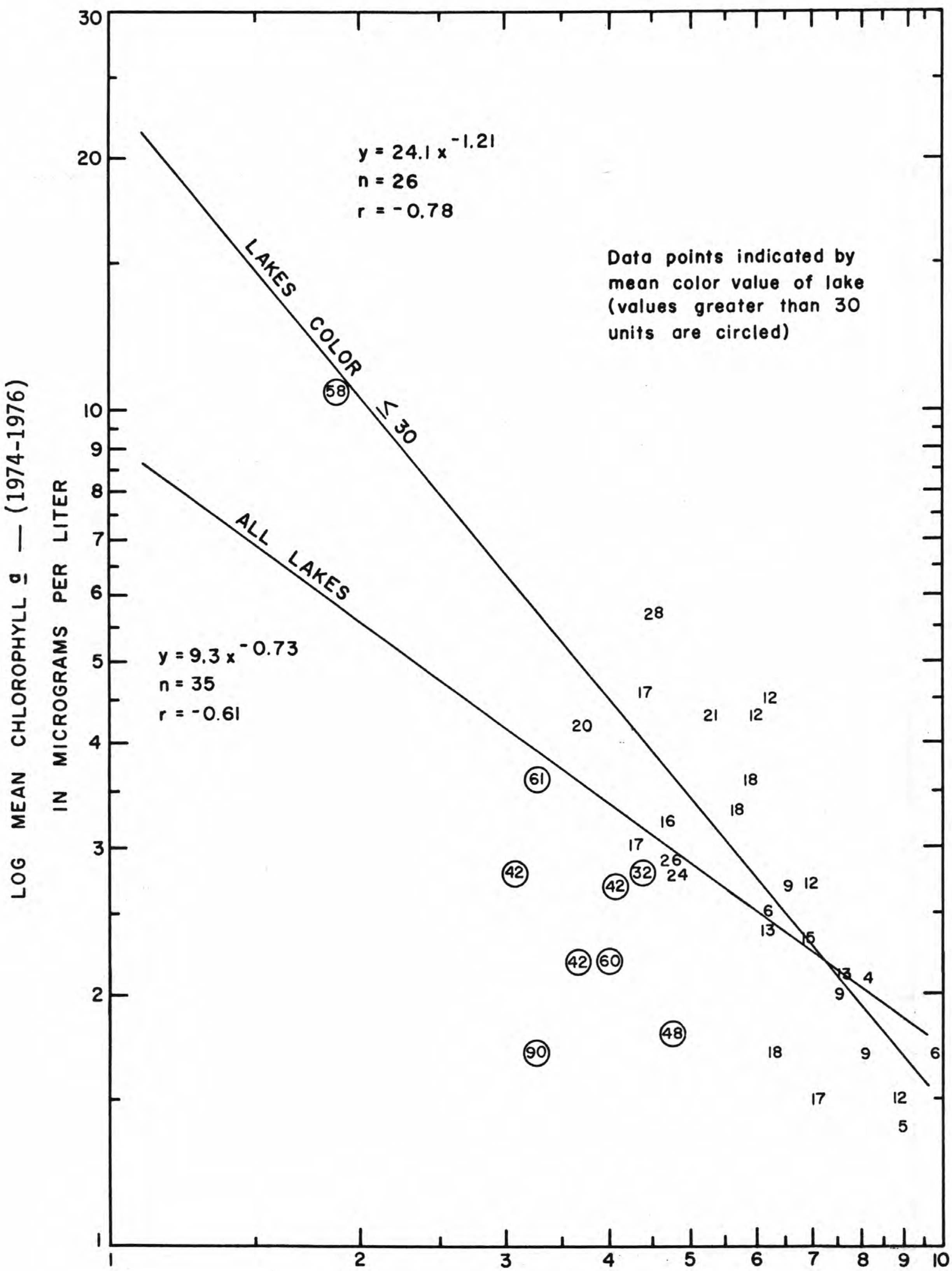


Figure 5.--Relationship between Secchi disk and chlorophyll a showing the effect of lake water color.

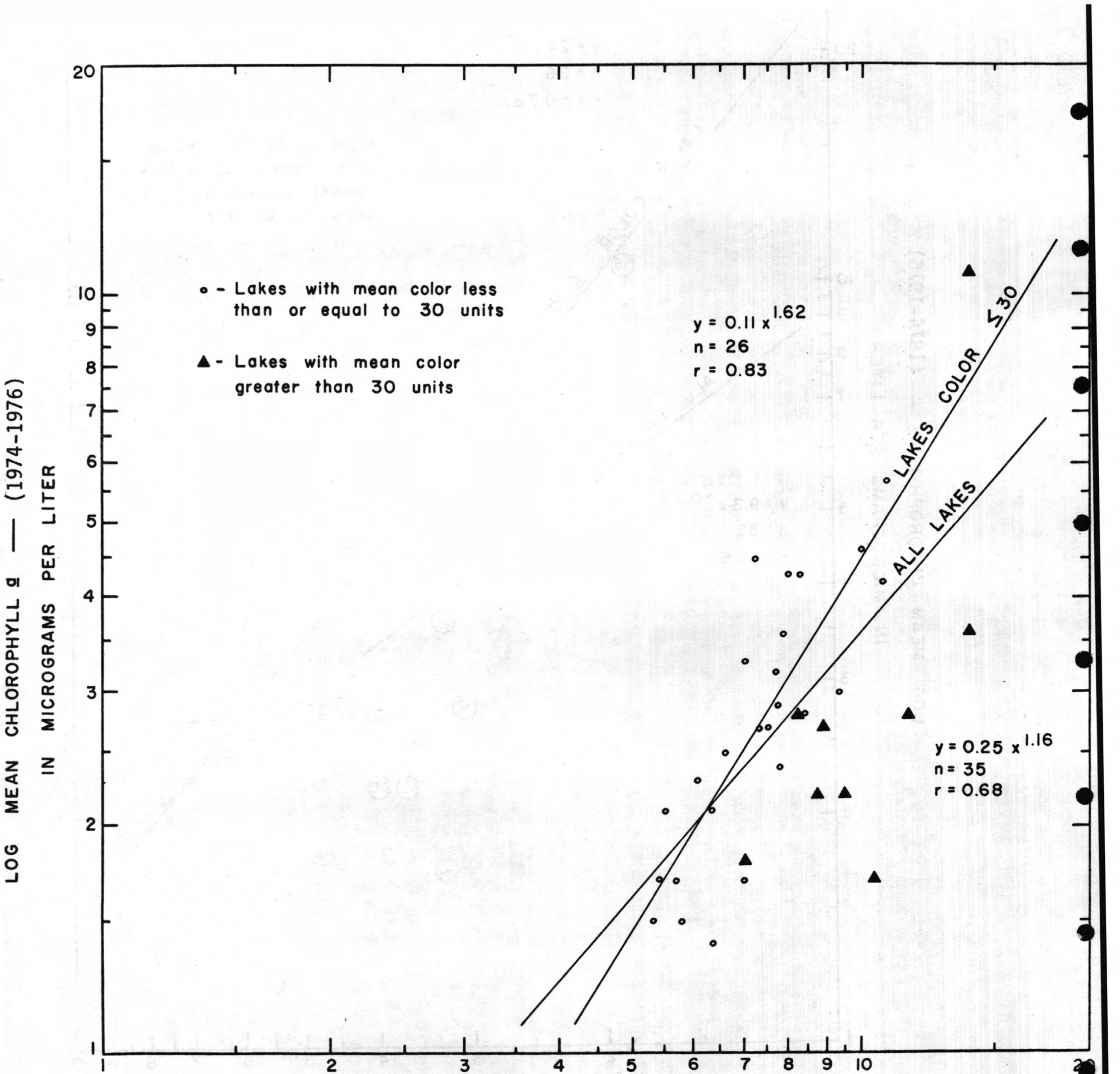


Figure 6.--Relationship between total phosphorus and chlorophyll a showing the effect of lake water color.

The best estimator of log mean chlorophyll a for the total phosphorus variable group was log mean total phosphorus. Figure 6 shows the effect of colored lake waters on the relationship. Values of r^2 for the regressions improved from 0.46 to 0.69, when lakes with color greater than 30 were not included. As with Secchi disk, calculation of TSI values for most highly colored lakes using total phosphorus values would overestimate lake productivity.

Color had little effect on the relationship between total phosphorus and Secchi disk. The value of r^2 for the log-log regression with all the lakes was 0.85, and without the nine highly colored lakes it was 0.81. In addition, the equations for the regression lines were nearly identical.

It seems that in lakes where color is greater than 30 units, phosphorus is tied up with the color producing compounds, such as humic acids, and not available for biological uptake. Carlson (1977) reported similar results in developing a lake trophic state index.

In an attempt to remove the effect of color on the chlorophyll a relationships, multiple regressions were run with lake color as a secondary independent variable. Lakes with colors less than or equal to 30 units were all assigned values of 1 (no color effect), and lakes with higher colors had color values assigned equal to the observed mean color minus 30 units. Results of the multiple regressions showed improvements in the ability to explain variations in mean chlorophyll a for both Secchi disk and total phosphorus.

Values of r^2 improved for the Secchi disk-mean chlorophyll a relationship from 0.37 to 0.54 and for the total phosphorus-mean chlorophyll a relationship from 0.46 to 0.60. Because only nine highly colored lakes were in the data set, caution should be exercised concerning the use of one general equation for Secchi disk and total phosphorus data. As color, total phosphorus, Secchi disk and chlorophyll a data become available for more lakes, improvement in the predictive relationships shown above should be sought.

Sampling Frequency

Ideally, sampling frequency could be adjusted according to lake trophic state. Annual variations of TSI parameters are low in lakes with excellent water quality (requiring few observations) and high in lakes with poor water quality (requiring many observations). However, in designing field data collection programs, the following need to be considered:

1. Sampling is conducted to establish trophic state.
2. Homogeneous data sets (with similar numbers and types of observations) are easier to analyze.
3. Practical limits of sampling frequency exist in any field sampling program.

The intensive sampling program of the USGS-DEP study was found to adequately describe variations of Secchi disk, total phosphorus, and chlorophyll a using a sampling frequency of once every two weeks from ice-out to November. This frequency results in a sample size between 12 to 15 depending on ice-out conditions.

Problems of the Intensive Sampling Program

Two major problems were encountered in the intensive sampling program:

1. Difficulties in sampling and transporting water samples for the determination of low-level phosphorus.
2. Difficulties with the "core technique in sampling for chlorophyll a in some stratified lakes.

The phosphorus problem had the greatest impact on project results. Split samples for low-level total phosphorus determinations between the DEP and USGS laboratories on two occasions during the first 2 years of the project showed variations between the analyses. The first group of split samples had differences ranging from zero to 50 percent, and in the second group, differences increased from 5 to 64 percent. Results of analyses of USGS samples in both groups were low compared with the DEP samples. Estimates of accuracy obtained from the two laboratories were about $\pm$ 0.002 mg/L, in the range commonly found in samples collected for this study (0.005 to 0.020 mg/L).

Both DEP and USGS samples were collected with acid-washed plastic bottles. USGS samples were air-mailed to the regional laboratory in Albany, New York, where sample water was removed and the bottles acid-rinsed to ensure capture of all phosphorus for the analysis. The analysis was then completed as outlined in the "Methods" section of this report. DEP samples were decanted from the plastic sample bottles into the glass flasks in which analysis was made within 3 to 10 hours of collection. The USGS laboratory and the DEP laboratory used the same analytical methods. Prolonged storage of the USGS samples in plastic bottles was suspected as a phosphorus loss problem.

In the spring of 1977, the DEP laboratory, under the direction of Gardner S. Hunt, completed a study of sample handling techniques for low-level phosphorus determinations. The results of that study indicated that the best method for handling samples was to collect the sample in the glass flask used for the analysis. The second best method was to collect the samples in pre-acidified (1 ml 11 N H_2SO_4 per 50 ml of sample - pH approximately 1.0) plastic bottles. Another method (significantly less desirable than the first two) was to collect samples in plastic bottles and then acidify (as above) just prior to transfer of the sample to the glass flask used for analysis. The least desirable of all methods was to collect the sample in a plastic bottle and transfer it to glass for analysis with no treatment. The study was done with samples containing three levels of phosphorus: 0.020 mg/L, 0.050 mg/L, and 0.25 mg/L. The high level (0.25 mg/L) sample showed little difference in results between methods of treatment. (Analyses in this range are reported only to the 0.0X mg/L level.)

Results of the study for the two low-level phosphorus samples are shown in table 5. The data show that substantial amounts of phosphorus were lost in the last two methods. In addition, the scatter of values around the mean increased. Loss of phosphorus to the container apparently varied from bottle to bottle.

After the above tests, all water samples collected by DEP for analysis of low-level phosphorus have been collected and analyzed in acid-washed glass flasks. The phosphorus data reported in the three annual data reports (Cowing and Scott, 1975, 1976, and 1977) and in this report were run by the USGS regional laboratory and thus are probably unrealistically low because of incomplete recovery of phosphorus from sample container walls. This loss increases the variability of results for individual analysis and lowers the mean values used in the regressions, thus decreasing the potential for correlating total phosphorus with other trophic state indicators.

Problems with chlorophyll a results were detected when samples from Brettuns Pond and Forest Lake were investigated.

Table 5.--Results of the low-level phosphorus sampling study conducted by the DEP Water Quality Laboratory

Sampling Handling Method	SAMPLE: Total "P" 0.020 mg/L		Total "P" 0.050 mg/L	
	Mean	Range	Mean	Range
Sampled and held one week in glass flask used for analysis	0.020	0.022 to 0.019	0.051	0.052 to 0.050
Sampled and held one week in pre-acidified plastic bottle, then transferred to glass flask for analysis	.019	.020 to .017	.049	.052 to .047
Sampled and held one week in plastic bottle, then acidified and transferred to glass flask for analysis	.016	.022 to .011	.035	.040 to .030
Sampled and held one week in plastic bottle, then transferred to glass flask for analysis	.013	.019 to .005	.025	.034 to .019

Extremely high chlorophyll *a* and *b* values were measured in late summer in water samples collected using the "core technique" in Forest Lake and Brettuns Pond. The values recorded for Forest Lake were as high as 36 ug/L for chlorophyll *a* and 33 ug/L for chlorophyll *b*. Normally, chlorophyll values of this magnitude would indicate an intense algal bloom, but Secchi disk readings of 5 to 6 m in Forest Lake and 4 to 5 m in Brettuns Pond were recorded during this period. Because the indicated algal blooms did not occur, it was apparent that something interfered with the chlorophyll *a* and *b* measurements.

In all other chlorophyll measurements, chlorophyll *b* values generally ranged from 0 percent to 20 percent of the associated chlorophyll *a* value and rarely exceeded 1 ug/L. Chlorophyll *b* values for the samples in question ranged from 1.5 ug/L to 33 ug/L. These values were consistently greater than 30 percent of the associated chlorophyll *a*, often greater than 70 percent, and on one occasion exceeded the chlorophyll *a* value.

The phytoplankton samples from Forest Lake and Brettuns Pond both contained sizeable populations of a chlorobacteria (Chlorobiaceae) identified as *Chlorochromatium aggregatum*. (This was originally misidentified and reported in the 1974 Brettuns Pond sample as *Microcystis holsatica*.) *Chlorochromatium aggregatum* is actually a consortium of two bacteria: an autotrophic green sulfur bacteria and a heterotrophic bacteria. There is a brown sulfur bacteria consortium, *Pelochromatium roseum*, which is similar to *C. aggregatum* morphologically and can best be distinguished from it on the basis of pigments present (Pfennig, 1977). The organisms recorded in samples for this study might have been *C. aggregatum*, *P. roseum*, or a community containing both taxa.

Bacteria of the Chlorobiaceae are characterized by a strictly anaerobic metabolism (Pfennig, 1977), and generally have their maximum production in the top layer of an anoxic hypolimnion (Rheinheimer, 1971). Both Forest Lake and Brettuns Pond have very small hypolimnia which are anoxic during late summer and would provide the necessary environment for Chlorochromatium and (or) Pelochromatium. The 10 meter water core would have penetrated at least 2 meters of this anoxic zone explaining the presence of the bacteria in the phytoplankton and chlorophyll samples.

Chlorobacteria contain different chlorophyll pigments than the chlorophylls a, b, and c present in algal cells. Two of the chlorophylls, bacteriochlorophylls c and e, have absorption spectra with maxima at 660-668 millimicrons (mu) (Stainer and Smith, 1960; Madigan and Brock, 1976; Brock, personal communication; Gloe and others, 1975) and 646 mu (Gloe and others, 1975) respectively The absorption maximum for bacteriochlorophyll c coincides with the algal chlorophyll a maximum (663 mu) used in chlorophyll a determinations. Similarly, the bacteriochlorophyll e absorption maximum at 646 mu nearly coincides with the 645 mu maximum measured in chlorophyll b determinations.

Bacteriochlorophylls c and d are the light harvesting pigments in green sulfur bacteria (ie. Chlorochromatium aggregatum) and bacteriochlorophyll e is the light harvesting pigment in brown sulfur bacteria (ie. Pelochromatium roseum) (Pfennig, 1977). Since there was no chromatographic separation of pigments done in chlorophyll analysis for this study, it could be expected that the presence of these pigments would interfere with chlorophyll a and b determinations. This interference may explain the extreme chlorophyll a and b values reported on Forest Lake and Brettuns Pond.

Questionable chlorophyll data for these lakes were removed from the data set prior to analyses. Results in this report were obtained using the edited data.

The use of the "core technique" to collect depth-integrated samples could be modified to include only epilimnetic water by using temperature profiles of the lake to establish the top of the metalimnion. The average epilimnetic depth for this study was 7.5 m (range 3.0 m to 11.0 m). Davis and others (1977) reported an average epilimnetic depth of 7.4 m (range 3.1 m to 11.3 m) for their study lakes.

Methods of TSI Determination

Based on the results of the intensive surveys, the following recommendations are made for updating the procedures used by the DEP to determine lake TSI values:

1. Use mean chlorophyll a as the primary method for determining TSI.
2. As a second alternative, use mean Secchi disk for lakes with colors less than or equal to 30 units and mean chlorophyll a on lakes with higher colors.
3. As a third alternative, use mean total phosphorus for lakes with colors less than or equal to 30 units and mean chlorophyll a on lakes with higher colors.
4. Where possible, measure the three trophic state parameters, Secchi disk, total phos phorus, and chlorophyll a, plus lake water color to further investigate the interrela tionships between these parameters. Phosphorus samples should be collected using acid-washed glass flasks.
5. Obtain TSI data approximately every two weeks in the open-water season to establish annual mean open-water values for the parameters measured.

6. When sampling for total phosphorus and chlorophyll a, use the "core technique" to take a depth-integrated sample from the epilimnion. Observations of temperature in one-meter increments from the surface to the bottom of the metalimnion should be recorded to establish the correct sampling depth (bottom of the epilimnion).

Recommended TSI Equations and Lakes for Which They are Valid

All lakes

TSI = 77.7 - 27.3 ($\log_{10}$ annual mean chlorophyll a, in micrograms per liter)

Lakes color $\leq$ 30 units

TSI = 40.0 + 33.0 ($\log_{10}$ annual mean Secchi disk, in meters)

-or-

TSI = 104.0 - 44.2 ($\log_{10}$ annual mean total phosphorus, in micrograms per liter)

These equations were developed using the form of the base equation for Secchi disk currently in use by DEP and the regression equations (shown in figures 5 and 6) relating chlorophyll a with Secchi disk and total phosphorus for lakes with color less than or equal to 30 units.

TSI values for the study lakes using all three equations are shown in table 6. TSI values calculated from chlorophyll a data are well distributed over the range of TSI values (74 to 57) for the first 34 lakes. Nubble Pond, the most productive of the study lakes, is separated by 7.4 TSI units from the lake with the next higher TSI.

Table 6.--TSI values for the regular study lakes, calculated using the updated TSI equations and mean values of chlorophyll *a*, Secchi disk, and total phosphorus from the 1974-75-76 data set.

Lake	TSI: Mean Chloro-phyll *a*	TSI: Mean Secchi Disk	TSI: Mean Total Phosphorus
Pleasant Pond	73.7	71.5	68.4
Beech Hill Pond	72.9	71.3	72.0
Green Lake	72.9	68.1	70.3
Beddington Lake	71.4	--*	--*
Clearwater Pond	71.4	72.7	71.6
Molasses Pond	71.4	66.4	66.6
Phillips Lake	71.4	70.0	70.6
Pleasant River Lake	70.7	--*	--*
Hopkins Pond	69.5	69.1	69.6
Branch Lake	68.9	69.1	71.3
Coffee Pond	68.9	70.2	68.7
Madawaska Lake	68.4	--*	--*
Spectacle Pond	68.4	--*	--*
Mopang Lake	67.8	67.7	69.3
Highland Lake	67.3	66.1	64.6
Lead Mtn Pond (Upper)	66.8	66.1	67.8
Crescent Lake	65.9	67.0	65.8
Panther Pond	65.9	67.9	65.3
Shin Pond (Upper)	65.9	--*	--*
Eagle Lake	65.5	--*	--*
Minnehonk Lake	65.5	62.5	63.6
Portage Lake	65.5	--*	--*
Webb Lake	65.1	62.5	64.8
Shin Pond (Lower)	64.7	60.9	61.2
Wilson Pond	63.9	62.2	64.8
Porter Lake	63.5	64.9	66.6
Pushaw Lake	62.5	--*	--*
Woodbury Pond	62.5	65.4	64.3
Long Pond	60.7	58.8	58.5
Forest Lake	60.4	63.9	63.4
Raymond Pond	60.4	65.7	64.1
Crystal Lake	59.9	66.1	66.1
Brewer Lake	59.6	61.2	59.6
Brettuns Pond	57.1	61.6	58.3
Nubble Pond	49.7	--*	--*

* No value calculated for lakes with mean color > 30 units.

Baseline Sampling Program

During the three year project, each of the 35 regular study lakes was baseline sampled during late summer and late winter. In addition, the eight special study lakes were baseline sampled during three summers and two winters. Results of these baseline surveys are included in reports by Cowing and Scott (1975, 1976, 1977). Many of these baseline parameters yield useful limnologic data for the study lakes.

In the following data analysis, the baseline information from lakes with multiple basins was composited to reflect the relative importance of each basin to the water quality of the entire lake. On lakes with nearly identical basins, the data were weighted equally. On lakes with one large and one very small basin, more weight was given to the larger basin in summarizing the water quality data for analysis. The potential for finding water quality differences between lake basins was great enough to justify the added cost of making multiple baseline profiles on some lakes.

The information used to characterize lake water quality is primarily from the summer baseline sampling trip. Nearly all the lakes showed maximum stress on water quality during this period of high water temperatures and maximum thermal stratification. The exceptions were lakes such as Pushaw Lake which were unstratified and well-oxygenated during summer, but showed depressed oxygen levels during the winter baseline sampling. Since the oxygen depressions during the winter were slight summer values were used for all the lakes.

Lake Water Quality Surveys

Of the parameters measured during the baseline surveys, dissolved oxygen and temperature profiles were the most valuable. Thermal characteristics of the lakes were indicated by summer and winter temperature profiles. The distribution of oxygen with depth gave insight to internal biological and chemical stresses.

Temperature and oxygen data from the late summer samples for the regular study lakes are summarized in able 7. Temperature profiles showed that six of the lakes were not stratified, nine had 1 to 10 percent of their volume stratified, six had 11 to 25 percent, nine had 26 to 50 percent, and five had from 51 to 75 percent stratification. All stratification classes were well distributed throughout the trophic range of the lakes, indicating that thermal stratification alone has little to do with establishing trophic state.

Table 7.--Thermal and hypolimnetic dissolved oxygen characteristics of the study lakes during late summer (lakes listed in descending TSI)

Lake	Percent Stratification[a]	Dissolved Oxygen Level in Hypolimnion (mg/L)			
		DO>5.	5.>DO≥2.	2.>DO≥0.5	DO<0.5
Pleasant Pond	22		X		
Beech Hill Pond	35		X		
Green Lake	29	X_1[b]	X_2		
Beddington Lake	12		X		
Clearwater Pond	61	X_1 X_2			
Molasses Pond	NS[c]	-			
Phillips Lake	50		X		
Pleasant River Lake	8	X			
Hopkins Pond	10	X			
Branch Lake	23	X_1	X_2		
Coffee Pond	47			X	
Madawaska Lake	4	X_1		X_2	
Spectacle Pond	NS	-			
Mopang Lake	12		X_1		X_2
Highland Lake	14		X		
Lead Mtn Pond (Upper)	4		X		
Crescent Lake	8				X_1 X_2
Panther Pond	32		X		
Shin Pond	54			X	
Eagle Lake	44	X_1 X_2	X_3		
Minnehonk Lake	57		X		
Portage Lake	NS	-			
Webb Lake	6				X
Shin Pond (Lower)	NS	-			
Wilson Pond	58		X		
Porter Lake	28			X	
Pushaw Lake	NS	-			
Woodbury Pond	12			X	
Long Pond	NS	-			
Forest Lake	4				X
Raymond Pond	4				X
Crystal Lake	38				X
Brewer Lake	5				X
Brettuns Pond	33				X
Nubble Pond	75				X

a, Percent stratification = $\frac{\text{Total volume-epilimnion volume}}{\text{Total volume}} \times 100$

b, X_1 indicates basin number one as shown in the annual data report
X_2 indicates basin number two, etc.

c, NS indicates not stratified.

Dissolved oxygen levels in the hypolimnion showed definite changes as TSI values declined. In stratified lakes with TSI's over 70.0, all hypolimnetic dissolved oxygen values were over 2.0 mg/L. Sixty-nine percent of the lakes with TSI values between 65.0 and 70.0 had dissolved oxygen concentrations greater than 2.0 mg/L. Of the lakes with TSI's below 65, only one had hypolimnetic dissolved oxygen greater than 2.0 mg/L, while 67 percent had dissolved oxygen concentrations less than 0.5 mg/L.

The seven lakes with greater than 5.0 mg/L dissolved oxygen in their hypolimnion are capable of supporting fisheries for landlocked salmon, lake trout, brook trout, and other cold water sport fish. Lakes with suitable habitat for these fish are currently being managed by State agencies to maintain high water quality conditions.

Temperature and dissolved oxygen profiles of lakes during late summer would be useful to supplement TSI data for monitoring lake trophic states and to help develop sound lake management strategies.

Three other field parameters measured during the baseline surveys yield general water quality information on the study lakes. Specific conductance, pH, and alkalinity reflected the effects of lake trophic conditions, but were not of much assistance in the overall classification of the study lakes. Summer epilimnetic values for these three parameters are shown in table 8. Lakes with low TSI's tended to have higher pH, alkalinity, and specific conductance values. However, there are also lakes with low TSI's which have low values for these parameters, Brewer Lake, for example (TSI = 59.6, pH = 6.9, alk. = 8, cond. = 31).

Specific conductance of study lakes varied from 21 to 70 micromhos (table 8). The mean epilimnetic specific conductance for all study lakes was 37 micromhos, reflecting the low levels of dissolved materials found in most Maine lakes. In lakes with anaerobic hypolimnia, specific conductance values of bottom waters were higher than surface waters. The maximum value, 88 miscrmhos, was observed in Crystal Lake.

Late summer epilimnetic alkalinities in the study lakes (table 8) ranged from 2 to 22 mg/L with a mean of 7.0 mg/L. Winter values of epilimnetic alkalinities for 33 of the study lakes were within 3 units of summer values (12 were the same, 9 were higher, and 14 were lower). Lower Shin Pond and Minnehonk Lake had winter alkalinities 7 mg/L lower and 6 mg/L higher than summer values respectively. Profile data showed higher summer and winter alkalinities in bottom waters of lakes with depressed hypolimnetic dissolved oxygen. The highest alkalinity (35 mg/L) was observed in the anaerobic hypolimnion of Nubble Pond.

Table 8.--Summer epilimnetic values of pH, alkalinity, and specific conductance for the study lakes (lakes listed in descending TSI).

Lake	pH, in Standard Units	Alkalinity, in mg/L, as $CaCO_3$	Specific conductance, in micromhos at 25°C
Pleasant Pond	6.9	7	- (32)*
Beech Hill Pond	6.8	4	26
Green Lake	6.8	7	29
Beddington Lake	6.8	9	36
Clearwater Pond	7.0	10	28
Molasses Pond	6.6	4	33
Phillips Lake	6.8	7	28
Pleasant River Lake	6.4	4	22
Hopkins Pond	6.9	4	25
Branch Lake	6.8	4	30
Coffee Pond	6.8	5	35
Madawaska Lake	7.1	15	48
Spectacle Pond	6.6	4	21
Mopang Lake	- (6.2)*	4	21
Highland Lake	6.8	6	42
Lead Mtn Pond (Upper)	6.8	5	26
Crescent Lake	6.9	11	52
Panther Pond	6.9	9	38
Shin Pond (Upper)	6.9	9	32
Eagle Lake	7.2	19	51
Minnehonk Lake	7.1	10	54
Portage Lake	7.1	22	- (67)*
Webb Lake	6.8	12	29
Shin Pond (Lower)	7.1	10	31
Wilson Pond	6.9	7	28
Porter Lake	6.9	6	24
Pushaw Lake	7.0	17	40
Woodbury Pond	7.2	19	70
Long Pond	6.8	10	45
Forest Lake	5.9	2	59
Raymond Pond	7.1	12	32
Crystal Lake	6.7	3	47
Brewer Lake	6.9	8	31
Brettuns Pond	7.5	13	43
Nubble Pond	7.6	14	30

*Summer value not available, winter value given in parentheses.

Summer epilimnetic values of pH (table 8) ranged from a maximum of 7.6 to a minimum of 5.9. Late summer baseline samples showed profiles of pH which were reflective of temperature profiles. In general, epilimnetic pH values were in the range of 6.6 to 7.2. In shallow, well-mixed lakes, the pH throughout the water column remained at or near the surface value. In lakes which were thermally stratified, most hypolimnetic pH values ranged from 5.6 to 6.4. Near-surface pH values were lower in winter than in summer, probably due to a general reduction of primary productivity under snow and ice. The winter profiles, in general, started out with pH values from 5.7 to 6.7 just under the ice and decreased by 0.1 to 1.0 units in the profile.

Analyses of nitrogen and phosphorus data collected in the baseline program was of limited value. Because the samples were analyzed in the USGS laboratory in Albany, New York, it was necessary to store them in cooled plastic bottles for 2 or more days. Problems in shipping, preservation, and analysis greatly reduced the reliability of determining speciation of nitrogen and phosphorus as it existed in the lake at time of collection. Only total values of phosphorus and nitrogen are considered in the following discussion.

In general, nitrogen and phosphorus show distributions which parallel temperature and dissolved oxygen profiles and lake trophic state. Summer epilimnetic values of total nitrogen and phosphorus are summarized in Table 9. Total nitrogen (as N) ranged from 0.05 mg/L for Pleasant Pond (highest TSI) to 1.1 mg/L for Nubble Pond (lowest TSI). The mean value for all lakes was 0.23 mg/L. Deleting Nubble Pond data, which was more than three times the next highest value, lowered the mean to 0.20 mg/L.

Total phosphorus values in Table 9 ranged from .004 to .015 mg/L (as P) and had a mean of .010 mg/L. Its utility in trophically classifying lakes is discussed more fully in the section: "Intensive Sampling Program".

Table 9 data shows that total nitrogen and phosphorus values are generally lower in the lakes with high TSI. No useful relationship could be established between TSI value and the single observations of epilimnetic nitrogen and phosphorus.

Table 9.--Summer epilimnetic values of total nitrogen and total phosphorus for the study lakes (lakes listed in descending TSI).

Lake	Total nitrogen (mg/L as N)	Total phosphorus (mg/L as P)
Pleasant Pond	0.05	0.005
Beech Hill Pond	.11	.009
Green Lake	.27	.011
Beddington Lake	.21	.009
Clearwater Pond	.17	.006
Molasses Pond	.14	.010
Phillips Lake	.13	.004
Pleasant River Lake	.21	.006
Hopkins Pond	.19	.010
Branch Lake	.19	.007
Coffee Pond	.15	.004
Madawaska Lake	.24	.006
Spectacle Pond	.24	.012
Mopang Lake	.16	.005
Highland Lake	.21	.010
Lead Mtn Pond (Upper)	.20	.006
Crescent Lake	.16	.014
Panther Pond	.18	.005
Shin Pond (Upper)	.26	.014
Eagle Lake	.21	.009
Minnehonk Lake	.24	.013
Portage Lake	.21	.015
Webb Lake	.17	.009
Shin Pond (Lower)	.29	.014
Wilson Pond	.18	.009
Porter Lake	.14	.010
Pushaw Lake	.32	.015
Woodbury Pond	.24	.013
Long Pond	.19	.010
Forest Lake	.24	.013
Raymond Pond	.15	.012
Crystal Lake	.18	.011
Brewer Lake	.35	.012
Brettuns Pond	.22	.010
Nubble Pond	1.1	.012

Nitrogen and phosphorus values, in unstratified lakes and lakes with well-oxygenated hypolimnia, tend to increase only slightly with depth. These slight increases are probably due to decomposition of organic matter settling from overlying waters. In lakes with depleted hypolimnetic oxygen, concentrations of hypolimnetic nitrogen and phosphorus were much higher than overlying waters. The highest values were found in lakes with dissolved oxygen values indicative of reducing environments (dissolved oxygen less than 0.5 mg/L, table 7). These high nitrogen and phosphorus values are most likely the result of decomposition of settling organic matter and dissolution of ferric phosphate precipitates (Hutchinson, 1957, and Stumm and Morgan, 1970).

Summer epilimnetic values for the nine remaining parameters are summarized in tables 10 and 11. These data, plus pH, conductivity and alkalinity, were analyzed with respect to general bedrock lithologies of the drainage basins as discussed in the section: "Characterization of Lakes, Geology".

Table 10.--Summer epilimnetic values of calcium, magnesium, sodium, and potassium for the study lakes (lakes listed in descending TSI).

Lake	Total Calcium (Ca, mg/L)	Total Magnesium (Mg, mg/L)	Total Sodium (Na, mg/L)	Total Potassium (K, mg/L)
Pleasant Pond	3.5	0.5	0.8	0.6
Beech Hill Pond	4.1	.5	1.7	.3
Green Lake	1.8	.1	1.8	.3
Beddington Lake	4.9	.4	2.2	.5
Clearwater Pond	3.1	.9	1.2	.5
Molasses Pond	4.8	.7	2.2	.4
Phillips Lake	3.0	.6	2.5	1.0
Pleasant River Lake	2.9	.6	2.5	.7
Hopkins Pond	8.0	.1	1.3	.2
Branch Lake	5.6	.3	2.0	.2
Coffee Pond	5.1	.8	3.2	.6
Madawaska Lake	10.	1.3	1.6	.3
Spectacle Pond	7.9	.7	2.0	.4
Mopang Lake	1.5	.5	1.5	.6
Highland Lake	11.	.4	3.6	.6
Lead Mtn Pond (Upper)	2.2	.2	1.7	.4
Crescent Lake	4.8	.8	3.3	.5
Panther Pond	3.7	.2	3.2	.4
Shin Pond (Upper)	3.7	.8	.9	.2
Eagle Lake	10.	.6	1.3	.2
Minnehonk Lake	5.9	.8	2.9	.6
Portage Lake	9.0	1.4	1.0	.4
Webb Lake	6.0	.7	1.1	.5
Shin Pond (Lower)	3.7	.7	1.0	.2
Wilson Pond	4.5	.7	2.3	.3
Porter Lake	5.0	.4	1.1	.2
Pushaw Lake	5.7	1.2	4.9	.6
Woodbury Pond	8.2	1.0	3.6	.7
Long Pond	5.4	.3	4.0	.6
Forest Lake	5.0	.1	5.8	.3
Raymond Pond	4.0	.8	2.6	.4
Crystal Lake	6.4	.2	1.5	.2
Brewer Lake	2.8	.2	2.0	.2
Brettuns Pond	9.0	.8	3.5	.9
Nubble Pond	2.9	.2	1.9	.9

Table 11.--Summer epilimnetic values of chloride, sulfate, silica, iron, and manganese for the study lakes (lakes listed in descending TSI).

Lake	Dissolved chloride (Cl) (mg/L)	Dissolved sulfate (SO_4) (mg/L)	Dissolved silica (SiO_2) (mg/L)	Total iron (Fe) (ug/L)	Total manganese (Mn) (ug/L)
Pleasant Pond	1.0	3.5	0.2	20	0
Beech Hill Pond	1.9	3.0	1.5	30	0
Green Lake	2.7	3.1	3.1	30	10
Beddington Lake	2.5	3.0	5.7	210	10
Clearwater Pond	1.4	5.0	2.4	10	70
Molasses Pond	4.5	3.1	1.5	60	10
Phillips Lake	6.1	3.0	2.9	20	0
Pleasant River Lake	3.8	3.2	3.1	250	40
Hopkins Pond	1.1	3.2	1.8	40	0
Branch Lake	3.5	3.0	1.7	60	10
Coffee Pond	5.4	4.5	.7	40	10
Madawaska Lake	1.8	4.4	2.2	230	20
Spectacle Pond	2.2	2.9	2.2	450	890
Mopang Lake	3.3	2.7	1.2	90	10
Highland Lake	4.3	4.8	.7	70	10
Lead Mtn Pond (Upper)	2.8	3.7	1.4	100	20
Crescent Lake	6.1	3.7	1.6	120	190
Panther Pond	5.0	3.2	.9	110	10
Shin Pond (Upper)	1.7	5.4	3.6	130	10
Eagle Lake	1.1	5.1	1.9	90	10
Minnehonk Lake	4.7	5.0	3.9	70	0
Portage Lake	.5	4.6	3.0	140	20
Webb Lake	1.8	3.8	4.9	210	90
Shin Pond (Lower)	2.2	4.2	2.9	120	10
Wilson Pond	3.7	4.0	1.8	60	10
Porter Lake	1.2	2.9	1.1	110	10
Pushaw Lake	4.2	3.2	.6	150	40
Woodbury Pond	6.4	5.1	1.2	230	10
Long Pond	6.0	3.7	.5	80	40
Forest Lake	10.	2.9	.3	140	20
Raymond Pond	6.2	8.6	2.9	100	190
Crystal Lake	2.3	2.7	1.1	310	10
Brewer Lake	2.5	3.4	.6	140	20
Brettuns Pond	4.7	4.5	1.8	80	20
Nubble Pond	1.6	1.4	4.2	70	20

Table 12 separates the study lakes into three groups by basin lithology: those dominated by granite, those with calcareous rocks occurring as lenses or interbeds with other lithologies, and those dominated by metasedimentary rocks. Comparison of mean values for the three groups of lakes shows those in metasedimentary rocks and those in granitic rocks to be similar in chemical quality except for higher SiO_2 values for the metasedimentary basins. Lakes underlain by calcareous deposits have higher values of specific conductance, alkalinity, calcium, and magnesium, as expected. Overall, the data show the study lakes to be very low in dissolved solids with corresponding low levels of productivity. Lakes having significant calcareous environments are slightly more productive, with seven of these eight lakes among the 16 lakes with the lowest TSI's (TSI $\leq$ 65.5).

Table 12.--Comparison of water quality data for lakes with drainage basins underlain by granitic, calcareous, and metasedimentary bedrock types.

Parameter (reported as units)	Lake drainage basin bedrock type		
	Granitic (23 lakes)	Calcareous (8 lakes)	Metasedimentary (4 lakes)
Specific conductance (micromhos at 25°C)	32[a] (21-59)[b]	52 (40-70)	30 (24-36)
pH (standard units)	(5.9-7.6)	(6.8-7.5)	(6.8-6.9)
alkalinity ($CaCO_3$, mg/L)	6.7 (2.-14.)	17.3 (10.-22.)	8.8 (6.-12.)
Dissolved chloride (Cl-, mg/L)	3.6 (1.0-10.)	3.7 (0.5-6.4)	2.2 (1.2-3.7)
Dissolved sulfate (SO_4=, mg/L)	3.7 (1.4-8.6)	4.4 (3.2-5.1)	3.4 (2.9-4.0)
Dissolved silica (SiO_2, mg/L)	1.8 (0.2-4.2)	1.9 (0.5-3.9)	3.3 (1.1-5.7)
Total iron (Fe^{+++}, ug/L)	110 (10-450)	130 (70-230)	150 (60-210)
Total manganese (Mn^{++}, ug/L)	70 (0-890)	20 (0-40)	30 (10-90)
Total calcium (Ca^{++}, mg/L)	4.4 (1.8-11.)	7.9 (5.4-10.)	5.1 (4.5-6.0)
Total magnesium (Mg^{++} mg/L)	0.5 (0.1-0.9)	0.9 (0.3-1.4)	0.5 (0.4-0.7)
Total potassium (K+, mg/L)	0.4 (0.2-1.0)	0.5 (0.2-0.9)	0.4 (0.2-0.5)
Total sodium (Na+, mg/L)	2.2 (0.8-5.8)	2.8 (1.0-4.9)	1.7 (1.1-2.3)

a, mean values for lake type

b, values in parentheses () are minimum-maximum

An attempt was made to correlate the water quality parameters in Table 12 within bedrock groups to evaluate the possibility of estimating chemical quality from field parameters (alkalinity, pH, and specific conductance). However, the low values of dissolved solids make quantitative relationships between parameters unreliable. The best correlation coefficient obtained was 0.47 between alkalinity and calcium for the calcareous group.

One problem encountered in the winter baseline sampling was the apparent occurrence of a significant layer of dilute melt water just under the ice. This layer was characterized by low specific conductance (mean of 12 micromhos) and low alkalinity (mean of 3 mg/L as $CaCO_3$). Other baseline parameters also exhibited small differences in water quality. The data for Hopkins and Lower Shin Ponds, Eastern Grand and Saddleback Lakes show the effect of this melt water layer.

Benthic Invertebrate Surveys

Benthic organisms were collected at least once in the deep basin of all study lakes. Distributions of the important taxonomic groups (Annelida, Ostracoda, Amphipoda, Insecta, and Mollusca) are listed for 34 of the lakes according to trophic ranking (tables 13 and 14). Stratified and unstratified lakes were tabulated separately due to the presence of different taxa. The epibenthic species, *Chaoborus punctipennis*, was considered separately from population totals. Since Nubble Pond (TSI 50) had only this species present, it was not included in the tables.

Table 13.--Distribution of benthic organisms found in the profundal zone of stratified lakes by TSI.

		Pleasant	Beech Hill, Green		Beddington, Clearwater, Phillips, Pleasant River	Hopkins	Branch, Coffee	Madawaska, Mopang	Highland, Upper Lead Mountain	Crescent, Panther, Upper Shin, Eagle, Minnehonk	Webb	Wilson, Porter		Woodbury		Forest, Raymond, Crystal, Brewer			Brettuns	
TSI →	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56
ANNELIDA																				
Limnodrilus		0	0		X	X	0	X	X	X	0	X		X		X			0	
Tubifex-Peloscolex		0	0		0	X	0	X	0	0	0	0		0		X			X	
Lumbriculus			0						X	X		X		X		X				
Nais			0						0	0		0		0		0				
ARTHROPODA																				
Ostracoda					0				0	X	0	0		0		0				
Amphipoda																				
<u>Hyallela azteca</u>																X				
Ephemeroptera																				
<u>Hexagenia</u>								0												
Diptera																				
<u>Procladius</u>		X	X		X	0	X	X	X	X	X	X		X		X			X	
<u>Conchapelopia</u>								0	0											
<u>Tanypus</u>																0				
<u>Ablabesmyia</u>																0				
<u>Chironomus</u>		0	0		X	X	X	X	X	X	X	X		X		X			X	
<u>Dicrotendipes</u>											0	0				0				
<u>Cryptochironomus</u>					0			0	0	0		0		0		0				
<u>Pseudochironomus</u>																0				
<u>Phaenopsectra</u> (Tribelos)		X	X		X	X	X													
<u>Phaenopsectra</u> (Phaenopsectra)		0	0		0				X	X		X		X		X				
<u>Endochironomus</u>		0	0		0		0				0	0								
<u>Tanytarsus</u>		X	X		X	0	X	0	X	X	X	X		X		X				
<u>Micropsectra</u>		X	X		X		X	0	0	0	0	0		0		0				
Unknown <u>Chironominae</u>		0	0		0	0	0									0				
<u>Zalutschia</u>					0		0		X	X	0	X		X		X				
<u>Cricotopus</u>		0	0		0		0													
<u>Psectrocladius</u>																0				
<u>Parametriocnemus</u>																0				
Unknown <u>Orthocladinae</u>								0								X				
<u>Palpomyia-Bezzia</u>		0	0		0	0	0		0		0	0		0		0				
MOLLUSCA																				
Pelecypoda																				
<u>Pisidium</u>		X	X		X		X		X	X	X	X		X		X				

X, abundant (>10% of population)
0, present (<10% of population)

Table 14.--Distribution of benthic organisms in unstratified lakes by TSI.

					Molasses			Spectacle		Portage	Lower Shin			Pushaw	Long	
TSI →	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60
ANNELIDA																
Limnodrilus					0						0				0	
Tubifex-Peloscolex											0					
ARTHROPODA																
Amphipoda																
Hyallela					0											
Ephemeroptera																
Hexagenia					0			0		0	X					
Diptera																
Procladius								X		X	X			X	X	
Coelotanypus								0						X		
Chironomus								0		X	X			0	0	
Cyrptochironomus					0			0							X	
Polypedilum								0								
Parachironomus					0											
Paralautern-borniella											X					
Tanytarsus					X			0			0			0		
Micropsectra					X			0			0					
Unknown *Chironominae*															0	
Psectrocladius											0				0	
Zalutschia															X	
Trissocladius					X											
Unknown *Ortho-cladinae*					0			0								
Palpomyia-Bezzia								0			0			0	0	
MOLLUSCA																
Pelecypoda																
Pisidium					0			X		0	X			X	0	
Unionidae					0									0		
Gastropoda																
Campeloma								0		0						
Valvata														0		

X, abundant (>10% of population)
0, present (<10% of population)

Benthic fauna are distinctly different between stratified and unstratified lakes. Populations of organisms found in stratified lakes are generally less diverse than those found in unstratified lakes. Ostracoda is a group which is restricted to the profundal zone among the study lakes. Unstratified lakes are characterized by the presence of the mayfly, *Hexagenia*, and amphipod, *Hyallela azteca*. Midge larvae (Chironomidae) are abundant in both lake types. Unstratified lakes tended to have more members of Tanypodinae and Orthocladinae sub-families. Mollusk populations were restricted to the pill clam, *Pisidium*, in well-oxygenated stratified lakes, but were more diverse in unstratified lakes and included both clams and snails.

Although distribution of organisms along the trophic scale is not distinctive, the following results were observed. Numbers of taxa are reduced as trophic rank declines. At what point on the scale particular organisms may be inhibited was not determined since there were few lakes in the lower range of TSI values. Among the Diptera, the genus *Chironomus* is ubiquitous throughout the scale. However, species change from *C. attenuatus*, *C. anthracinus*, and others to *C. plumosus* with declining trophic rank. *Micropsectra* sp. appears to be more associated with lakes having high TSI values. The genus *Phaenopsectra* appears to be a true obligate profundal organism, generally restricted to deep, cold water lakes. *Phaenopsectra* (Tribelos) is most prevalent in the higher TSI range while *Phaenopsectra* (Phaenopsectra) occurs in the lower range. The genus *Zalutschia* is distributed from 60 to 71 on the scale but is most abundant in the mid-range TSI values.

Annelids show no trend in distribution along the trophic scale. The more numerous populations of the genus Limnodrilus and the genus Tubifex occur in ponds where hypolimnetic oxygen depressions occur during at least one stratification period. Annelids tend to show dominance where populations of the predatory midge larvae, Procladius spp., are not abundant.

Certain factors, such as hypolimnetic oxygen, may overide the other effects of trophic state on benthic populations. Lakes with anaerobic hypolimnia during winter months were essentially limited to populations of Chaoborus spp., Chironomus sp., Procladius sp., and certain Annelids. Chaoborus punctipennis has adaptions to cope with extreme anaerobia and was the only organism present in Nubble Pond. Its distribution was fairly universal and it was numerically abundant in all lakes except the deeper ones (>40m). The migratory behavior of Chaoborus allows them to periodically escape anaerobic conditions, but restricts their distribution to the shallow portions of the hypolimnion.

Lake classifications utilizing benthic invertebrates have been attempted by numerous investigators (Deevey, 1941; Brundin, 1949 and 1956; Saether, 1975, and others) usually by means of associating "indicator" organisms with subjective lake categories (oligotrophic, eutrophic, etc.). This study attempted to associate frequency of occurrence with a continuous lake classification scale.

Certain limitations must be considered regarding the significance of the benthic invertebrate data. The approach taken was to sample each lake at the most characteristic place and time. It was assumed that winter stratification would have the most stable population with respect to seasonal abundance of emerging species. The profundal zone was considered the most characteristic of a lake as a whole (Saether, 1975).

Collection was arbitrarily limited to five dredge samples in close proximity to each other. Homogeneity of the population was therefore assumed; however, this assumption has been disproved by Eggleton (1931). Depth, time, and location within a given lake are important criteria in determining distribution. Other investigators have taken 1 to 6 dredges per site (Juday, 1921; Eggleton, 1931;, Deevey, 1941; Johnson and Brinkhurst, 1971). Statistical confidence associated with the use of five dredges will vary depending on density and homogeneity of the populations.

Sensitivity of the ranking approach can be directly related to the level of taxonomy attained. Lack of discrimination beyond the generic level, together with a lack of lakes in lower trophic ranges, restricts the use of benthic organisms in predicting trophic state.

Despite these shortcomings, the method appears to function. Phaenopsectra (Tribelos) and Micropsectra occupy trophic ranges described by others (Saether, 1975). Inclusion of data from additional lakes to fill the TSI scale may lead to a more objective and sensitive means of arraying characteristic fauna types. With genera such as Chironomus and Tanytarsus, whose representative species occupy wide-ranging trophic niches, the ranking becomes inappropriate without further taxonomic distinction.

Aquatic Macrophyte Surveys

Aquatic macrophyte surveys were done during the late summer at each study lake to provide baseline data for comparison with data from future surveys and to study the relationship between macrophytes and lake TSI. To facilitate comparison of plant communities among the lakes, each field data sheet was reviewed, and frequency of occurrence of each identified plant type was assigned to an abundance category based on the following criteria:

D-Dominant - occurring in 50 percent or more of stands and at least twice as abundant as any other

A-Abundant - occurring in 50 percent or more of stands

C-Common - occurring in 25 percent or more of stands

R-Rare - occurring in less than 25 percent of stands

Table 15 shows the relative abundance of the plants in each lake in order of descending TSI values. Vegetation is listed by groups as emergent, floating-leaved, and submerged. Lakes where *Eriocaulon* was dominant had high TSI values. Highly colored lakes had plant communities primarily composed of *Scirpus* and floating-leaved plants. *Pontederia* and floating-leaved plants were generally more abundant in lakes with lower TSI's.

Table 15.--Abundance of aquatic plants in the lakes by TSI.

		Pleasant	Beech Hill, Green		Beddington, Clearwater, Molasses, Phillips, Pleasant River	Hopkins	Branch, Coffee	Madawaska, Spectacle, Mopang	Highland, Upper Lead Mountain	Crescent, Panther, Upper Shin, Eagle, Minnehonk, Portage	Lower Shin, Webb	Wilson, Porter		Pushaw, Woodbury	Long	Forest, Raymond, Crystal, Brewer			Brettuns	
TSI →	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56
EMERGENT																				
Scirpus			C		A	R	R	A	R	A	R	R		D						
Eleocharis			R		R	R	R	R	R	R	A	A				R				
Typha			C		R		R	R	R	R	R			A	R					
Pontederia			R		R			R	A	A	A	C		A	A	R			R	
Juncus			R					A	R	R										
Cyperaceae			R		C		R		R	R	R	R		C		R				
Sagitarria			C								C			R						
Sparganium			C		R			R		C	A	R		C		R				
Polygonum												R								
Dulichium			C		R						R	R		R						
Equisetum			R							R	R									
Graminae			R						R	R										
Ericaceous					R				R	C										
FLOATING																				
Nuphar		R	A		C	R	C	C	C	C	C	R		C	R	A				
Brasenia			R		C	R	R	R		R	A	C		C						
Nymphaea		R	R		C	A		C	R	R	A	C			R	R				
Valisneria					C	R	C		C	R	A	R		R	R	R				
SUBMERGED																				
Eriocaulon		D	A		A	D	A	D	D	D	R	A		A		C				
Potamogeton		R	C		A			C	R	C	C	R		R	R	C				
Lobelia								C		R		R								
Ceratophyllum											R									
Myriophyllum			R			R					C	C			R					
Utricularia			R		R			R	R			R								
Isoetes					R	R			R	R	R	R				R			R	
Elodea											R			R						
Zachinella			R																	

D, dominant (occurring in 50 percent or more of stands and at least twice as abundant as any other)
A, abundant (occurring in 50 percent or more of stands)
C, common (occuring in 25 percent or more of stands)
R, rare (occurring in less than 25 percent of stands)

The relative abundance of rooted aquatic vegetation is dependent upon the availability of a substrate which is high in organic matter and a water column which allows sufficient light penetration and provides required nutrients. Thus, lakes with rocky-gravelly-sandy littoral zones do not usually have abundant populations of rooted aquatic plants and usually have high TSI values. Vegetation in these lakes is usually dominated by sparse populations of Eriocaulon. However, other lakes with suitable substrates and an abundance of vegetation, do not characteristically have either high or low TSI values, because TSI is more specifically a measure of the productivity of the water column than of the benthic zone.

Cottage Counts

As part of the baseline sampling program, cottages within about 75 m (246 ft) of the shore were counted and their locations noted on a field map. These data are being tabulated by the DEP in an effort to document development around Maine lakes and its potential impact on water quality.

Attempts to relate near-shore development and lake TSI values for the study lakes were unsuccessful. Current shore development on these lakes apparently has little measurable impact on the water quality as indicated by the TSI value.

However, because much of the development on Maine lakes has taken place during the last thirty years, the steady-state effect of near-shore cottages on lake water quality may not yet have been reached for most lakes.

Phytoplankton Community Surveys

Selection of a parameter to adequately express the structure and size of a phytoplankton community is difficult. Simple cell counts (numbers) do not reflect cell size, because they assign the same value to a small coccoid cyanophyte as to a large dinoflagellate. The cell volume of the latter may be 10,000 times that of the former. Counting organisms or colonies by taxa is an improvement over single cell counts, but the variations in the size of colonies are not accounted for and the importance of small solitary flagellates and diatoms is exaggerated. Cell volume accounts for the size of each cell and gives a better estimation of phytoplankton biomass (Findenegg, in Vollenweider, 1969). However, it tends to overestimate the importance of large taxa, especially diatoms, because their cell volume includes the entire frustule which may or may not be completely filled with cytoplasm. An estimation of cell surface area appears to be a good compromise between cell numbers and volumes. Paasche (1960) compared the relationship of numbers, volumes, and surface areas of cells to rates of photosynthesis in samples from the Norwegian Sea, and found surface area to be the most highly correlated.

Because surface area is difficult to calculate, especially for the more irregularly-shaped taxa, total cross-sectional cell area (TCA) was selected as an alternate parameter to express structural and quantitative differences in phytoplankton communities. Total cross-sectional areas of organisms were assumed to be proportional to surface areas. For a few organisms, such as those with long, thin bodies, this assumption is poor.

Analysis of 1974 Data (Single Samples).--During 1974, each of the regular study lakes was sampled once for phytoplankton at a low Secchi disk visibility during the late summer or early fall sampling periods. This was an attempt to sample the maximum biomass for the period when phytoplankton problems most often occur in Maine lakes.

Figure 7 illustrates the distribution of TCA values observed for the study lakes during the 1974 sampling. The information in this figure is intended to show only general levels of TCA observed, because data from the single phytoplankton samples were not closely related to lake TSI.

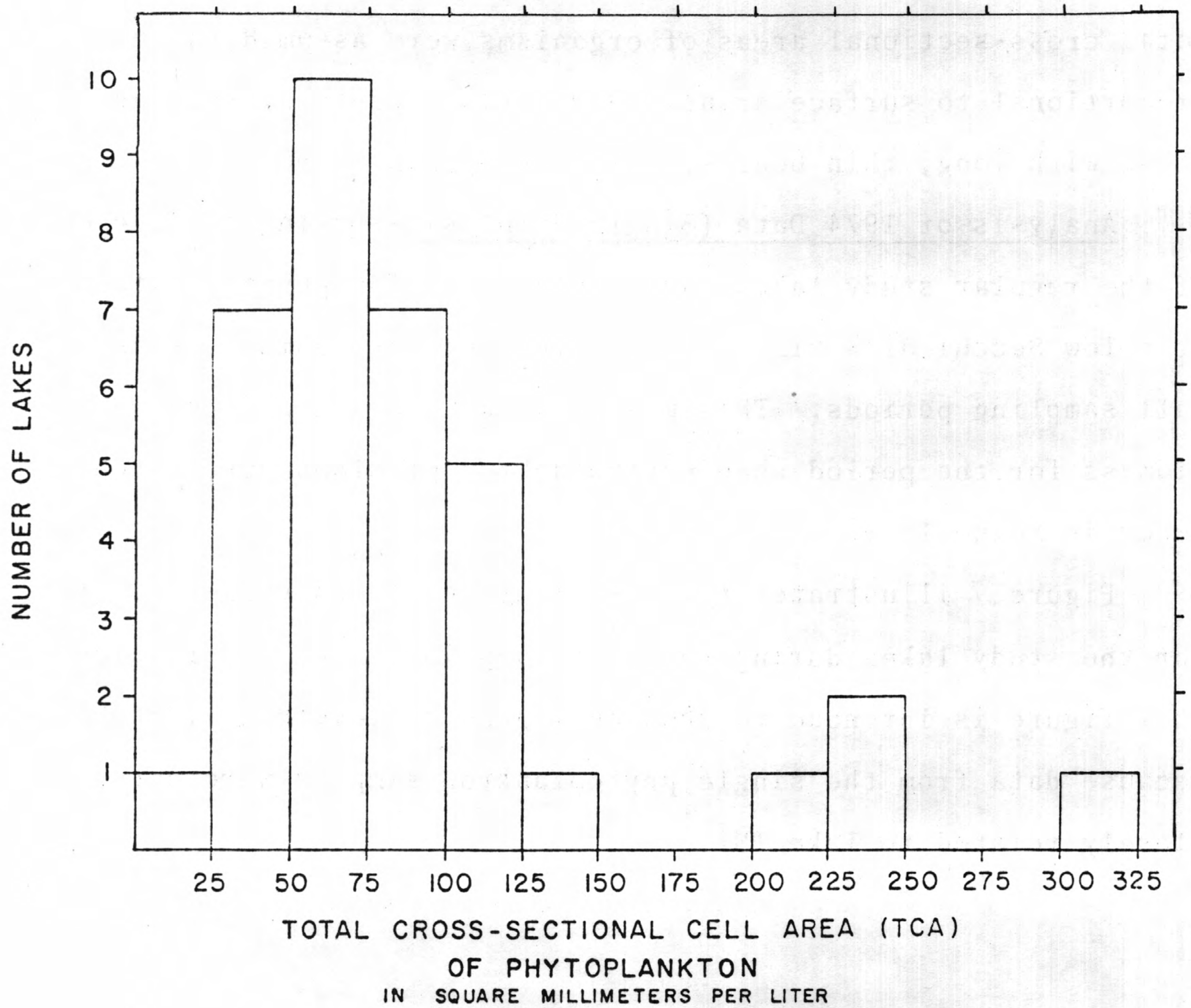


Figure 8.--Distribution of TCA values calculated using single phytoplankton samples taken from the regular study lakes.

Comparison of species composition for the 1974 samples was difficult. Some were taken in August and early September when the lakes were strongly stratified and water temperatures and solar illumination were still high. Others were sampled after fall overturn when water temperatures and illumination were lower and some nutrients, especially silica, were more available. Variations in these factors may have an effect on species composition (Hutchinson, 1967). However, it is possible to identify from this data the phytoplankton taxa generally important in Maine lakes.

The phytoplankton communities of 70 percent of the lakes were dominated by members of the Division Chrysophyta, as shown in figure 8. Cyanophytes were dominant in 15 percent of the lakes. Pyrrophyta, Chlorophyta, and Euglenophyta, though numerous in some communities, were never dominant.

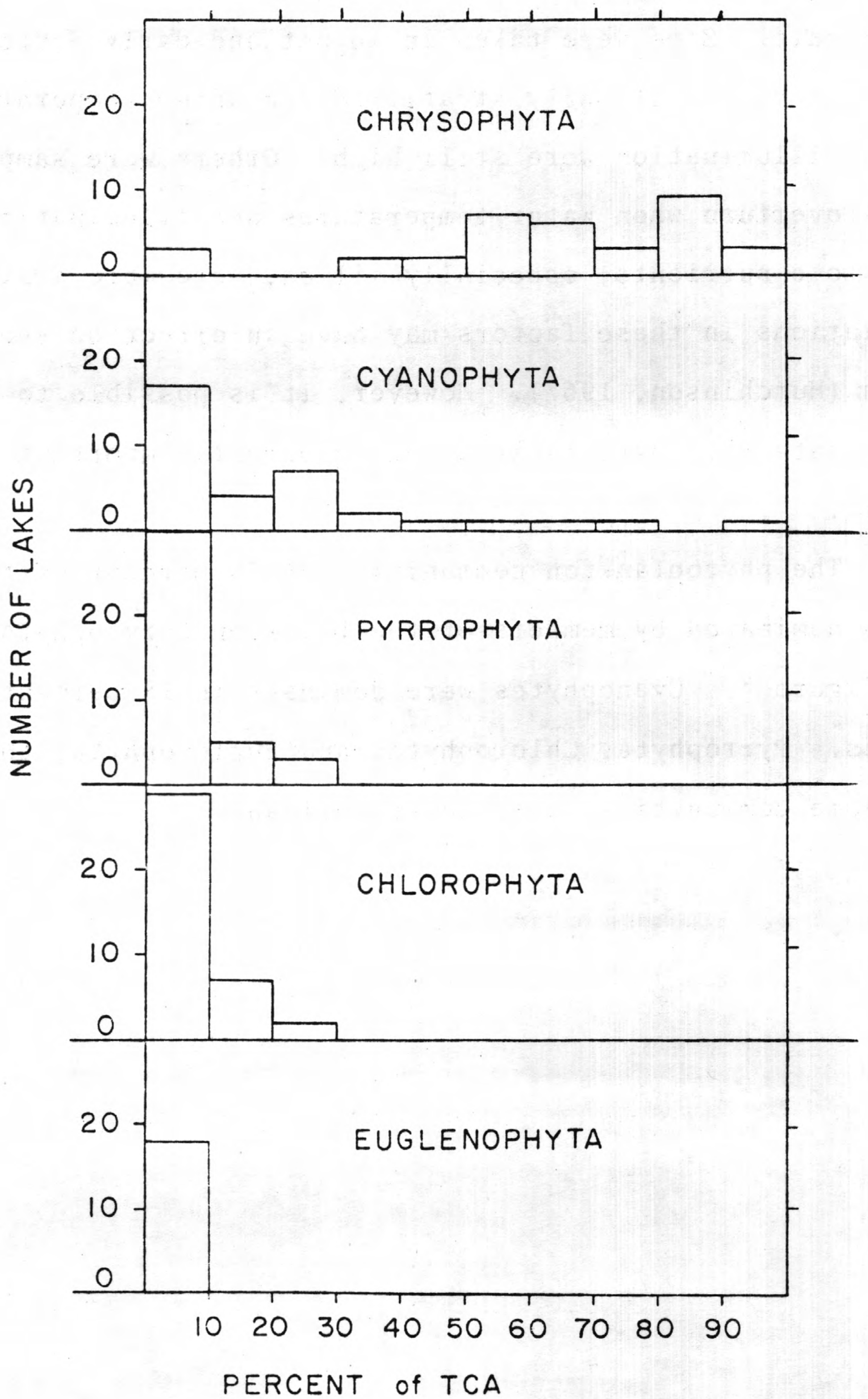


Figure 8.--Relative contribution of major phytoplankton groups to TCA values.

Most of the lakes had many of the same taxa with different community structures. Although a few associations were common to several lakes. Porter Lake, Coffee and Wilson Ponds, and Highland Lake had phytoplankton communities dominated by Tabellaria fenestrata with lesser populations of other Chyrsophytes, especially Cyclotella bodanica, C. michiginiana and Chrysorphaerella longispina. Communities strongly dominated by Cyclotella bodanica with either C. michiginiana or C. stelligera present were found in Crescent Lake, Long Pond, and Pushaw Lake. Significant populations of Chrysosphaerella longispina, Rhizoselinia eriensis, Tabellaria fenestrata, and chrysophyte statospores (probably Dinobryon spp.) were common to Mopang, Crystal, and Branch Lakes, and Molasses Pond. Webb and Forest Lakes, both moderately productive, were dominated by Tabellaria and Asterionella respectively, but both had large populations of Chlorophyta, especially Gloeocystis planctonica. Significant populations of the chyrsophyte flagellates Ochromonas spp., Mallomonas spp., and Dinobryon spp., were present in a majority of the lakes but were dominant only in Panther and Clearwater Ponds, and Phillips and Green Lakes. These four lakes all have TSI values greater than 65.

Pyrrophyta were important in many of the lakes but were never dominant. Cyanophytes were dominant in five lakes; Pleasant River Lake, Brettuns Pond, Upper Shin Pond, Brewer Lake, and Nubble Pond.

Table 16 summarizes the relative importance of the most common taxa. Taxa included in this table occurred in at least five of the lakes sampled in 1974 or accounted for more than 5 percent of the TCA in the lake in which they occurred.

Chlamydomonas spp. was the most commonly found green alga, though it was never a very significant part of the phytoplankton community. *Gloeocystis planctonica* was the most important green alga found since it accounted for an average of 6 percent of the TCA in nine of the lakes.

Table 16.--Important phytoplankton taxa in the study lakes during the 1974 sampling.

Taxa Reference	Number of lakes in which taxa occurred	Mean percent of total cell cross-sectional area
CHLOROPHYTA		
Ankistrodesmus falcatus (Corda) Ralfs	10	1.1
Arthrodesmus incus (Brebisson) Hassall	10	.4
Chlamydomonas spp.	23	.4
Crucigenia quadrata Morren	7	.4
Elakatothrix gelatinosa Wille	6	1.0
Gloeocystis planctonia (W. + G.S. West) Lemmermann	9	6.0
Gloeocystis vesiculosa Naegeli	9	3.3
Nephrocytium lunatum W. West	12	1.5
Oocystis parva W. + G.S. West	9	.4
Oocystis pusilla Hansgirg	8	.7
Oocystis spp.	6	.9
Pediastrum tetras (Ehrenberg) Ralfs	1	7.6
Planktosphaeria gelatinosa G.M. Smith	5	1.5
Quadrigula closterioides (Bohlin) Printz	11	2.1
Scenedesmus spp.	6	1.0
CHRYSOPHYTA (Diatoms)		
Amphiprora ornata Bailey	1	7.8
Asterionella formosa Hassall	24	6.8
Asterionella gracillima (Hantzsch) Heiberg	9	11.8
Asterionella spp.	1	15.2
Cyclotella bodanica Eulenst	18	10.8
Cyclotella comta (Ehrenberg) Kutzing	1	10.4
Cyclotella michiginiana	10	6.0
Cyclotella stelligera Cleve + Grunow	32	2.9
Cyclotella spp.	1	12.1
Fragilaria crotonesis Kitton	9	4.3
Melosira ambigua Grunow	13	5.8
Melosira distans (Ehrenberg) Kutzing	8	1.3
Melosira italica (Ehrenberg) Kutzing	6	3.1

Table 16.--Important phytoplankton taxa in the study lakes during the 1974 sampling--Continued.

Taxa Reference	Number of lakes in which taxa occurred	Mean percent of total cell cross-sectional area
CHRYSOPHYTA (Diatoms)--Continued		
Rhizosolenia eriensis H.L. Smith	23	6.4
Stephanodiscus spp.	1	11.2
Synedna rumpens var. scotica Grunow	7	1.2
Synedra spp.	8	1.9
Tabellaria fenestrata (Lyngbye) Kutzing	30	10.9
Pennate diatom	21	1.6
CHRYSOPHYTA (Non-diatoms)		
Bicoeca lacustris J. Clark	12	.9
Chlorobotrys spp.	1	7.2
Chromulina spp.	30	1.3
chrysophyte statospore	30	5.7
Chrysosphaerella longispina Lauterborn	15	14.4
Dinobryon bavaricum Imhof	16	1.2
Dinobryon divergens Imhof	12	.8
Dinobryon sertularia Ehrenberg	11	5.7
Kephyrion ovale (Lackey) Huber-Pestalozzi	18	.4
Mallomonas caudata Iwanoff	5	2.3
Mallomonas globosa Schiller	6	1.2
Mallomonas spp.	14	4.4
Ochromonas spp.	29	4.6
Salpingoeca frequentissima (Zacharias) Lemmermann	7	1.5
Synura uvella Ehrenberg	6	4.8
CYANOPHYTA		
Anabaena flos-aquae (Lyngbye) Brebisson	1	5.4
Anabaena levanderi Lemmermann	2	44.4
Anabaena spp.	6	1.8
Aphanocapsa elachista W. + G.S. West	15	2.4
Aphanothece clathrata W. + G.S. West	23	2.0
Aphanothece nidulans Richt	5	2.0

Table 16.--Important phytoplankton taxa in the study lakes during the 1974 sampling--Continued.

Taxa Reference	Number of lakes in which taxa occurred	Mean percent of total cell cross-sectional area
CYANOPHYTA--Continued		
Chroococcus dispersus (Kessler) Lemmermann	7	4.7
Chroococcus limneticus Lemmermann	20	2.4
Chroococcus prescottii Drouet + Daily	3	12.2
Coelosphaerium kuetzingianum Naegeli	5	5.6
Coelosphaerium naegelianum Unger	8	9.5
Gomphosphaeria aponina Kutzing	14	7.0
Merismopedia tenuissima Lemmermann	26	1.1
Microcystis aeruginosa Kutzing	9	10.1
Microcystis incerta Lemmermann	9	.6
Oscillatoria rosea Utermohl	1	6.4
Oscillatoria tenuis Agardh	1	6.4
EUGLENOPHYTA		
Euglena spp.	3	2.6
Trachelomonas spp.	11	1.0
PYRROPHYTA		
Ceratium hirundinella (O.F. Mueller) Dujardin	8	3.1
Peridinium sp. 1	11	1.1
Cryptomonas spp.	30	3.0
Rhodomonas minuta var. nannoplanctica Skuja	22	2.7
unidentified Cryptomonad	1	5.5
CHLOROBACTERIA		
Chlorochromatium aggregatum Lauterborn	1	14.4

Asterionella spp., *Cyclotella bodinica*, *Cyclotella stelligera*, *Rhizoselenia eriensis* and *Tabellaria fenestrata* were the most common diatoms. Of these, *Tabellaria fenestrata*, *Asterionella* spp., and *Cyclotella bodanica* often dominated the phytoplankton. *Cyclotella stelligera* occurred in nearly all of the lakes, but averaged only 2.9 percent of the TCA. Facultatively planktonic diatoms such as *Melosira* and *Fragilaria* are more important in lakes which were sampled after fall overturn when there was sufficient circulation in the lake to keep them suspended in the water column. Truly planktonic forms such as *Asterionella*, *Cyclotella*, and *Tabellaria* were important in lakes sampled during mid and late summer stratification.

The Chrysophyceae, although generally less important than the diatoms, were always present and often numerous. *Chromulima spp*. and *Ochromonas spp*. were very common, occurring in 30 and 29 of the lakes respectively. *Chrysophaerella longispina* was quite common and often made up a large portion of the biomass.

The most common members of the Pyrrophyta were *Cryptomonas sp*. *1* (possibly a *Rhodomonas*) and *Rhodomonas minuta var*. *nannoplanctica*. Although they were very common, they rarely accounted for a large portion of the community.

The most common blue-green algae were Merismopedia tennuissima, Aphanothece clathrata, and Chroococcus limneticus. These taxa were rarely present in significant numbers. The only case of a Cyanophyte bloom occurred in 1974 in Nubble Pond. The blooming species was identified as Anabaena levanedieri, and it accounted for 85 percent of the TCA, which was the maximum recorded in 1974.

Analysis of 1975 Data (Multiple Samples).--Five of the project lakes were selected for a study of phytoplankton community succession during the open-water season of 1975. Six samples were analyzed from each lake.

Pleasant Pond

Pleasant Pond, the least productive of the five lakes analyzed, exhibited classic vernal and autumnal diatom maxima with a midsummer minimum dominated by non-diatom (figure 9). During spring turnover the community was dominated by *Tabellaria fenestrata*, *Asterionella formosa*, and *Dinobryon divergens*. Biomass peaked in June (TCA = 112 mm^2/L) with *Tabellaria* spp. and *Fragilaria crotonensis* being dominant. Diatoms accounted for 85 percent of the TCA in June samples. In July, biomass decreased dramatically (TCA 15 mm^2/L). The diatom community was greatly reduced, accounting for only 40 percent of the TCA, and the euglenophyte *Trachelomonas* spp. was the most abundant taxa. Biomass levels remained low through August but increased again starting in September, reaching an autumn maximum in October. Diatoms, mostly *Asterionella formosa*, accounted for 67 percent of the community. The mean TCA value for all Pleasant Pond data was 64 mm^2/L.

Pleasant River Lake

Mean phytoplankton biomass parameters for the six periods sampled indicate that Pleasant River Lake was only slightly more productive than Pleasant Pond (figure 10). Mean TCA for Pleasant River Lake was 82 mm^2/L. The major difference between the two communities was in the amount of seasonal fluctuation in biomass parameters. Variations in these parameters were more pronounced in Pleasant Pond than in Pleasant River Lake.

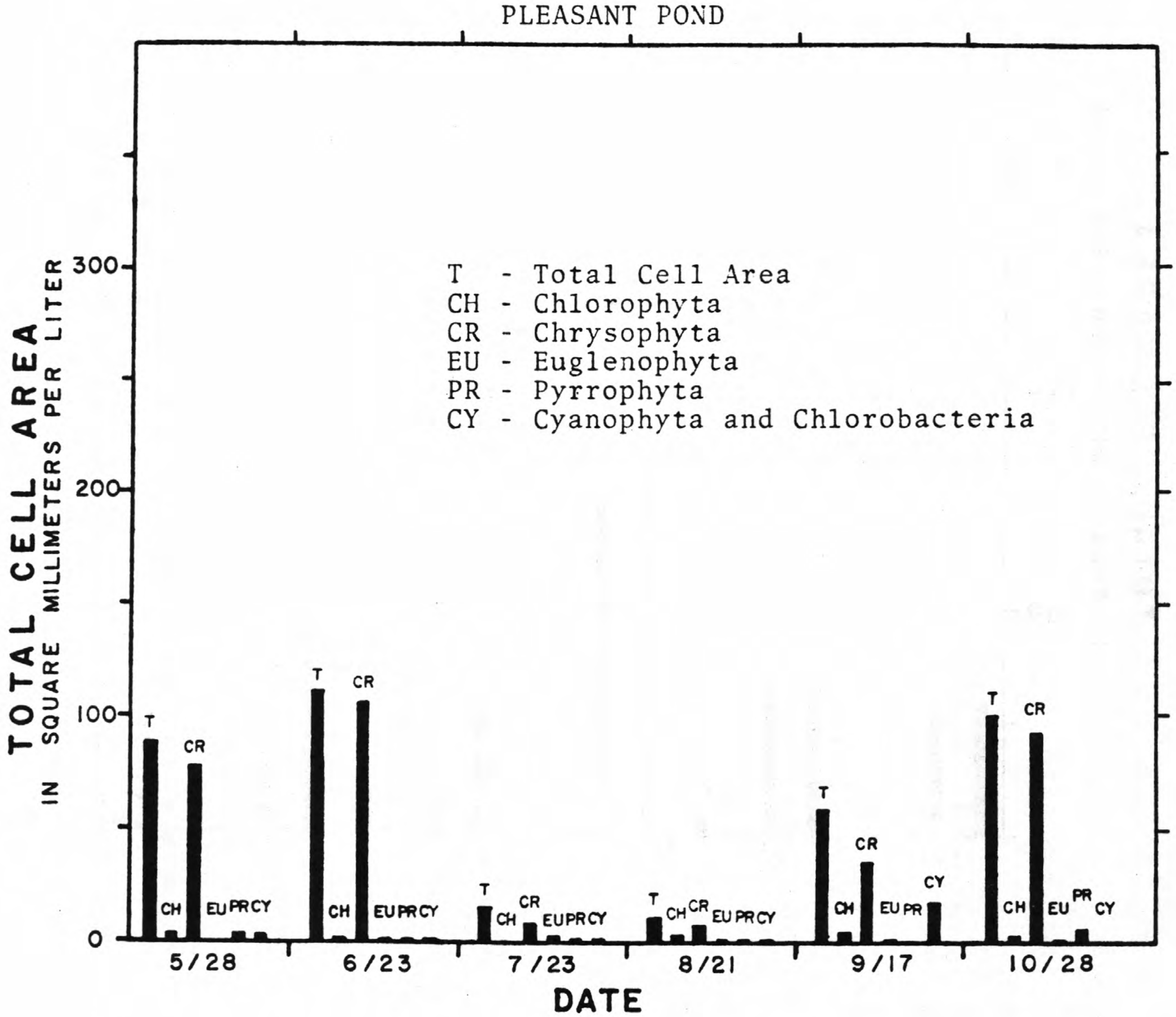


Figure 10.--Phytoplankton communities of Pleasant Pond during the open-water period of 1975.

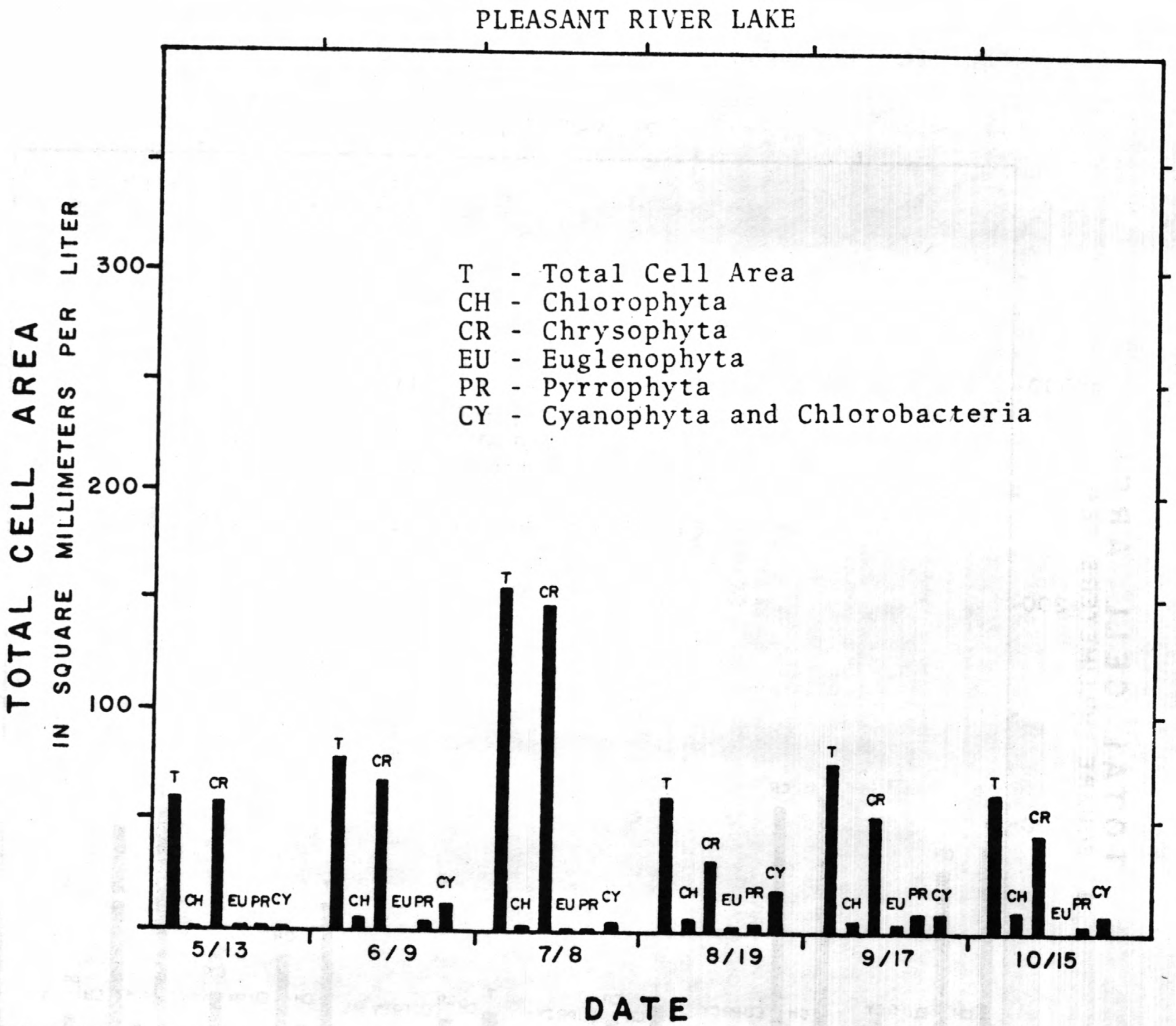


Figure 11.--Phytoplankton communities of Pleasant River Lake during the open-water period of 1975.

Asterionella formosa was the most significant phytoplankton in Pleasant River Lake. It accounted for 39 percent of a relatively sparse community (TCA = 60 mm^2/L) in May and grew to 65 percent of the maximum community (TCA = 156 mm^2/L) in July. By mid-August, the biomass had returned to May levels with *Asterionella formosa* accounting for only 1.5 percent of the community. *Asterionella formosa* was replaced by *Melosira ambigua*, *Cyclotella stelligera*, and several coccoid cyanophytes (*Microcystis*, *Aphanocapsa*, and *Aphanothece*). Biomass increased slightly in September but the *Asterionella formosa* population remained low until October when it returned to co-dominate with *Rhizoselenia eriensis* and *Gomphosphaeria aponina*.

Upper Lead Mountain Pond

Secchi disk and total phosphorus values for Upper Lead Mountain Pond suggest that it is less productive than Pleasant River Lake. However, phytoplankton biomass parameters, including chlorophyll *a*, indicate that Upper Lead Mountain Pond is more productive. This discrepancy is probably due to the high color of Pleasant River Lake. Color-producing compounds tend to decrease Secchi disk measurements and contain phosphorus which is not readily available for algal production (see the section: *Intensive Sampling Program*).

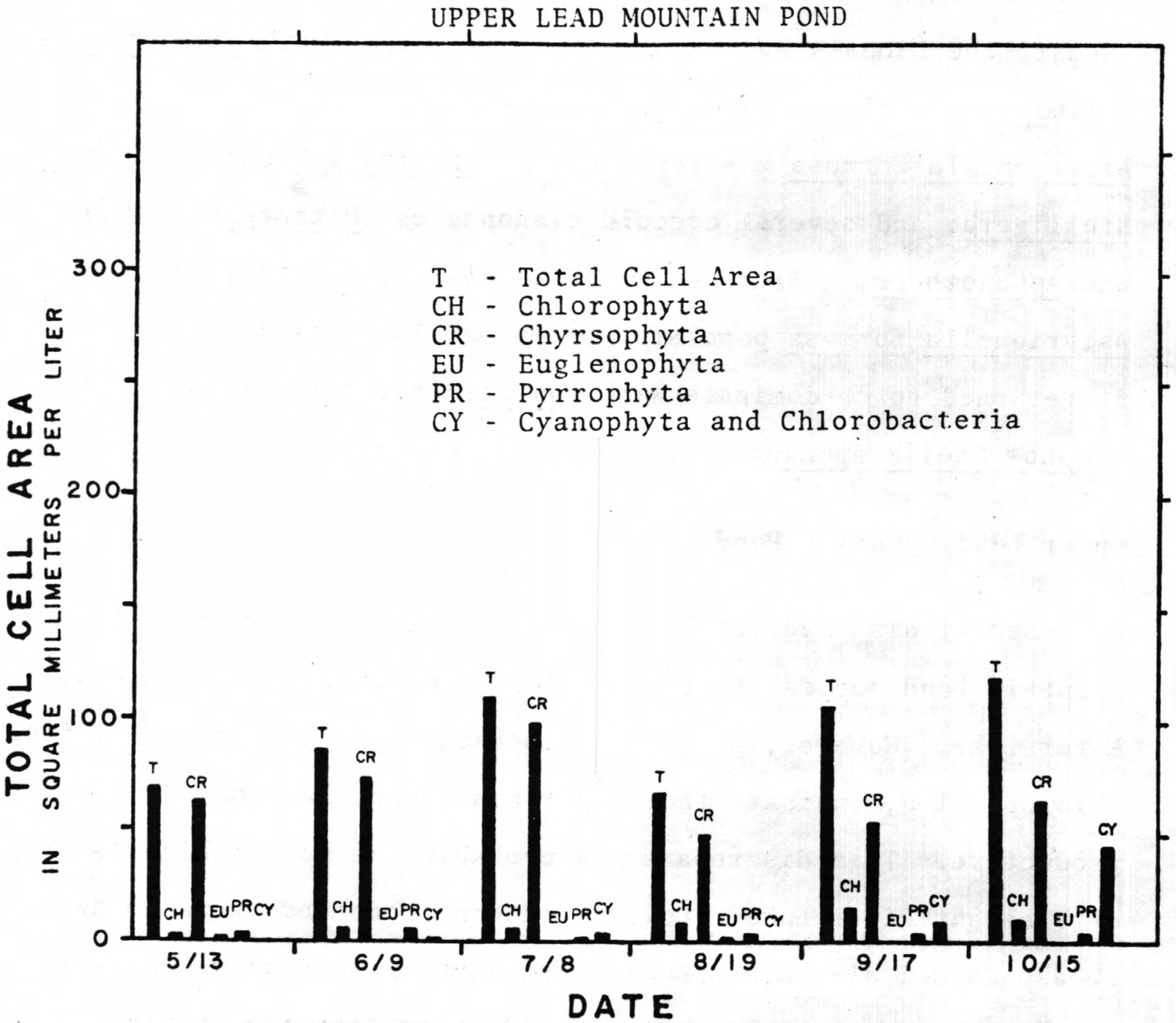


Figure 12.--Phytoplankton communities of Upper Lead Mountain Pond during the open-water period of 1975.

Upper Lead Mountain Pond had a July phytoplankton biomass maximum followed by an August minimum and a second maximum in October (figure 11). This pattern was much more subdued than in Pleasant Pond or any of the other lakes analyzed. The mean TCA value for this pond was 92 mm^2/L. The community was dominated by a succession of diatoms, beginning with *Cyclotella stelligera* and shifting to *Cyclotella bodanica* in July, *Tabellaria fenestrata* in August, and *Asterionella formosa* in September. In October, the coccoid cyanophytes *Gomphosphaeria aponina* and *Chroococcus limneticus* dominated.

Forest Lake

Although Forest Lake was considerably more productive than the three lakes already discussed (mean TCA = 253 mm^2/L), it exhibited vernal and autumnal maxima similar to Pleasant and Upper Lead Mountain Ponds (figure 12). The vernal maximum in Forest Lake occurred shortly after ice-out in late April and early May. It was a nearly monotypic community of the chyrsophyte flagellate *Ochromonas* spp., which accounted for 90 percent of the 519 mm^2/L TCA. By mid-June, the TCA had dropped to 251 mm^2/L with *Tabellaria fenestrata* and *Asterionella formosa* being dominant. The minimum TCA of 85 mm^2/L occurred in July. Diatoms were essentially absent and the flagellate *Mallomonas candata* was the most numerous taxon.

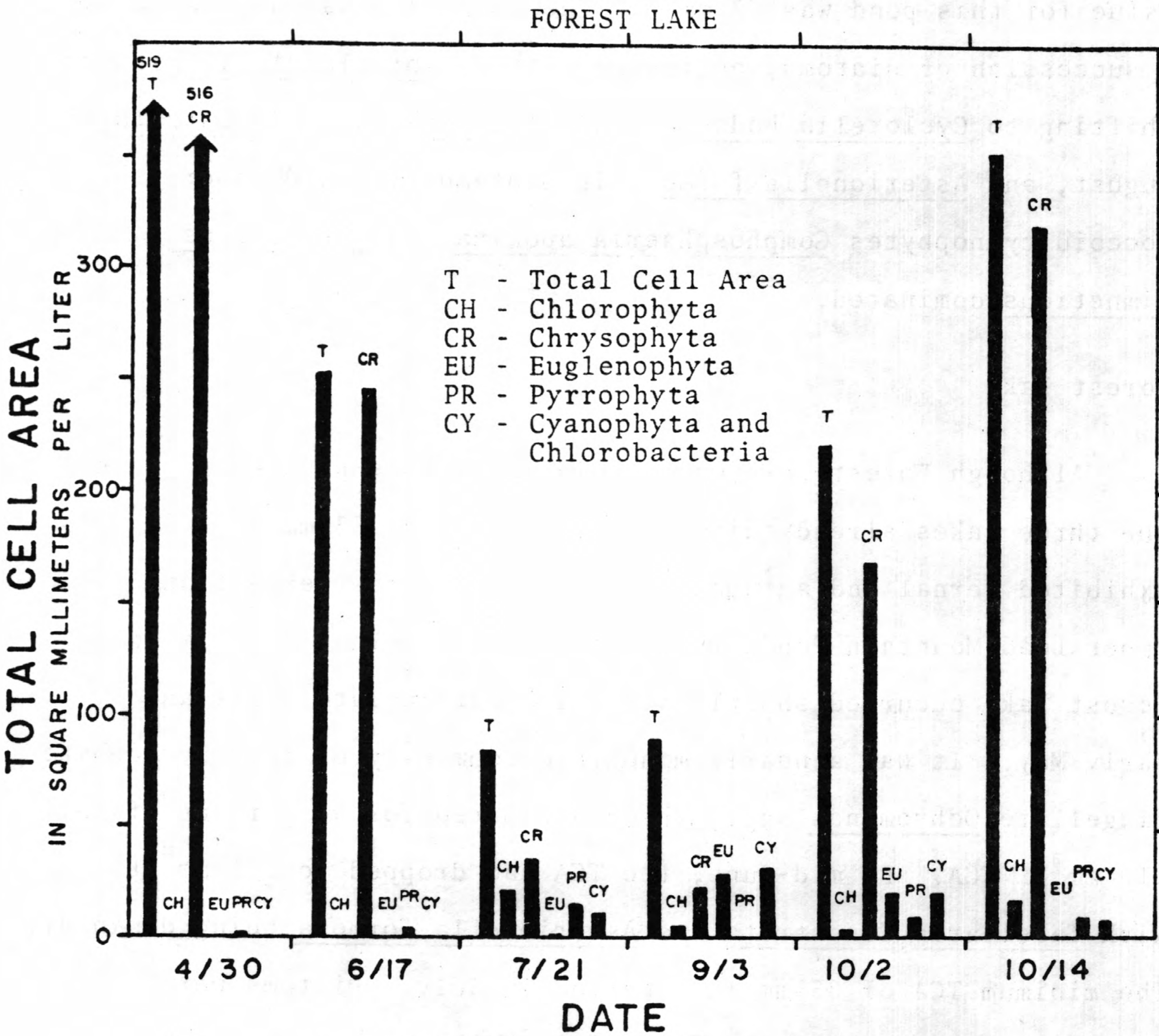


Figure 13.--Phytoplankton communities of Forest Lake during the open-water period of 1975.

By early September, dominance had apparently shifted to the chlorobacteria *Chlorochromatium aggregatum* and to an euglenophyte flagellate which could not be identified more specifically. Though TCA and TCV values were still quite low, chlorophyll values for this period were extremely high, especially chlorophyll *b*. This discrepancy was probably linked with the incidence of *Chlorochromatium*, as discussed in the section on "Problems of the Intensive Sampling Program". Biomass values rose in October, with the return of *Tabellaria fenestrata* and *Asterionella formosa* to dominance of the community.

Brewer Lake

Brewer Lake had a bimodal pattern of succession (figure 13). An *Asterionella* TCA maximum of 340 mm^2/L occurred in early June. Diatoms accounted for 95 percent (by TCA) of the phytoplankton. In July, *Asterionella* was absent, only 26 percent of the community were diatoms, and TCA dropped to 64 mm^2/L. There was a significant amount (12 percent of the TCA) of *Aphanizomenon flos-aquae* in this sample. Total biomass declined slightly in August, but *Aphanizomenon* showed a threefold increase. This trend continued through September and October and into early November, when there was a dense bloom of *A. flos-aquae*. This species made up 90 percent of the TCA, which was 7000 mm^2/L. This was by far the largest total phytoplankton value reported during the project. The mean TCA value for Brewer Lake was 1345 mm^2/L (including samples during the autumnal bloom) or 211 mm^2/L (excluding the samples during the autumnal bloom.

BREWER LAKE

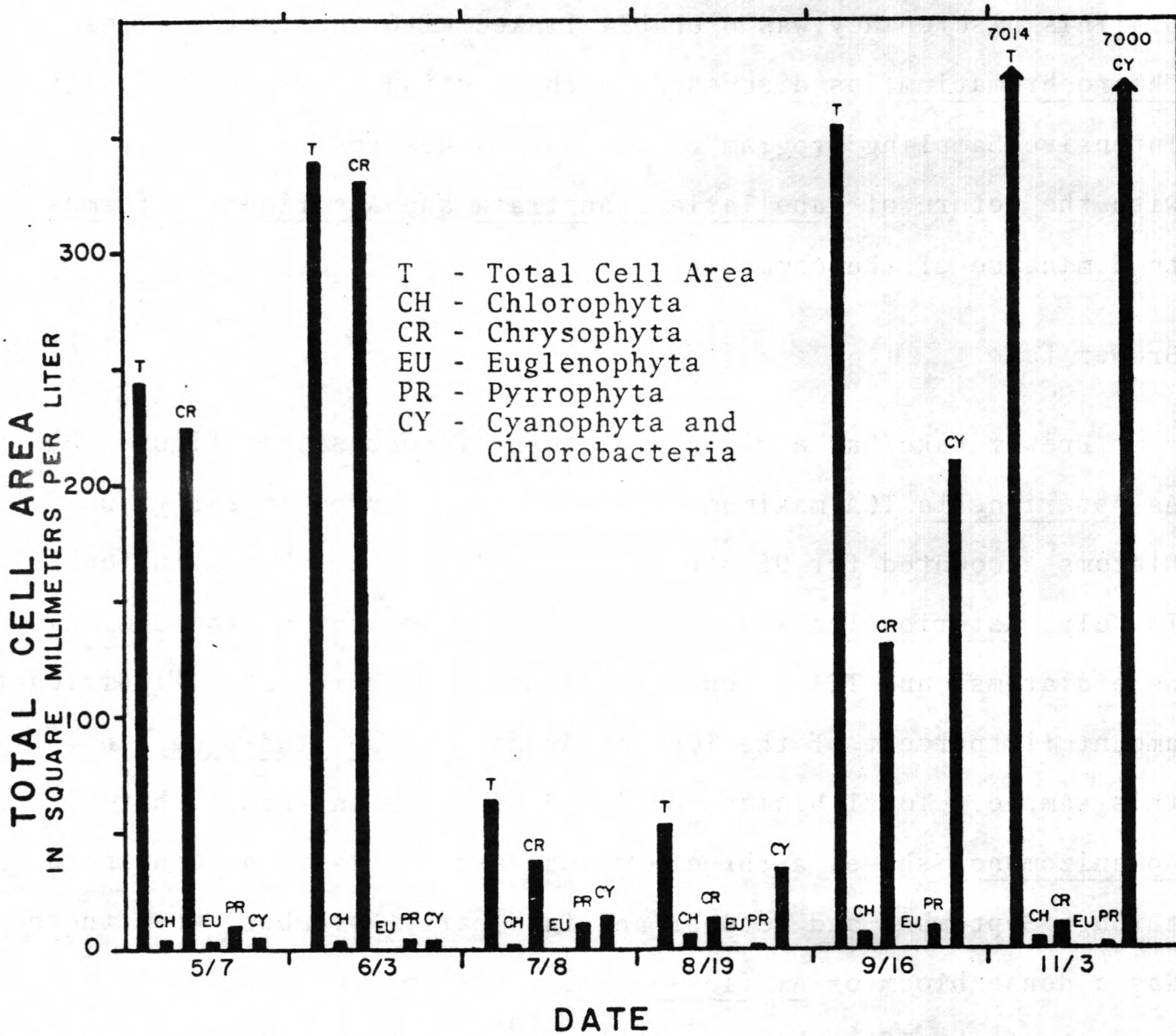


Figure 14.--Phytoplankton communities of Brewer Lake during the open-water period of 1975.

Discussion of 1975 Data.--The classic pattern of vernal and autumnal maxima with a distinct midsummer minimum was observed on three of these lakes. This cycle has been reported by many researchers and is described in detail by Hutchinson (1967) and Fogg (1975). There are several possible explanations for this pattern in Pleasant Pond. A popular theory, originally proposed by Pearsall (1930) and refined by Lund (1950), combines the effects of illumination and nutrient limitation. The spring maximum is a result of the coincidence of high nutrient concentrations following turnover with a period of maximum solar illumination Since the maximum in Pleasant Pond is almost entirely diatoms, the dramatic decrease to the summer minimum might be explained, as Lund (1950) suggests for *Asterionella* in Windermere, by nutrient depletion, especially silica. The dissolved silica profile from the previous summer (Sept. 10, 1974) shows concentrations to be 0.2 ug/L or less throughout the epilimnion and metalimnion. These values support silica depletion as the cause of diatom limitation.

There is another, purely hydrodynamic, hypothesis which might explain the pattern. Pleasant Pond has exceptional clarity with a mean Secchi disk transparency of 8.9 m. With a maximum depth of only 20 m, it is likely that the euphotic zone contacts most, if not all, of the lake bottom, thus creating a favorable environment for extensive periphitic production. It is possible that the vernal diatom maximum results from the mixing of the bottom waters and suspension of facultative plankton into the water column. After stratification is established, probably in late June, and turbulence diminishes, these organisms would settle out and resume their periphytic phase, thus causing the summer phytoplankton minimum. This mechanism has been observed for Melosira italica in the English Lakes District (Fogg, 1975) and in Lac Hertel in Quebec (Knoechell and Kalff, 1975). As autumn approaches, the thermocline drops and more of the lake bottom comes in contact with the mixed epilimnion. This allows resuspension of the facultative plankton and a gradual build-up of planktonic diatoms to an autumn maximum following complete turnover. The gradual rise in phytoplankton concentrations (especially diatoms) from August through October support this hypothesis.

It appears that the midsummer minimum in Forest Lake might be the result of silica depletion as described by Lund (1950). In June, diatoms accounted for 86 percent of the TCA, or a cell area of 216 mm^2/L. In July, this dropped to 14 percent of a much smaller TCA (12 mm^2/L). Diatoms remained insignificant in September and TCA remained low. Both percent diatoms and TCA rose in October following turnover. The dramatic reduction in diatoms in July suggests silica depletion, especially considering the low epilimnetic dissolved silica (0.3 mg/L) in the September 1975 nutrient profile. Silica would be recycled during fall turnover, thus allowing the October diatom maximum.

Silica depletion may also have been the cause for the midsummer minimum in Brewer Lake. Diatom concentrations dropped dramatically and epilimnetic dissolved silica was low in the September profile. Profile data for Brewer Lake indicates a buildup of total phosphorus in the anaerobic hypolimnetic waters. The concentration 1 m above the bottom was 0.116 mg/L. Incorporation of these enriched waters into the epilimnion during turnover could explain the increase in total phosphorus concentrations from mid-September through November from 0.008 mg/L to 0.014 mg/L. This increase in phosphorus during turnover parallels the rise in chlorophyll a and Anabaena flos-aquae. This pattern of autumnal blue-green blooms following turnover of a highly enriched anaerobic hypolimnion has been observed on other Maine lakes.

Neither of the two theories discussed for the previous lakes are completely adequate in explaining the pattern of succession in Pleasant River Lake. The lake is relatively shallow and by mid-August the thermocline has dropped so that 80 to 90 percent of the lake bottom is in contact with the mixed epilimnion. This mixing, along with the fact that *Asterionella* is known to be a relatively buoyant diatom (Fogg, 1975), makes it unlikely that settling is the sole cause for the drastic August reduction. It also casts doubt on the silica depletion hypothesis. With 80 to 90 percent of the bottom exposed to mixing, it seems likely that silica would be recycled into the water column. The silica profile in September 1974, which indicated more than 3 mg/L throughout the stratified water column, supports the concept of recycling into the water column.

Parasitism is a possible cause for the August decline in the *Asterionella* population. An epiphyte was found on *Asterionella* which was originally identified as the colorless flagellate *Salpingoeca frequentissima* and so reported by Cowing and Scott (1975). Upon further inspection, this identification seemed questionable. *Salpingoeca* was present, but most of the cells were very indistinct, and were assumed to be *Salpingoeca* because they were epiphytic on the diatom. The ratio of the epiphyte cells to *Asterionella* cells increased as *Asterionella* peaked and continued to rise dramatically as *Asterionella* declined, as shown in table 17.

Table 17.--Relationship between *Asterionella* and a parasitic epiphyte.

	Cells per ml		Ratio
Date	Epiphyte	Asterionella	Epiphyte/Asterionella
June 1975	4	170	.02
July 1975	63	504	.12
August 1975	9	5	1.80

The August population appears to be heavily colonized with nearly two epiphytes on each *Asterionella* cell. Lund (*in* Hutchinson, 1967) has reported instances when the chytrid *Rhizopodium planktonicum* had infested autumn populations of diatoms and resulted in rapid reduction of the infected species. If the epiphyte in question was parasitic, it may have been in part responsible for the August decline in *Asterionella*.

Phytoplankton Parameters as Measures of Trophic State.--Because phytoplankton chlorophyll *a* is a measure of phytoplankton biomass, it should correlate with the phytoplankton parameters TCA, Total Cell Volume (TCV), and Total Cell Number (TCN). Linear regressions of these parameters on corresponding instantaneous chlorophyll *a* values yielded r values of 0.61 for TCA, 0.65 for TCV, and 0.27 for TCN. Although none of these values indicates strong correlation, they indicate that cell area and cell volume are considerably better estimators of biomass than are simple cell counts.

Samples from Nubble Pond, 1974 and Brewer Lake, July 1975 were left out of the analysis, because their extremely high values for all variables during blue-green blooms gave high correlations which were not indicative of the relationship between the parameters for the other 33 lakes. When additional data become available throughout the trophic scale, additional analyses relating these parameters might be useful.

The poor correlations between chlorophyll _a_ and the phytoplankton parameters can be partially attributed to variations in composition of the phytoplankton. In figure 14 (chlorophyll _a_ vs. TCV) the samples which contained a large percentage of diatoms are somewhat clustered below the regression line. Sixty-seven percent of the samples below the regression line had greater than 50 percent diatoms by volume, as compared to 22 percent for those above. It appears that, as the percentage of diatoms in the community decreases, the ratio of chlorophyll _a_ to TCV increases. This would indicate that diatoms have lower densities of chlorophyll _a_ than the average of other phytoplankton. This may be a result of the method used to estimate cell volume which tends to overestimate the cytoplasmic volume of diatoms.

It is also possible that the poor correlations are, in part, a result of actual variations in the chlorophyll _a_ densities in the cytoplasm of different phytoplankton types.

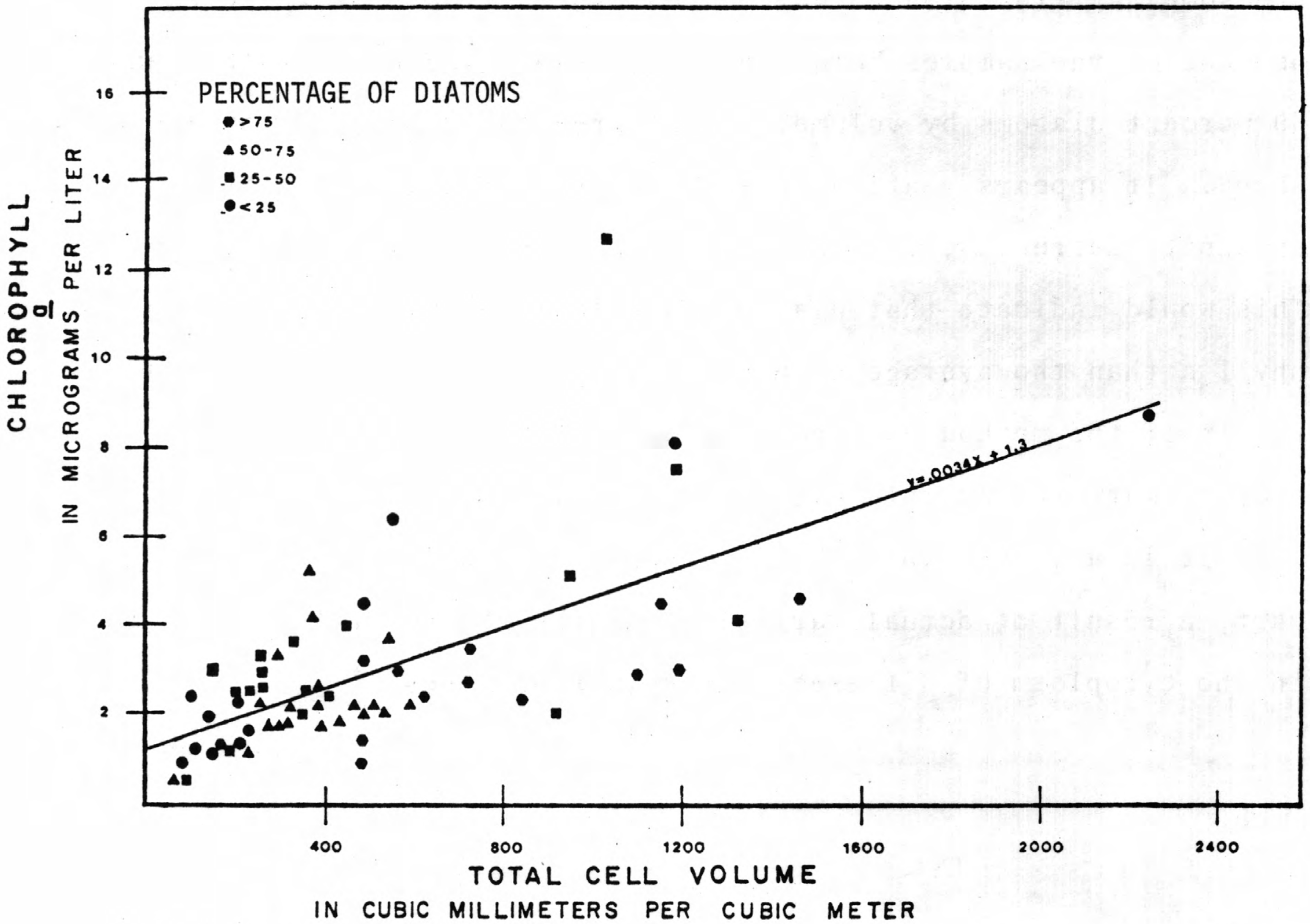


Figure 14.--Relationship between instantaneous observations of chlorophyll a and TCV with respect to percentage of diatoms in the phytoplankton community.

Suggested Modifications for Baseline Sampling Program

The baseline sampling program used during this study yielded valuable limnologic data for each of the study lakes. However, modifications of the program, to substantially reduce its cost and manpower requirements, can be accomplished with minimal loss in limnologic data. Suggested modifications include:

1. Elimination of the winter sampling trip.
2. Elimination of tributary samples.
3. Restriction of the use of phytoplankton analysis to the investigation of specific phytoplankton related problems, such as the chlorobacteria-chlorophyll *a* relationship in Forest Lake or nuisance algal blooms.

The use of the remaining elements of the baseline program should be continued, because they are either valuable limnologic data (dissolved oxygen and temperature profiles) or provide inexpensive data which could be useful in the future. For instance, dissolved chloride data collected over a period of years would provide information on the effects of deicing chemicals on lake water quality conditions and data on pH trends would provide information on the impact of acid precipitation on lake water quality.

CONCLUSIONS

The results of this study indicate that by following a systematic data collection program, the trophic status of a lake can be defined using a numerical scale for TSI. In addition, supplemental information can be made available to help develop guidelines for the management of Maine's lakes and to observe the impact of increased cultural development in the lake basins.

The most reliable parameter for determining the trophic state of Maine lakes using a numerical scale is chlorophyll a. An acceptable alternate parameter for use in a closely supervised monitoring program for lakes with color less than or equal to 30 units is Secchi disk transparency. Total phosphorus can also be used to derive TSI values for lakes of colors less than or equal to 30 units, but is not as dependable as chlorophyll a or Secchi disk due to problems in sampling for and analyzing phosphorus at low concentrations. As techniques improve, total phosphorus may become an important parameter for determination of lake TSI values. The equations derived for TSI calculation and the lake types for which they are valid are:

All Lakes

TSI = 77.7-27.3 ($\log_{10}$ annual mean chlorophyll a, in micrograms per liter)

Lakes color < 30 units

TSI = 40.0+33.0 ($\log_{10}$ annual mean Secchi disk transparency, in meters)

TSI = 104.0-44.2 ($\log_{10}$ annual mean total phos phorus, in micrograms per liter)

In future data collection programs, chlorophyll _a_, Secchi disk transparency, total phosphorus, and color should all be determined when conditions allow the work to be done by trained personnel. This would allow better definition of the relationships between these parameters as more data becomes available throughout the TSI scale and as data collection techniques improve.

Supplemental information important to the management of lakes includes: profile water quality data, field reconnaissance surveys and compilation of data available from published and unpublished sources.

Profile water quality data collected on each of the major basins of a lake during the late summer thermal stratification period provides information at the most critical time during the year for most Maine lakes. Some of the most important parameters to determine in the profile at this time are: dissolved oxygen, water temperature, color, pH, specific conductance, alkalinity, nitrogen species, phosphorus species, major anions, major cations, iron and manganese. During this same visit to a lake during late summer, field reconnaissance surveys of aquatic vegetation and cottage development as well as benthic invertebrate sampling could be completed.

The information most important to obtain either directly or by derivation from available sources includes:

1. Morphometric data
   a. surface area
   b. drainage area
   c. volume
   d. mean depth
   e. maximum depth
   f. length of shoreline
   g. altitude

2. Geologic data
   a. drainage basin lithology
   b. lake origin

3. Hydrologic data
   a. annual runoff from the lake drainage basin
      ($R = Q_a = 1.329 \times 10^2 A^{0.985} P^{1.347}$)
   b. hydraulic retention time
      ($Tw = \frac{1000V}{DAxR}$)

Note: Explanations of the terms in these equations are included in the section: "Hydrology".

To facilitate handling and analysis of this data, DEP should expand its basic data storage and retrieval system to include those parameters which are not currently in the program.

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