THE UNIVERSITY OF MICHIGAN

Biological Station

A Water Quality Survey of Otsego Lake, Michigan

Technical Report No. 10

by

Marion M. Secrest*, Stanley Pollack*, and Arthur J. Gold*

Douglas Lake

* Coauthors

NEMCOG

The University of Michigan Biological Station was established in 1909 at Douglas Lake near Pellston, Michigan, as a teaching and research facility. It occupies a 10,000-acre tract of semi-wilderness in northern lower Michigan, surrounded by a remarkable variety of upland and lowland deciduous and coniferous forests, meadows, marshes, bogs, dunes, lakes and streams. The three upper Great Lakes - Michigan, Huron and Superior - are nearby. As the largest and one of the most distinguished inland biological stations in the world, it serves as an intellectual meeting place for biologists and students from the United States and around the world.

The Biological Station is well-equipped for investigations of the diverse natural environments around it. In addition to the modern, winterized Lakeside Laboratory, which was funded by the National Science Foundation, the Station has 140 buildings, including laboratories, classrooms, and living quarters for up to 300 people. Special facilities include a library, study collections of plants and animals, a large fleet of boats, and a full array of modern laboratory and field equipment. The Station offers tranquility and harmony with nature - it is a place where plants and animals can be studied as they live.

Dr. David M. Gates, Director of the Station since 1971, and Mark W. Paddock, Assistant to the Director, have promoted new and exciting fields of research, including problem-oriented research to help cope with emerging environmental problems.

The Station is currently undertaking specific investigations in northern lower Michigan to provide information about the land, the water, and the people in the area. Results are made available to community leaders for use in long-term land-use planning. In addition, many research projects are underway, geared toward a better understanding of the structure and function of both aquatic and terrestrial ecosystems.

This publication is one of a series of reports that are issued periodically to disseminate information on research generated at the Biological Station. For further information concerning other publications in this series or information on the Biological Station in general, address inquireies to: The University of Michigan Biological Station, Pellston, Michigan 49769 (Phone 616-539-8406)

NEMCOG

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DATE: 2 November 1979

TO: Readers of the Otsego Lake Water Quality Study

FROM: Staff of Northeast Michigan's Clean Water Program

RE: Otsego Lake Water Quality Study

We are pleased to present this study undertaken by the University of Michigan Biological Station for your use.* It is through quality efforts like this that water quality management becomes a reality. We hope this study is only the first of many that can be developed on a cooperative basis between lake residents, the Clean Water Program of Northeast Michigan, and Institutions like the University of Michigan. We commend the Otsego Lake Association and the authors of this report for their dedication and contribution towards protecting and enhancing this region's water resources.

* This project was partially supported by a grant from the U.S. Environmental Protection Agency.

A WATER QUALITY SURVEY

OF

OTSEGO LAKE, MICHIGAN

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Arthur J. Gold*

Final Report prepared
in cooperation with
Northeast Michigan
Council of Governments
(NEMCOG)

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CONTENTS

CONCLUSIONS i
RECOMMENDATIONS ii

INTRODUCTION 1
DESCRIPTION OF STUDY AREA 2
The Origin of the Lake 2
Watershed Characteristics 2
Lake Area to Watershed Ratio 7
Shoreline Development Factor 7
Sediments 8
Discharge and Inflow 8
METHODS 12
Limnological Characteristics 12
Watershed Characteristics 13
Nutrient Loading Determinations 13
Septic System Nutrient Contributions 15
Precipitation and Dryfall 16
Flushing Rate 16
TROPHIC STATUS 17
Physiochemical Features 21
Limiting Growth Factor 21
Alkalinity, pH, and Conductivity 21
Temperature and Dissolved Oxygen 23
Oxygen Depletion: Possible Impact on Water Quality . . 23
BIOLOGICAL FEATURES 25
Phytoplankton 25
Zooplankton 29
Benthos 30
Fish 30
Aquatic Plants 31
WATER QUALITY OF MAN-MADE CANAL 34
NUTRIENT CONTRIBUTIONS 35
Sources of Nutrient Loading 35
Direct Precipitation and Dry Fallout 35
Watershed Inputs: Some Hydrological Considerations . . 35
Nutrient Contributions from the Watershed 37
Shoreline Development and Nutrient Loading 38
Sediment Contriubtion 42
Direct Use 43
RESPONSIVENESS OF OTSEGO LAKE TO NUTRIENT LOADING 44
LAKE RESTORATION 47
REFERENCES CITED 49

APPENDICES

A. Land Use Data 52
B. Limnological Data: Physiochemical Features 55
C. Phosphorus Adsorption/Release by Bottom Sediments . . . 60
D. Limnological Data: Biological Features 66

CONCLUSIONS

1. Otsego Lake is a productive water body classified as being in the mid to late stages of mesotrophy (moderately productive).

2. The shallow depth of the lake enhances prospects for maintaining present water quality. However, the low buffering capacity and long water retention time of the lake increases the influence of pollutants upon water quality.

3. The lake is well-suited for warm water fisheries and supports healthy populations of game fish. However, the dominant algae in the lake are blue-green which appears in blooms throughout the summer.

4. Under oxygenated conditions, the bottom sediments are capable of adsorbing large quantities of phosphorus and function as a phosphorus sink. Laboratory experiments demonstrate that the sediment will release high concentrations of phosphorus during anaerobic periods.

5. The lake is fed by groundwater that enters along the western and northern shore and drains through the ground towards the North, East and Main Branches of the AuSable River.

6. Shoreline pollution is more evident along the west shore than the east shore, in agreement with expected groundwater movements.

7. Water quality in all the canals is much worse than the water quality of the lake.

RECOMMENDATIONS

1. Curtail major sources of nutrient inputs to the lake:

   * Upgrade septic systems particularly along the west shore; pinpoint other areas where septic system contamination may be occurring using "septic snooper".

   * Insure that storm water run-off is drained away from the lake.

   * Prohibit fertilization of lakeside lawns.

2. Dredge and fill operations in and near the lake should be avoided.

3. New canals should not be established.

4. Additional study of the lake is recommended:

   * Winter oxygen and phosphorus levels of the bottom waters must be sampled.

   * Well water quality in Arbutus Beach should be monitored.

   * The impact of motorboating on lake water quality should be investigated.

5. Lake residents should work with Township and County Governmental Units to plan and monitor land use changes within the Otsego Lake watershed and in areas which supply groundwater to the lake.

INTRODUCTION

Otsego Lake is a large lake in northern Michigan used primarily for recreation. Otsego Lake is the largest lake in Otsego County with 12 miles of shoreline and long expanses of sandy beaches.

The lake is easily accessible to the population centers of the state and has attracted resort-oriented development since the turn of the century. Today, over 1200 homes are located within one quarter mile of the lakeshore with over 550 homes directly bordering the water.

In addition, the lake receives heavy use from a State Park and a County Park, as well as numerous public accesses along its shore.

Use of the lake is expected to rise in the future. Bagley Township, which borders the lake on the north, experienced 93.4% population growth between 1970 and 1975. Otsego Lake Township, the south border of the lake, grew 66.3% between 1960 and 1970.

In recent years, the residents of Otsego Lake have become concerned about the water quality of the lake. In particular, the Otsego Lake Association is considering various management practices which could improve and enhance the lake's water quality. This study arose from the awareness that lake management requires considerable ecological information to be effective. The purpose of the study is to document the present condition of the lake and to suggest where future research attention should be directed.

The study was conceived and set up under the auspices of the Northeast Michigan Council of Governments which provided valuable assistance throughout the project. Support for the study was provided from the Otsego Lake Association and through the generosity of the Elizabeth Kennedy Foundation. In addition, special thanks are given to Mark Paddock, Robert Koch, E. Zapata, and Lillian Bering.

DESCRIPTION OF THE STUDY AREA

Otsego Lake, located in Otsego County, Michigan (T29.30N. R3W.) is a shallow, relatively softwater lake of glacial ice block origin. The lake has a maximum length of 5 miles and a maximum width of 1 mile. The lake surface area of 1,964 acres (794.8 hectares) is large relative to the mean and maximum depths of 9.8 feet (3.0m) and 23 feet (7.0m) respectively. (Fig. I, Table I)

The Origin of the Lake

The depression of Otsego Lake was formed by the melting of a buried ice block left by the retreat of the glaciers over 12,000 years ago. The lake lies in an outwash valley between sandy, rolling "moraines" (glacial deposits of sand, clay and rocks of all sizes). Although many of the lakes north of Otsego Lake were engulfed by the Great Lakes after the glacier receded, the high relief of Otsego Lake kept it above the ancient lake levels. Consequently, Otsego Lake is approximately 7,000 - 10,000 years older than the lakes of Emmet and Cheboygan Counties. (Dorr & Eschman, 1977).

Watershed Characteristics

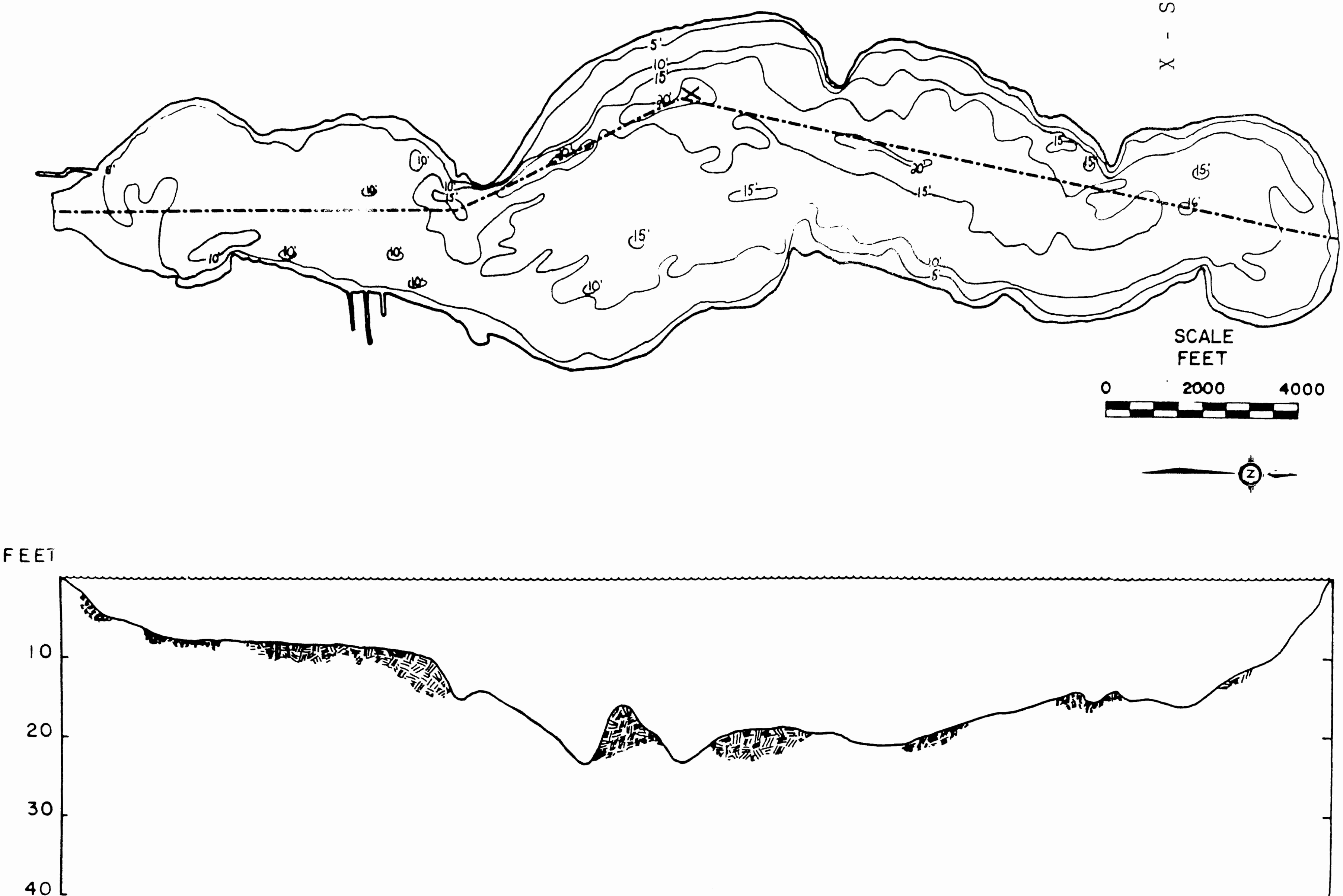
The watershed of Otsego Lake encompasses parts of two townships and consists primarily of second growth deciduous and mixed (deciduous and coniferous) forest (Fig. II, Table II). Urban/residential land, including commercial areas, residentials areas (39% developed) and roads, constitutes the next largest land use type within the watershed. Agriculture and grasslands comprise a relatively small fraction of land-use and are located, for the most part, in upland areas away from the lakeshore. Marshy and swampy wetlands, found primarily near the northwest tip of the lake, constitute only a small percentage of the total watershed area but are nonetheless an important feature in the lake environment.

OTSEGO LAKE

MORPHOMETRIC FEATURES

Fig. I

X - Sampling Station



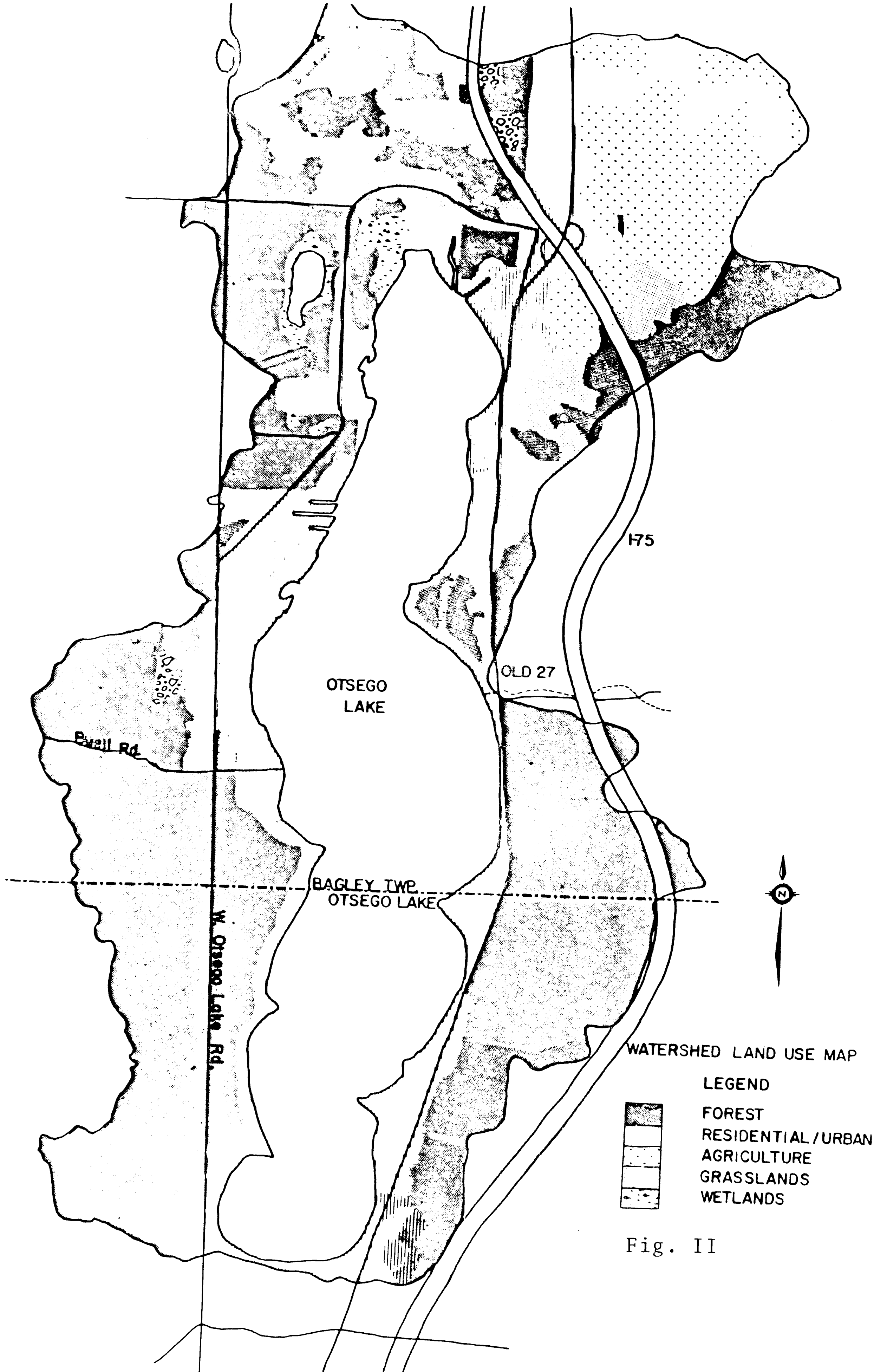

OTSEGO
LAKE
OLD 27
I-75
Byell Rd
W. Otsego Lake Rd.
BAGLEY TWP.
OTSEGO LAKE
N
WATERSHED LAND USE MAP
LEGEND
FOREST
RESIDENTIAL/URBAN
AGRICULTURE
GRASSLANDS
WETLANDS

Fig. II

OTSEGO LAKE

MORPHOMETRIC FEATURES

TABLE I

MAXIMUM DEPTH	23 ft. (7.0m)
MEAN DEPTH	9.8 ft. (3.0m)
MAXIMUM WIDTH	1 mi. (1.6km)
MAXIMUM LENGTH	5 mi. (8.1km)
SHORELINE LENGTH	11.9 mi. (19.1km)
SURFACE AREA	1963.9 acres (794.8ha)
WATERSHED AREA	6971.18 acres (2821.2ha)
VOLUME	23,649,016m^3
SHORELINE DEVELOPMENT FACTOR	1.91
RATIO OF LAKE AREA TO WATERSHED AREA	1:2.6
INFLOWING/OUTFLOWING STREAMS	None *

* An artificial drain connects Otsego Lake to the North Branch of the Au Sable River

TABLE II LAND-USE TYPES IN THE OTSEGO LAKE WATERSHED BASED ON AERIAL PHOTOGRAPHS (MICHIGAN DEPARTMENT OF NATURAL RESOURCES, 1968)

LAND-USE TYPE	MI^2	KM^2	%
FOREST	4.11	10.64	52.7
GRASSLANDS	.71	1.84	9.2
AGRICULTURE	.74	1.92	9.5
WETLANDS	.13	.32	1.6
URBAN/RESIDENTIAL	2.10	5.45	27.0
TOTAL	7.79	20.17	100.0

Lake Area to Watershed Ratio

Lake water quality protection involves minimizing the input of undesirable materials to the lake from the watershed. Otsego Lake has a small lake area to watershed area ratio --- 1:2.6*, a positive factor for lake protection efforts. Table II compares the lake to watershed ratio of Otsego Lake with other lakes in northern Michigan

TABLE III

Ratio of Lake Area to Watershed Area

Crooked Lake	1:5.49
Houghton Lake	1:1.60
Lake Margrethe	1:4.01
Otsego Lake	1:2.60
Walloon Lake	1:5.30

Shoreline Development Factor

The Shoreline Development Factor (SDF) gives an indication of the amount a shoreline configuration varies from being completely circular. A lake with a large SDF (a long, narrow, high irregular lake) will have more shore areas that can be developed, produce runoff, or otherwise contribute nutrients to a water body, than will a lake with a low SDF (a round lake).

Otsego Lake has a moderate SDF of 1.91. The Table below compares Otsego Lake with other northern Michigan lakes.

TABLE IV

Shoreline Development Factors

Crooked Lake	2.62
Houghton Lake	1.53
Lake Margrethe	1.49
Otsego Lake	1.91
Walloon Lake	3.17

* This figure is somewhat smaller than that given in the Mi. Inland Lakes and Their Watersheds atlas because of different interpretation of watershed boundaries.

Sediments

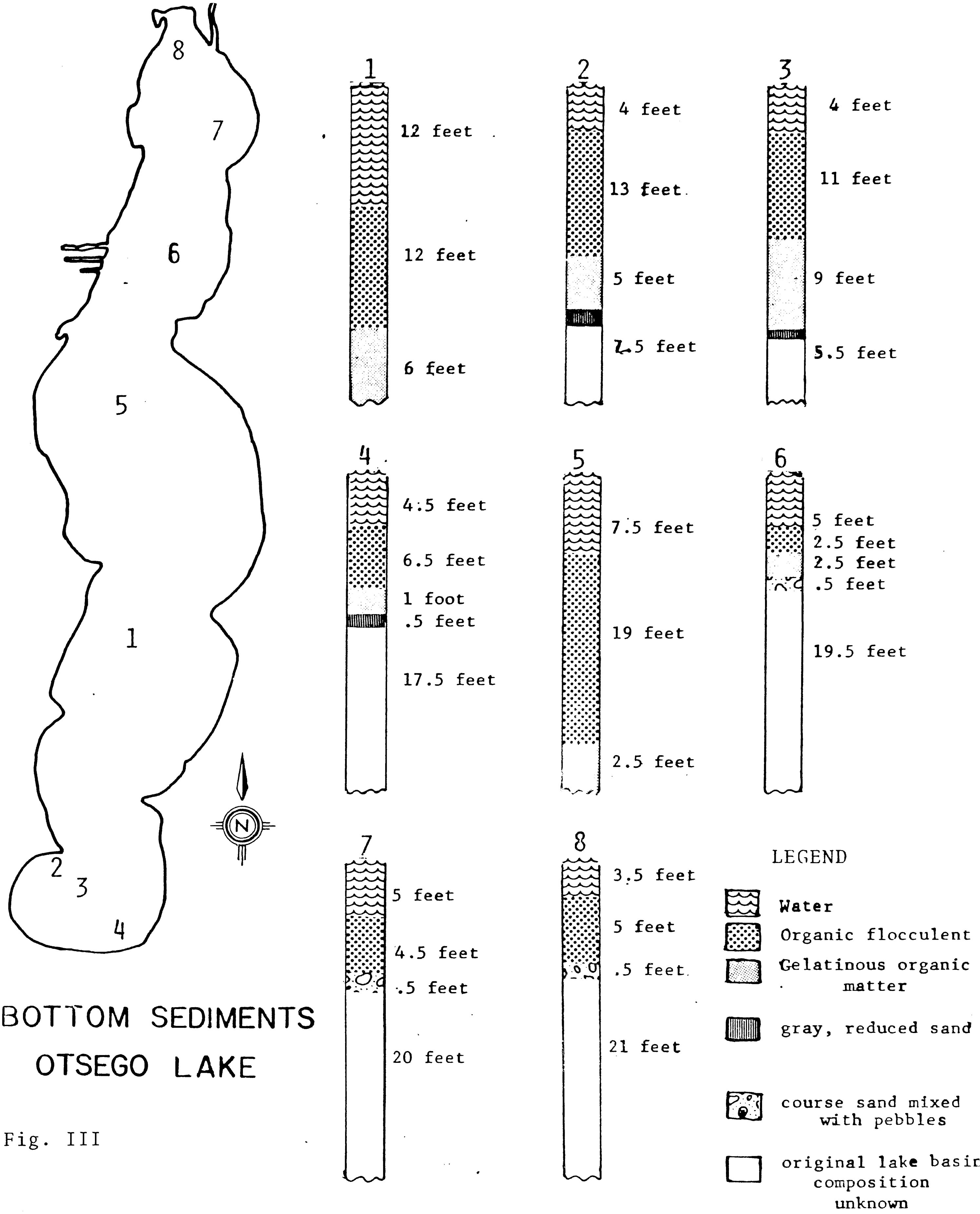
The shallow mean depth of Otsego Lake is primarily the result of a gradual filling in of the original basin since its formation 12,000 years ago (Door & Eschman, 1977). In order to determine the depth of the original lake, a series of cores were taken using 6 foot lengths of 3/4 inch galvanized steel pipe joined with plumbers fittings. The cores were taken at 8 locations on the lake on July 11, 1979. (Fig. III).

The sediments throughout the lake consist of flocculent, brown-green organic matter. The organic sediments become compacted and gelatinous with depth. The sediment accumulation is comparatively shallow at the north and south ends of the lake (5 feet and 7.5 feet respectively) and quite deep in the center of the lake (18 feet at Station 1 and over 21.5 feet at Station 5). On the six sites where a firm substrate was reached, the bottom material was a gray, reduced sand. The sediment at the north end of the lake was coarser and included pebbles.

Particular analysis of Otsego Lake bottom muck indicates that the flocculent sediments consist of water (96.7%); organic matter (2.5%) and fine grain inorganic material (0.8%). The analysis suggests that the sedimentation in Otsego Lake results primarily from deposition of plant and animal material from the lake water. This hypothesis is strengthened by information from Scott (1921) who found that little sediment entered the lake with surface runoff.

Discharge and Inflow

Groundwater inflow is the primary source of water to Otsego Lake. An extensive groundwater aquifer underlies the entire area surrounding the lake and the highly permeable soils (Rubicon and Grayling sands) allow direct



BOTTOM SEDIMENTS
OTSEGO LAKE

Fig. III

and rapid recharge of the aquifer from precipitation (Dunn Geoscience Corporation, 1979).

The mean water residence time in Otsego Lake is 3.6 years, resulting in approximately 28% of the lake's water volume being replaced each year. Precipitation accounts for 44% of the annual hydrological input; groundwater seepage and springs comprise the remaining 56%.

There has been a great deal of controversy surrounding the out-flow channel of Otsego Lake. Scott (1921) suggested that in glacial times the lake naturally drained eastward to the North Branch of the Au Sable River. Scott speculated that following the disappearance of the glaciers, groundwater and lake water levels declined and the outlet was abandoned.

In 1972, after three years of very high water levels (U.S.G.S. unpublished data) an effort was made to stabilize lake levels (Otsego County Circuit Court Case No. 136-2). An artificial drain was built to connect the lake to the North Branch of the Au Sable River. The artificial drain, located on the eastern shore, is operated by the County Road Commission and is used to maintain the upper legal level of the lake (1,273.5 feet). Although no formal records are kept of outflow, personal communication with the operators has allowed drainage estimations to be made (Table V).

According to law, the drain may be open for a maximum of 90 days each year (March 15 - June 5). If it is opened for the maximum time, the lake level would drop 15.36 inches (3,303,978.3m^3). In 1978 and 1979 however, the drain accounted for a drop in lake level of one inch and six inches respectively. Further decreases in the lake level are the result of groundwater flow out of the lake towards the North, East, and Main Branches of the Au Sable River.

TABLE V

Surface Discharge from Otsego Lake

	1978	1979
Period Drain Opened	April 1-7th (7 days)	March 30 - April 1 April 23 - May 25 (32 days)
Total Discharge 9,072,000 cfw	256,919m^3	1,174,119.8m^3
% of Total Lake Volume	1	5
Impact on Lake Level	1.2 inch decrease	6 inch decrease

METHODS

Limnological Characteristics

Morphometric features of Otsego Lake were determined from hydrographic maps compiled by the Institute for Fisheries Research, Michigan Department of Natural Resources, 1935-36. Surface area was calculated using a Gelman Planimeter (Lind, 1979), and lake volume was calculated using frustrum volumes (Welch, 1948).

All physical, chemical, and biological samples were taken from a single deepwater station indicated on Figure I. Samples were taken June 11, June 28, July 11, August 1, and August 30, 1979. Temperature profiles were recorded at one meter intervals using a YSI Tel-Theromometer. Light transparency was measured with a Hellige Turbidmeter.

Water samples were obtained with a three liter horizontal Van Dorn bottle. Dissolved oxygen was determined titriometrically with the azide modification of the Winkler method (APHA, 1975) for the August samples and with a YSI Model 57 dissolved oxygen probe for the June and July samples.

Plankton samples were obtained by bottom to surface tows of a cylinder-cone plankton net with a No. 20 (80 um) nylon mesh. Plankton samples were examined qualitatively using live and preserved samples. Phytoplankton samples were preserved in 1% Lugol's iodine. Zooplankton samples were preserved in 5% buffered formalin. Phytoplankton samples were also obtained on August 30 by treating unfiltered lake water with Lugol's iodine to allow settling for the enumeration of nannoplankton.

Rooted aquatic vegetation were qualitatively collected using a grappling hook suspended from a motorboat. Dredge samples were collected with an Ekman dredge and sieved with a No. 30 mesh screen. Total alkalinity was measured titriometrically with a mixed indicator solution of bromocresol-green-methyl-red (APHA, 1975). Determinations of pH were made potentiometrically on a Beckman Selectmeter pH meter.

Conductivity was measured on an Industrial Instruments Model RC-16B2 Conductivity Bridge. Conductivity readings were corrected to umhos/cm at 25°C (Wetzel and Likens, 1979).

Hardness, calcium, and magnesium were determined titriometrically with an EDTA solution (APHA, 1975). Ammonia-nitrogen, nitrate/nitrate-nitrogen, soluble phosphorus, total phosphorus, and silica were all determined colorimetrically on a Technicon Dual Channel Autoanalyzer II using methods discussed in Gannon and Paddock (1974).

Chlorophyll a was determined flourometrically on a Turner Model III flourometer using methods described in Gannon and Paddock (1974).

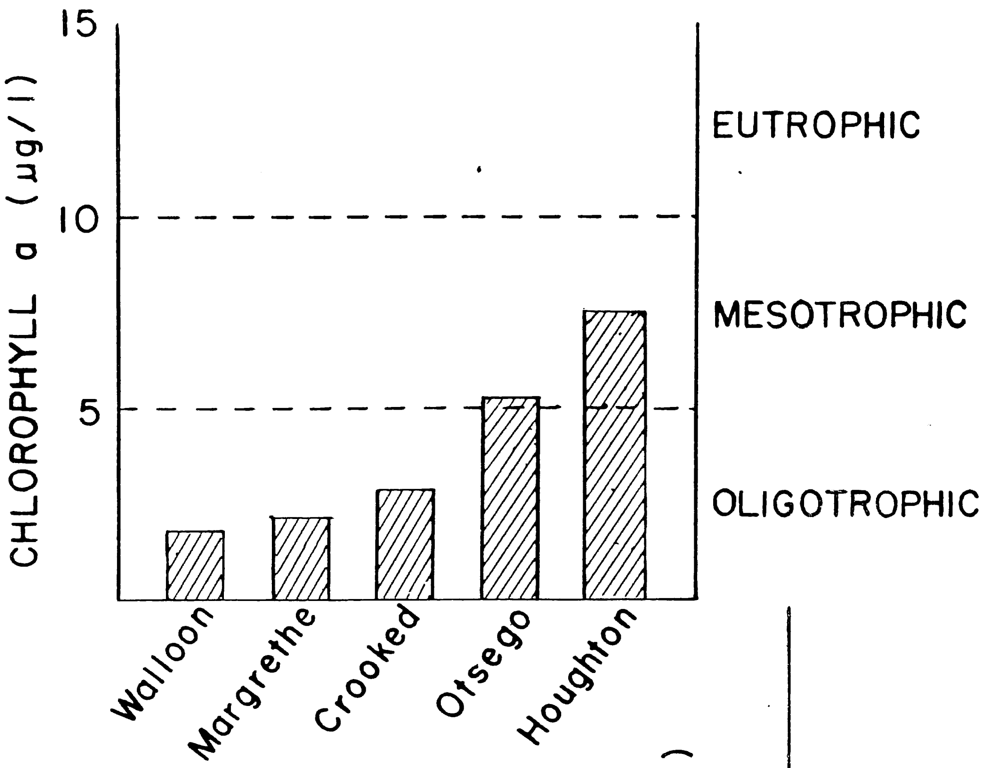
Watershed Characteristics

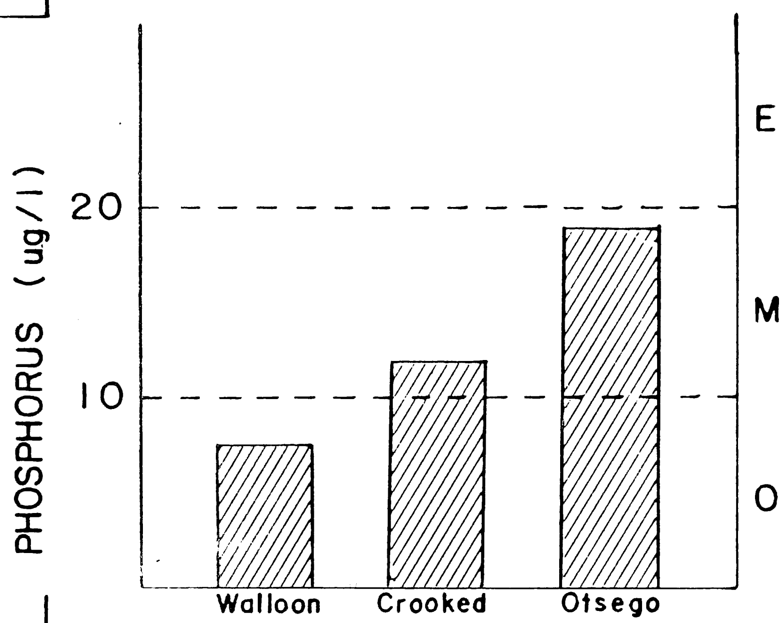
Total watershed area is defined here as the area bounded by the highest elevation which continually surrounds a given lake. The Otsego Lake watershed was traced from U.S. Geological Survey quadrangle maps (1:24,000, 7.5 minute and 1:62,000, 15 minute) and the area was determined using a Gelman Planimeter (Lind, 1979).

Land-use/land cover types within the watershed were determined from aerial photographs (U.S. Forest Service, 1968, Fig. IV). The area of each land type was determined using a Gelman Planimeter.

Nutrient Loading Determinations

Values on phosphorus and nitrogen loading from various land cover types to Otsego Lake were taken from Omernik (1976). Watershed land cover data





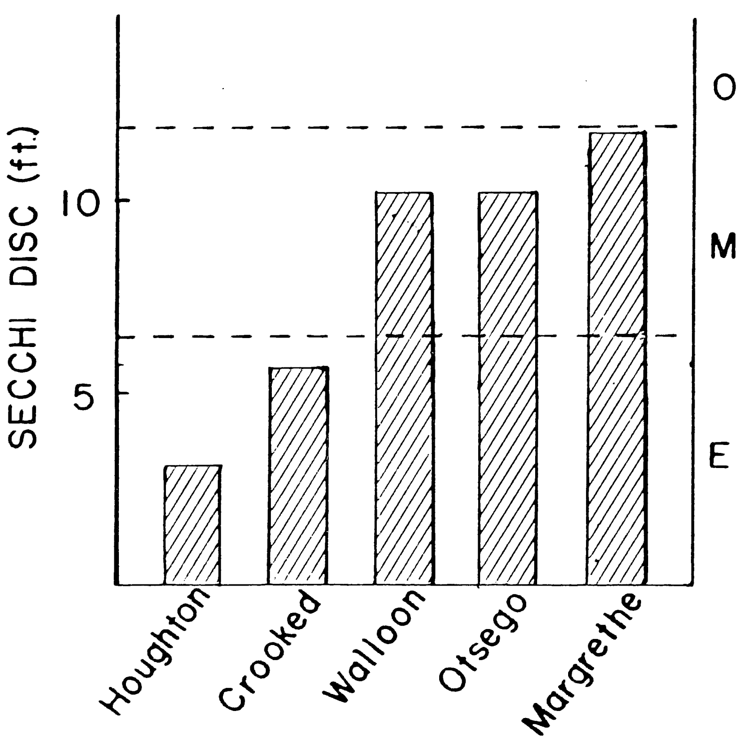


Fig. IV. Water quality parameters of northern Michigan lakes.

and nutrient export values from the north and northeastern forest and forage region of the U.S. were employed (Appendix A-1). Omernik's "mostly agriculture" category was chosen instead of his "agriculture" category since "mostly agriculture" grouping contains both active and fallow farmland.

Septic System Nutrient Contributions

The loading of phosphorous and nitrogen to Otsego Lake from septic systems was calculated using information on household size, length of occupancy, soil types, groundwater flow, and information obtained from a shoreline algal survey.

Based on the algal survey only 210 septic systems on the western shore of the lake were considered to contribute nutrients to the lake. The septic systems were counted using the Facilities Plan Maps prepared by Williams and Works, Inc. (1976). It was estimated that average household size was 3.4 persons/dwelling unit (U.S. Census, 1970). The type of residence was weighted for year-round occupancy (1.0) and seasonal occupancy (.25) using an estimate of 70% seasonal residents (Williams and Works, 1976). Septic system loading values of 1.37 kg/household/year phosphorus and 14.52 kg/household/year nitrogen were used (U.S. EPA, 1972). The percentage of phosphorus and nitrogen that would reach the lake from each septic system was calculated based on soil characteristics such as natural drainage, depth to seasonal high groundwater and phosphorus and nitrogen adsorption capabilities (Appendix A-2). Soil types were determined from generalized soils map (U.S.D.A., 1949). Total septic system nutrient loading was then calculated from the number and type of residence on each soil type, the total nutrient input/household/year and the % of nutrients reaching the lake.

Precipitation and Dryfall

In order to quantify nutrient loading from precipitation, information on the quantity and nutrient chemistry of precipitation was taken from work done by Gannon and Mazur (1978) in Northern Michigan.

Total phosphorus loading from precipitation was determined to be the amount of phosphorus falling on 1 hectare of land per year (.45 kg) times the surface area of the lake (794.8 hectares). Total nitrogen loading from precipitation was determined to be the amount of nitrogen falling on 1 hectare of land per year (7.9 kg) times the surface area of the lake (794.8 hectares).

Flushing Rate

Flushing rate was determined theoretically using methods described by Dillon and Rigler (1975). By their method, yearly outflow is equal to the runoff from the watershed plus the difference between precipitation and evaporation from the lake itself. Using groundwater flow information from Dunn Geoscience Corp. (1975), coupled with the results of the algal survey, the groundwater drainage basin was calculated to be 12.64 kilometers (62.8% of the surface watershed).

The estimate used for calculating annual runoff ($.29m^3/m^2$) was derived from the work of Pentland (1968). Average precipitation (32.5 inches/yr) was obtained from NOAA (1978) and estimates of annual evaporation (18 inches/yr) from Kazmann (1972).

TROPHIC STATUS

Over thousands of years, even the clearest and deepest lakes begin to "age". Lakes gradually fill with sediment and aquatic plants and undergo changes in clarity and fish composition. The rate at which a lake ages is determined by the extent and type of inputs from the watershed and by its morphometric and chemical features. Limnologists use the term oligotrophic to describe a lake which does not show signs of aging. An oligotrophic lake is characteristically clear, deep and has low concentrations of algae and aquatic plants (Table VI, Level 1). Lake residents normally equate oligotrophic lakes with good water quality.

A eutrophic lake exhibits characteristics of extensive aging such as abundant plant growth, organic sediment deposition and low oxygen levels during stratification (Table VI, Level 3-4). Lake residents usually regard eutrophic lakes as undesireable for water contact recreation. "Mesotrophic" lakes (TABLE VI, Level 2) fall inbetween oligotropic and eutrophic bodies.

Productive lakes can be valuable natural resources. For example, fisherman often enjoy the benefits of the higher productivity of mesotrophic and eutrophic waters. However, in extreme eutrophic conditions, sport fish species decline and are replaced by coarse species.

TABLE VI WATER QUALITY CLASSIFICATION SYSTEM
(After Dillon and Rigler, 1975)

	Secchi Depth (ft)	chl *a* (p.p.b.)	Total Phosphorus (p.p.b.)	Expected Water Quality
Level 1	over 16	less than 2	less than 10	Very High water quality, waters clear, well oxygenated, capable of preserving cold water fisheries.
Level 2	7 to 16	2 to 5	10 to 20	Good water quality limited ability to to sustain cold water fisheries.
Level 3	3 to 7	5 to 10	20 to 30	Fair water quality. Not ideal for body contact recreation. Oxygen depletion is common Danger of winter kill in shallow lakes. Well suited for bass, walleye, pike, bluegill and yellow perch. Aquatic plants common.
Level 4	less than 3	over 10	over 30	Poor water quality. Aquatic vegetation and algae predominate. Suitable only for warm water fisheries.

The terms oligotrophy, mesotrophy and eutrophy are general terms of lake classification. Many schemes have been developed to more precisely rate lake water quality and to enable comparisons with other lakes. One such method breaks lake classification down into four levels based primarily on three parameters of water quality: secchi disc reading, chlorophyll *a* concentration, and total phosphorus concentration. In this scheme, oligotrophy is represented by Level 1 and eutrophy is represented by Level 4. Levels 2 and 3 describe the states which lead from oligotrophy to eutrophy. Table VI shows the four levels, and the parameter ranges and water quality characteristics typically exhibited by each level.

Under this classification system, Otsego Lake is rated as a Level 2 and Level 3 lake. Mean summer chlorophyll *a* concentrations, a measure of one of the photosynthetic pigments in algae, averaging 5.2 ($\pm$ 5.5) p.p.b. rate the lake at the upper limit of Level 2.

Other more visible aspects of Otsego Lake which indicate a Level 2 or Level 3 classification include:

- a productive warm water fishery
- a dominance of blue green algae during summer
- widespread growth of submerged aquatic plants
- abundant organic sediments.

An important feature of this classification system is that new data can be applied to detect fluctuations in lake rating. Continuous participation in the DNR's Self Help Program will guarantee data for long term comparisons. Fig. V compares the water quality of Otsego Lake with other northern Michigan lakes.

Satellite Imagery

Prior to the present study, little water quality information had been gathered on Otsego Lake. However, Landsat satellite imagery of Otsego Lake from 1975 is available (Rogers, 1977). The imagery displays Otsego Lake as a water body with both mesotrophic and eutrophic characteristics. Based on this single information source, it appears that drastic changes in water quality have not occurred on Otsego Lake in the last 4 years.

PHYSIOCHEMICAL FEATURES

Light Penetration

Otsego Lake has clear, unstained water that allows good light penetration. The method of measuring light penetration which is most frequently used both as an absolute measure and as a means of comparing different waters is the secchi disc.

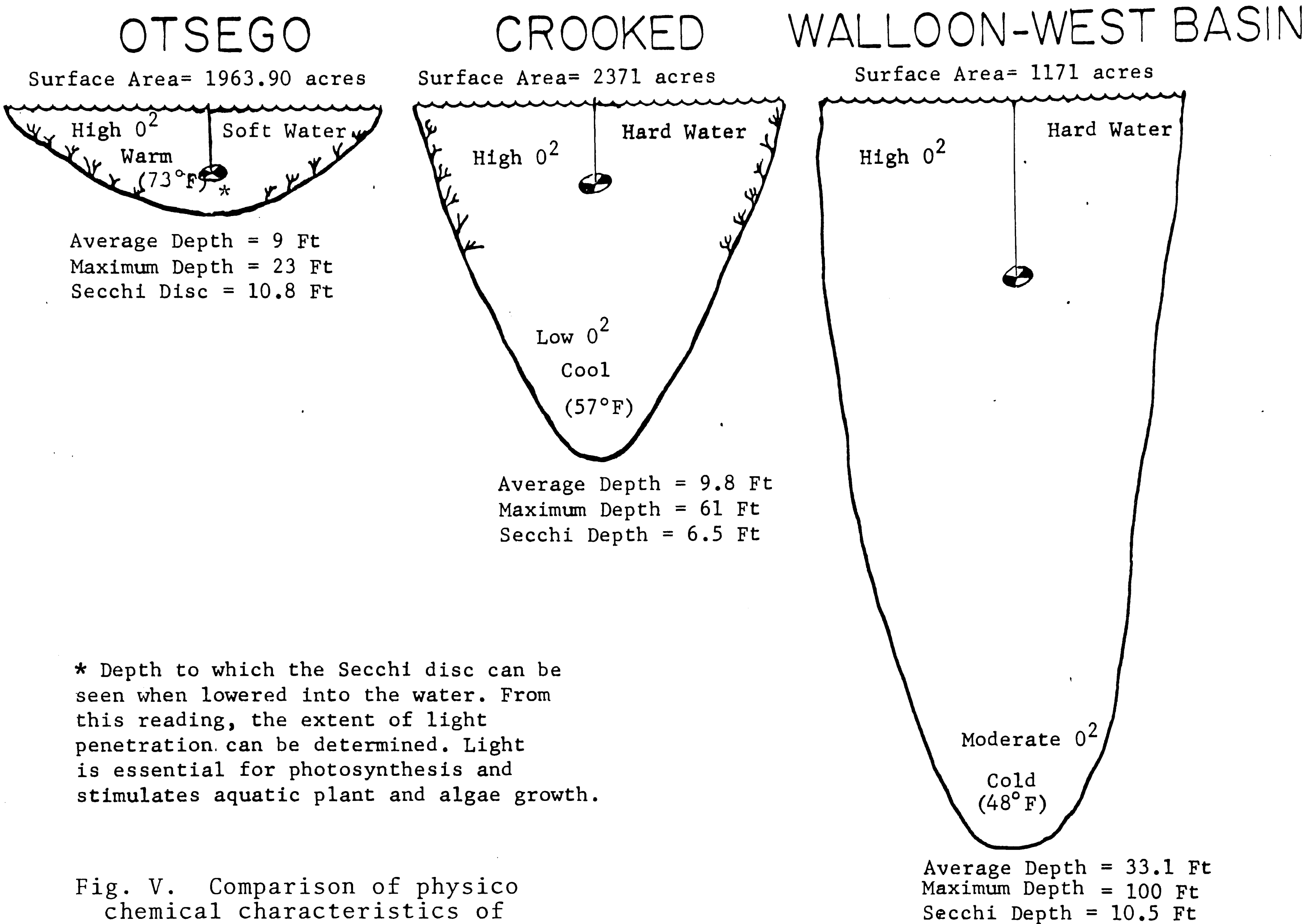
Secchi disc readings on Otsego Lake ranged from 10 ft. (3.0m) to 14.8 ft. (4.5m) during the summer months. The euphotic zone (the portion of the lake where light intensity is sufficient to promote photosynthesis) is usually considered to extend twice the depth of the secchi disc measurement. On Otsego Lake, the euphotic zone extends to the lake bottom throughout most of the lake. Light penetration should not be a limiting factor to plant growth. Rooted aquatic plants were not found however, at depths below 14.8 ft. (4.5m). Healthy algal populations were identified below this depth.

Limiting Growth Factor

The primary producers of Otsego Lake, the rooted plants and algae, each require slightly different nutrients to flourish. Natural algal communities utilize nitrogen and phosphorus in the ratio 12:1 to 14:1 (Cole 1975). In the spring of 1979, the ratio of inorganic nitrogen to total phosphorus in Otsego Lake was approximately 18:1. This suggests algal production is usually limited by the availability of phosphorus.

Alkalinity, pH, and Conductivity

Otsego Lake contains softer water than many of the large recreational lakes in northern lower Michigan and has a limited capacity to buffer phosphorus and other pollutants. Total alkalinity measured 65 mg/ℓ; calcium concentrations were 20 p.p.m., and specific conductance ranged from 122-152 umhos/cm^2. Most



* Depth to which the Secchi disc can be seen when lowered into the water. From this reading, the extent of light penetration can be determined. Light is essential for photosynthesis and stimulates aquatic plant and algae growth.

Fig. V. Comparison of physico chemical characteristics of Otsego, Crooked, and Walloon Lakes.

Michigan lakes have a mean alkalinity of 104-151 mg/ℓ. The soft waters of the Otsego Lake are a result of the calcareous-poor soils within the watershed.

Temperature and Dissolved Oxygen

The shallow nature and comparatively large size of Otsego Lake result in virtually continuous wind driven mixing of the entire water column during ice-free periods (Fig. V). The water temperature is nearly uniform from the surface to the sediments and little change occurs in the chemical qualities of the water with depth.

High dissolved oxygen concentrations are found throughout the water column during the ice-free months. At certain times during the summer the upper waters become supersaturated with oxygen, a result of photosynthesis and a common occurrance in mesotrophic and eutrophic lakes (Appendix B, 1-7).

During the months when ice covers Otsego Lake, oxygen cannot enter into the water from the atmosphere and photosynthetic oxygen contribution is negligible due to low levels of light and temperature. In addition, oxygen is depleted from the water by the death and decay of aquatic plants and animals and the incumbant bacterial respiration.

Although the scope of this project did not permit winter sampling, it is speculated that oxygen depletion does occur during ice cover. A critical, and as yet unanswered question, is to what extent the depletion occurs.

Oxygen Depletion: Possible Impact on Water Quality

Winter oxygen levels are cruicial for maintenance of game fish populations. Lakes which undergo severe oxygen depletion will experience fish kills and may eventually undergo a change in fish species composition: from northern pike, smallmouth bass, and perch to coarser fish such as sucker and bullheads.

Dissolved oxygen levels may also play a dominant role in the nutrient cycles of Otsego Lake. Laboratory experiments conducted on the sediments of the lake demonstrated major differences in phosphorus cycling under aerobic and anaerobic conditions (Appendix C). Under aerobic conditions the sediment appears capable of acting as a sink for phosphorus. In one series of experiments a mixture of lake water and sediment in a ration of 50:1 was injected with varying concentrations of phosphorus and shaken for 6 hours at constant temperature. The sediment water mixture which was injected with a phosphorus concentration similar to that of Otsego Lake, removed 40-67% of the added phosphorus. Based on this experiment, the sediments of Otsego Lake act as a phosphorus sink under aerobic conditions.

In experiments performed under anaerobic conditions, the sediments did not exhibit phosphorus adsorption. On the contrary, phosphorus levels in the water increased markedly. After 72 hours of anaerobic conditions, phosphorus content of the water increased from 3.4 to 22 times the initial measured levels.

No data is available concerning the extent of anoxic conditions during ice cover so it is not possible to gain a total picture of nutrient cycling within the lake. Results extrapolated from the laboratory experiments indicate that if the bottom waters become anaerobic, nutrient release from the sediments could raise the mean orthophosphorus concentration in the lake water by 0.7 - 6.1 p.p.b. Considering the limited buffering capacity of the water, phosphorus increases of this magnitude could cause heavy spring and summer growths of algae and aquatic plants. The occurance of blue-green algae blooms in spring 1975 and 1979 suggest that phosphorus levels are high following ice break up; the blooms would be expected if anoxic conditions prevailed in the bottom waters.

BIOLOGICAL FEATURES

Phytoplankton

Phytoplankton, or algae, are microscopic plants which are the primary producers in lake systems and form the base of the entire lake food chain. Analysis of the algal population of a lake can provide insight into the health of aquatic life within a water body. Algae can also serve as biological indicators of overall water quality when considered within the context of all limnological data.

A monthly survey of the algal flora of Otsego Lake was conducted during the summer of 1979 as part of a comprehensive water quality survey. The results of the algal survey are illustrated in Appendix D,1.

Table D-1 indicates that many taxa of freshwater algae were found in Otsego Lake. The plankton was dominated by the blue-green and golden algae. Relatively moderate amounts of diatoms, and very few green algae were also present.

Chlorophyll *a* concentrations are useful in determining the total abundance of algae in a lake. Chlorophyll *a* is the substance used by algae in the photosynthetic process to convert solar energy into chemical energy and is found in all types of algae (Smith, 1959). The measured concentrations of chlorophyll *a* found in Otsego Lake are represented in Appendix B-3.

Blue-green algae represented the largest component of the Otsego Lake phytoplankton during the summer months. Blue-green algae are considered to be a "nuisance algae" because they float in the surface waters and are inedible to most zooplankton and fish predators. The algae contain gas vacuoles which keep them bouyant at the lake surface even after they have died.

In 1975, the surface of Otsego Lake was covered with a blue-green algal bloom of noxious proportions. Throughout the summer of 1979, the waters of Otsego Lake were visibly spotted with *Gleotrichia echinulata* , a planktonic blue-green algae. On July 11, the waters of the County Park were heavily spotted with *Gleotrichia* and the following surface chlorophyll *a* measurement readings were found:

Location	Chl. *a*	Phaeo.
East (Arbutus Beach)	3.84 ppb	- .95
Center (Deep Depression)	2.28 ppb	- .59
West (South of County Park)	22.50 ppb	-17.20

On August 1, a heavy blue-green bloom was noted which coincided with a very high Chlorophyll *a* reading on that date. The results of the Chlorophyll *a* tests are noteworthy because the values on the west side of the lake indicate extreme eutrophic conditions while the center of the lake exhibited extremely clean oligotrophic conditions (EPA, 1974). These cursory results point out the need for further detailed water quality investigations on Otsego Lake.

All algae thrive in lakes with high nutrient levels, but blue-green algae in particular can dominate the algal flora in lakes with low levels of alkalinity that experience phosphorus loading (King 1979). Phosphorus loading will increase algal production which reduces carbon dioxide concentrations more quickly in softwater, low alkalinity lakes than in hard water lakes. Blue-green algae dominance occurs under conditions of low carbon dioxide concentrations (King 1979). It follows that low alkalinity lakes with high concentrations of phosphorus, such as Otsego Lake, will be susceptible to blue-green algal blooms.

Otsego Lake has total alkalinity of 65 p.p.m. (Appendix B). The mean alkalinity for most Michigan lakes ranges from 104 p.p.m. to 151 p.p.m. (Edmands 1976). Figure VIa compares the low alkalinity of Otsego Lake with other lakes in Northern Michigan. Figure VIb illustrates the phosphorus concentrations required to establish blue-green algae as the dominant algae in the phytoplankton in these lakes (after King, 1979). The softwater of Otsego Lake becomes dominated by blue-green algae when the concentration of phosphorus is 16 p.p.m. Total phosphorus concentrations exceeded 16 p.p.m. on both dates that phosphorus was sampled (Appendix B-2, B-4). Otsego Lake will be susceptible to blue-green algal dominance as long as phosphorus levels remain over 16 p.p.m.

Microcystis aeruginosa was abundant in all plankton samples. This blue-green algae is a common component of algal blooms in eutrophic lakes although it is found in a wide variety of habitats (Prescott, 1975). The interface between the bottom waters and the surface of the flocculent "false bottom" was sampled on August 1, 1979. *Mycrocystis* was found to be densely growing at the interface causing chlorophyll *a* concentrations in excess of 370 p.p.b.

Diatoms are microscopic algae composed of silica frustules ("shells"). Silica is an essential nutrient for diatoms, and their abundance can be limited by low ambient silica concentration of the lake water (Wetzel, 1975). Several studies indicate that diatoms are limited in nature by silica concentrations of less than .5 p.p.m. (Hutchinson, 1957). Summer silica concentrations in Otsego Lake ranged from .18 to .35 p.p.m., below the optimal levels for diatom growth. As expected, diatom concentrations were relatively low in the plankton samples.

The specific environmental requirements for the existence of most fresh-water diatoms have been compiled (Lowe, 1975). Consequently, diatoms are often

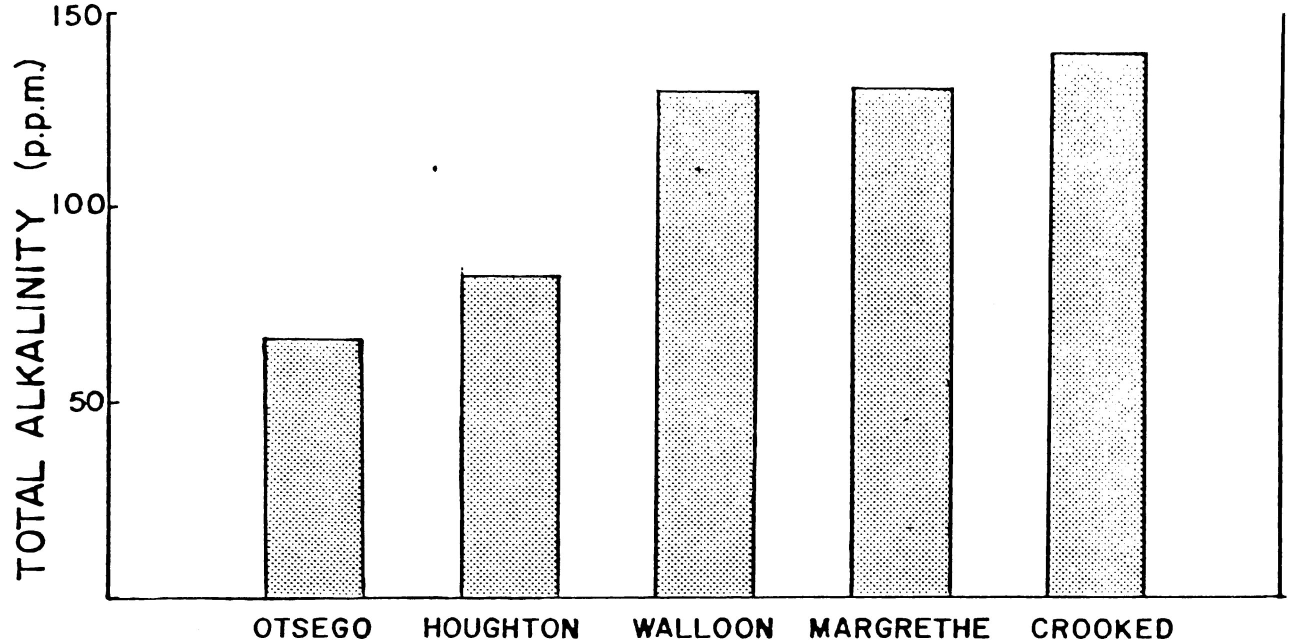


Fig. VIa. Total alkalinity of northern Michigan lakes.

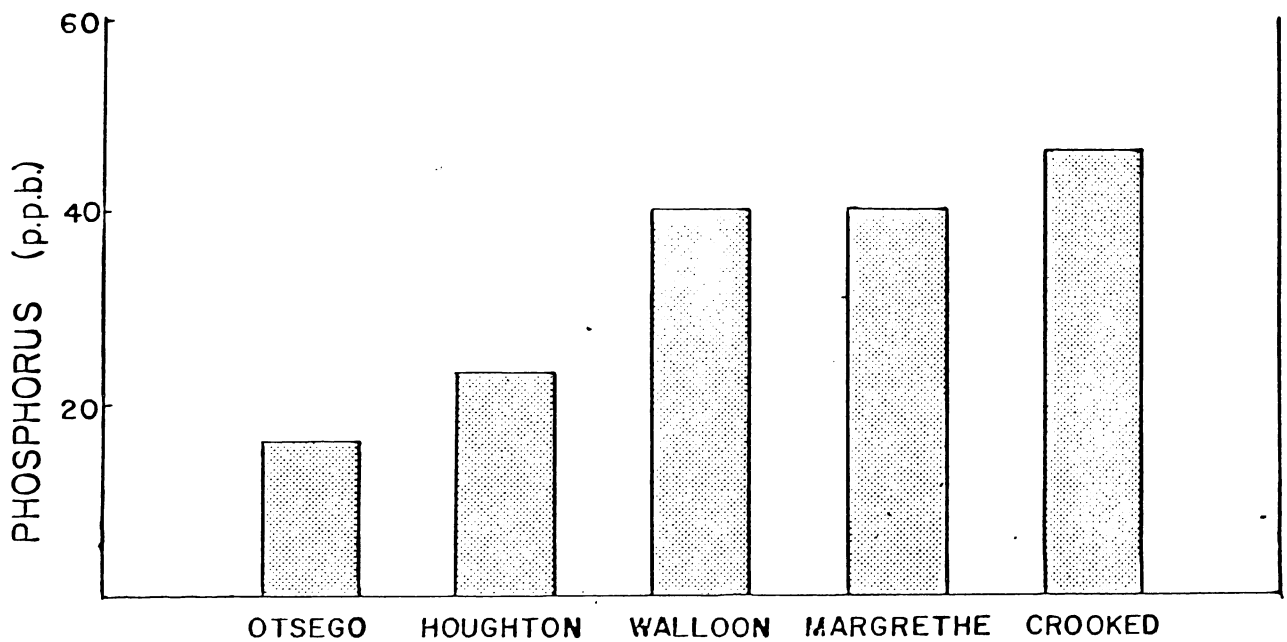


Fig. VIb. Concentration of phosphorus required for blue-green algal dominance (after King, 1979).

used as biological indicators of water quality. The Otsego Lake diatom population was dominated by *Synedra delicatissima*, a diatom found in eutrophic waters (Lowe, 1974).

Several species of *Dinobryon*, a golden algae, consistently comprised a significant portion of the summer phytoplankton. It has been speculated that the loricas (the structural support) of *Dinobryon* contain some silica (Smith, 1950) and may compete with the diatoms for dissolved silica. The low levels of silica found in Otsego Lake do not appear to inhibit the growth of *Dinobryon*.

The algal community of Otsego Lake suggests that the lake is in an advanced stage of mesotrophy along the continuum between oligotrophy and eutrophy. The dominance of blue-green algae along with the relative scarcity of diatoms is consistent with mesotrophic and eutrophic lakes (Hutchinson, 1967). The summer algae of Otsego Lake included both *Staurastrum* sp., a green algae found in oligotrophic lakes, and *Microcystis aeruginosa*, a blue-green algae found in eutrophic lakes. The simultaneous presence of both oligotropic and eutrophic indicator organisms is typical of mesotrophic lakes (Gannon and Stockwell, 1978).

Zooplankton

Zooplankton are the microscopic animals which feed on algae or smaller zooplankton, and which in turn are fed upon by most fish. The zooplankton of Otsego Lake consists primarily of the non-colored, small-sized genera of rotifers and crustaceans (Appendix D-2). The abundance of small, non-colored genera is expected in shallow lakes with large fish populations and good water clarity such as Otsego Lake (Wetzel, 1975).

Chydorous sphaericus was very common in the August zooplankton tows when large blue-green algal colonies were visible in the water column. *Chydorus* is not common to the open water plankton except under eutrophic conditions when algal colonies are present (Gannon and Mazur, 1979). The abundance of *Chydorus* in August coincided with the observed blue-green algal bloom and chlorophyll *a* maximum and reinforces the need for careful water quality monitoring in the future.

Benthos

Numerous dredges were taken at the sample site, but only one red *Chironomid* was found out of 8 samples throughout the entire summer. The virtual absence of benthos is typical of lakes with flocculent substrates. The flocculent sediments of Otsego Lake make benthos colonization extremely difficult.

Fish

The Department of Natural Resources (DNR) has extensively surveyed the fish community of Otsego Lake. Results indicate that Otsego Lake is a high quality fishing lake with relatively low fishing pressures, particularly during the winter fishing season. The nutrient rich mesotrophic waters of Otsego Lake coupled with the low fishing pressure give Otsego Lake a healthy fish community (Appendix D1). Most of the fish netted by the DNR were found to be growing at rates which are slightly higher than statewide averages.

Lake inventories conducted since 1949 indicate that northern pike has thrived in the mesotrophic waters of Otsego Lake. Northern pike was stocked in 1953 by the Otsego Lake Chamber of Commerce, and a dam was constructed in 1958 to improve the pike spawning marsh at the north end of the lake.

Walleye have not flourished in the relatively warm water of Otsego Lake. The optimal temperature for walleye is 17°C (Edmands 1976). The average summer temperature of the water in Otsego Lake was 21.4°C, ideal for sunfishes, but a little too warm for walleye.

The lake was stocked with muskellunge ("tiger musky") in 1976 and 1977. The "tiger musky" frequents the edges of the aquatic weed patches during the warm summer weather and is predacious on yellow perch and pumpkinseeds (Scott, 1967). The abundance of aquatic weeds and sunfishes in Otsego Lake suggest that the muskellunge stocking experiment will be successful.

<u>Aquatic Macrophytes</u> (Aquatic Plants)

The aquatic macrophytes, together with the algal community comprise the primary production component of Otsego Lake. Rooted aquatic plants are abundant throughout the littoral zone (shallow areas) of the lake. Macrophytes play an important role in the food web by providing diverse habitats and substrates for phytoplankton and zooplankton, and aquatic plant beds are used by fish for spawning and feeding. The diversity of habits afforded by aquatic plants results in higher diversity of algae and zooplankton in the littoral zones than in the limnetic (open water) zones.

Aquatic macrophytes play an intergral part of the nutrient cycling in Otsego Lake. Aquatic macrophytes compete with the algae for nutrients essential for plant growth. As the macrophytes dies, they decompose, release nutrients, and consume oxygen. The consumption of oxygen in bottom waters can have adverse effects on the fish population and can further the release of nutrients from the sediments. Dredges of Otsego Lake indicate that plant detritus is a significant component of the flocculent sediment.

A qualitative survey of rooted aquatic plants was conducted around the perimeter of the lake. Preliminary surveys indicated that dense beds of aquatic plants did not occur at depths greater than 14 feet. The survey of aquatic plants was made in the zone 100-200 feet offshore at depths of 6-14 feet.

Figure VII illustrates the locations of the aquatic plant beds of Otsego Lake. *Potamogeton amplifolius* (pondweed) and *Najas flexilis* were widespread throughout the lake. *Myriophyllum spicatum* (water milfoil) was also found in the southern end of the lake.

Emergent plants observed along the water's edge included: *Nymphea odorata* (white water lily) *Nuphar* sp. (yellow water lily), *Scirpus* sp. (bulrush), *Pontederia cordata* (pickerel weed), and *Typha* sp. (cattail).

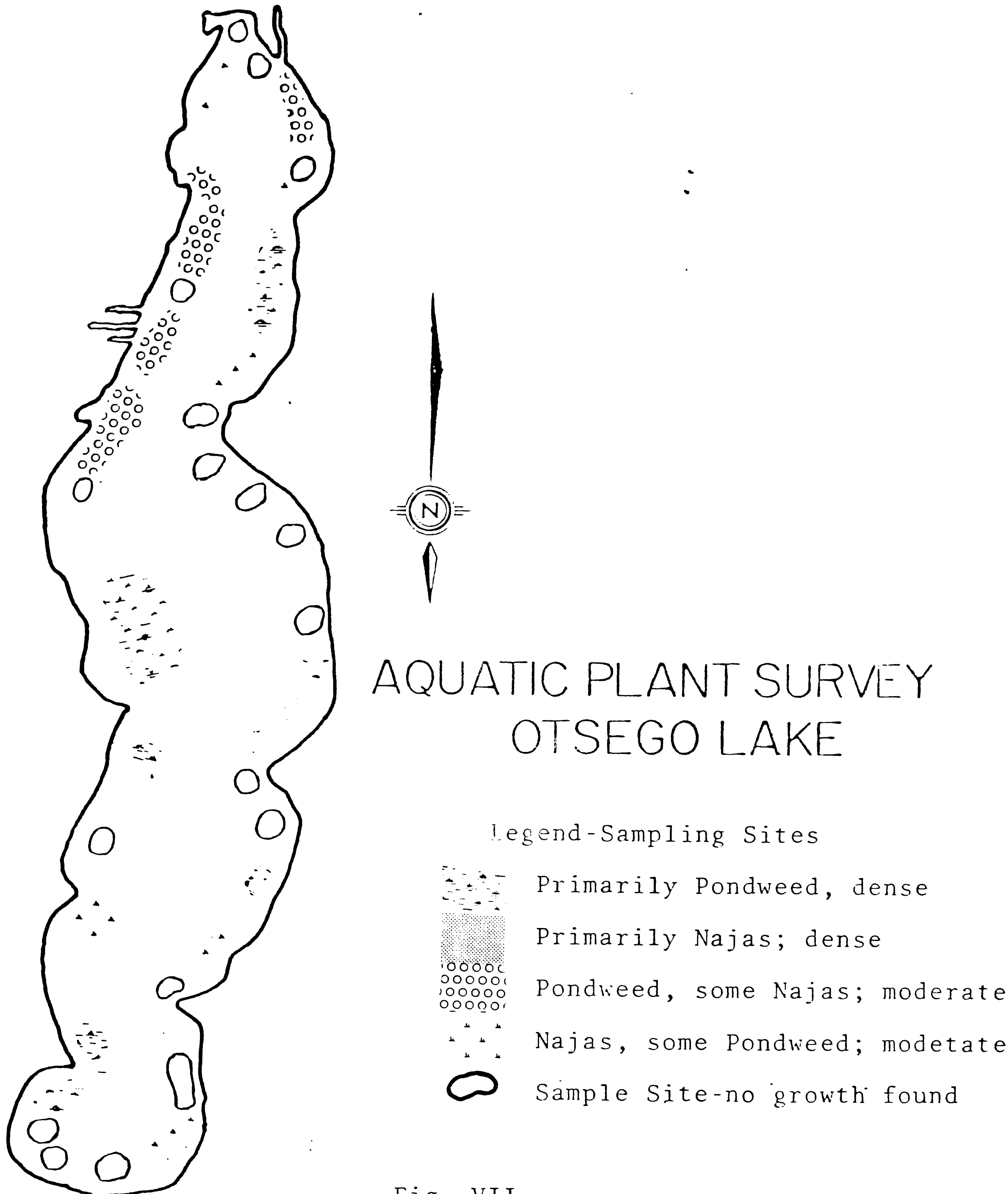

AQUATIC PLANT SURVEY
OTSEGO LAKE
N
Legend-Sampling Sites
Primarily Pondweed, dense
Primarily Najas; dense
Pondweed, some Najas; moderate
Najas, some Pondweed; modetate
Sample Site-no growth found

Fig. VII

WATER QUALITY OF THE MAN-MADE CANALS

Five man-made canals connect with Otsego Lake. The water quality of the canals is more eutrophic than that of the lake. On July 11, 1979 water clarity in the canals as measured with a secchi disc was less than five feet, compared with 11 feet in the center of the lake. The canals were choked with aquatic plants and a filamentous green algae (*Spirogyra*) which was not found in abundance elsewhere.

NUTRIENT CONTRIBUTIONS

In order to facilitate efforts to maintain and/or improve Otsego Lake water quality a nutrient budget study was conducted to illuminate sources of nutrient inputs to the lake. It is important to emphasize that several of the nutrient loading determinations are estimations based on studies of hydrology and land use conducted in areas similar to the Otsego Lake region. The nutrient budget defines the sources of nutrient contamination that can be most easily controlled.

Sources of Nutrient Loading

The yearly nutrient load to Otsego Lake (Table VII) was estimated to be the sum of the inputs: from groundwater and overland run-off orginating on various land use types within the watershed; from direct precipitation and dryfall; and septic systems bordering the lakeshore. Also considered in the study, but not included in the estimate of total nutrient input, were the nutrient contributions of bottom sediments, and from direct use.

Direct Precipitation and Dry Fallout

The largest source of nutrient input to Otsego Lake is from rainfall and atmospheric fallout (leaves, dust, and pollen). Phosphorus contributions from this source represent 42% of the total phosphorus input; nitrogen contribution represents 35% of the total nitrogen input (Table VII). Because these sources are largely uncontrollable, lake management efforts must focus on the curtailment of the remaining nutrient inputs.

Watershed Inputs - Some Hydrological Considerations

The amount of nutrients which actually reach the lake from different land use types is difficult to predict. The problems encountered in the prediction of nutrient input to Otsego Lake from the watershed are twofold:

TABLE VII SOURCES AND QUANTITIES OF NUTRIENTS TO OTSEGO LAKE

		PHOSPHORUS		NITROGEN	
		KG/YR	%	KG/YR	%
PRECIPITATION & DRYFALL		267.40	42	5875.16	35
LAND COVER	%				
Forest	63.4	110.08	18	5081.60	30
Agriculture	9.5	31.30	5	1008.00	6
Urban	27.0	172.77	27	3646.05	22
SEPTIC SYSTEMS		52.24	8	1258.75	7
Total		633.79	100	16869.56	100

(1) Otsego Lake is a seepage lake fed primarily by groundwater. Therefore, most of the hydrological inputs to the lake receive some, unknown, degree of purification before they enter the lake.

(2) The nutrient inputs from the hydrological sources of Otsego Lake were calculated based on the percentage of each land cover type within the topographical watershed. It is suspected that water which falls on the southeastern portion of the topographical watershed never actually reaches the lake but instead percolates through the soil, enters the groundwater table and flows away from the lake basin. (Fig. IX).

The two problems listed above indicate the need for a detailed study of the hydrology of the Otsego Lake region. It should be recognized, that because of the hydrological uncertainties, nutrient loading estimates presented here may be somewhat higher than actual contributions. Land use within the watershed should nonetheless be monitored. In particular, special attention should be paid to changes of land uses and to any instances of direct run-off to the lake from road drains, ditches, or small, seasonal creeks.

Nutrient Contributions from the Watershed

The largest component of nutrients that enter the lake from the watershed are from urban/residential lands. Urban/residential lands are defined as lands greater than 39% developed. These lands account for 27% of the watershed area and contribute 27% of the total phosphorus load and 35% of the total nitrogen load to the lake. Forest lands (including wetlands and scrub grasslands) on the other hand account for 63.4% of the land cover, yet contribute only 18% of the total phosphorus input and 30% of the total nitrogen input. Agricultural lands (including hayfields) make up 9.5% of land cover and contribute 5% of the total phosphorus and 6% of the total nitrogen input. The above figures indicate that further conversion of forest and agricultural lands to urban/residential land will increase total nutrient loading to the lake; urban/residential areas contribute 5 to 10 times more phosphorus than lands in forest or agricultural use.

Shoreline Development and Nutrient Loading

There are presently over 550 riparian homes on Otsego Lake. A survey of the entire lakeshore was undertaken to pinpoint areas of nutrient contamination to the lake. The survey relied on the presence of *Cladophora* as the main indicator of shoreline pollution. *Cladophora*-sp. is an attached green algae that has been proven to thrive where nutrient loading is occurring (Kerfoot, 1979).

A *Cladophora* survey was conducted on the entire shoreline of Otsego Lake on July 2, 1979. Dense growth of *Cladophora* were found on a four mile stretch of the west shore. *Cladophora* was entirely absent from the eastern shore with the exception of two dense, localized growths (Fig. VIII). These results were surprising considering that cottage development on the east side is generally older and denser than development on the west side (Arbutus Beach in particular).

The answer appears to lie with groundwater flow patterns. The average depth to static groundwater on the west side of the lake is only 12 feet while on the east side groundwater is found at an average depth of 64 feet (Michigan Geological Survey., Unpublished data, Table VIII). A steep

TABLE VIII

Depth to Static Groundwater Levels in Lakeside Wells Surrounding Otsego Lake (Michigan Geological Survey Well Log Data, Unpublished)

Areas of Suggested Groundwater Input		Mean Depth	Range
N.W. Shore	(Sec. 20, Bagley Twp.)	12.0 ft.	(11-22 ft.)
West Shore	(Sec. 32, Bagley Twp.)	12.1 ft.	(4-20 ft.)
S.W. Shore	(Sec. 5, Otsego Lake Twp.)	16.6 ft.	(11-22 ft.)
N.E. Shore	(Sec. 21, Bagley Twp.)	24.0 ft.	(6-30 ft.)
Areas of Suggested Groundwater Output			
East Shore	(Sec. 33, Bagley Twp.)	63.1 ft.	(5-173 ft.)
S. East Shore	(Sec. 4, Otsego Lake Twp.)	65.0 ft.	(12-144 ft.)

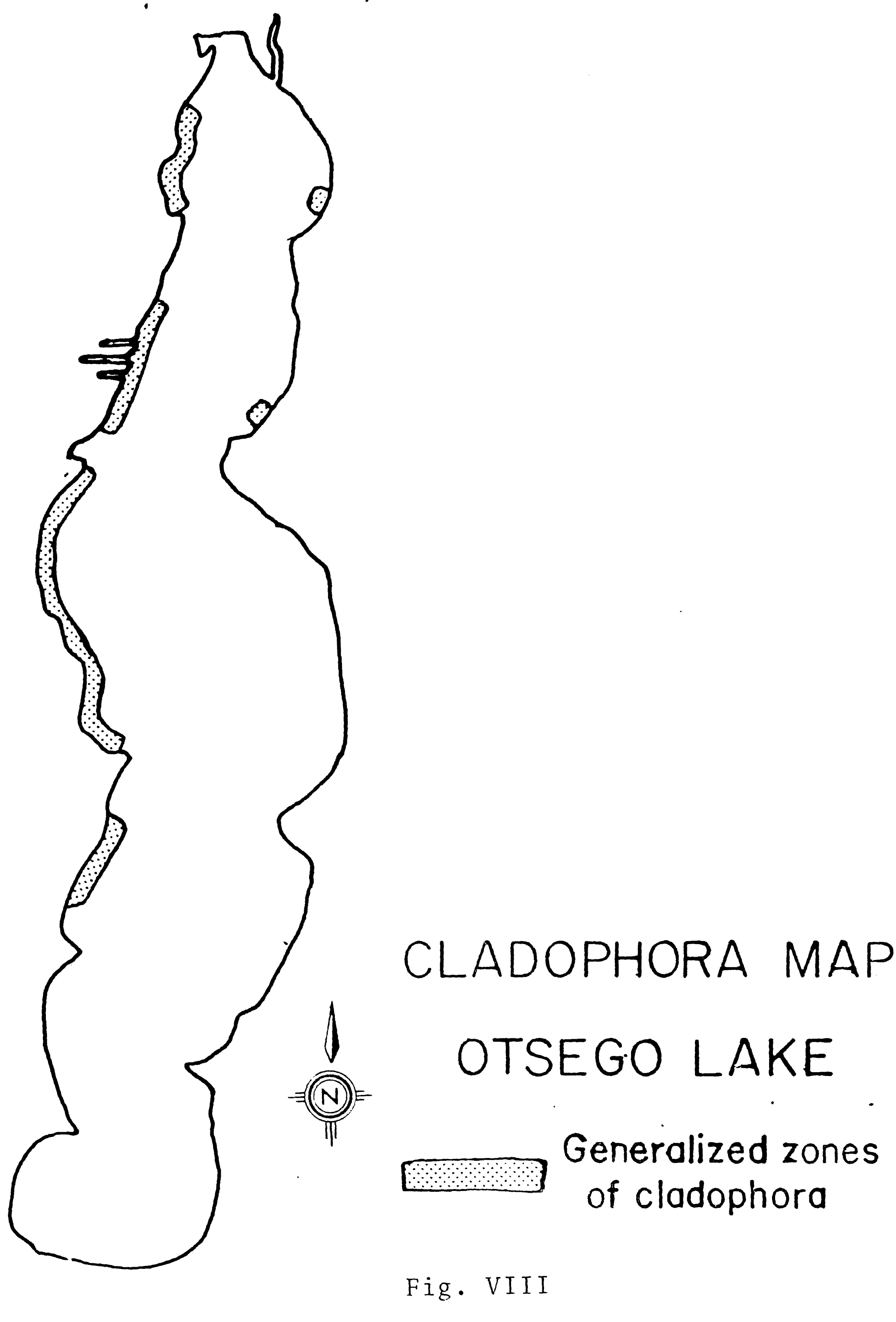

CLADOPHORA MAP
OTSEGO LAKE
N
Generalized zones
of cladophora

Fig. VIII

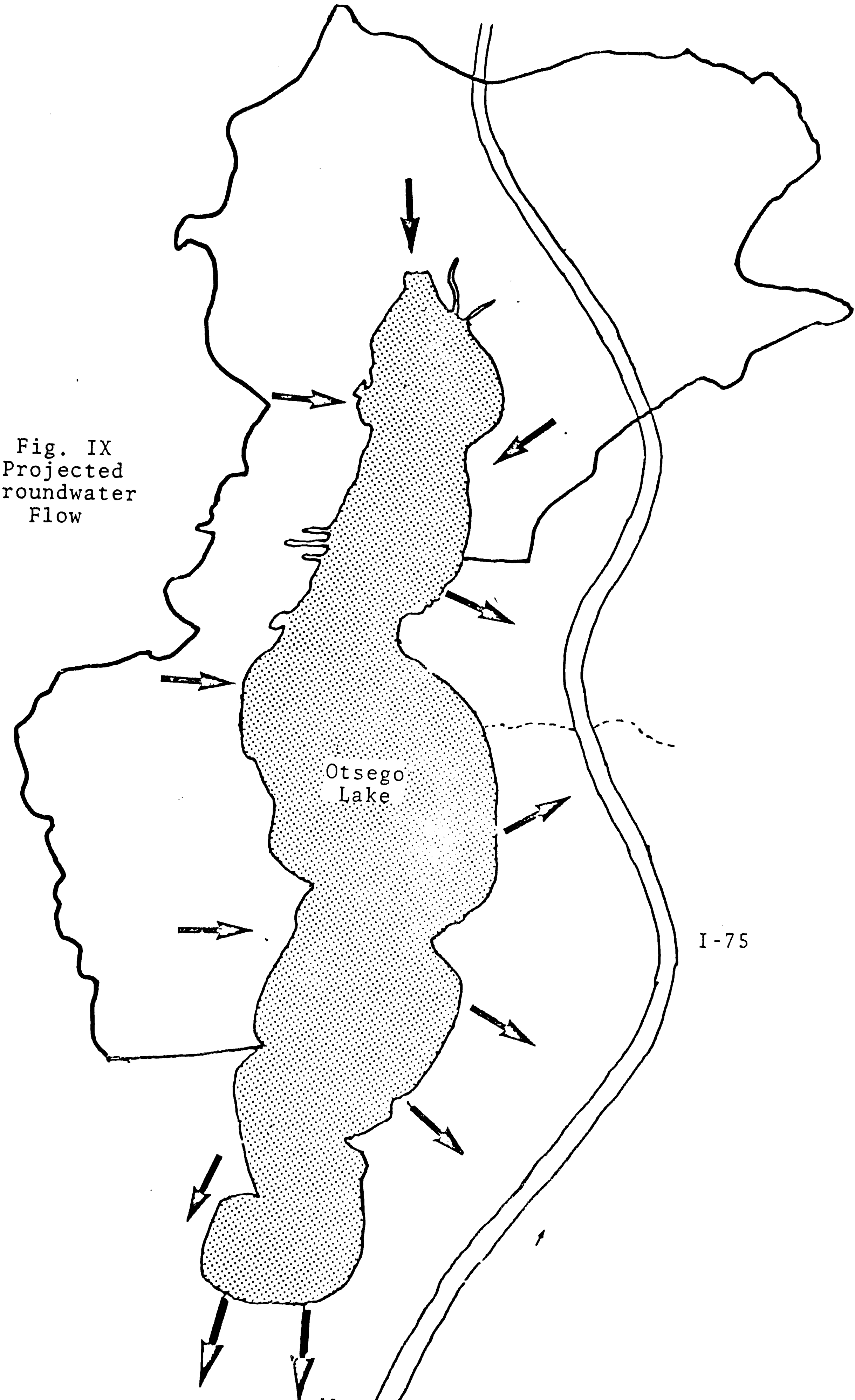


Fig. IX
Projected
Groundwater
Flow

TABLE IX NUTRIENT LOADING FROM SEPTIC SYSTEMS

	# SYSTEMS	P KG/YR	N KG/YR
SEPTIC SYSTEMS DIRECTLY BORDERING LAKE	555	115.84	2295.19
SEPTIC SYSTEMS DIRECTLY BORDERING LAKE ON WEST SIDE, NORTH TIP, & NORTHEAST SHORE.	271	52.24	1258.75

gradient exists which carries water (and pollution) from the lake and lakeshores to the regions that are east and south of the lakes. Areas of groundwater input to the lake seem to be along the northern and western shore (Fig. IX). Pollution arising from these homes is apparently released directly into Otsego Lake. The proposed groundwater gradient concurs with groundwater flow patterns described by Dunn Geoscience Corp. (1979) for the northern 1/3 of the lake.

Based on the *Cladophora* survey and the proposed groundwater gradient, it was hypothesized that only the shoreline areas where *Cladophora* was found were contributing nutrients to the lake. Only the septic systems in the zones of *Cladophora*, a total of 210, (total number of septic systems immediately bordering lakeshore is 553), were included in the nutrient budget for Otsego Lake. These septic systems are estimated to contribute 8% of the total phosphorus and 7% of the total nitrogen input to the lake (Table IX).

Septic systems are important to the management of Otsego Lake because they represent a controllable nutrient source. Furthermore, nutrient inputs from septic systems are not diluted or purified to the same extent as nutrient sources which originate in the upper reaches of the watershed and may have a greater impact on water quality. It is expected that the *Cladophora* beds will disappear if suitable improvements occur on the septic systems along the west shore of the lake.

Sediment Contribution

A potential source of phosphorus input to Otsego Lake which must be considered is the bottom sediments. Under aerobic conditions the bottom sediments appear to act as a nutrient sink, capable of adsorbing phosphorus. However, if anaerobic conditions are found to exist in the winter, phosphorus could move from the sediments back into the overlying water. Based on laboratory tests, under anaerobic conditions the bottom sediments could release from 16.1 kg. 144.2 kg. of phosphorus to the water column each winter, or a 2-24% increase in the total phosphorus loading to the lake. In this case, reduction of phosphorus inputs to the lake from all other sources may cause only minor reductions in the severity of algal blooms. Further investigation of the sediments as a nutrient source to the lake is necessary.

Direct Use

Direct use of thelake by waterfowl and by humans (boating, fishing, swimming, etc.) is a potential source of nutrients; however, it was not considered to have a significant impact on total nutrient loading to Otsego Lake. Although waterfowl have been shown to contribute significant amounts of nutrients to certain small lakes, the size and volume of Otsego Lake makes it unlikely that they influence the total nutrient loading to the lake. Motorboating is the direct use which has the greatest potential to increase nutrient loading to Otsego Lake. Studies done on lakes in Florida have shown increases in phosphorus concentrations resulting from long term mixing of lake water and bottom sediment by motorbotas (Yousef, et. al., 1979). Motorboat mixing can resuspend flocculent organic sediments from the lake bottom which could subject organically bound phosphorus to mineralization through bacterial decay. The shallow mean depth of the lake coupled with the high number of motorboats on the lake indicate that this could be a major source of nutrient input. However, for nutrient budget estimations, the influence of motorboating and other types of direct uses of Otsego Lake were not considered. Further investigations are required in this area.

RESPONSIVENESS OF OTSEGO LAKE TO NUTRIENT LOADING

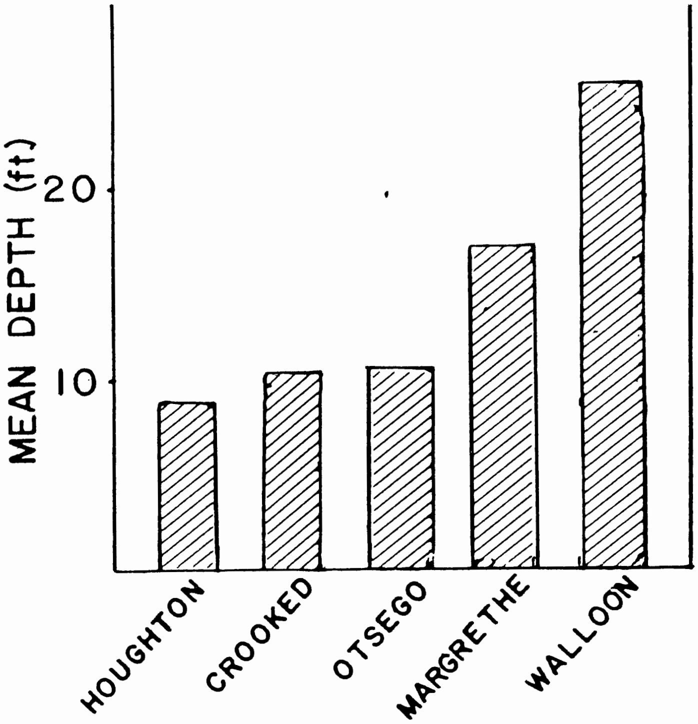
The impact of nutrient loading can be interpreted by a look at some morphometric and chemcial features of the lake. Interactions among the following features are of particular importance:

* Flushing rate (water retention time)
* Buffering capacity
* Volume and mean depth

Whereas deep oligotrophic lakes such as Walloon and Torch Lakes are extremely sensitive to nutrient loading (Gannon et. al., 1977) shallow, more naturally eutrophic lakes such as Houghton Lake have been found to withstand recreational development with little change in water quality (Pecor et. al., 1973). In shallow productive lakes like Otsego and Houghton Lakes, oxygen levels remain high throughout the ice free periods because of wind driven circulation. Increases in algae and aquatic plants will affect oxygen depletion in the winter however. Until the yearly buildup of detritus from plants and algae is sufficient to deplete oxygen in the bottom waters during the winter, no "dramatic" changes such as fish kills, or phosphorus release from the sediments should occur.

Although the shallow nature of Otsego Lake reduces the likelihood of major water quality disasters, other factors such as its flushing rate and limited buffering capacity indicate that increases in nutrient loading to the lake will increase the size and frequency of the nuisance algal blooms which presently occur.

The calculated time water remains in Otsego Lake is 3.6 years. This is much longer than the retention periods of other shallow lakes in the area (Fig. X). Nutrients that enter Otsego lake have a longer period of time to promote plant and algal growth. The 3.6 year retention period also reduces the ability of the lake to rebound from periods of increased nutrient loading.



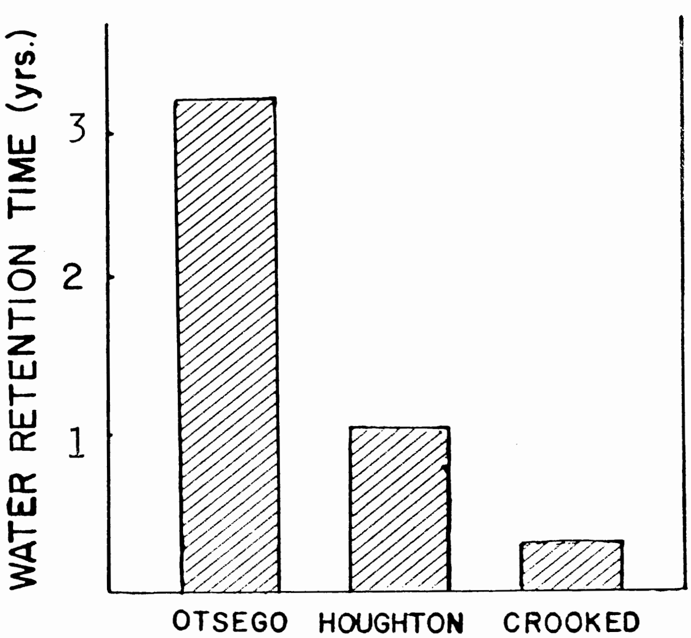


Fig. X. Water quality characteristics which influence a lake's ability to buffer pollution.

The response time of Otsego Lake as calculated from the mean depth and flushing rate (Dillon & Rigler, 1975) varies from 0.57 year to 0.95 year. In simple terms, the lake should respond to changes in nutrient loading within a period of 1 year.

The chemical composition of Otsego Lake water is also limited in its capacity to buffer incoming phosphorus. In hard water, alkaline lakes, phosphate complexes with calcium and is removed from the water column (Wetzel, 1977). Otsego Lake has relatively soft alkaline waters which are low in calcium and phosphate in the lake water is not removed as readily as in neighboring water systems. (Fig. X).

LAKE RESTORATION

Although Otsego Lake is more productive than many of the large lakes in northern Michigan, its water quality compares favorably to the majority of the inland lakes that have been tested in the State (DNR, 1978). However, in order to maintain or improve the water quality of the lake, the phosphorus concentrations must be lowered. This can be accomplished by two methods: 1) through reduction of nutrient loading from the watershed (Vollenweider, 1968) or 2) through in-lake alterations.

The nutrient budget identified the controllable sources of nutrient contamination to the lake. Curtailing these sources through wastewater treatment improvements, elimination of lawn fertilization, and drainage of storm runoff away from the lake should enhance the water quality of the lake. The importance of limiting nutrient inputs to Otsego Lake cannot be overemphasized.

In-lake alterations represent another avenue for lake improvement. However, "common" alterations such as dredging, phosphate precipitation, and weed harvest are still in experiemental stages (Theis, 1979). Scientists can not accurately predict the exact results from such lake manipulations.

Dredging is often proposed as a possible lake improvement technique. It was suggested that the current study consider the feasibility of removing the bottom organic sediment in order to expose the original sand bottom. The sediment cores indicate that 5-20 feet of organic muck overlies the original sand throughout most of the lake. Cost estimates for dredging vary from \$0.52 to \$2.08 per cubic meter (Peterson, 1979). If only 5% of the lake was selected to be deepened by 0.5 meters (19.5 inches), the expected costs would range from \$100,000 to \$400,000. Eliminating 0.5 meters would not expose the sand bottom in those areas. Disposal of dredged materials may present an additional problem. The bottom sediment is very flocculant and would require well constructed holding beds for long term storage. Dumping sites may be difficult to locate considering the high cost of land around the lake.

In lakes where large quantities of phosphorus are released from the bottom sediments, aluminum sulfate and other chemical salts have been applied, resulting in dramatic decreases in algae and increased water clarity. (Funk and Gibbons, 1979). Few lakes as large as Otsego Lake have received such treatment, and all have had significantly higher total phosphorus concentrations than Otsego Lake. Costs of such treatment might be as high as $200,000 and treatment would only be effective for one to three year periods. Until it is verified that nutrient release from the sediments does degrade the lake, this alternative should not be considered.

If severe winter oxygen depletion occurs, harvest of aquatic weeds in the autumn might be considered. Large masses of plants die each fall and decompose throughout the winter. As a result of this process, the lakes finite supply of oxygen is consumed. Mechanical harvesting costs between $80 and $120/acre (Burton, et. al., 1979). If 25% of the lake surface was harvested, harvest costs would vary between $40,000 and $60,000 each year.

From the previous discussion it is evident that in-lake treatment is costly and fraught with problems. Curtailing nutrient inputs from the drainage basin represents an effective and practical approach to the management of Otsego Lake.

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APPENDIX A

LAND USE DATA

TABLE A1. TOTAL PHOSPHORUS AND TOTAL NITROGEN EXPORT ($kg/km^2/yr.$) FROM LAND COVER. VALUES ARE MEANS FOR THE NORTH AND NORTHEASTERN UNITED STATES (OMERNIK, 1976), AND WERE USED IN THE OTSEGO LAKE NUTRIENT LOADING CALCULATIONS.

Land Cover	Phosphorus	Nitrogen
Forest	8.6	397
Agriculture (mostly)	16.3	525
Urban	31.7	669

TABLE A-2. ESTIMATED PHOSPHORUS (P) AND NITROGEN (N) INPUTS FROM SEPTIC SYSTEMS ON THE NORTHERN TIP, NORTHEAST, AND WESTERN SHORE OF OTSEGO LAKE IN 1979.

	# of Septic Systems	Percent Reaching Lake		Number of Dwellings		Amount Reaching Lake	
		P%	N%	Y-R	S	P(KG/YR)	N(KG/YR)
SOIL TYPE							
GREENWOOD PEAT	16	75	60	5	11	7.05	67.55
SAUGATUCK SAND	47	35	50	14	33	10.64	261.54
RUBICON-GRAYLING SAND	208	25	65	62	146	33.65	929.65
TOTAL	271			81	190	52.24	1258.75

APPENDIX B

LIMNOLOGICAL DATA:
PHYSICAL-CHEMICAL FEATURES

TABLE B-1

July 7, 1949*

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) ph-th	Alkalinity (ppm) total	pH
Surf.		24.4	8.2	98	1.0	70.0	7.6
1		24.2					
1.8		24.0	8.1	96			
2.7		23.8					
3.5		23.8	8.1	96			
3.7		23.2					
4.6	3.7	22.9	8.1	94	1.0	70.0	7.8
5.2		22.3					

* Data collected by Institute for Fisheries Research, Michigan Department of Natural Resources. Similar data exists for samples taken at north and south ends of lake.

TABLE B-2

April 26, 1979 **

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) ph-th	Alkalinity (ppm) total	pH
Surf.		10.0	10.4	92			
0.75		10.0	9.8	87		63	7.3
1.50		10.0	9.4	84			
2.25		10.0	9.0	80		63	7.35
3.00		10.0	8.8	78			
3.75		10.0	8.7	77			
4.50		10.0	8.6	76		64	7.3
5.25	4.5	10.0	6.2	55			

Depth (m)	Spec. Cond. (umhos)	NO_3-N NO_2-N (ppb)	NH_3N (ppb)	total p (ppb)
.75	120	106	176	9
2.25	111	107	173	10
4.50	122	106	181	12

** Data collected by Northeast Michigan Council of Governments.

TABLE B-3

June 11, 1979 ***

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) total	pH	Spec. Cond. (umhos)	Turb. (ppm)
Surf.		19.8	7.3	83	60	8.1	152	14
1		19.5	7.0	77				
2		19.5	6.5	75				
3		19.2	5.8	72	69	8.15	140	17
4		19.2	5.9	72				
5	4.5	19.0	5.3	59	69	8.3	122	14
6		18.9	4.8	54				
Bottom		18.7	1.8	18				

Depth (m)	NO_2 NO_3-N (ppb)	NH_3-N (ppb)	total P (ppb)	ortho P (ppb)	SiO_2 (ppb)	Hard. (ppm)	Chl. *a* (ppb)	Phaeo. (ppb)
Surf.			15.48		180	68	3.01	.72
3			11.83		190	72	3.32	-1.03
5			46.3		225	74	1.87	- .87

*** Samples taken at north and south ends of lake are similar to the data taken at deep spot, lake center.

TABLE B-4

June 28, 1979

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) total	pH	Spec. Cond. (umhos)
Surf.		24.0	7.15	87	67	8.5	149
1		24.0	7.5	91			
2		23.8	7.6	92	61	8.4	151
3		23.6	7.4	89			
4	3.5	23.5	7.4	89			
5		23.3	7.2	86	63	8.5	157

Depth (m)	Total P (ppb)	ortho P (ppb)	hard. (ppm)
Surf.	21	14	80
3	24	15	80
5	--	--	80

TABLE B-5

July 11, 1979

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Chl. *a* (ppb)	Phaeo. (ppb)
Surf.		25.2	10.5	126	2.28	- .59
1		24.5	10.4	124		
2		24.1	--	--		
3		23.6	10.2	120		
4	3.5	23.0	9.5	112		
5		22.5	8.0	95		
Bottom		21.8	.1	.11		
East Shore					3.84	- .95
West Shore					32.50	-17.20

TABLE B-6

August 1, 1979

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) (ppm)	Alkalinity (ppm) total	pH
Surf.		24.0	7.15	87	20	65	8.3
1		24.0	7.5	91	--	55	7.1
2		23.8	7.6	92	--	64	7.9
3		23.6	7.4	89	30	64	8.4
4	3.5	23.5	7.4	89	40	71	8.5
5		23.3	7.2	86	--	65	8.2

Depth (m)	SiO_2 (ppb)	Hard (ppm)	Chl. *a* (ppb)	Phaco (ppb)
Surf.	300	84	8.43	- .68
1	--	82	7.06	- .59
2	--	80	12.55	- .75
3	350	68	7.55	- .30
4	--	72	--	--
5	--	80	--	--
Bottom	--	--	372.84	-47.19

TABLE B-7

August 31, 1979

Depth (m)	Secchi Depth (m)	Temp. (°C)	O_2 (ppm)	O_2 (% sat.)	Alkalinity (ppm) total	pH	Spec. Cond. (umhos)	Turb. (ppm)
Surf.		19.8	7.6	85	63	8.0	138	22
1		19.6	7.6	85	62		155	20
2		19.5	8.2	92	62	8.0	154	20
3		19.5	6.6	75	62		150	44
4	3.5	19.5	8.1	91	63		142	41
5		19.5	7.1	80	62	8.0	137	35
Bottom		18.5						

Depth (m)	Ca (ppm)	Mg (ppm)	Hard (ppm)	Chl. *a* (ppb)	Phaco (ppb)
Surf.	20.4	7.3	80	4.03	- 1.15
1	21.6	6.3	80	3.39	- 1.05
2	20.8	6.8	80	3.05	- .77
3	21.6	7.2	80	3.31	- .78
4	20.8	7.3	82	3.98	- .81
5	21.6	6.8	82	4.68	- .95

APPENDIX C

PHOSPHORUS ADSORPTION/RELEASE BY BOTTOM SEDIMENTS

Purpose

Three sets of laboratory experiments were conducted to determine the phosphorus adsorption/release capacity of bottom sediment under aerobic and anaerobic conditions.

Methods

In all experiments water from Otsego Lake was added to bottom sediment in a ratio of 50 mls water to 1 gram sediment (wet weight). Sediment was collected with an Eckman dredge and water samples were taken with a horizontal Van Dorn bottle 1/2 meter from the bottom. Sediment and water from three sites were used in the experiments. Upon collection formalin was added to the water to inhibit biological activity.

All experiments were performed at room temperature. In experiments I and II aerobic conditions were maintained by shaking 100 ml samples in capped, acid washed 250 ml beakers continuously for 6 hours. Anerobic conditions were produced in experiment III by purging the water with nitrogen gas for 15 minutes before combining it with sediment. These samples were then placed for 72 hours in 65 ml poly-urthene bottles which were filled completely before capping and sealing with parafilm.

Upon completion of each experiment all samples were filtered through acid washed millipore filters (42 μm) and frozen. All samples were quick thawed and analyzed for orthophosphorus in a Technicon Autoanalyzer II after the methods described by Gannon and Paddock 1974.

Experiment I was performed on sediment and water from two sites. An additional water sample without sediment from each site was used in the experiment as a control.

In experiment II the water sediment mixture (50:1) was injected with 4 different concentrations of phosphorus before shaking. The experiment was performed in quadruplicate at each concentration. An additional water sample without sediment was injected with each concentration to serve as a control.

Experiment III was run in triplicate with anaerobic water and sediment from 2 different sites. An additional anaerobic sample containing only water from each site was used as the control.

Results

Experiment I

Phosphorus Adsorption from Bottom Sediments under Aerobic Conditions

Results (after 6 hours of shaking)

	Control (no sediment) P.P.B. PO_4	Test Samples (with sediment) P.P.B PO_4
Site 1	11	11.0 (±4.9) N=4
Site 2	12	13.3 (±4.2) N=3

Conclusions: No significant alteration occurred in orthophosphorus concentration under conditions similar to those existing in Otsego Lake during summer.

Experiment II

Phosphorus Adsorption at Varying PO_4 Concentration under Aerobic Conditions

Results (after shaking 6 hours)

Control (no sediment) PO_4 P.P.B.	Test Samples (with sediment) PO_4 P.P.B.	% Removal
77	25.1 (±4.2) N=4	67%
65	39.4 (±2.0) N=4	40%
34	21.2 (±3.5) N=4	38%
13.4	5.9 (±0.8) N=4	56%

Conclusions: The sediments of Otsego Lake have the ability to adsorb added phosphorus from the lake water under aerobic conditions.

Experiment III

Phosphorus Release by Bottom Sediments under Anaerobic Conditions

Results (after 72 hours)

	Control (no sediment) PO_4 P.P.B.	Test Samples (with sediment) PO_4 P.P.B.
Site 1	17.0	383 (±14) N=3
Site 2	18.0	62 (±16.0) N=3

Conclusions: Under anaerobic conditions the bottom sediments of Otsego Lake will release appreciable quantities of phosphorus.

Discussion

The results of the laboratory experiments can be used to predict the potential phosphorus contribution (Table C-1) to the lake during anaerobic conditions. The following assumptions are required. Each assumption represents a conservative approach to phosphorus release.

1) After 72 hours of anaerobic conditions the sediments release all available phosphorus to the lake water.

2) Only the top centimeter of the sediment releases orthophosphorus during anaerobic conditions.

3) The bottom area is equal to the surface area.

TABLE C-1

THE FOLLOWING TABLE REPRESENTS THE EXTRAPOLATION FROM THE ANAEROBIC LAB EXPERIMENTS

	(A) Water:sediment	(B) Mean Rise in PO_4 conc. in sample P.P.B.	(C) Total PO_4 release from sediment (AxB) P.P.B.	(D) Mean volume of water column overlying cm^2 sediment	(E) Predicted increase in phosphorus concentration throughout water column (P.P.B.) (C/D)
Site 1	50:1	42	2,200	298 cm^3	0.7
Site 2	50:1	366	18,300	298 cm^3	6.1

APPENDIX D

LIMNOLOGICAL DATA:
BIOLOGICAL FEATURES

TABLE D-1

A. PHYTOPLANKTON TAXA OF OTSEGO LAKE, SUMMER 1979

TAXA	6/11/79	7/11/79	8/1/79	8/30/79
BACILLARIOPHYTA (Diatoms)				
Asterionella formosa Hass.	**	**	**	**
Cyclotella sp.	--	--	--	--
Cymatopleura sp.	--	*	--	--
Fragillaria crotenensis Kitton	**	***	***	**
Fragilaria sp.	--	**	**	**
Melosira sp.	--	--	--	*
Navicula radiosa Kutz.	*	*	**	**
Navicula sp.	*	*	*	*
Neidium dubium (Ehr.) Cl.	--	--	*	*
Pinnularia gibba Ehr.	--	--	*	--
Stauroneis sp.	--	*	--	*
Surirella ovata Kutz.	--	*	*	--
Synedra acus Kutz.	**	**	**	**
Synedra delicatissima var. *angustissima* Grun.	***	***	***	****
Synedra ulna (Nitz.) Ehr.	**	**	**	**
Tabellaria fenestrata Kutz.	*	*	**	**
CHLOROPHYTA (Green Algae)				
Botryococcus sp.	--	--	*	**
Cosmarium sp.	--	--	*	*
Kirchneriella lunaris (Kirch.) Moebius	--	--	--	*
Mougeotia sp.	--	--	N	--
Oedegonium sp.	--	--	--	N
Pediastrum duplex Meyen	*	--	*	**
Pleurotaenium sp.	--	--	--	*
Scenedesmus bijuga (Turp.) Lagerheim	--	--	*	*
Spirogyra sp.	--	--	N	N
Staurastrum sp.	*	*	**	**
Tetraedron sp.	--	--	--	*
CHRYSOPHYTA (Golden Algae)				
Dinobryon bavaricum Imhof	**	**	**	**
Dinobryon cylindricum Imhof	**	**	***	***
Dinobryon sertularia Ehrenberg	****	****	****	****
Dinobryon sociale Ehrenberg	***	***	***	***
Mallomonas sp.	--	--	--	*

TABLE D-1 continued

TAXA	6/11/79	7/11/79	8/1/79	8/30/79
CYANOPHYTA (Blue-Green Algae)				
Anabena circinalis Rabenhorst	****	***	***	**
Aphanocapsa sp.	--	*	*	**
Chroococcus dispersus (Keissl.) Lemmermann	**	**	***	**
Chroococcus limneticus var. *distans* G.M. Smith	*	***	*	*
Chroococcus sp.	**	**	**	**
Coelosphaerium Kuetzingianum Naegeli	--	--	--	*
Coelosphaerium Naegelianum Unger	***	***	***	***
Gleotrichia echinulata (J.E. Smith) P. Richter	***	***	****	*
Gomphosphaeria lacustris Chodat	--	--	*	--
Lyngbia Birgei G.M. Smith	*	*	**	*
Merismopedia glauca (Ehr.) (Ehrenberg) Naegeli	--	--	*	--
Microcystis aeruoginosa Kuetz.; *emend.* Elenkin	****	****	****	****
Oscillatoria sp.	*	**	*	**
EUGLENOPHYTA (Euglenoids)				
Trachelomonas sp.	?	?	?	**
PYRRHOPHYTA (dinoflagellates)				
Ceratium hirundinella (O.F. Muell.) Dujardin	****	****	****	****
Unidentified taxa	?	?	?	**

* Rare/Insignificant
** Present
*** Common
**** Abundant
N Not normally in planton
? Absence may be due to mesh size of net
-- Not found in sample

TABLE D-2

ZOOPLANKTON GENERA OF OTSEGO LAKE, SUMMER 1979

	June	July	August	August
ROTIFERA				
Asplanchna	--	*	**	**
Chromogaster	--	--	*	*
Gastropus	*	***	***	*
Kellicottia	***	**	*	--
Keratella	****	****	****	****
Monostyla	--	*	*	*
Polyarthra	--	--	--	***
Tricocerca	**	***	***	***
CRUSTACEA				
CLADOCERANS				
Bosnina	**	**	**	**
Ceriodaphnia	*	*	**	**
Chydorus	**	**	***	**
Daphnia	***	**	*	**
Diaphanasoma	--	--	**	**
Holopedium	--	--	*	*
Leptadora	--	--	*	*
Simocephalus	--	--	*	**
COPEPODS				
Diaptomus	**	**	**	**
Cyclops	**	**	**	**
Mesocyclops	--	--	*	--
Nauplius	***	***	***	***
HYDRACARINA	--	*	*	--
OSTRACODA	*	--	--	*

KEY

*	Rare/Insignificant
**	Present
***	Common
****	Abundant
--	Not found in sample

TABLE D-3

PRINCIPAL GAME FISH SPECIES OF OTSEGO LAKE
(DNR Trap Net Analysis 10-5-78)

FISH SPECIES	Common Name	Age Class	Number Sampled	Length Range (inches)	Mean Length (inches)	State Average (inches)
CENTRATCHIDAE	(SUNFISHES)					
Ambloplites rupestris (Rafinesque)						
	Rock Bass	II	4	3.9-4.7	4.3	4.5
		III	20	4.7-6.7	5.6	5.6
		IV	14	6.3-7.1	6.4	6.5
		V	10	7.5-7.8	7.5	7.4
		VI	4	7.8-7.8	7.8	8.2
		VII	1	8.7	8.7	8.9
Lepomis gibbosus (Linnaeus)						
	Pumpkinseed	II	3	5.1-5.5	5.2	4.4
		III	65	5.1-7.1	6.3	5.2
		IV	8	6.7-7.5	7.2	5.9
		V	10	7.1-7.9	7.5	6.4
		VI	1	7.8	7.8	6.4
Lepomis mactochirus (Rafinesque)						
	Bluegill	III	17	5.1-7.5	6.7	5.5
		IV	11	6.3-7.9	7.4	6.4
		V	24	7.5-8.7	7.9	7.0
		VI	2	8.3-8.3	8.3	7.5
		VII	1	8.3	8.3	7.9
Micropterus dolomieui (Lacepede)						
	Small Mouth bass	I	2	7.9-8.7	8.3	6.1
		II	1	10.2	10.2	9.2
		V	1	15.7	15.7	14.9
Micropterus salmoides (Lacepede)						
	Large Mouth bass	I	1	6.7	6.7	6.1
		II	16	8.3-10.2	9.3	8.6
		III	17	10.6-13.4	11.8	10.6
Pomoxis nigromaculatus (LeSueur)						
	Black crappie	II	11	8.3-9.0	8.4	6.8
		III	11	8.7-9.1	8.8	8.2
		IV	9	9.5-10.6	10.1	9.0
		V	5	9.8-11.4	10.7	9.5
		VI	4	11.8-12.6	12.0	10.6
		VII	6	12.2-13.0	12.6	10.9
		VIII	1	13.4	13.4	11.8

TABLE D-3 CONCLUDED

FISH SPECIES	Common Name	Age Class	Numbered Sampled	Length Range (inches)	Avg. Length (inches)	State Avg. (inches)
ESOCIDAE	(PIKES)					
Esox lucius Linnaeus						
	Northern Pike	II	3	18.5-20.5	19.6	19.4
		III	2	22.8-23.2	23.0	22.2
		IV	3	25.2-29.1	27.1	24.6
		V	2	31.5-31.9	31.7	26.5
Esox masquinongy Mitchill						
	Muskellunge "Tiger Musky"	I	31	20.0-23.0	21.2	--
		II	1	31.1	31.1	--
PERCIDAE	(PERCH)					
Perca flavescens (Mitchill)						
	Yellow perch	I	4	3.9-5.1	4.5	4.6
		II	8	5.1-6.7	6.0	6.1
		III	26	5.9-7.1	6.4	7.0
		IV	6	6.7-8.3	7.5	8.0
		V	3	7.8-9.0	8.4	9.0
		VI	2	9.0-9.0	9.0	9.9
		VIII	1	10.2	10.2	11.3

TABLE D-4

AQUATIC MACROPHYTES OF OTSEGO LAKE

TAXA	COMMON NAME
Myriophyllum spicatum	water milfoil
Najas sp.	
Nymphea odorata	white water lily
Nuphar sp.	yellow water lily
Pontederia cordata	pickeral weed
Potamogeton amplifolius	pond weed
Scirpus sp.	bulrush
Typha sp.	cattail